Dark Photon Search Experiments

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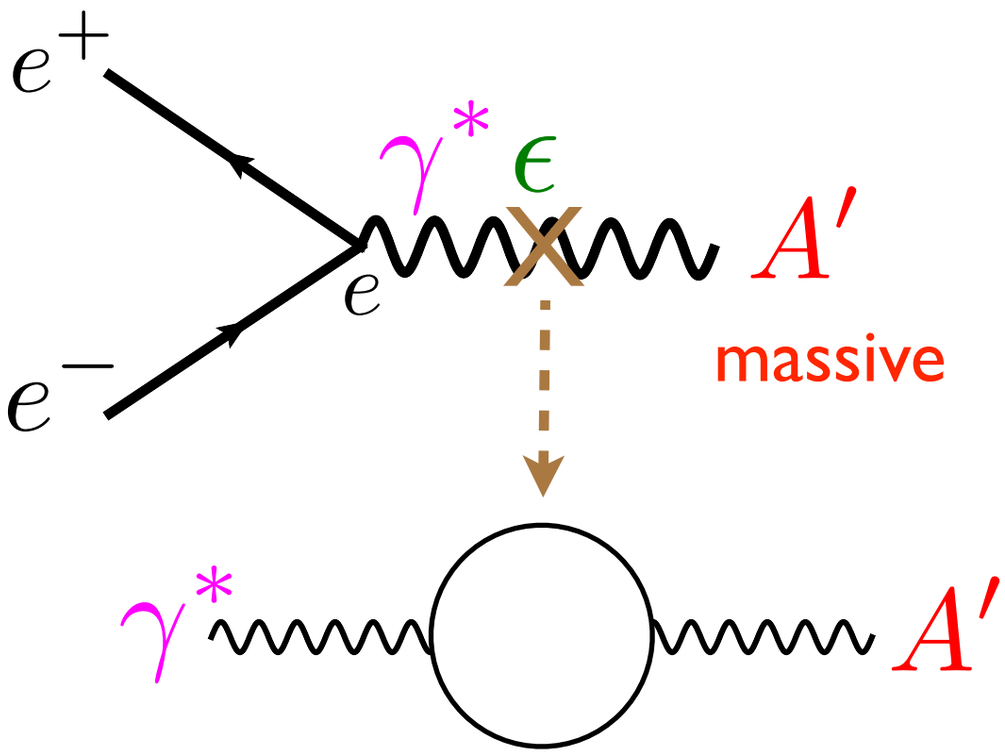
SLAC NATIONAL ACCELERATOR LABORATORY

LELAND STANFORD JUNIOR UNIVERSITY
DIE LUFT DER FREIHEIT WEHT
1891

Hidden Sector Vector Boson: A'



$$\Delta\mathcal{L} = \frac{\epsilon}{2} F^{Y,\mu\nu} F'_{\mu\nu}$$

"Kinetic Mixing" generated by heavy particles interacting with γ and A' [Holdom - 1986]

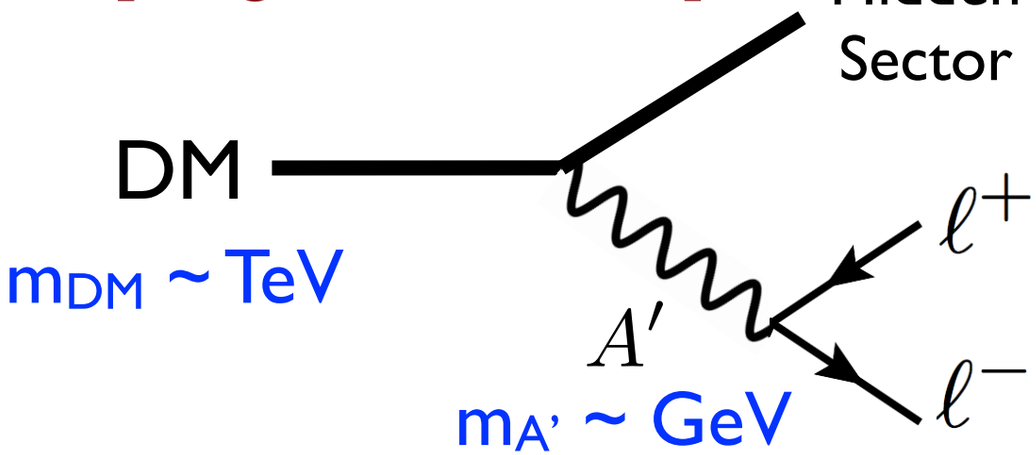
quarks & charged leptons have $e \cdot \epsilon$ coupling to A′

What Makes It Interesting?

