Experimental Search for Weakly Coupled Light Gauge Bosons

A', U, γ', γ_d, ...

- Worldwide searches underway based on existing experiments

No observations to date!

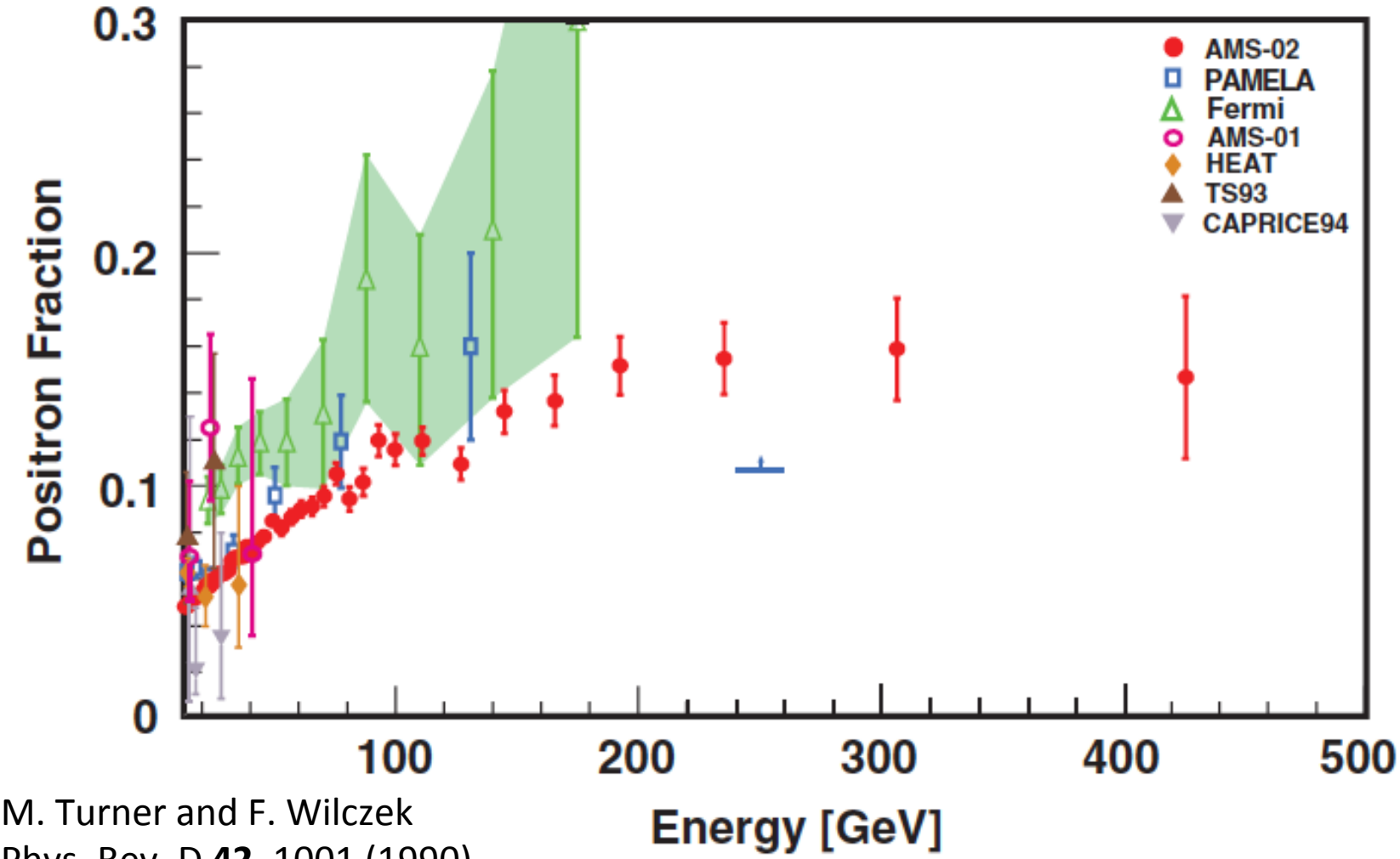
- Dedicated experiments to search being prepared at Jefferson Laboratory

The Alpha Magnetic Spectrometer Experiment on the International Space Station

AMS is an MIT led International Collaboration
16 Countries, 60 Institutes and 600 Physicists

New AMS-02 Data: Positron fraction vs. energy

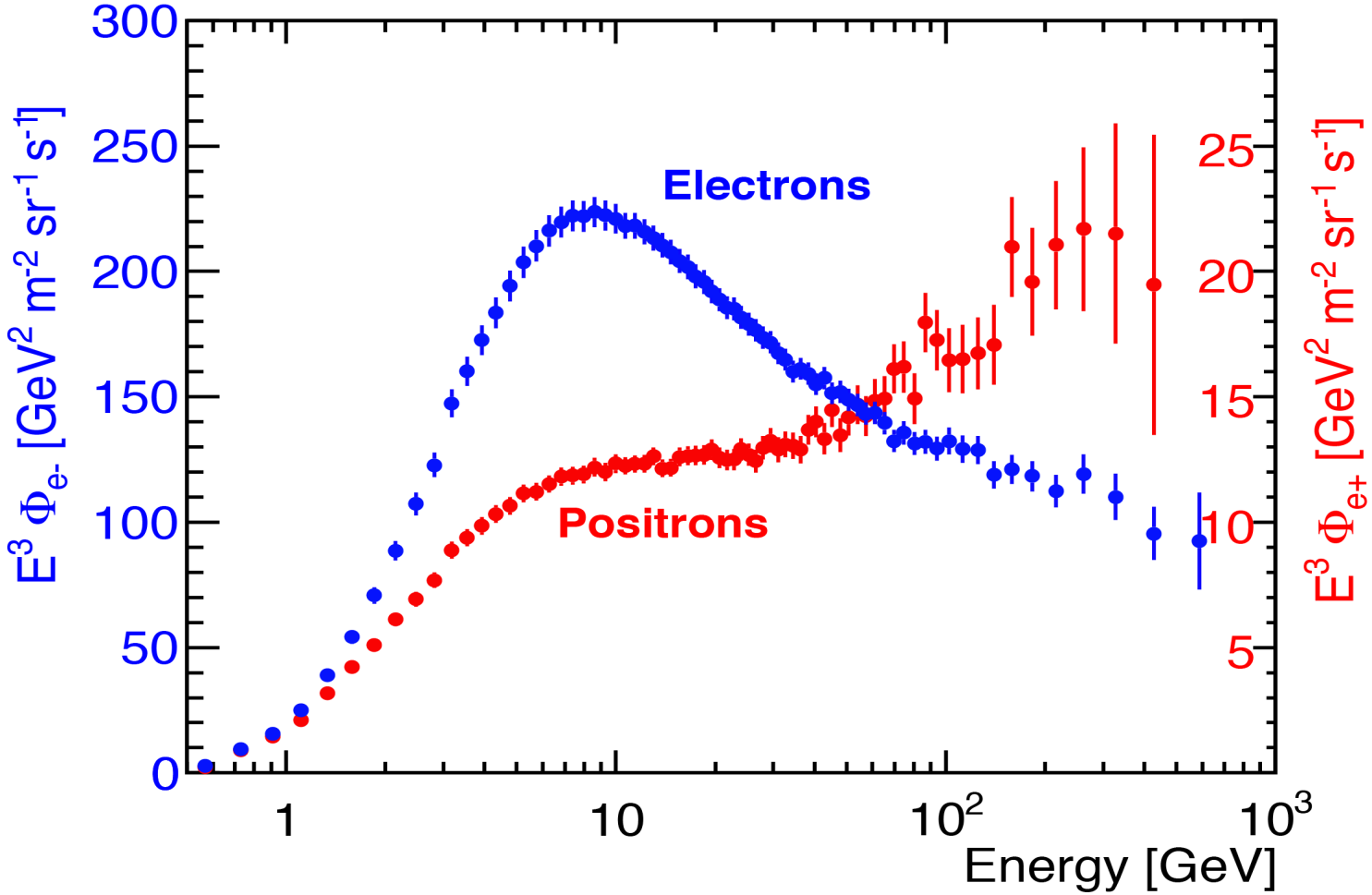
Phys. Rev. Lett. 113, 121101



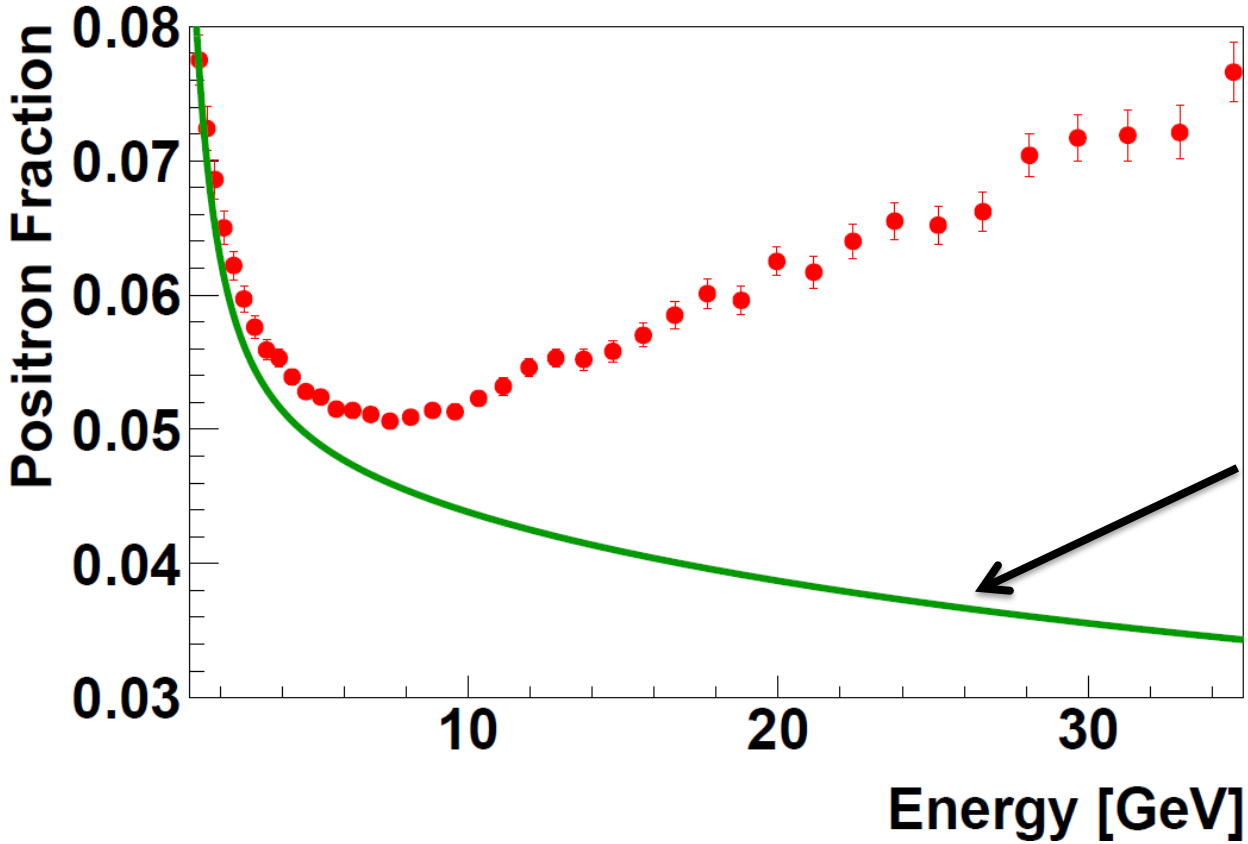
M. Turner and F. Wilczek
Phys. Rev. D **42**, 1001 (1990)

