Search for dark photon, dark scalar, axion-like pseudo-scalar, and light dark matter particles in Compton-like processes

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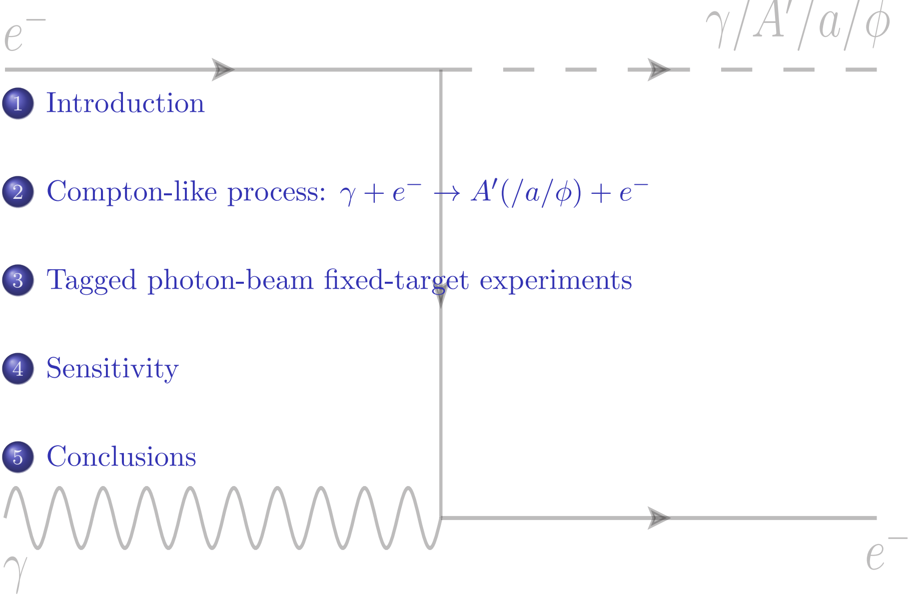
Based on arxiv:1903.06225 Sankha S. Chakrabarty & **IJ**

Outline



1. Introduction
2. Compton-like process: $\gamma + e^- \rightarrow A'(/a/\phi) + e^-$
3. Tagged photon-beam fixed-target experiments
4. Sensitivity
5. Conclusions

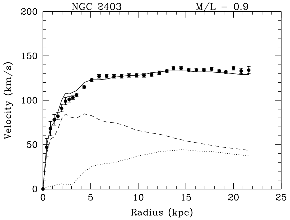
The Universe missing mass "problem"?

First observed by Fritz Zwicky in 1933 and reported in Helvetica physica acta, vol. 6, p. 110

- Missing mass problem, gravitational mass of galaxies in Coma galaxy cluster is much higher than expected
- Dunkle Materie or dark matter?

Validated by Vera Rubin and Kent Jr. W. Ford in 1970 and reported in Astrophysical Journal, vol. 159, p.379

- Measure rotation curves of spiral galaxies
- Observe: outermost components of the galaxy move as quickly as those close to the center



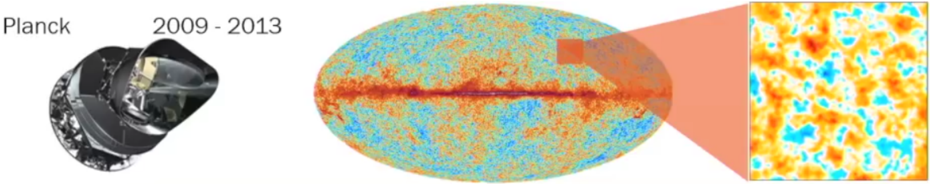
Rotation curve of NGC 2403. The points are the observed rotation curve, the dashed and dotted curves are the Newtonian rotation curves of the baryonic components (stars and gas respectively), and the solid curve is the MOND rotation curve, R. H. Sanders CJP 93 2 (2015).

There are different ways to solve this relation problem between mass and gravity:

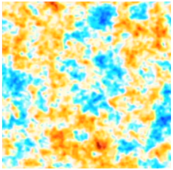
- Add an extra mass (most popular solution) which is not
  - Baryonic (Standard Model of Particles does not apply)
  - Interacting with known electromagnetic force (missing force(s))
- Modify the theories of gravity, eg MOdified Newton Dynamics (MOND) theories
- Combination of the above
- None of the above

Universe missing mass “problem” at different ages

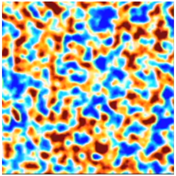
Cosmic Microwave Background (CMB) observed by Planck (arXiv:1807.06205) cannot be explained by MOND (so far).



- CMB MC simulation with DM and visible matter



- CMB MC simulation with visible matter only



Difference between data and model is an indication of the proportion of:

- Visible (luminous) matter (∼5 %)
- Non-luminous (dark) matter (∼25 %) to bind cosmic structures: Galaxies & clusters of Galaxies
- Dark energy (∼70 %) to drive cosmic acceleration: now and at primordial inflation

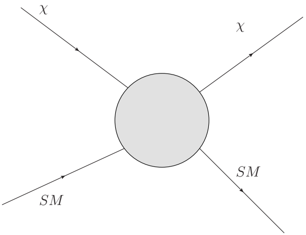
The Weakly Interacting Massive Particle (WIMP)

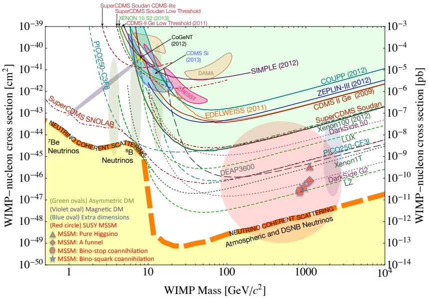
Can be naturally explained by a minimal Supersymmetry extension of the Standard Model