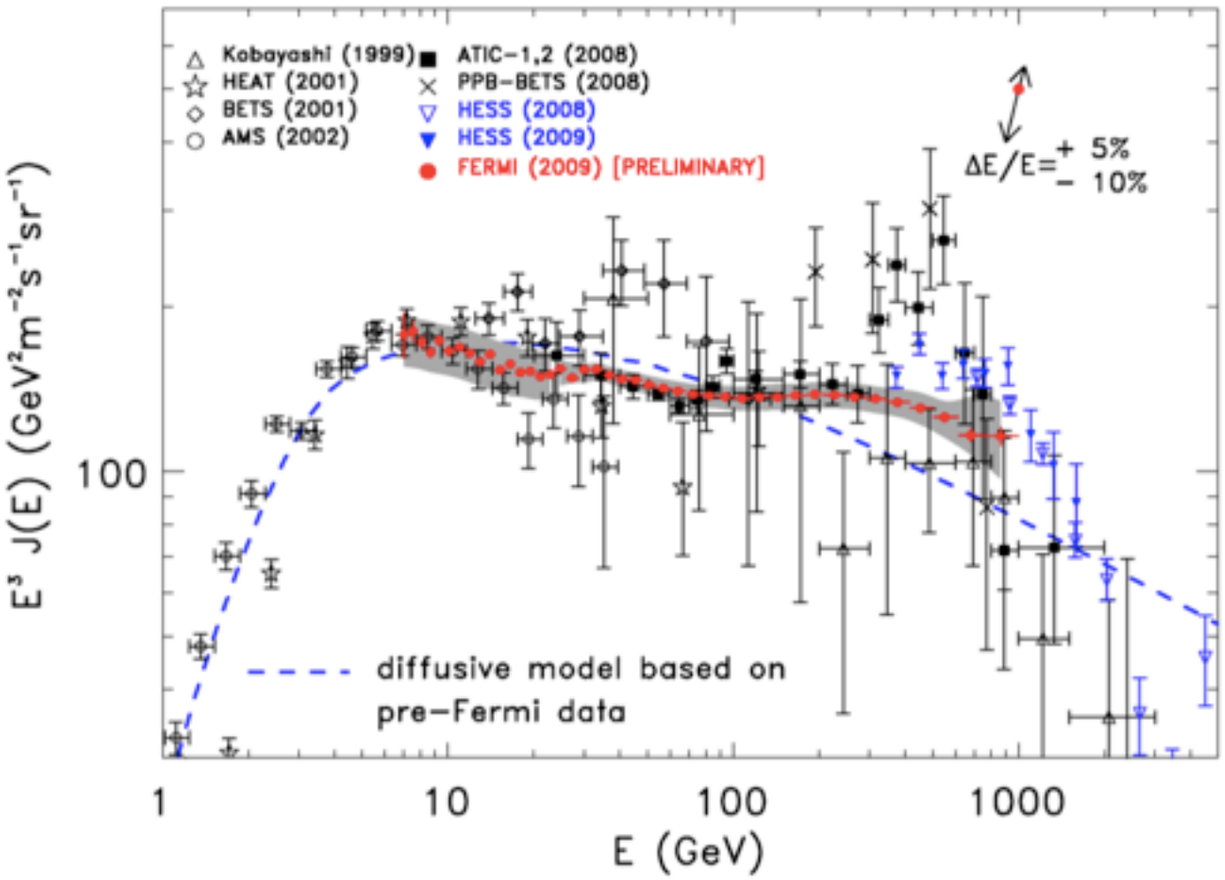
A′ can be light!

What if dark matter annihilates/decays to A′ ?

[Essig Schuster, Toro]