AMS-02 flux data

Phys. Rev. Lett. 113, 121101
Phys. Rev. Lett. 113, 121102

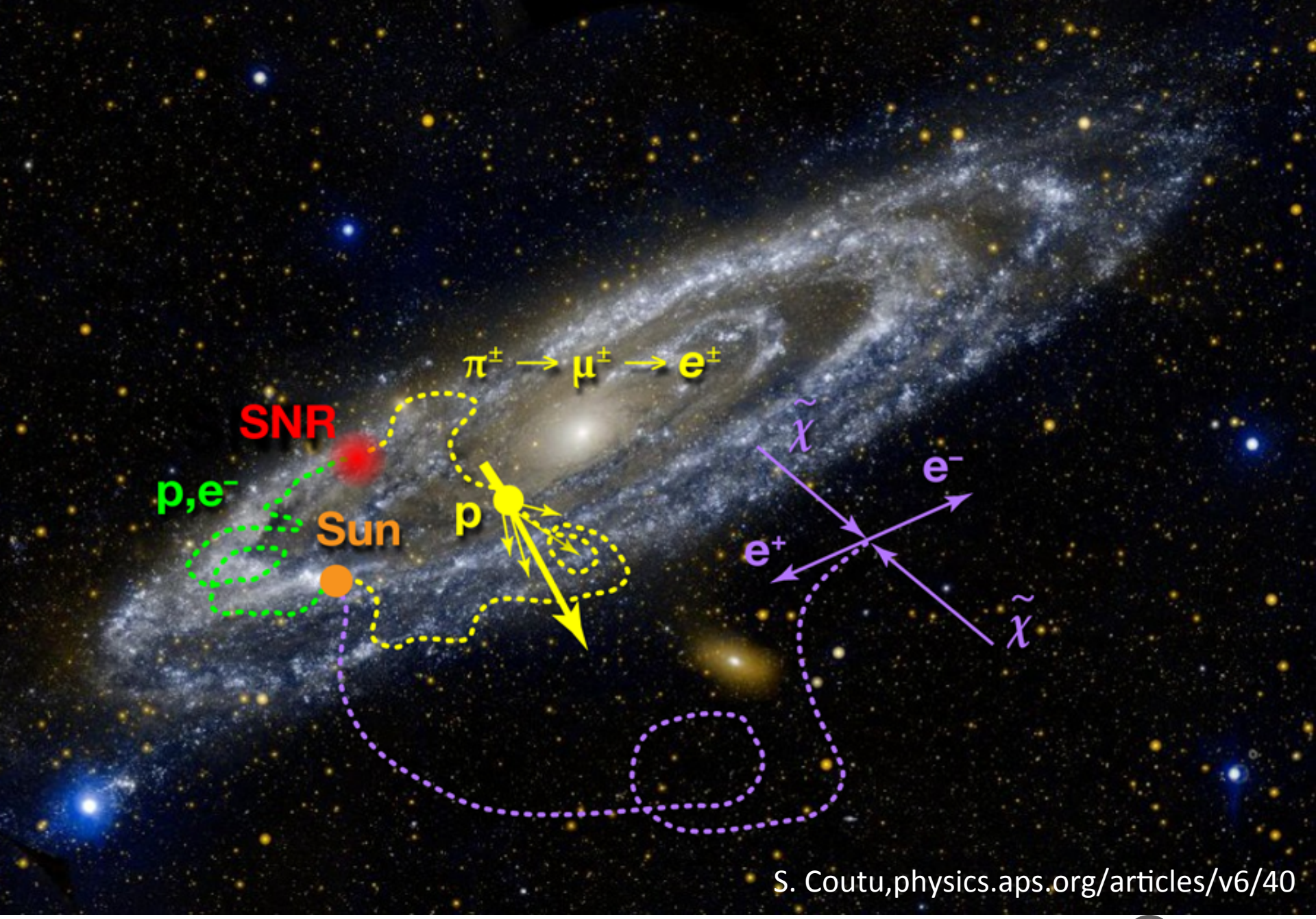


AMS-02 data: positron yield rises above 8 GeV



Phys. Rev. Lett. 113, 121101
Phys. Rev. Lett. 113, 121102

Expectation based on collision of ordinary cosmic rays



S. Coutu,physics.aps.org/articles/v6/40

Searching for a Dark Photon

Kinetic mixing:

$$\frac{\epsilon}{2} F^{Y}_{\mu\nu} F'^{\mu\nu}, \text{ where } F'_{\mu\nu} = \partial_{[\mu} A'_{\nu]}$$

$$\alpha' = \epsilon^2 \alpha_{\mathrm{EM}}$$

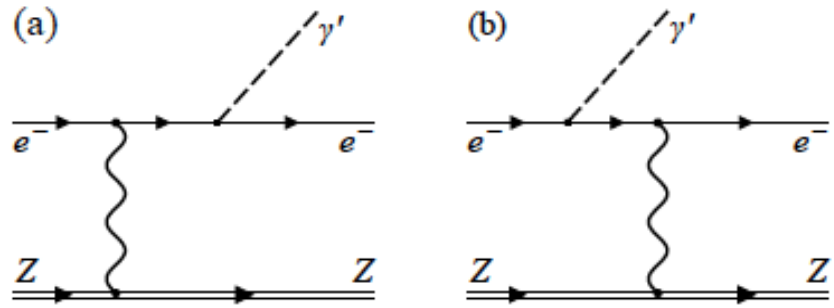


FIG. 1. Radiative production of a γ' in final (a) and initial state (b) on a heavy target nucleus Z. The subsequent decay of the γ' to an electron-positron pair would be the unique signal of such a γ' with a sharp mass distribution.

Warning!
Check variable on vertical axis in sensitivity plots

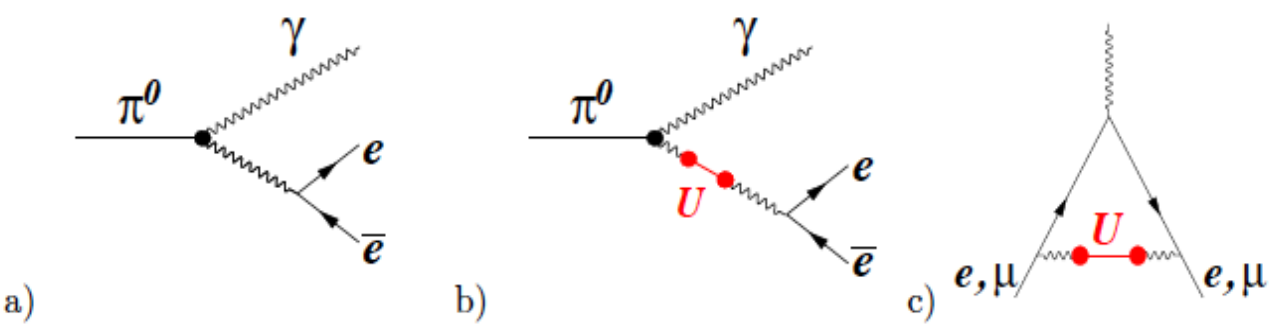
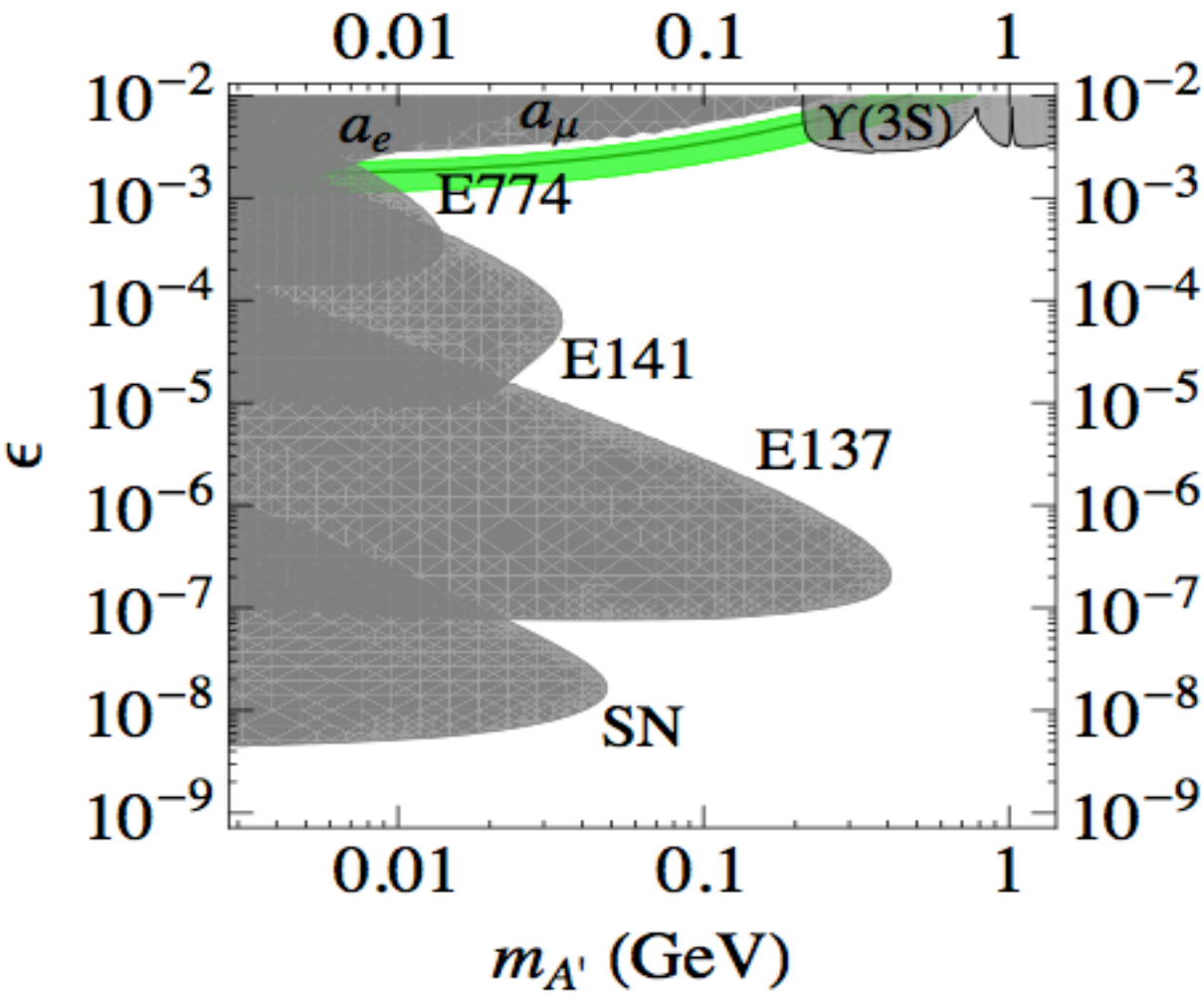