WIMP with a mass of 100's of GeV/c^2 can explain

$\sim$80% of all matter is dark
Dark matter density at different ages of the Universe

If true, in this room there is 1 WIMP every 10 cm with a velocity of $\sim$ 200 km/s





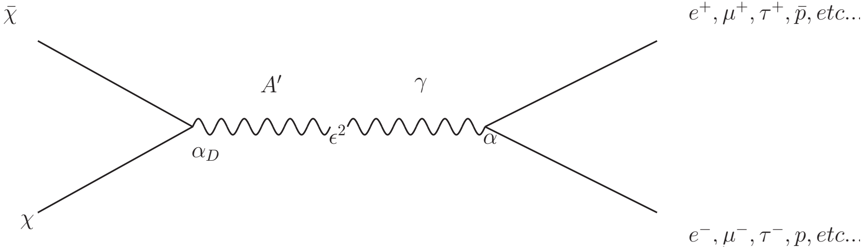
arXiv:1401.6085, Planning the Future of U.S. Particle Physics (Snowmass 2013)

- WIMP was not detected so far at underground laboratory
- Supersymmetry particles were not detected so far at LHC

The dark sector hypothesis

Introduction of a new force mediated by a "Dark Gauge vector Boson"

- Formulated first by P. Fayet and B. Holdom in the 80's
- Reformulated 30 years later by M. Pospelov, H. Arkani-Hamed, R. Essig, P. Shuster, N. Toro, et al. in light of the different anomalies observed
  - Anomalous magnetic dipole moment of a muon, E821 Collaboration PRL 92 1618102 (2004)
  - e^+ flux excess, AMS-02 Collaboration PRL 113, 221102 (2014)



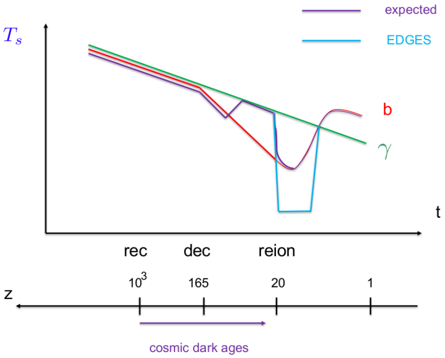
- α_D: dark matter, χ, coupling to dark photon, A' ($m_{A'} \neq 0$ GeV/c^2)
- $m_{A'}$ between 1.022 MeV/c^2 and 10's of GeV/c^2
- $\epsilon = \sqrt{\alpha'/\alpha}$: kinetic mixing between A' and Standard Model γ ($m = 0$ GeV/c^2)
  - α = 1 / 137: SM electromagnetic coupling constant
  - α': A' coupling to SM fermions

Mediator can also be a scalar (ie Higgs-like) or neutrino ie α' replaced by y_e, ...

EDGES 21-cm hydrogen signal at cosmic dawn

Experiment to Detect the Global Epoch of Reionization Signature (EDGES), Nature volume 555, pages 67–70 (2018)

- Baryon temperature cooler than expected, 3.8σ discrepancy, and not confirmed yet by another collaboration
  - More 21-cm radiation at cosmic dawn than expected (generally considered unlikely)
  - Baryon cooling by dark matter, R. Barkana Nature volume 555, pages 71–74 (2018)



Artistic view of the Hydrogen spin temperature vs. Universe age by Pierre Sikivie.

- Millicharged dark matter possible if very small fraction (< 1 %) of total dark matter, mass m_χ between 0.5 and 35 MeV/c^2, and ϵ between 10^{-6} and 10^{-4}, E. D. Kovetz et al. arXiv:1807.11482
- Dark matter is axions (QCD axion and/or axion-like), P. Sikivie arXiv:1805.0557
- Composite dark matter?
- Or something else?

Meanwhile on Earth

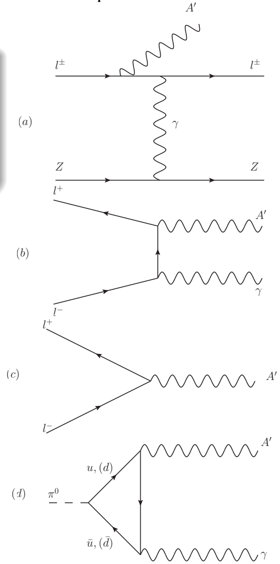
Most accelerator based experiments are looking for sub-GeV to GeV dark particles

Produced in the processes:

(a) "Dark" Bremsstrahlung in nucleus scattering
(b) "Dark" Bremsstrahlung in l^+l^- or pp annihilation
(c) "Dark" resonance in l^+l^- or pp annihilation
(d) "Dark" meson decay
(e) "Dark" atomic deexcitation

With:

- Lepton or hadron beam on a thin or thick fixed target
  E137, E141, E774, KEK, Orsay, A1, APEX, BDX, DarkLight, (Super-)HPS, LDMX, PADME, VEPP-3, NA48, NA64, MAGIX, MMAPS, Mu3a, SeaQuest, SHIP, ATOMKI
- Lepton or hadron colliders
  KLOE, KLOE II, BABAR, Belle, Belle II, BESI/II/II, LHCb, CMS, and ATLAS
  Much less SM backgrounds than fixed target experiments
- Photon-beam on a fixed target
  GlueX ("Dark" meson decay)

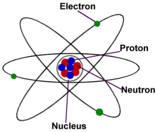


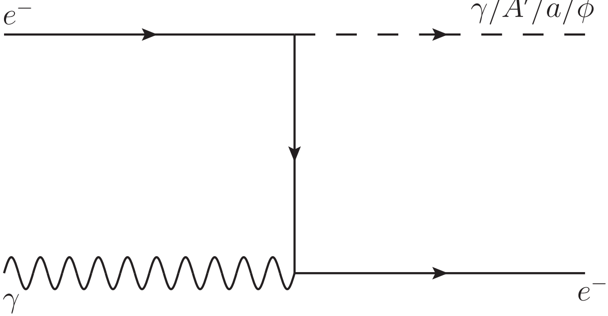
Do we use all the processes capable of producing dark particles/matter in a Laboratory?