[SLAC] Fermi $e^+ + e^-$ flux

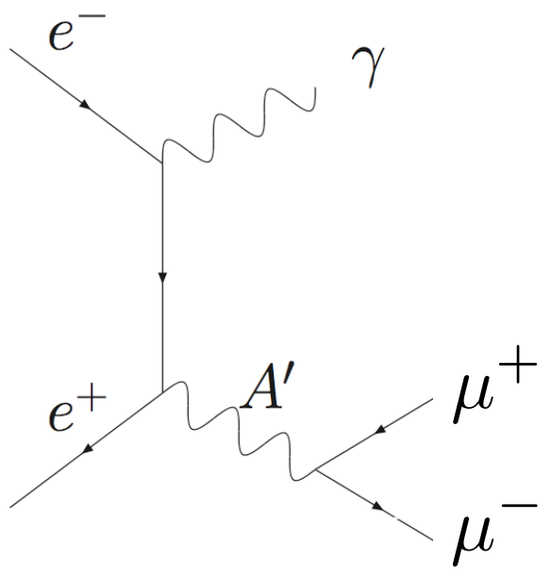


PAMELA sees e^+ excess, but no proton excesses $\Rightarrow m_{A'} < 2m_p$

hypothesis consistent with DAMA/LIBRA and CoGeNT data

Direct Searches

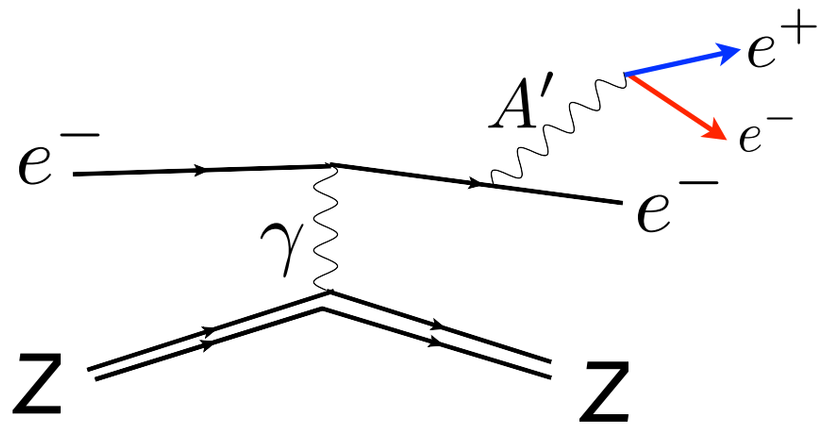
Collider vs. Fixed Target