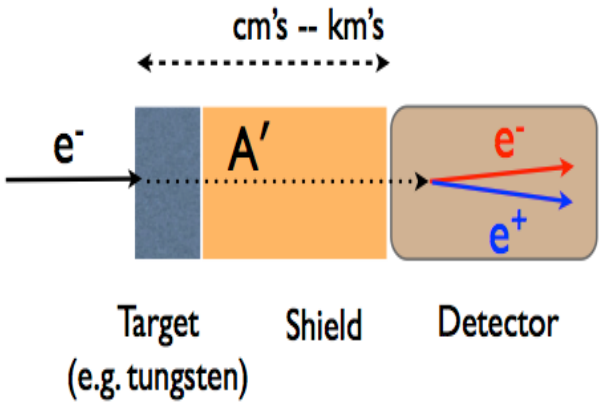
Figure 1: Feynman diagrams for a) the lowest order electromagnetic $\pi^0 \to e^+e^-\gamma$ decay and a possible contribution of U vector boson to: b) $\pi^0 \to e^+e^-\gamma$ and c) lepton $g-2$.

BABAR
Search for resonance in dimuon inv. mass distribution in Υ(2S,3S)➔γA' followed by A' ➔μ+μ-

Beam dump constraints



J.D. Bjorken et al., arXiv: 0906.0580



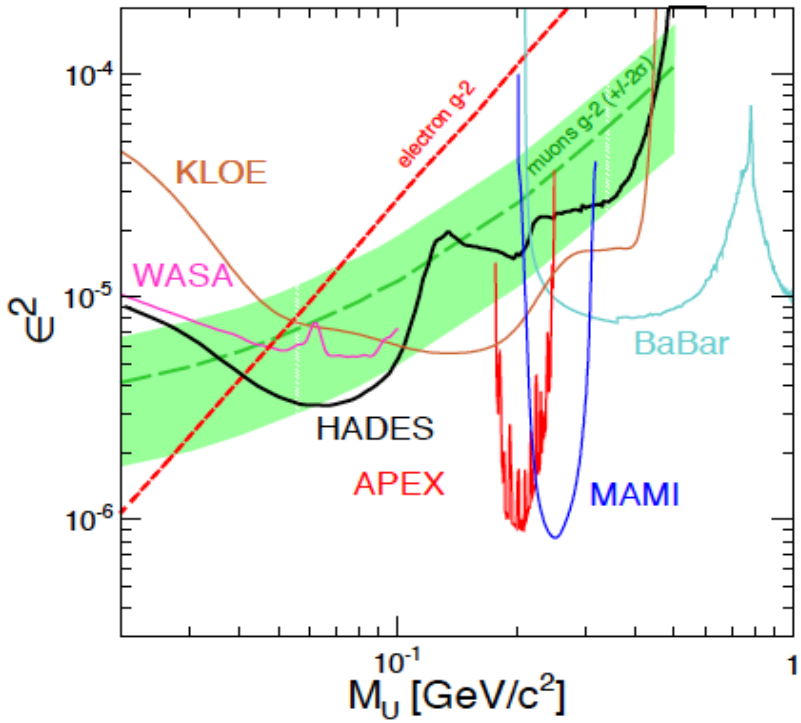
Look for resonant peak In the in. mass distr. of e+e- pairs appearing after thick shielding

Ongoing A' Searches

- KLOE-2@DAϕNE(ϕ➔ϕA' followed by A'➔e+e-)
- HADES@GSI (p+p, p+^{93}Nb, p+^{40}Ar, ^{84}K+^{35}Cl production: π^0,η, Δ decay followed by A'➔e+e-)
- BaBar@SLAC (e+e-➔ϒ➔γA' with A'➔μμ)
- WASA@COSY (π^0 decay)
- PHENIX@RHIC (π^0 decay)
- A1@MAMI (e on ^{181}Ta)
- ATLAS and CMS @LHC
- SeaQuest @ FNAL
- milliQ@SLAC: invisible search
- APEX@JLab (e on ^{181}Ta)
- HPS@JLab (e on ^{184}W)
- DarkLight @ JLab ERL (e-p elastic scattering below π threshold)

HADES

arXiv:1311.0216



90% confidence limit

Fig. 5. (Color online) The 90% CL upper limit on ϵ^2 versus the U-boson mass obtained from the combined analysis of HADES data (solid black curve). This result is compared with existing limits from the MAMI/A1, APEX, BaBar, WASA, and KLOE-2 experiments, as well as with the $g-2$ constraints (see the text for citations).

EM decays of few-GeV interactions, e.g.

$\pi \rightarrow \gamma A'$ $\eta \rightarrow \gamma A'$

$\Delta \rightarrow \gamma A'$

followed by

$A' \rightarrow e^+e^-$

WASA@COSY

arXiv: 1304.0671

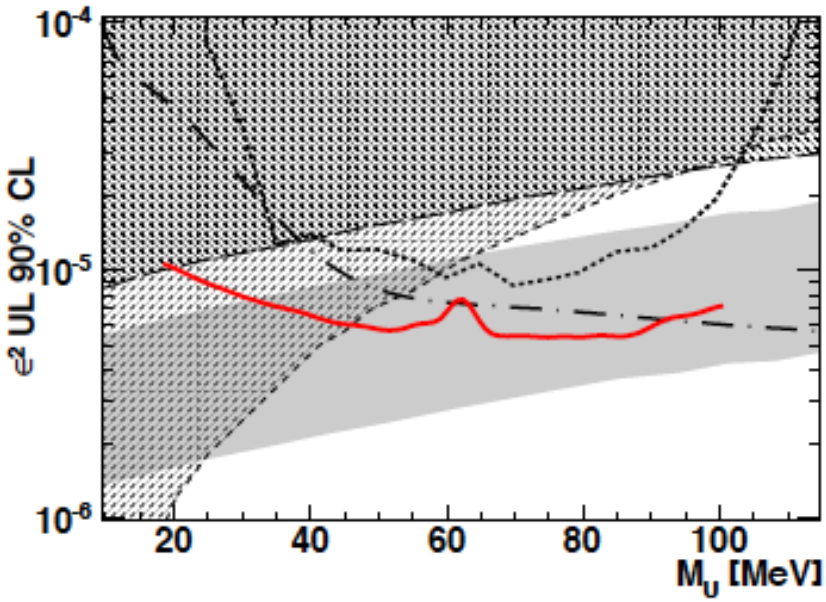
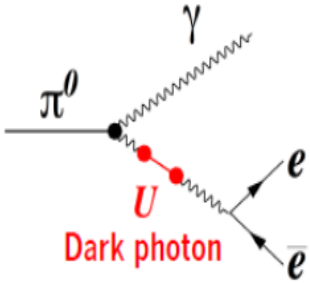


Figure 8: Summary of the 90% CL upper limits for the mixing parameter ϵ^2 from WASA-at-COSY (red solid line) compared to SINDRUM $\pi^0 \to e^+e^-\gamma$ [37] (dotted line) and recent combined KLOE $\phi \to \eta e^+e^-$ [47] (dashed dotted) upper limits. The long respectively short dashed lines (and the corresponding hatched areas) are the upper limits derived from the muon and the electron $g-2$ [32]. In addition the gray area represents the $\pm 2\sigma$ preferred band around the present value of the muon $g-2$.