Compton-like process

$\gamma_{beam} + e^-_{target} \to A'/a/\phi + e^-_{recoil}$

- A': dark photon
- a: axion-like pseudo-scalar
- ϕ: dark scalar





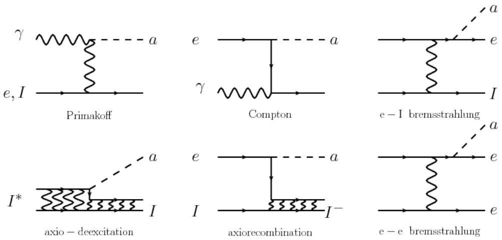
Possible dark particle production mode (in Laboratory).

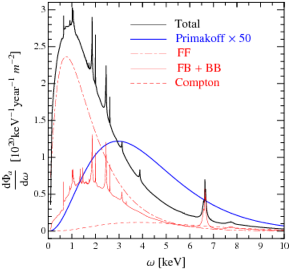
Always considered for calculation of axion flux or even dark photon flux in "outer-space"

Small detour in the (QCD) axion world

First axion helioscope proposed by P. Sikivie

- P. Sikivie, Experimental Tests of the "Invisible" Axion, PRL 51, 1415; Erratum PRL **52**, 695 (1984)
- Idea refined by K. van Bibber et al. by using buffer gas to restore coherence over long magnetic field, K. van Bibber et al., Design for a practical laboratory detector for solar axions, PRD **39**, 2089 (1989)
- J. Redondo, Solar axion flux from the axion-electron coupling, JCAP 1312 008 (2013)





- ABC reactions responsible for the solar axion flux in non-hadronic axion models.
- Flux of solar axions due to ABC reactions driven by the axion-electron coupling (for $g_{ae} = 10^{-13}$). The different contributions are shown as red lines: Atomic recombination and deexcitation (FB+BB, solid), Bremsstrahlung (FF, dot-dashed) and Compton (dashed). The Primakoff flux from the axion-photon coupling is shown for comparison using $g_{a\gamma} = 10^{-12}$, a typical value for meV axions having $g_{ae} = 10^{-13}$. Note that has been scaled up by a factor 50 to make it visible

One can learn a lot from these searches that are in their third decade

γ-production of dark particles off free electrons

Electron at rest

Lagrangians:

$$\begin{aligned} \mathcal{L}(\gamma e^- \to A' e^-) &\supset \epsilon e\, \bar{\psi}_e \gamma^\mu \psi_e A'_\mu \\ \mathcal{L}(\gamma e^- \to a e^-) &\supset g_{ae}\, \bar{\psi}_e \gamma_5 \psi_e a \\ \{\mathcal{L}(\gamma A \to a A) &\supset g_{a\gamma}\, a F_{\mu\nu} \widetilde{F}^{\mu\nu}\}^* \\ \mathcal{L}(\gamma e^- \to \phi e^-) &\supset y_e\, \bar{\psi}_e \psi_e \phi \end{aligned}$$

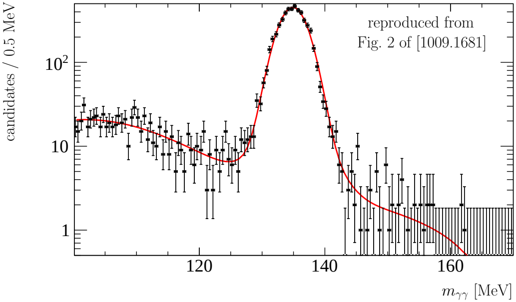
With

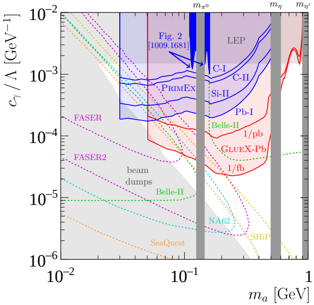
ϵ: kinetic mixing between A' and γ for $m_{A'} > 0$
If $m_{A'} = 0$ millicharge scenario: $\gamma + e^- \to \chi_e + e^-$
g_{ae}: axion-like pseudo-scalar coupling to electron
y_e: dark scalar coupling to electron
$g_{ae} = y_e = \sqrt{\alpha} \times \epsilon$
* Primakoff photoproduction of axion-like pseudo-scalar off nucleus highlighted by J. D. Bjorken et al. PRD **38**, 3375 (1988)

Primakoff photoproduction of axion-like pseudo-scalar off nucleus

D. Aloni and al. performed first search with a real photon-beam arXiv:1903.03585 by re-interpreting PrimEx results

- $\gamma A \to a A$ and $a \to \gamma\gamma$
- $g_{a\gamma} = c_\gamma / \Lambda$





- No need to know form factor and photon flux
- GlueX expected sensitivity is competitive compared to Belle II expected sensitivity
- (Effort to re-interpret the data taken by TAPS in Bonn and Mainz since 2002 started)

γ-production of dark particles off quasi-free electrons

Electrons at rest do not exist in Laboratory

- Atomic electron
- Accelerator electron

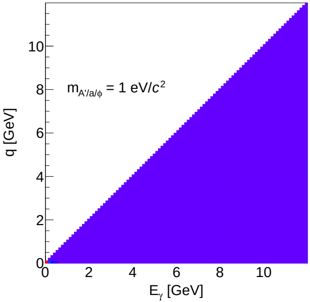
We have to do the so-called

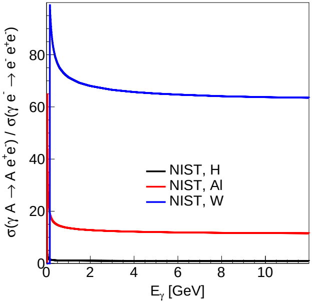
Screening and radiative corrections

K. Mork,H. Olsen PR 140, 1661 (1965)
L.C. Maximon, H.A. Gimm PRA 23, 1, (1981)
$\sigma_{\text{quasi-free}} = S(q,Z) \times \sigma_{\text{free}} (\approx Z \times \sigma_{\text{free}})$ where
$S(q,Z) = S(q) \times R(Z)$ with

