Light neutral boson searches with TREK and DarkLight

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Abstract

Hidden-sector light bosons can provide simultaneous explanations of dark matter and solutions of recent puzzles in particle physics such as the muon anomalous magnetic moment or the proton charge radius.
The TREK program at J-PARC, Japan, provides opportunity to search for light bosons in the mass region below 200 MeV/c^2 via rare decay of positively charged kaons in several decay modes.
A dedicated search for a dark photon below 100 MeV/c^2 is being pursued with the DarkLight program at Jefferson Lab, Virginia, USA, using electron scattering from a hydrogen gas target internal to an energy recovery accelerator.
A large production data set has been acquired with TREK in 2015, while preparations are ongoing for the initial phase of the DarkLight program in 2016-17. The status of both programs will be presented.

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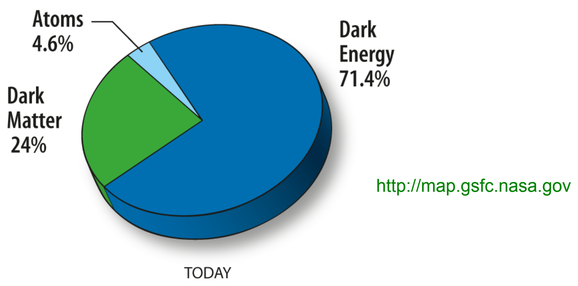
Dark Photon

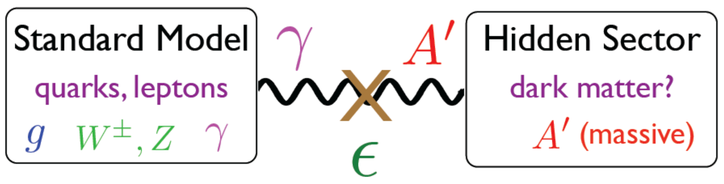


http://map.gsfc.nasa.gov

TODAY

- 24% of the universe are Dark Matter (DM)
  → Rotation of galaxies; gravitational lensing; WMAP
- DM is diffusely distributed, could be particles (e.g. WIMPs)
- U(1) hidden sector extension of the Standard Model:
  Dark Matter interacting with SM via U(1) gauge boson (Fayet 2004)
- Astrophysical motivation for Dark Matter annihilation:
  positron excess – PAMELA, FERMI, AMS-02
- Muon anomalous magnetic moment g_μ–2
  → Kinetic mixing model (Holdom 1986, Pospelov 2009)
- Be-8 signal and its implication: protophobic boson
- Beyond kinetic mixing: Proton radius puzzle R_p
- Lepton-flavor non-universal interaction
  (preferred coupling to muons)
  → Coupling to right-handed muons (Batell, McKeen, Pospelov)
  due to constraints from neutrino scattering
  → Fine-tuned non-universal couplings (Carlson, Rislow)
  → Electrophobic bosons (Miller)

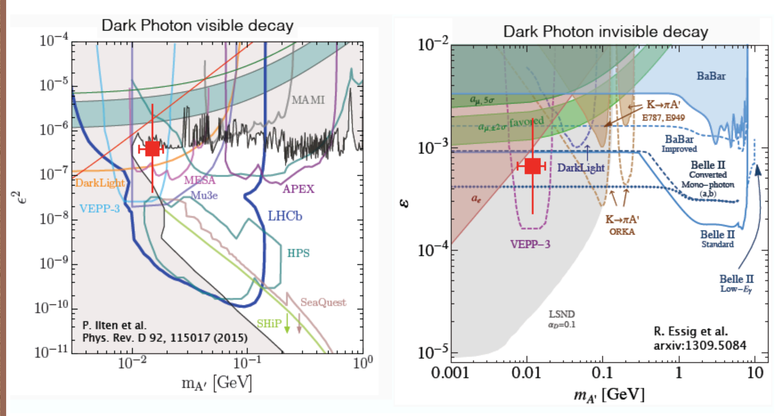
Dark Sector



Simultaneous explanation for

- Cosmic ray positron excess (PAMELA, FERMI, AMS02)
- Absence of anti-proton excess (PAMELA)
- Anomalies in direct detection experiments (e.g. DAMA/LIBRA)
- Natural explanation for muon g_μ–2

Comparison of A' searches

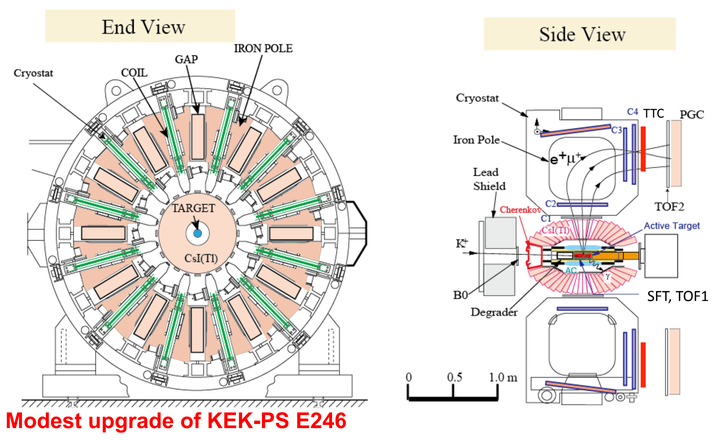


Prediction of 17-MeV protophobic neutral boson (approximate)
DarkLight will be optimized for sensitivity in low-mass region