PHENIX@RHIC



arXiv: 1409.0851

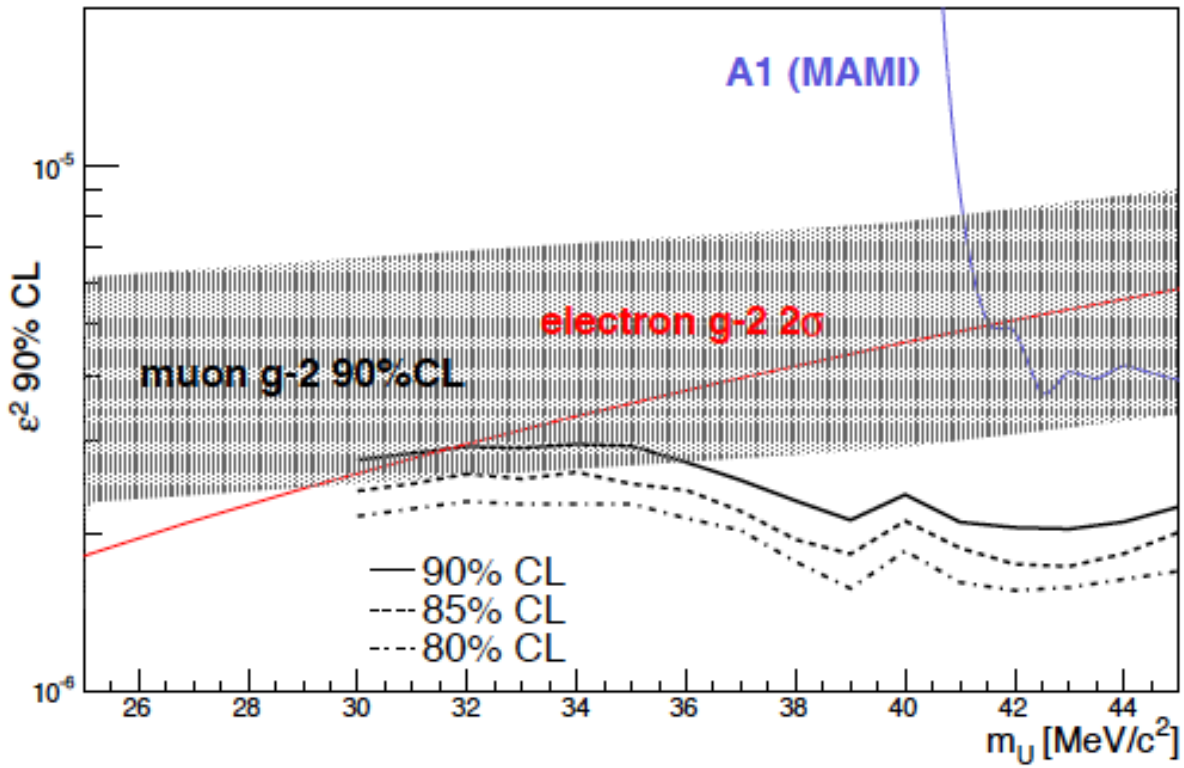
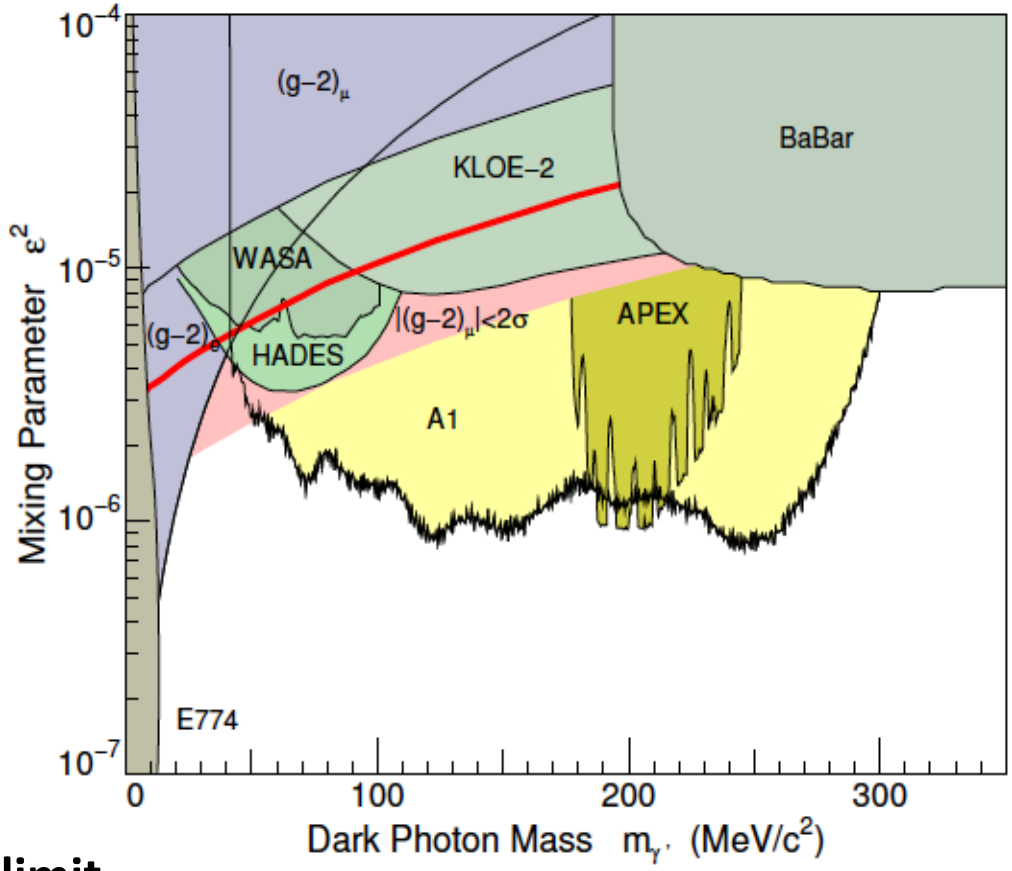


Figure 4: Dark photon limits with different confidence levels with the 90% CL $(g-2)_\mu$ anomaly explainable band.

A1@MAMI 2014

arXiv: 1404.5502



E_0: 180-855 MeV

BABAR and KLOE-2 are 90% confidence limits

2σ exclusion limit

FIG. 3. (color online). Exclusion limits in terms of mixing parameter ϵ. The yellow (light shaded) area marked with A1 is excluded by this experiment.

@ LHC

arXiv:1409.0746

Search for long-lived neutral particles decaying into lepton jets in proton–proton collisions at $\sqrt{s}$ = 8 TeV with the ATLAS detector

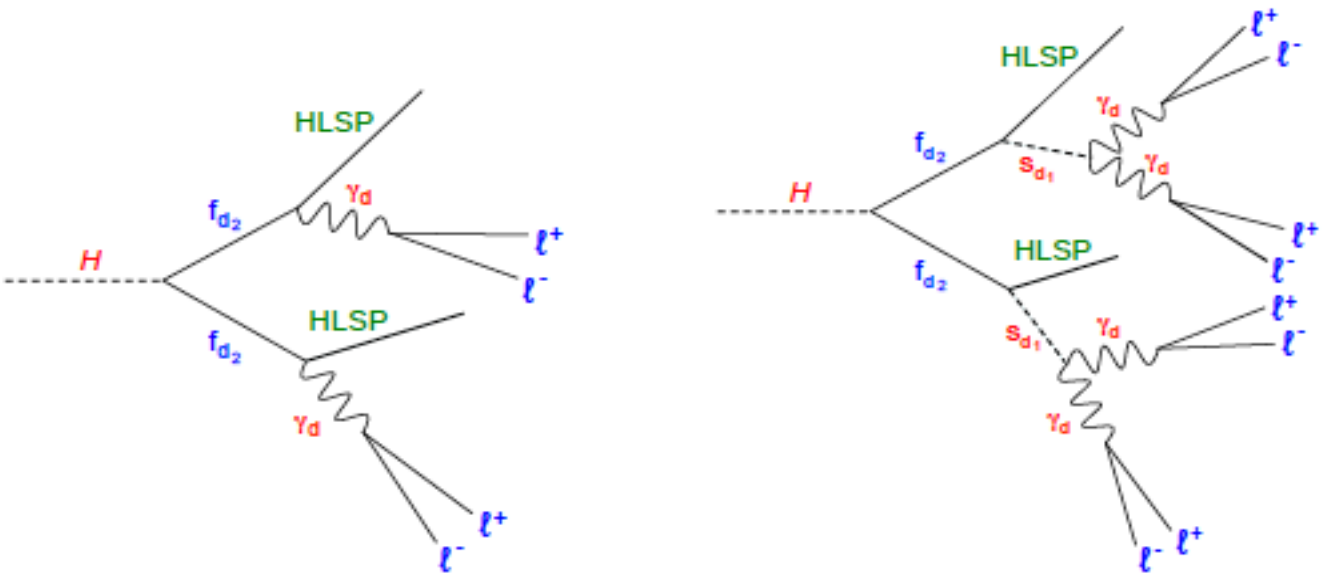
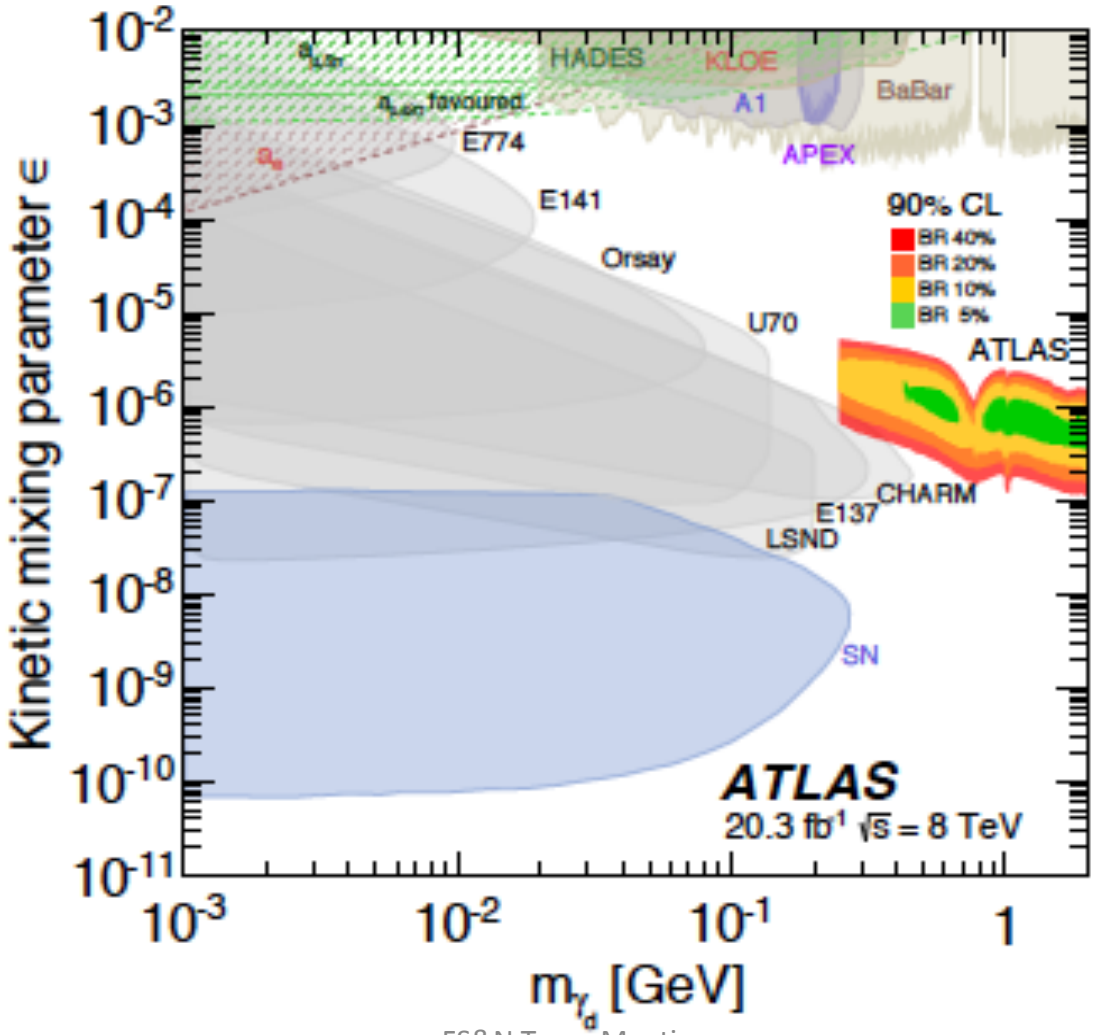