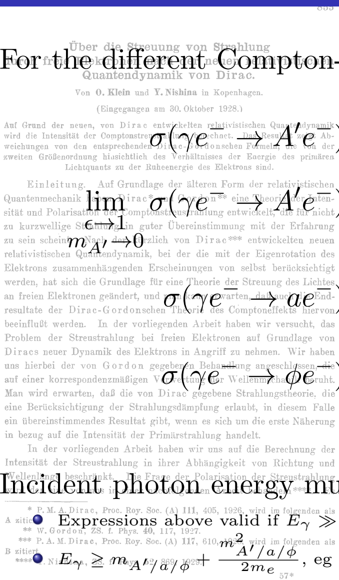
- $S(q) = 1 - F^2(q)$
  - $F(q) = (1 + \frac{a^2 q^2}{4})^{-2} \rightarrow 0$ if q large
  - a Bohr radius
  - q momentum transfer to the recoil electron
- $R(Z) = Z \cdot (1 + c \frac{\sigma(\gamma A \rightarrow A e^+ e^-)}{\sigma(\gamma e^- \rightarrow e^- e^+ e^-)})$
  - c radiative correction which is independent of Z
  - $\sigma(\gamma A \rightarrow A e^+ e^-)$ NIST pair cross section
  - $\sigma(\gamma e^- \rightarrow e^- e^+ e^-)$ NIST triplet cross section

NIST: `http://physics.nist.gov/PhysRefData/Xcom/html/xcom1.html`
Same as in M. Dugger et al. NIMA 867 (2017) 115-127





Cross section expression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Über die Streuung von Strahlung durch freie Elektronen nach der neuen relativistischen Quantendynamik von Dirac.

Von O. Klein und Y. Nishina in Kopenhagen.

(Eingegangen am 30. Oktober 1928.)

Auf Grund der neuen, von Dirac entwickelten relativistischen Quantendynamik wird die Intensität der Comptonstreustrahlung berechnet. Das Resultat zeigt Abweichungen von den entsprechenden Dirac-Gordonschen Formeln, die von der zweiten Größenordnung hinsichtlich des Verhältnisses der Energie des primären Lichtquants zu der Ruheenergie des Elektrons sind.

Einleitung. Auf Grundlage der älteren Form der relativistischen Quantenmechanik haben Dirac* und Gordon** eine Theorie der Intensität und Polarisation der Comptonstreustrahlung entwickelt, die für nicht zu kurzwellige Strahlung in guter Übereinstimmung mit der Erfahrung zu sein scheint. Nach der kürzlich von Dirac*** entwickelten neuen relativistischen Quantendynamik, bei der die mit der Eigenrotation des Elektrons zusammenhängenden Erscheinungen von selbst berücksichtigt werden, hat sich die Grundlage für eine Theorie der Streuung des Lichtes an freien Elektronen geändert, und man kann erwarten, daß auch die Endresultate der Dirac-Gordonschen Theorie des Comptoneffekts hiervon beeinflußt werden. In der vorliegenden Arbeit haben wir versucht, das Problem der Streustrahlung bei freien Elektronen auf Grundlage von Diracs neuer Dynamik des Elektrons in Angriff zu nehmen. Wir haben uns hierbei der von Gordon gegebenen Behandlung angeschlossen, die auf einer korrespondenzmäßigen Verwertung der Wellenmechanik beruht. Man wird erwarten, daß die von Dirac gegebene Strahlungstheorie, die eine Berücksichtigung der Strahlungsdämpfung erlaubt, in diesem Falle ein übereinstimmendes Resultat gibt, wenn es sich um die erste Näherung in bezug auf die Intensität der Primärstrahlung handelt.

In der vorliegenden Arbeit haben wir uns auf die Berechnung der Intensität der Streustrahlung in ihrer Abhängigkeit von Richtung und Wellenlänge beschränkt. Die Frage der Polarisation der Streustrahlung [illegible] ****.

* P. M. A. Dirac, Proc. Roy. Soc. (A) 111, 405, 1926, wird im folgenden als A zitiert.

** W. Gordon, ZS. f. Phys. 40, 117, 1927.

*** P. A. M. Dirac, Proc. Roy. Soc. (A) 117, 610, 1928, wird im folgenden als B zitiert.

**** Y. Nishina, ZS. f. Phys. 52, 869, 1929.

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- For the different Compton-like processes:

$$\sigma(\gamma e^- \to A' e^-) \approx 1.4\ \text{pb} \left(\frac{\epsilon}{10^{-4}}\right)^2 \left(\frac{0.1\text{GeV}}{\sqrt{s}}\right)^2$$

$$\lim_{\substack{\epsilon \to 1 \\ m_{A'} \to 0}} \sigma(\gamma e^- \to A' e^-) = \sigma^{\text{Klein-Nishina}}(\gamma e^- \to \gamma e^-)^*$$

$$\sigma(\gamma e^- \to a e^-) \approx 6.5\ \text{pb} \left(\frac{g_{ae}}{10^{-4}}\right)^2 \left(\frac{0.1\text{GeV}}{\sqrt{s}}\right)^2$$

$$\sigma(\gamma e^- \to \phi e^-) \approx 20.2\ \text{pb} \left(\frac{y_e}{10^{-4}}\right)^2 \left(\frac{0.1\text{GeV}}{\sqrt{s}}\right)^2$$