- Be-8 signal: A.J. Krasznahorkay et al., PRL116, 042501 (2016) [arXiv:1504.01527v1]
- Protophobic boson: J. Feng et al., arXiv:1604.07411v1

TREK/E36

- Stopped K^+ beam (target)
- 12-Sector Iron-Core Superconducting Toroidal Spectrometer



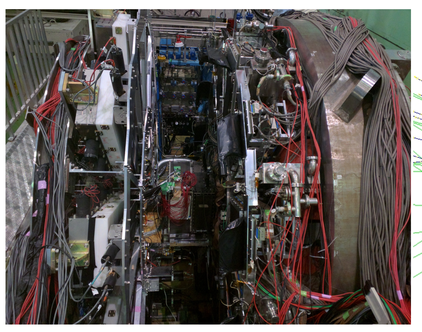
Modest upgrade of KEK-PS E246

Stopped K method
- K1.1BR beamline
- Fitch Cherenkov
- K^+ stopping target

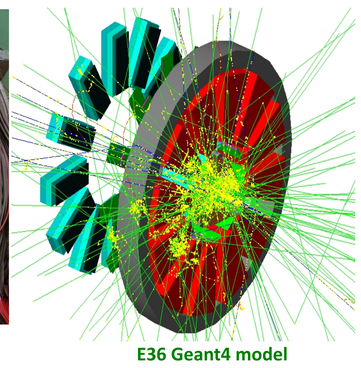
Tracking
- MWPC (C2, C3, C4)
- Spiral Fiber Tracker (SFT)
- 256 longit. fibers (TGT)

PID
- TOF (TOF1, TOF2. TTC)
- Aerogel Cherenkov (AC)
- Pb glass counter (PGC)

Gamma ray
- CsI(Tl)



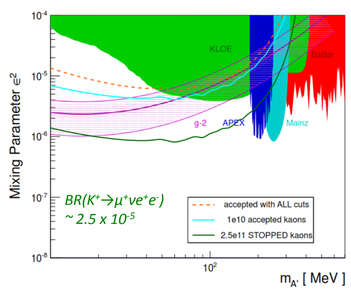
E36 Apparatus



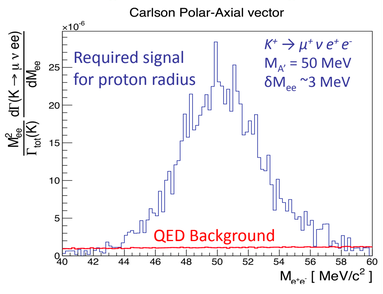
E36 Geant4 model

- Search for visible decay mode of $A' \to e^+e^-$ in K^+ decays
  Kaons: $K^+ \to \mu^+ \nu A'$; $K^+ \to \pi^+ A'$ (also invisible decay);
  Pions: $\pi^0 \to \gamma A'$, *using* $K^+ \to \pi^+\pi^0$ (21.13%), $K^+ \to \mu^+ \nu \pi^0$ (3.27%)
- E36 sensitive to dark photons with masses < 200 MeV/c^2
  in the region of the g_μ–2 welcome band
- E36 can rule out or confirm with very high confidence
  all new theories with non-universal light bosons explaining
  the proton radius puzzle and g_μ–2