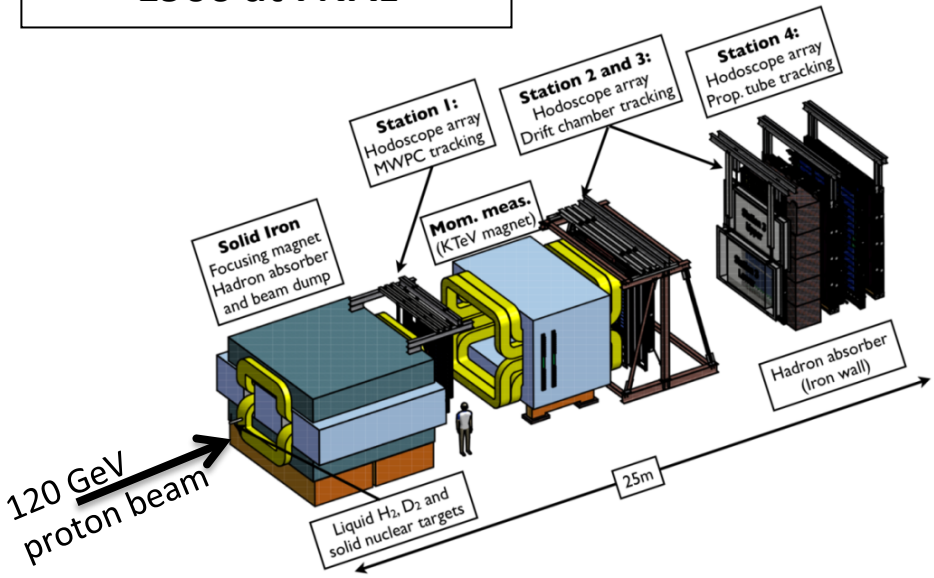
Figure 1. Diagrams of the two FRVZ models used as benchmarks in the analysis. $\ell^+\ell^-$ corresponds to electron/muon/pion pair decay in the final state.

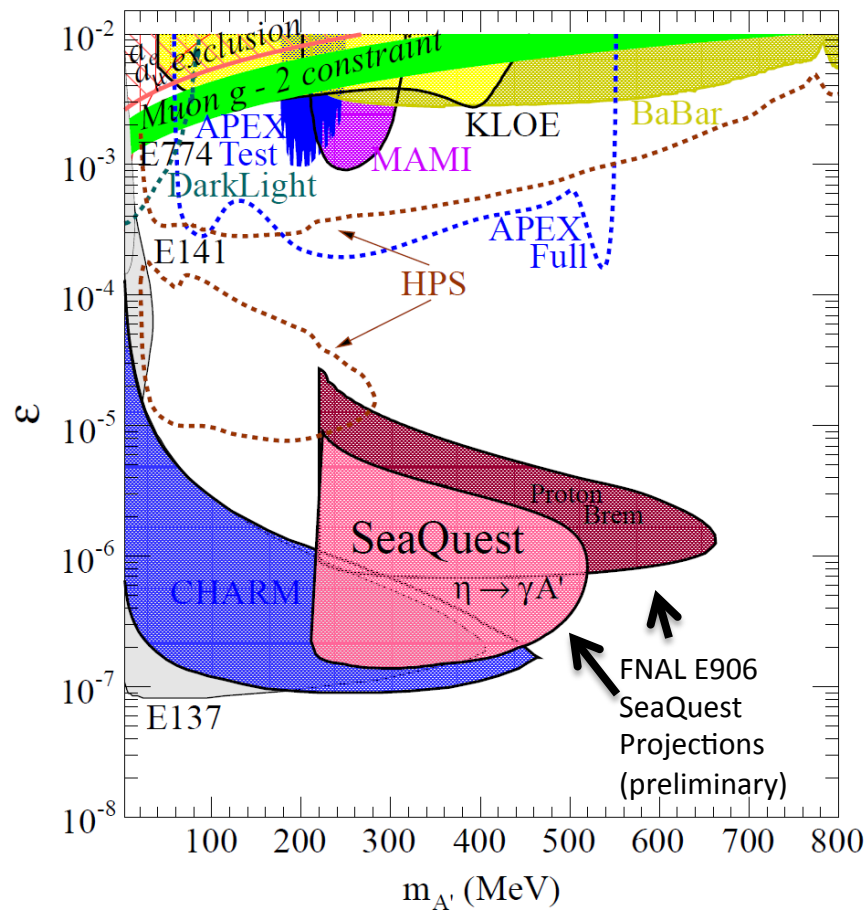
@ LHC


Kinetic mixing parameter ε
m_{γ_d} [GeV]
HADES
KLOE
BaBar
A1
APEX
E774
E141
Orsay
U70
90% CL
BR 40%
BR 20%
BR 10%
BR 5%
ATLAS
CHARM
E137
LSND
SN
ATLAS
20.3 fb^{-1} $\sqrt{s}$ = 8 TeV

Search for Dark Photons at SeaQuest

Drell-Yan experiment
E906 at FNAL



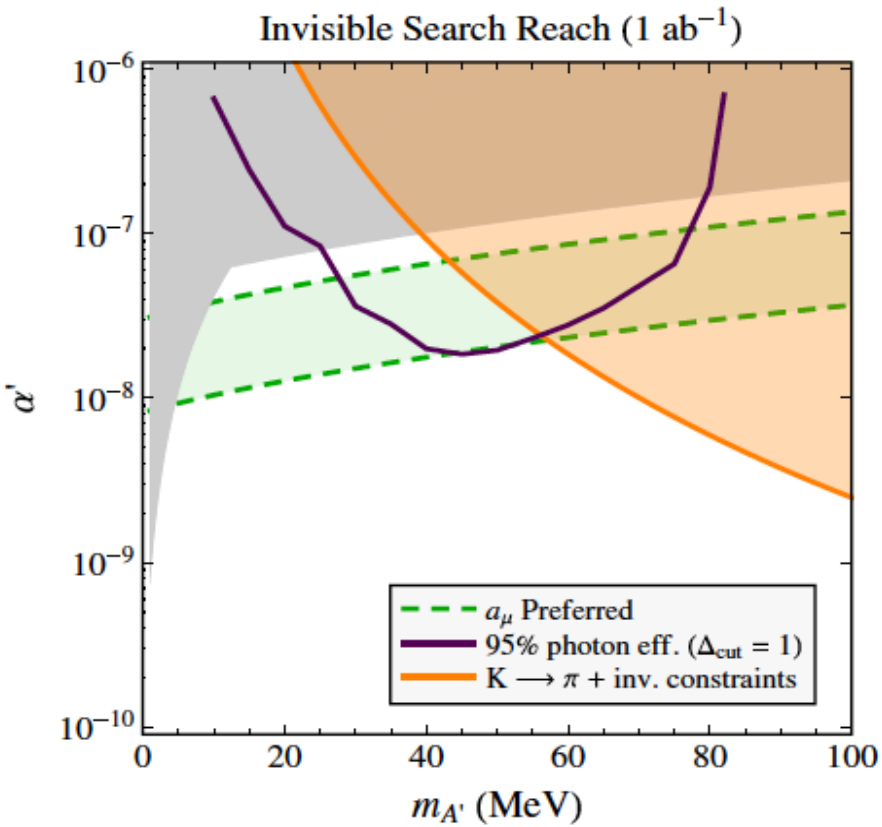


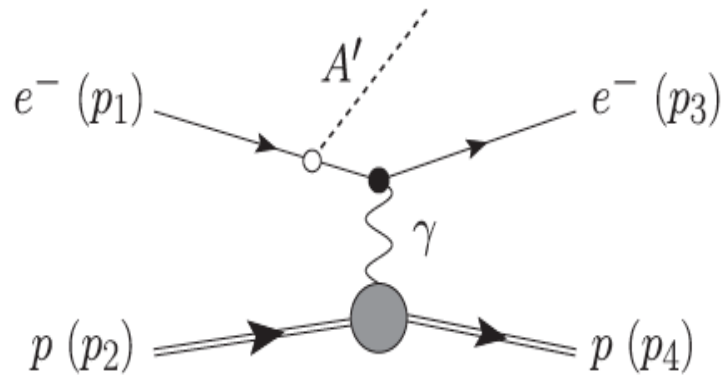
- Nearly ideal beam-stop experiment
- Underway for at least the next year

$$L \sim -\frac{1}{4}F^{SM}_{\mu\nu}F^{\mu\nu}_{SM} - \frac{1}{4}F^{hidden}_{\mu\nu}F^{\mu\nu}_{hidden} + \frac{1}{2}\epsilon F^{SM}_{\mu\nu}F^{\mu\nu}_{hidden} + m^2_{A'}A^{hidden}_{\mu}A^{\mu}_{hidden}$$

Invisible searches

Kahn and Thaler, Phys. Rev. D **86**, 115012 (2012)