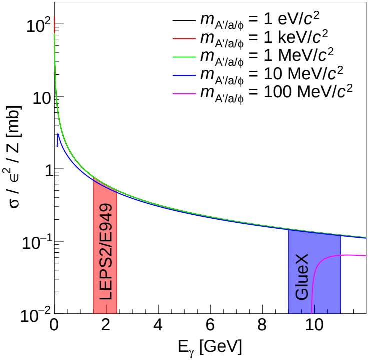
- Incident photon energy must be:
  - Expressions above valid if $E_\gamma \gg m_e$
  - $E_\gamma \geq m_{A'/a/\phi} + \frac{m^2_{A'/a/\phi}}{2m_e}$, eg for $m_{A'/a/\phi} = 16.8$ MeV/c^2, $E_\gamma \geq E_\gamma^{\text{thres.}}$ =292.965 MeV

* O. Klein and Y. Nishina, Z. Phys. **52**, 853 (1929)

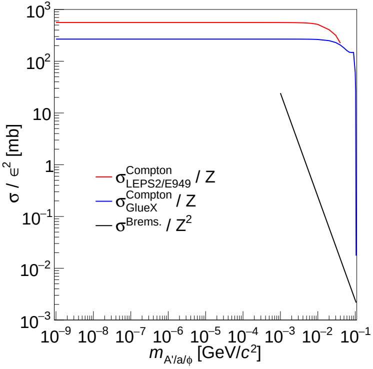
$\gamma + e^- \to A'/a/\phi + e^-$ cross section vs. E_γ / $m_{A'/a/\phi}$

Additional points to keep in mind:

- If $E_\gamma \gg E_\gamma^{\text{thres.}}$, cross section is independent of $m_{A'/a/\phi}$ or $m_{\chi e}$
- No restriction on $m_{A'/a/\phi}$: can be sub-eV or above-GeV
- Four tagged photon-beam experiments, based at electron accelerator, could be suited:
  - LEPS2/E949 and LEPS/BGOegg at SPring8 (8 GeV e^-), Sayo, Japan
  - FOREST at ELPH, Tohoku, Japan
  - GlueX at JLAB (12 GeV e^-), Newport News, USA

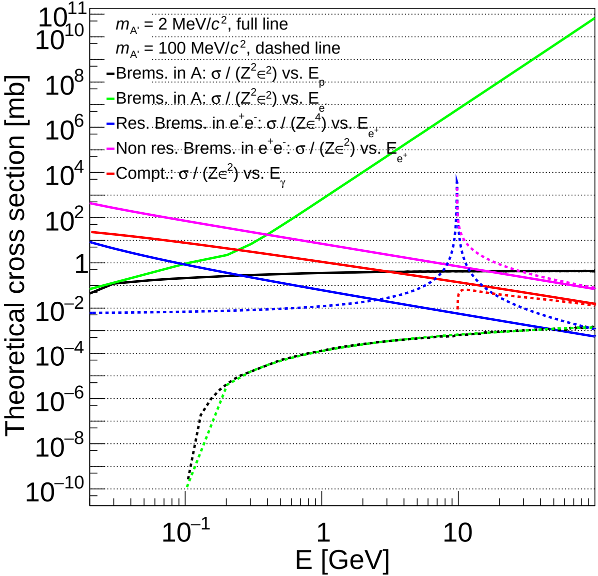


Cross section vs. E_γ.



Cross section vs. $m_{A'/a/\phi}$.

Comparison to other production processes



List of searches and observables

We can search for with the Compton-like processes:

- Dark photon with and w/o a displaced vertex
  - Visible $A' \to l^+l^-$ by using
    - Inv. mass of l^+l^- pair
    - Missing mass of electron recoil
  - Invisible $A' \to \chi\bar{\chi}$
    - Missing mass of electron recoil
- Axion-like pseudo-scalar with and w/o a displaced vertex
  - Visible $a \to l^+l^-$ by using
    - Inv. mass of l^+l^- pair
    - Missing mass of electron recoil
  - Visible $a \to \gamma\gamma$ by using
    - Inv. mass of $\gamma\gamma$ pair
    - Missing mass of electron recoil
  - Invisible a or $a \to \chi\bar{\chi}$
    - Missing mass of electron recoil
- Dark scalar with and w/o a displaced vertex
  - Visible $\phi \to l^+l^-$ by using
    - Inv. mass of l^+l^- pair
    - Missing mass of electron recoil
  - Visible $\phi \to \gamma\gamma$ by using
    - Inv. mass of $\gamma\gamma$ pair
    - Missing mass of electron recoil
  - Invisible $\phi \to \chi\bar{\chi}$ by using
    - Missing mass of electron recoil

Before starting, some basics maths

In a real photon-beam fixed-target experiments:

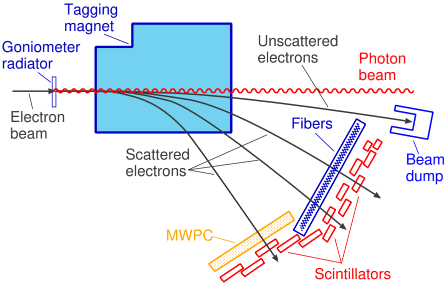
- Luminosity: $\mathcal{L} = \frac{\mathcal{N}_A}{A} \cdot \rho \cdot l_{\rm target} \cdot \Phi_\gamma \cdot \Delta t$
- Assuming:
  - Molar mass, A
  - LH_2 density: $\rho = 0.071$ g/cm^3
  - Target length: $l_{\rm target} = 1$ cm
  - Photon flux: $\Phi_\gamma \sim \Phi_\gamma^0 \frac{E^0_{e^-}}{E_\gamma}$
  - Beam-time duration: $\Delta t = 1$ month
  - Detection efficiency: $\varepsilon \sim 1$
  - Branching Ratio: $BR \sim 1$
  - $E_\gamma^{\rm min} = 9$ GeV
  - $E_\gamma^{\rm max} = 11$ GeV
  - 0 background
  - No event observed, $N^{90\%{\rm up}}_{\rm obs.} = 2.3$
- Expected observed event number: $N_{\rm expected} = \mathcal{L} \cdot \varepsilon \cdot BR \cdot \int_{E_\gamma = E_\gamma^{\rm min}}^{E_\gamma^{\rm max}} \sigma(E_\gamma) dE_\gamma$
- $\frac{\epsilon_1^{90\%{\rm up}}}{\epsilon_0^{90\%{\rm up}}} = \left(\frac{\mathcal{L}^0}{\mathcal{L}} \frac{\Delta_M}{\Delta_M^0} \frac{\varepsilon^0}{\varepsilon} \right)^{0.25}$, Δ_M is the observable resolution

m [MeV/c^2]	ϕ_γ^0 [γ/s]	σ/ϵ^2 [mb]	$\mathcal{L}$ [mb^{-1}]	$N_{\rm expected}/\epsilon^2$	$\epsilon^{90\%{\rm up}}$
2	10^8	267.316	$1.10827 \cdot 10^{10}$	$2.96 \cdot 10^{12}$	$8.81 \cdot 10^{-7}$
10	10^8	262.893	$1.10827 \cdot 10^{10}$	$2.91 \cdot 10^{12}$	$8.88 \cdot 10^{-7}$
20	10^8	249.636	$1.10827 \cdot 10^{10}$	$2.76 \cdot 10^{12}$	$9.11 \cdot 10^{-7}$
100	10^8	59.4691	$1.10827 \cdot 10^{10}$	$6.59 \cdot 10^{11}$	$1.86 \cdot 10^{-6}$

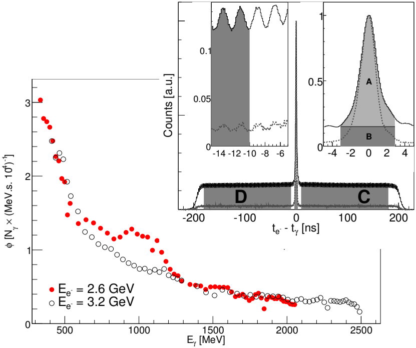
Photon beam produced by bremsstrahlung

$e^-_{accelerator} A \to e^- A\gamma$

- A:
  - $\sim 100\mu m$ Cu for unpolarized photon beam
  - $\sim 100\mu m$ C (diamond) for linearly polarized photon beam
- Emitted (unpolarized) photon energy spectrum: $\Phi \sim \frac{1}{E_\gamma}$
- Emitted photon half-angle: $< \theta^2 >^{\frac{1}{2}} = \frac{1}{e^-} = \frac{m_e c^2}{E_{e^-}^{accelerator}}$
- Electrons emitting bremsstrahlung deflected downwards by dipole magnetic field onto focal plane of tagging system
  - Energy and timing extracted
  - $E_\gamma = E_{e-}^{accelerator} - E_{e-}^{deflected}$



Typical tagging spectrometer setup.

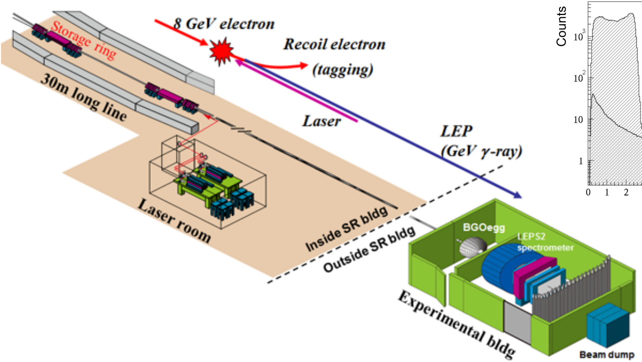


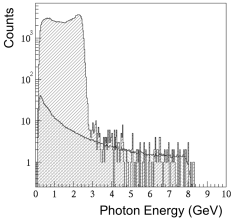
More details in I. Jaegle et al., EPJ A **47** (2011) 89

Photon beam produced by Laser-backscattering

$e^-_{accelerator}\gamma_{\text{laser}} \to e^-\gamma$, inverse Compton process

- Tagged photons backscattered from 8 GeV electrons reach max. energies of 2.9 GeV
- Scattered electrons momentum analyzed by last bending magnet before straight section of beam line and then detected in tagging counter



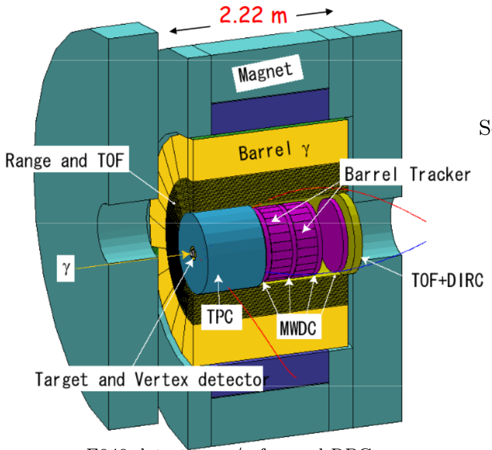


Backscattering of laser light (eV) from high energy electrons (Gev).

More details in N. Muramatsu et al. NIM A737 (2014) 184-194

LEPS2/E949

Commissioned in 2015, based on BNL-E949 magnet



E949 detectors w/o forward RPC.

Physics Motivation

- Search for the missing resonances
- Search for meson-nuclei states
- Study of $s\bar{s}$ mesons
- Study of Hyperon resonances
- ...