E36: Dark photon exclusion limit

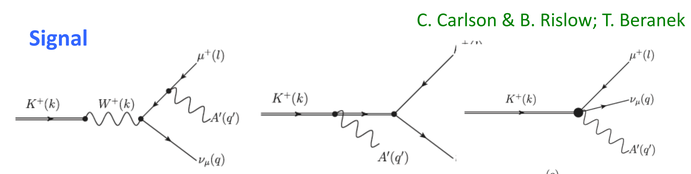


E36: Light boson expected signal

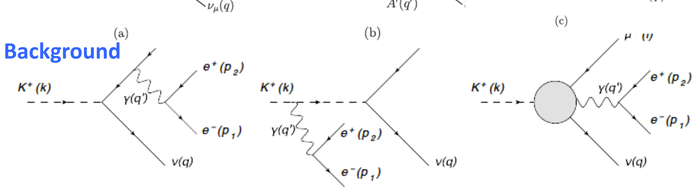


C. Carlson & B. Rislow; T. Beranek

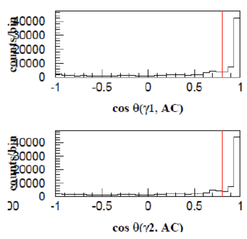
Signal



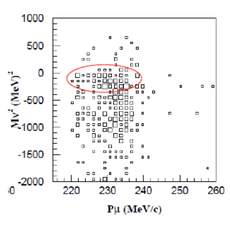
Background



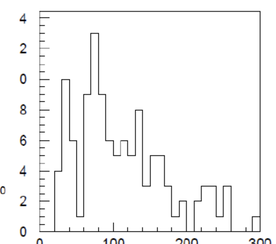
- Background: SM process with time-like (virtual) photon exchange
  - Calculable in QED, BR($K^+ \to \mu^+ \nu \ e^+ \ e^-$) = 2.49 x 10^{-5}
    J. Bijnens et al., Nucl. Phys. B396, 81 (1993), hep-ph/9209261
  - Measured for m_{ee} > 145 MeV/c^2
    A. Poblaguev et al., Phys. Rev. Lett. 89, 061803 (2002), hep-ex/0204006
- A first, very preliminary look at the data:



Correlate CsI e^+e^- hits with AC sector



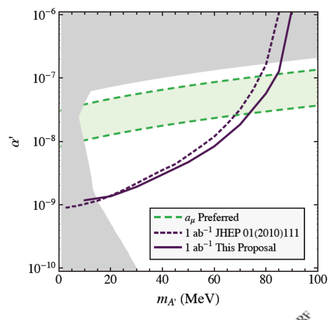
Evaluate $K^+ \to \mu^+ e^+ e^- \nu$ missing mass



Select μ^+ momentum > 205 MeV/c ($K_{\pi 2}$)
Evaluate $A' \to e^+ e^-$ invariant mass

DarkLight

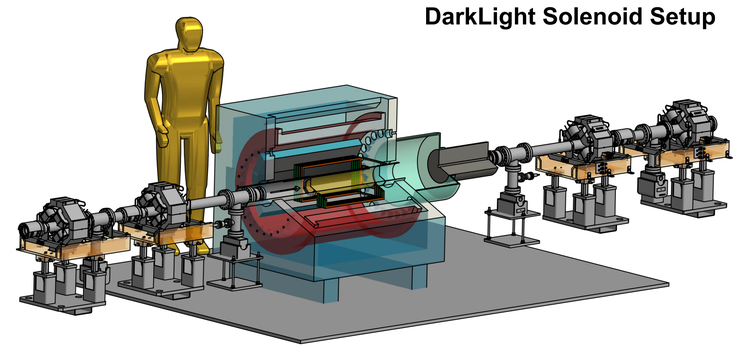
- Dark photons (universal coupling) well motivated by dark matter observations (astronomical, direct, positrons)
  in combination with g_μ–2 anomaly
- To be run at the Low Energy Recirculator Facility (LERF) at Jefferson Lab
- Search for visible decay modes of
  $A' \to e^+e^-$ in ep → e p $A' \to$ e p e^+e^-
- Search for invisible decays $A' \to X$ in ep → e p X



LERF (formerly known as FEL)

- **DarkLight phase I:**
  - ✓ Funded (NSF-MRI) in 2014, HU responsible for lepton tracker
  - ✓ Prepare to run phase 1a in 2016 and phase 1b/c in 2017
  - ✓ Re-use an existing GEM telescope with 4th chamber added

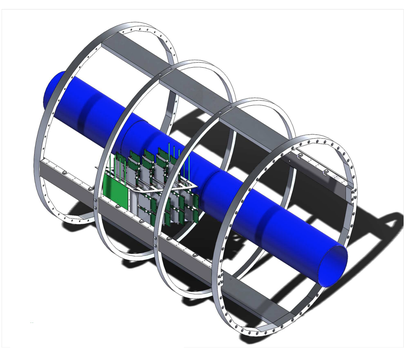
DarkLight Solenoid Setup

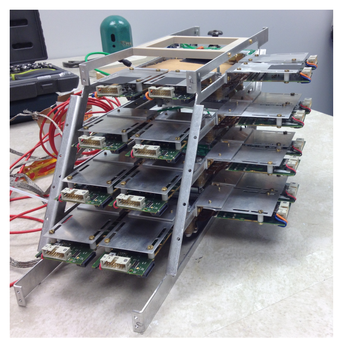


Three science goals:

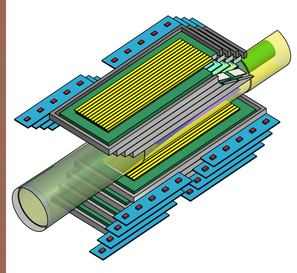
1) Accelerator physics: Demonstrate operation of energy-recovery beam with internal target at full luminosity
2) Precise measurement of Standard Model processes
3) Search for the A'

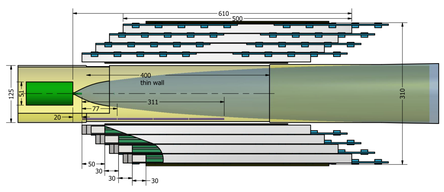
Phase 1a: 4 GEM chambers 10x10 cm² (summer 2016)





Phase 1c:
8 GEM chambers 12x40 cm² (~2017)





Constructed at Hampton University (NSF MRI award PHY-1436680)