VEPP-3 proposal
arXiv: 1207.5089

K➔π constraint absent if A' does not couple to quarks

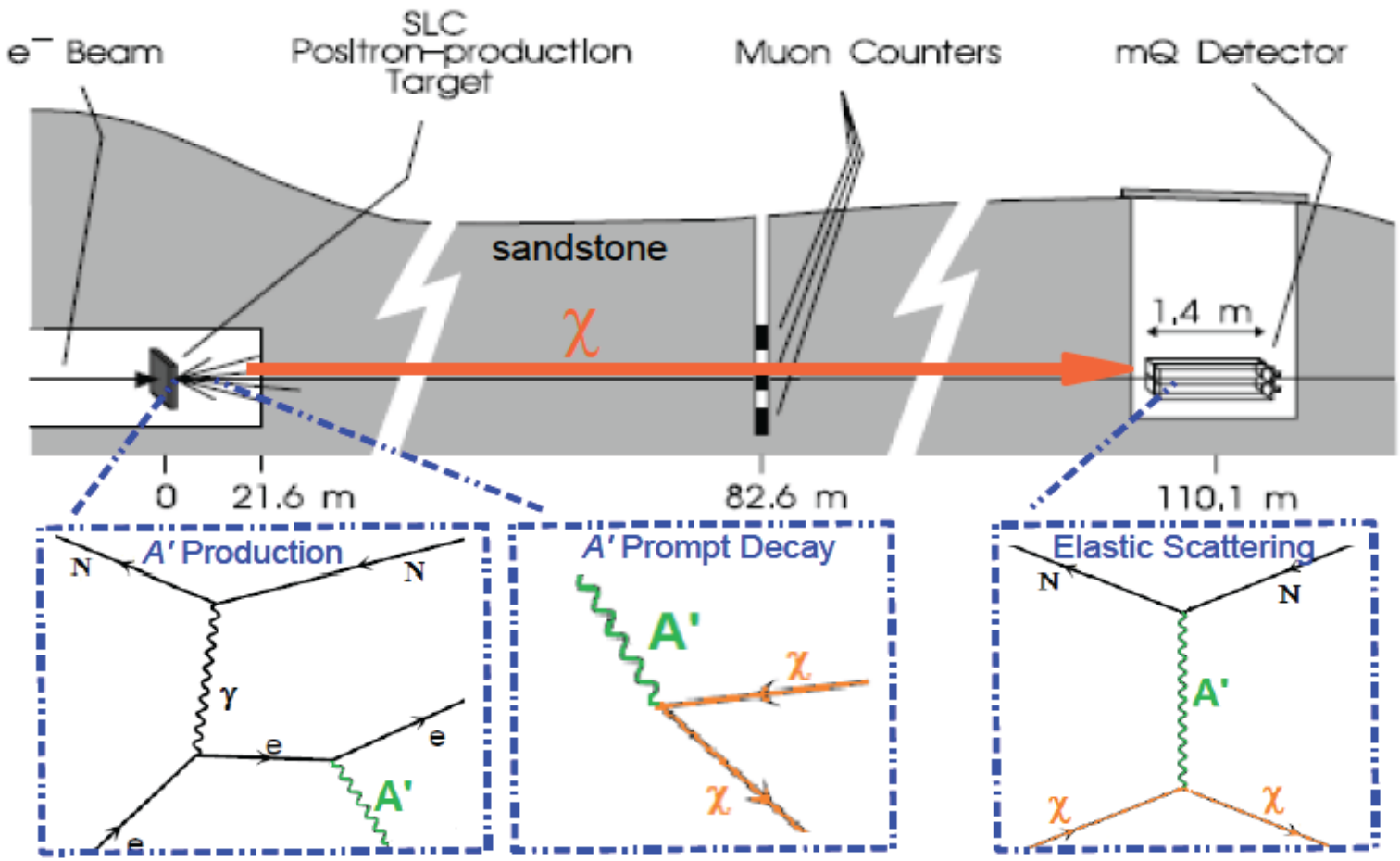
Searching for Light Dark Matter with the SLAC Millicharge Experiment

M. Diamond[1,*] and P. Schuster[1,†]

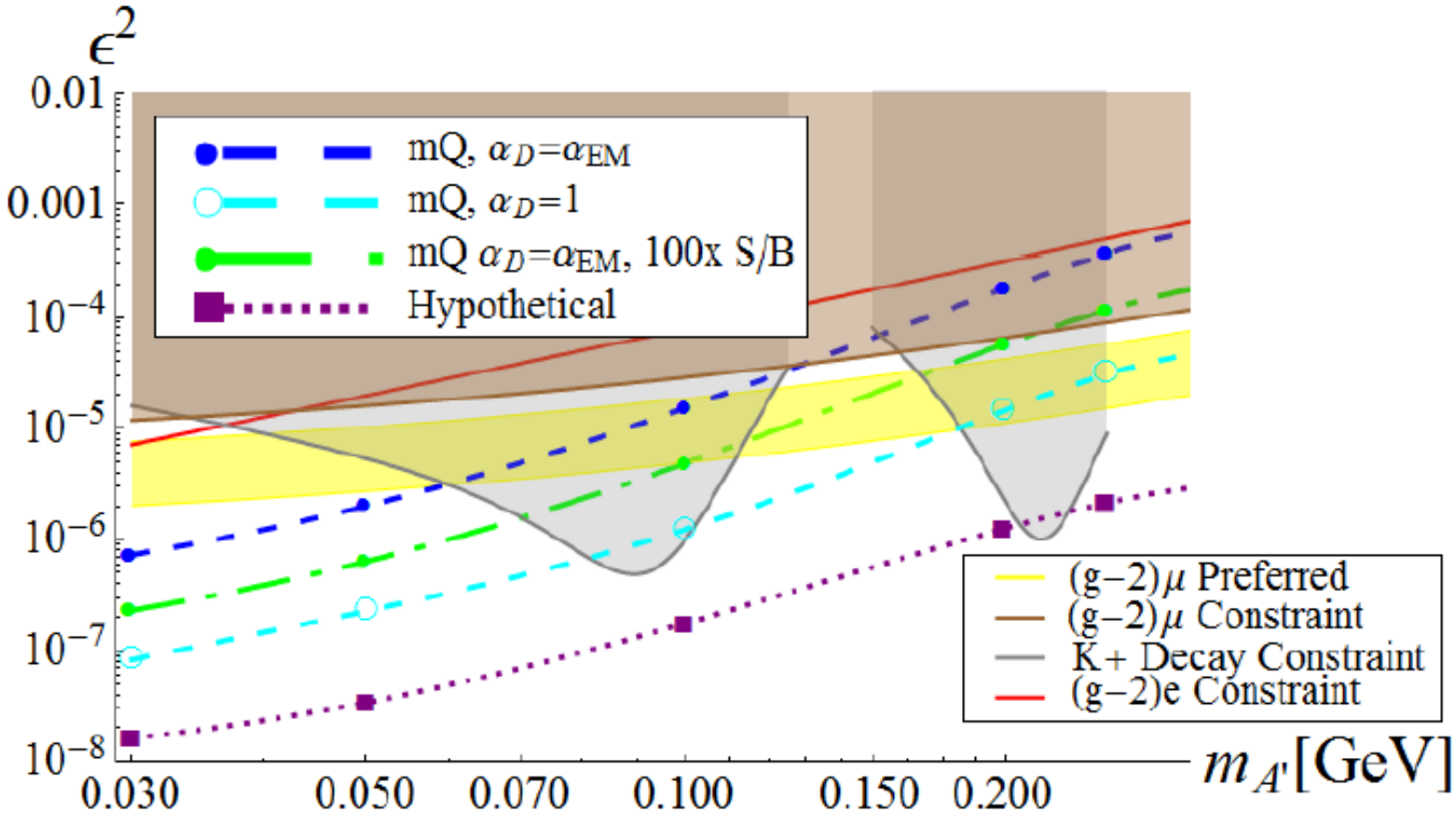
[1]*Perimeter Institute for Theoretical Physics, Waterloo, ON N2L 2Y5, Canada*

(Dated: July 29, 2013)

arXiv:1307.6861

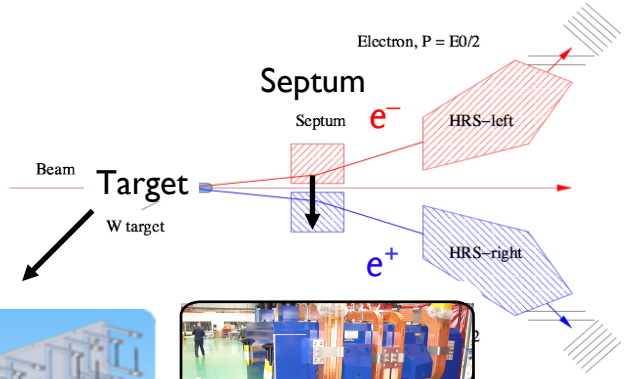


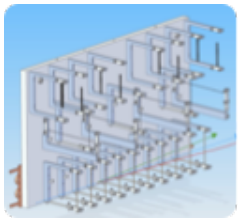
Assuming m_χ = 10 MeV

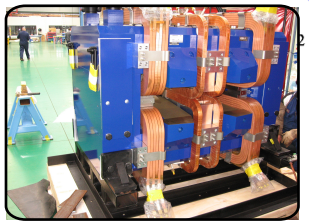


APEX

Search for new gauge boson A' using Hall A high-resolution spectrometers (HRS)







HRS detectors

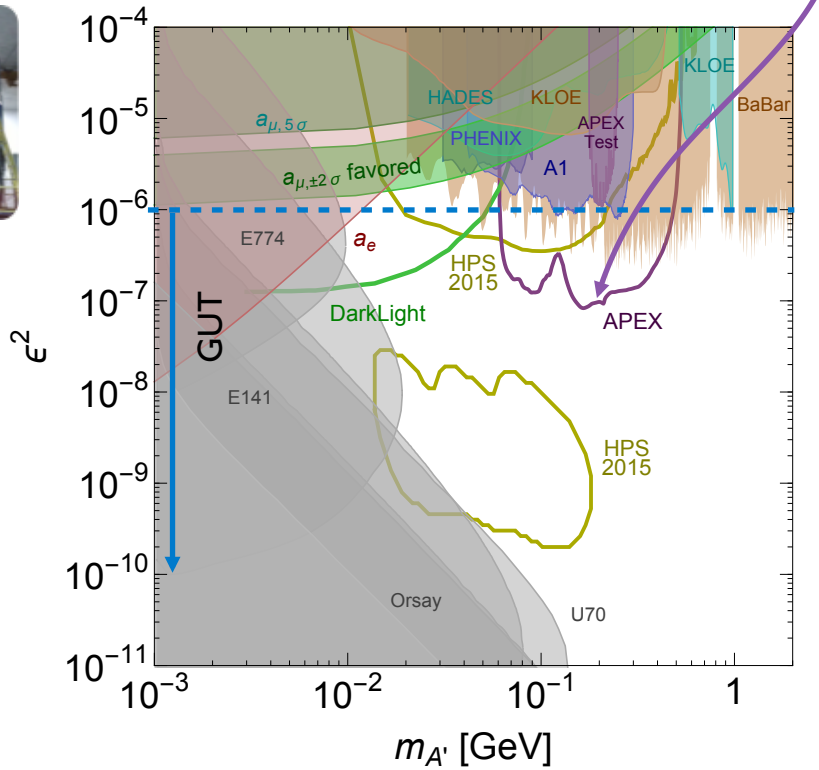
- Theory: Test of new forces in Nature, whose mixing with photons induces small coupling ϵ to charged matter