Setup characteristics used in our fast MC

ϕ_γ [γ/s]	E_γ range [GeV]	ΔE_γ [MeV]
5×10^6	1.5 - 2.4	12

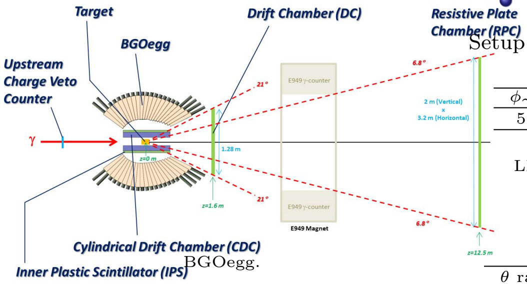
LEPS2/E949 tagging system key numbers.

θ range [^{o}]	$\frac{\Delta P}{P}$ [%]	$\Delta\theta$ [^{o}]	$\Delta\phi$ [^{o}]
5 - 110	1	$\theta \cdot \frac{\Delta P}{P}$	$\Delta\theta$

LEPS2/E949 detectors key numbers.

LEPS/BGOegg

2020?



BGOegg.

Physics Motivation

- Search for the missing resonances
- Search for meson-nuclei states
- Study of $s\bar{s}$ mesons
- Study of Hyperon resonances
- ...

Setup characteristics used in our fast MC

ϕ_γ $[\gamma/s]$	E_γ range [GeV]	ΔE_γ [MeV]
5×10^6	1.5 - 2.4	12

LEPS2/E949 tagging system key numbers.

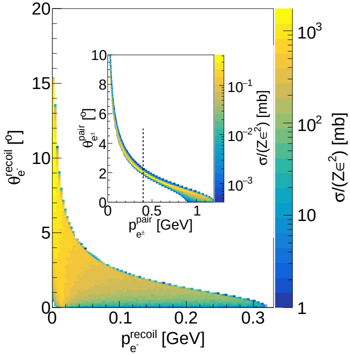
θ range $[^o]$	$\frac{\Delta P}{P}$ [%]	$\Delta\theta$ $[^o]$	$\Delta\phi$ $[^o]$
0 - 20	0.5	$\theta \cdot \frac{\Delta P}{P}$	$\Delta\theta$

LEPS/BGOegg detectors key numbers.

Few words on the process kinematics

Correlation between momentum and polar angle

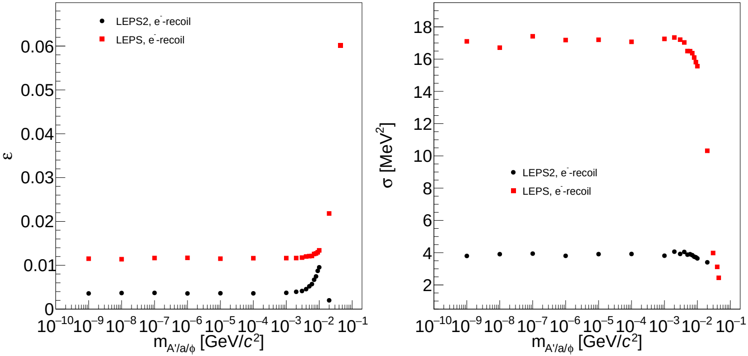
- Slow momentum => “large” polar angle
- “Large” polar angle => slow momentum
- eg for a 10 MeV/c^2 dark photon and FOREST tagged photon-beam
  - Detectable tracks on a very narrow lab. polar angle
  - Recoiling Atomic electron and e^+e^- pair not necessarily detectable simultaneously



Single electron analysis for invisible or long-lived decay

One single track measured (long-lived $\tau \sim 10^{-13}$ to 10^{-14} s)

- Identified as an electron
- p $\geq$ 100 / 200 MeV/c for LEPS2/LEPS
- Polar angle below 6^o/ 4^o
- Transverse momentum cuts to remove pair/triplet production
- Dark particle missing mass reconstructed from: $M^2_{A'/a/\phi} = s + m^2_{e^-} - 2E^*_{e^-}\sqrt{s}$

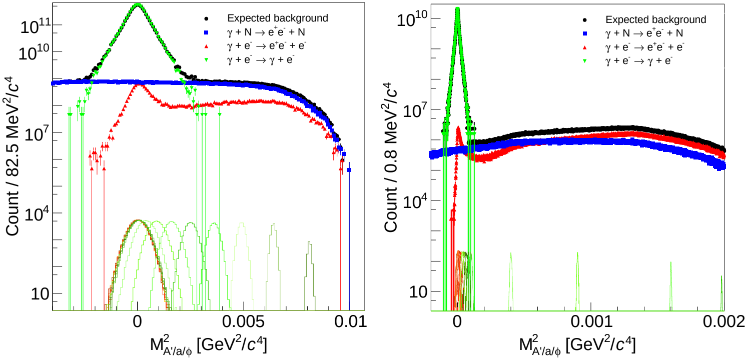


Efficiency (left) and resolution (right)

Expected background for single electron analysis for invisible or long-lived decay

From SM Compton, SM pair, and SM triplet

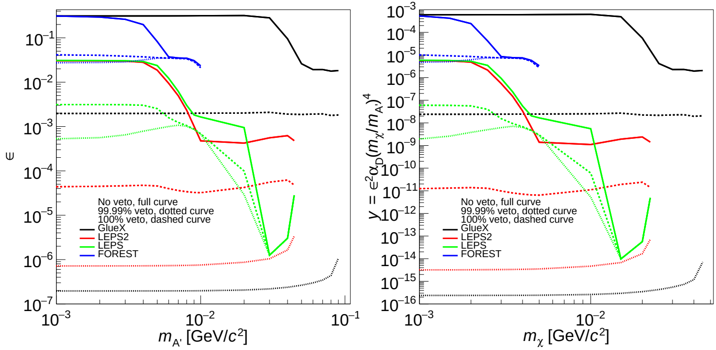
- For one month beam-time and 30 cm (left/GlueX) and 5 cm (right/LEPS2) LH_2 target
- Background can be suppressed by a γ and e^+e^- pair veto



Expected sensitivity for $A'/a/\phi \to \chi\bar{\chi}$

90% C.L. on ϵ/y for the Compton process determined by a shape experiment (peak search)

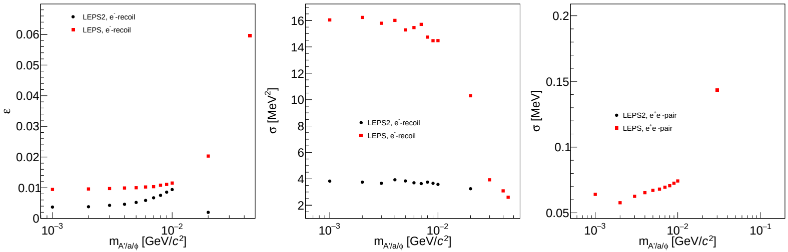
- Liquid hydrogen target
- One month of data taking
- NB: $g_{ae} = y_e = \sqrt{\alpha} \times \epsilon$
- $\alpha_D = 0.5$ and $m_{A'} = 3m_\chi$



Visible analysis

LEPS2: one track + e^+e^--pair veto recording hits
LEPS: three tracks

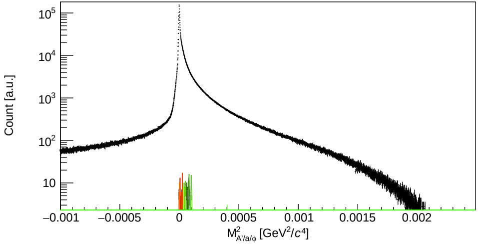
- Identified as electron(s) and positron
- p $\geq$ 100 / 200 MeV/c for LEPS2/LEPS
- Polar angle below 6^o / 4^o
- Transverse momentum cuts to remove pair/triplet production
- LEPS2, M^2, and LEPS: Dark particle invariant mass reconstructed from the e^+e^--pair

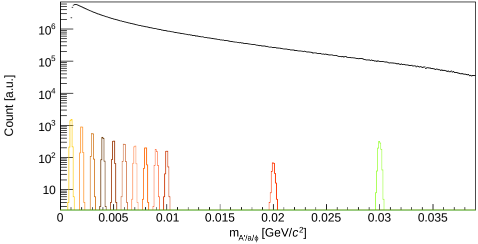


Efficiency (left) and resolution (middle and right).

Expected background for visible analysis

From e^-e^+-pair of pair and triplet productions



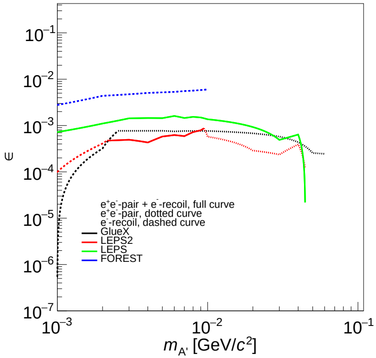


LEPS2 (up) and LEPS (down) expected background and signal ($\epsilon = 10^{-4}$) for one month beam time.

Expected sensitivity for $A'/a/\phi \rightarrow e^+e^-$

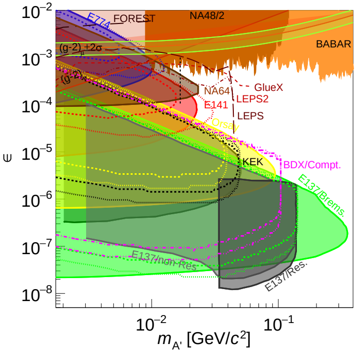
90% C.L. on $\epsilon/g_{ae}/y$ for the Compton process determined by a shape experiment (peak search)

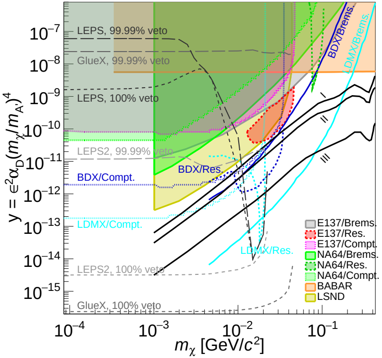
- Liquid hydrogen target
- One month of data taking
- NB: $g_{ae} = y_e = \sqrt{\alpha} \times \epsilon$



Photon-beam fixed-target experiments are competitive provided they are tuned

- Heavy Z target
- Veto detector
- *Be* anomaly region can be scanned





- $$\frac{\epsilon_1^{90\%\mathrm{up}}}{\epsilon_0^{90\%\mathrm{up}}} = \left(\frac{\mathcal{L}^0}{\mathcal{L}} \frac{\Delta_M}{\Delta_M^0} \frac{\varepsilon^0}{\varepsilon}\right)^{0.25}$$, Δ_M is the observable resolution

Conclusions

Cosmological anomalies are observed at different scales and ages of the Universe

- Dark matter could explain these anomalies but other explanations are also possible

First study of the Compton-like photoproduction of dark photon, axion-like, or dark scalar particles off electrons with accelerator based experiments

- Did we turn on all the lamp-posts? **No, we did not.**
- Is the "dark" Compton process a lamp-post that we should turn on? **YES, in my opinion.**
- Photon-beam fixed-target experiments such as GlueX, LEPS2/E949, LEPS/BFOegg, and FOREST can:
  - Potentially detect dark photon, axion-like, or dark scalar particles of a mass below 100 MeV/c^2 and light dark matter of a mass below 50 MeV/c^2
  - Or if no signal is found, extract competitive limits on ϵ, g_{ae}, y_e, and y

Thank you