APEX first to explore deep into coupling region motivated by gauge unification (GUT),

$$\epsilon^2 \sim 10^{-10} - 10^{-6}$$

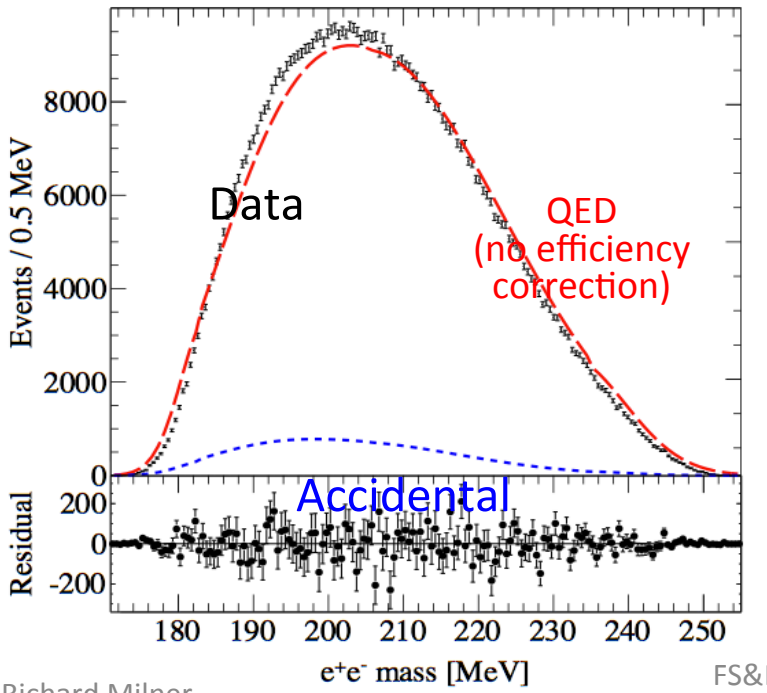
Status

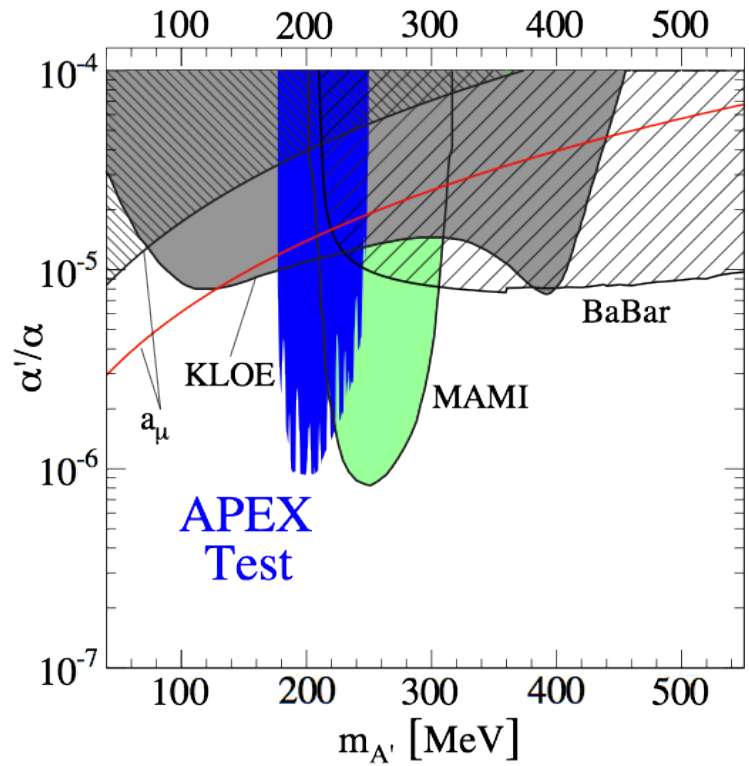
- Test run (2010): concept demonstration and world-record sensitivity
- Full run: Prioritized by JLab, funded, projected to run 2016
  - Optimized septa magnet constructed
  - Smaller beam line items funded
  - HRS detectors ready to go



APEX

- Test run performed in Hall A, July 2010
- **Verified all key aspects of apparatus performance**
  - VDC tracking performance at 4–6 MHz singles rates
  - Gas Cerenkov detector in coincidence trigger to reject π^{+}' s
  - spectrometer optics & mass resolution
  - measurement of physics backgrounds
- Resonance search on 700K good trident events

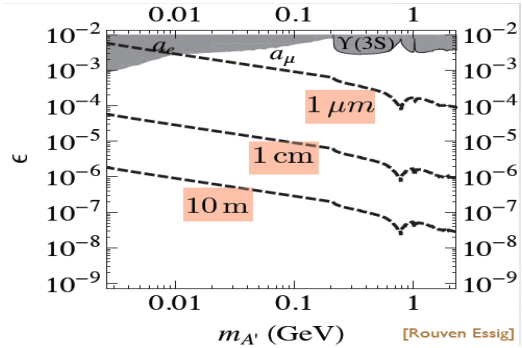




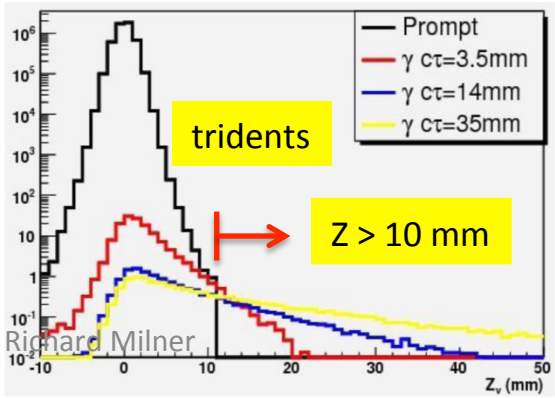
Heavy Photon Search at JLab

- **HPS explores very small couplings**
  $10^{-8} > \varepsilon^2 > 10^{-10}$ for $15 < m_{A'} < 200$ MeV
- **Small couplings mean**
  * small signals and large backgrounds
  * long lived A' with detached vertices

$c\tau_{A'}$

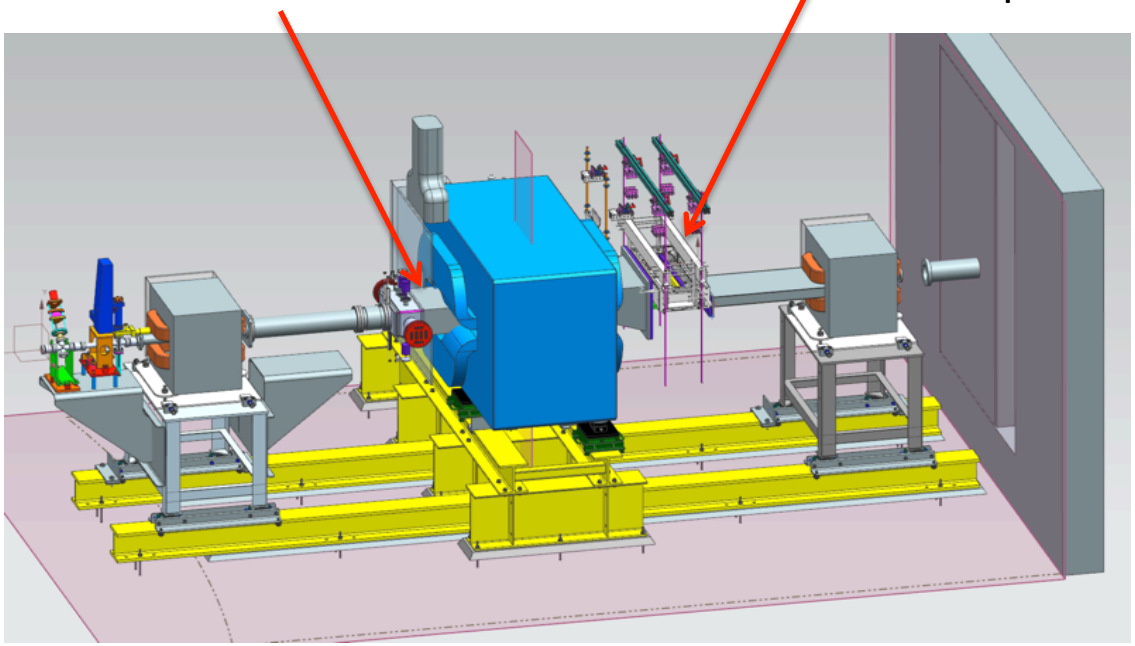


- **Small signals need large luminosities:** good acceptance, fast electronics, high data rates, good mass resolution
- **Vertex cut eliminates trident backgnd**



Si Vertex Tracker

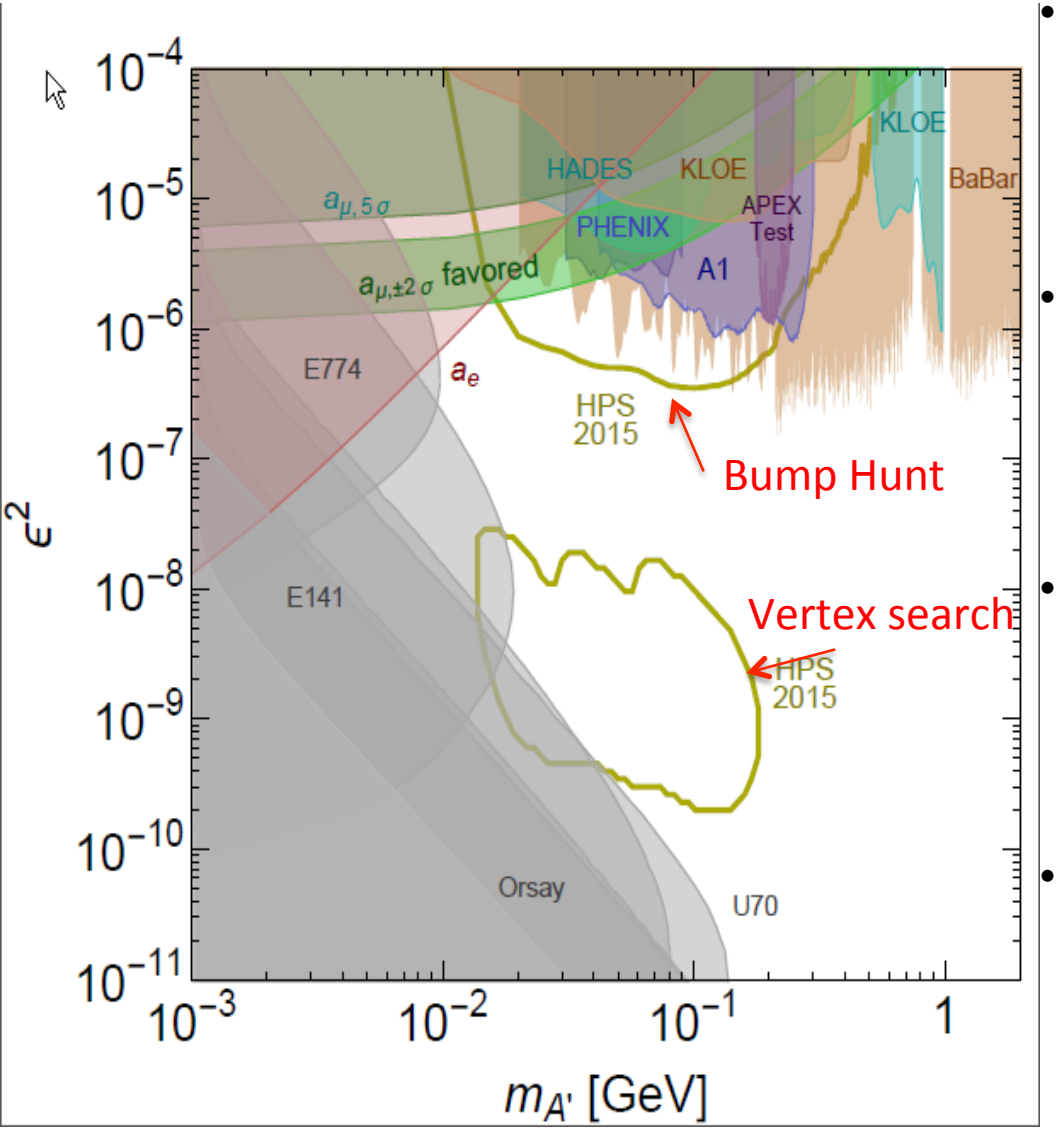
$PbWO_4$ ECal



A magnet chicane directs the CEBAF 12 electron beam onto a W foil, producing heavy photons. They decay to e^+e^- pairs, which are measured by the Si vertex tracker inside an analyzing magnet. A $PbWO_4$ ECal provides a fast trigger. https://confluence.slac.stanford.edu/display/hpsg/Heavy+Photon+Search+Experiment

Heavy Photon Search at JLab

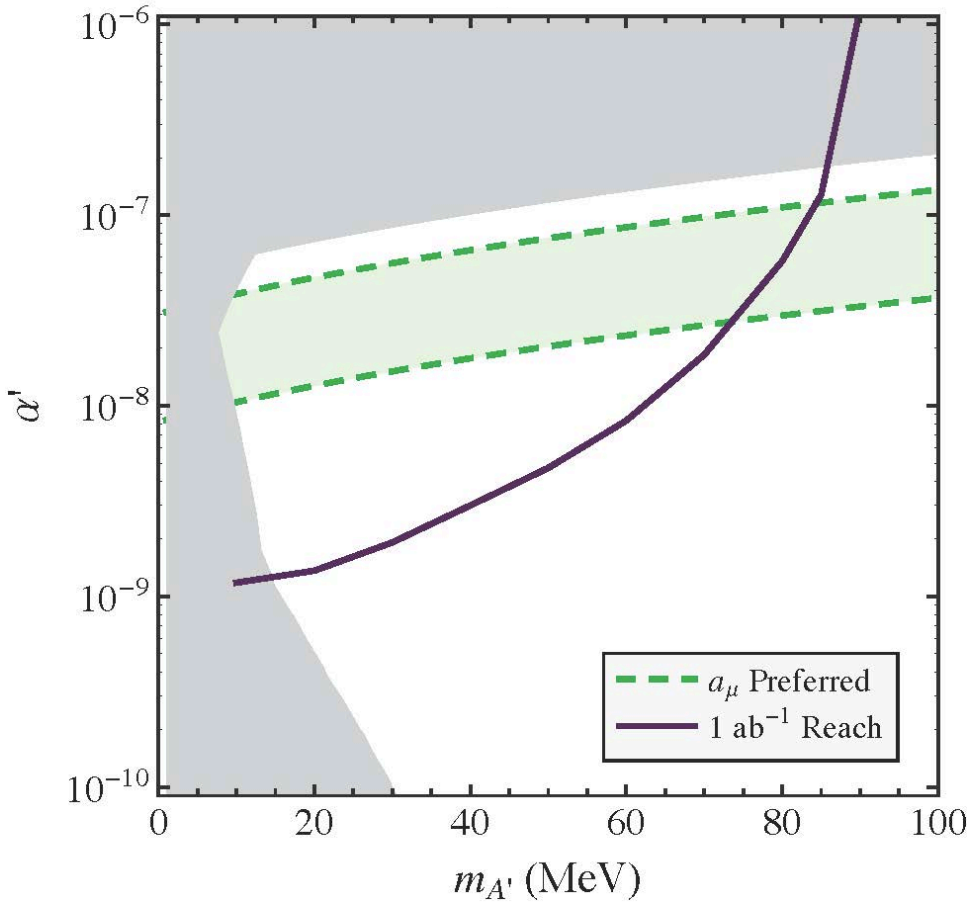
2015 HPS Reach and Existing Limits



Status

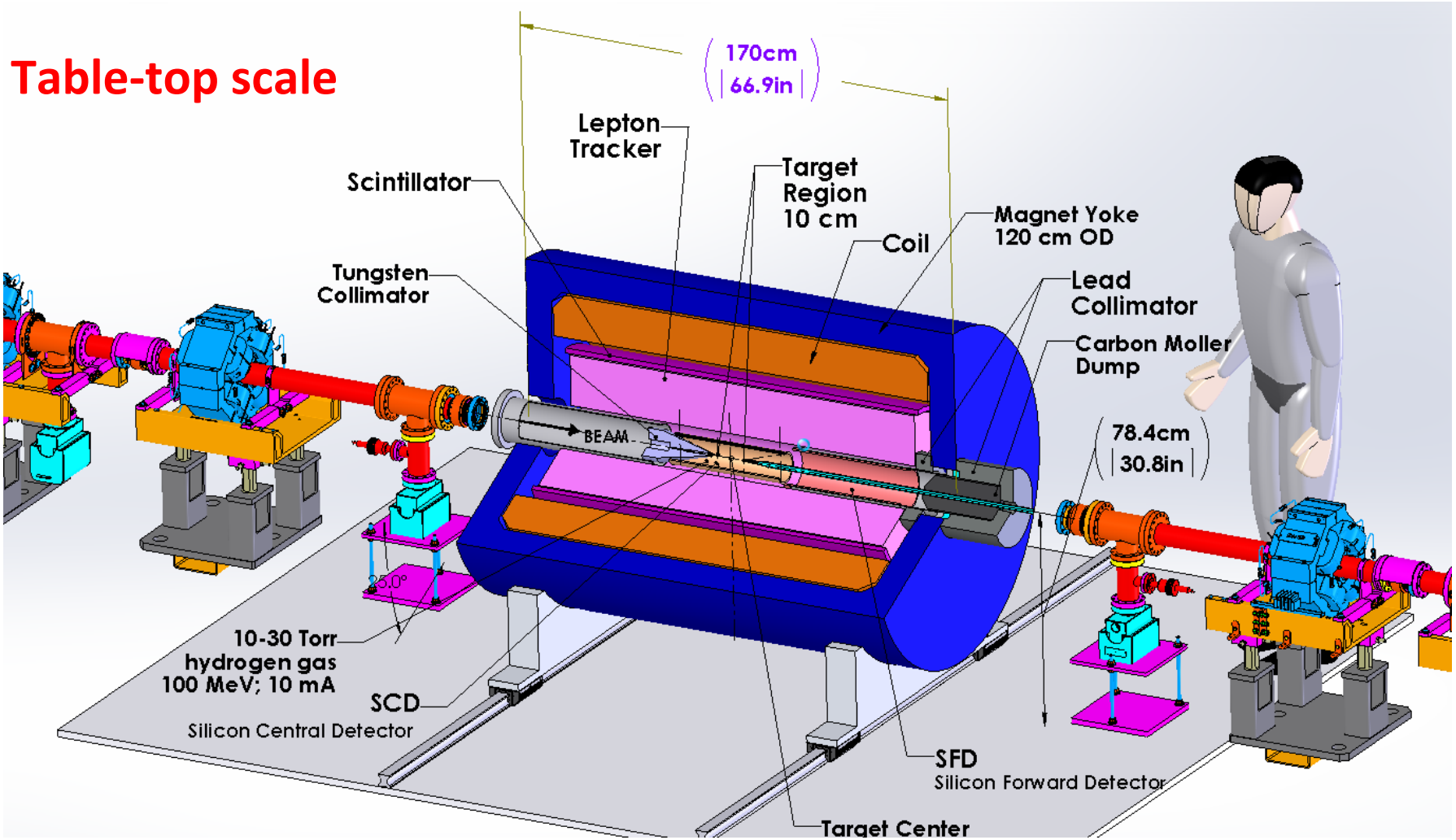
- After a successful test run in 2012, HPS has been approved, funded, and is now completing construction. HPS will be installed in Hall B at JLAB in Fall 2014.
- HPS is approved for running in Spring 2015 with 2.2 GeV electron beams. Additional running at 1.1 and 4.4 GeV is possible.
- The 2015 running will search for A's at small couplings with the vertex search. The same date is sensitive to larger couplings with a traditional bump hunt.
- Additional running in 2017 and beyond will extend the reach to higher masses, and discover True Muonium ($\mu^+\mu^-$ atom)

DARKLIGHT Experiment



- Precision test of QED radiative processes in electron-proton elastic scattering below pion threshold
- Search for both e+e- and invisible decays
- Completely calculable
- Complete reconstruction of final-state
- 5σ discovery limit
- 1 ab^{-1} attained in several months of data taking with 10 mA at 100 MeV on 10^{19} cm^{-2} target
- Green region is present muon (g-2) result explained by a dark force
  Freytsis, Ovanesyan, and Thaler JHEP **1001**, (2011) 111

DARKLIGHT Layout



DARKLIGHT Schedule

- DarkLight proposal approved at JLab PAC 39 in June 2012 with "A" scientific rating, conditional upon successful test being completed
- Test successfully completed in July 2012
- Full scientific approval granted in May 2013
- **Phase-I experiment funded by NSF MRI July 2014**
- Use existing 0.5 T solenoid at Stony Brook University and elements of OLYMPUS target at MIT
- Anticipate it will take about 2 years to carry out phase-I experiment
- Detailed simulations in progress to finalize design: lepton tracker, trigger and readout
- In parallel, finish design of complete (phase-II) experiment and pursue funding approx. $ 6 million

Summary

- Measured positron and electron yields by AMS-02 show interesting energy dependence.
- Many running experiments reporting exclusion limits at 90% confidence for A' decaying to charged e+e-
- No reports of observation to date
- New experiments in preparation to look for evidence of decay of A' to charged leptons and via invisible decay