$$\sigma \sim \frac{\alpha^2 \epsilon^2}{E^2} \sim O(10\ fb)$$

e.g. BaBar

$O\ ab^{-1}$ per decade

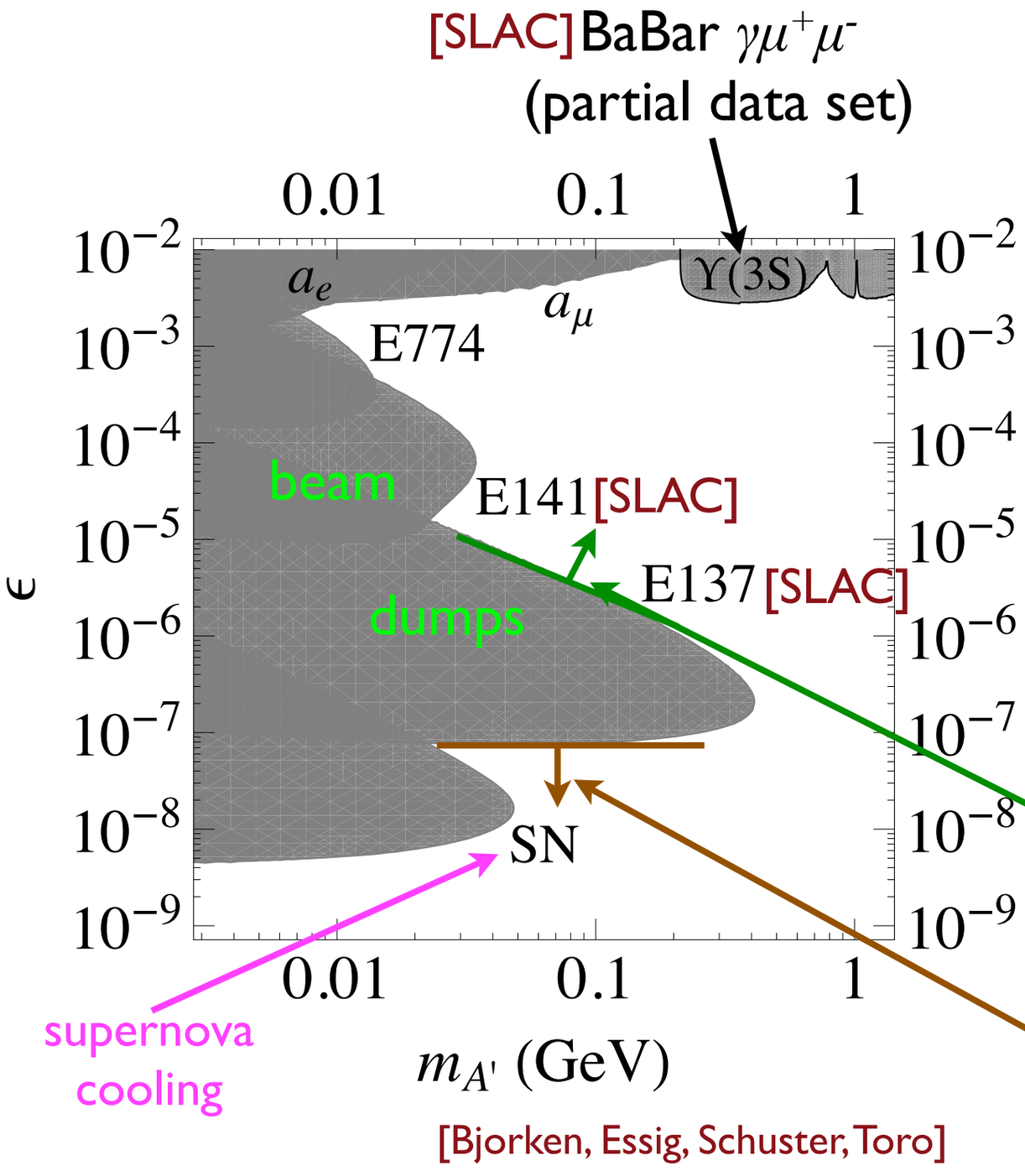


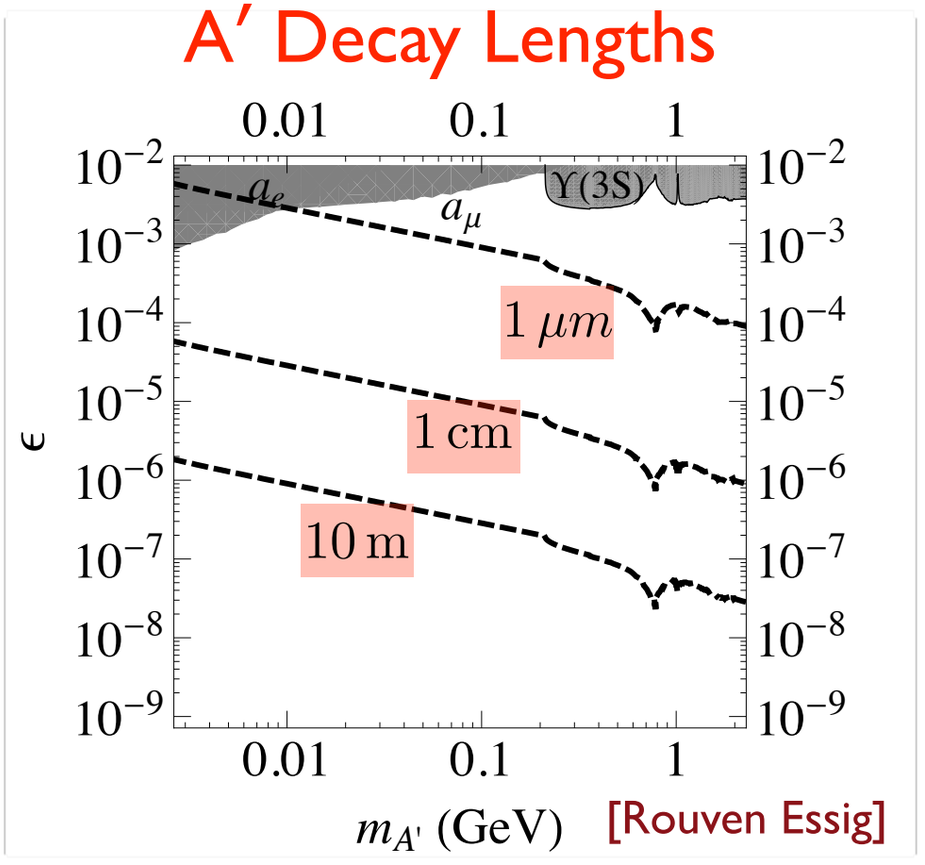
$$\sigma \sim \frac{\alpha^3 Z^2 \epsilon^2}{m^2} \sim O(10\ pb)$$

$O\ ab^{-1}$ per day

[Bjorken, Essig, Schuster, Toro]

Existing Limits





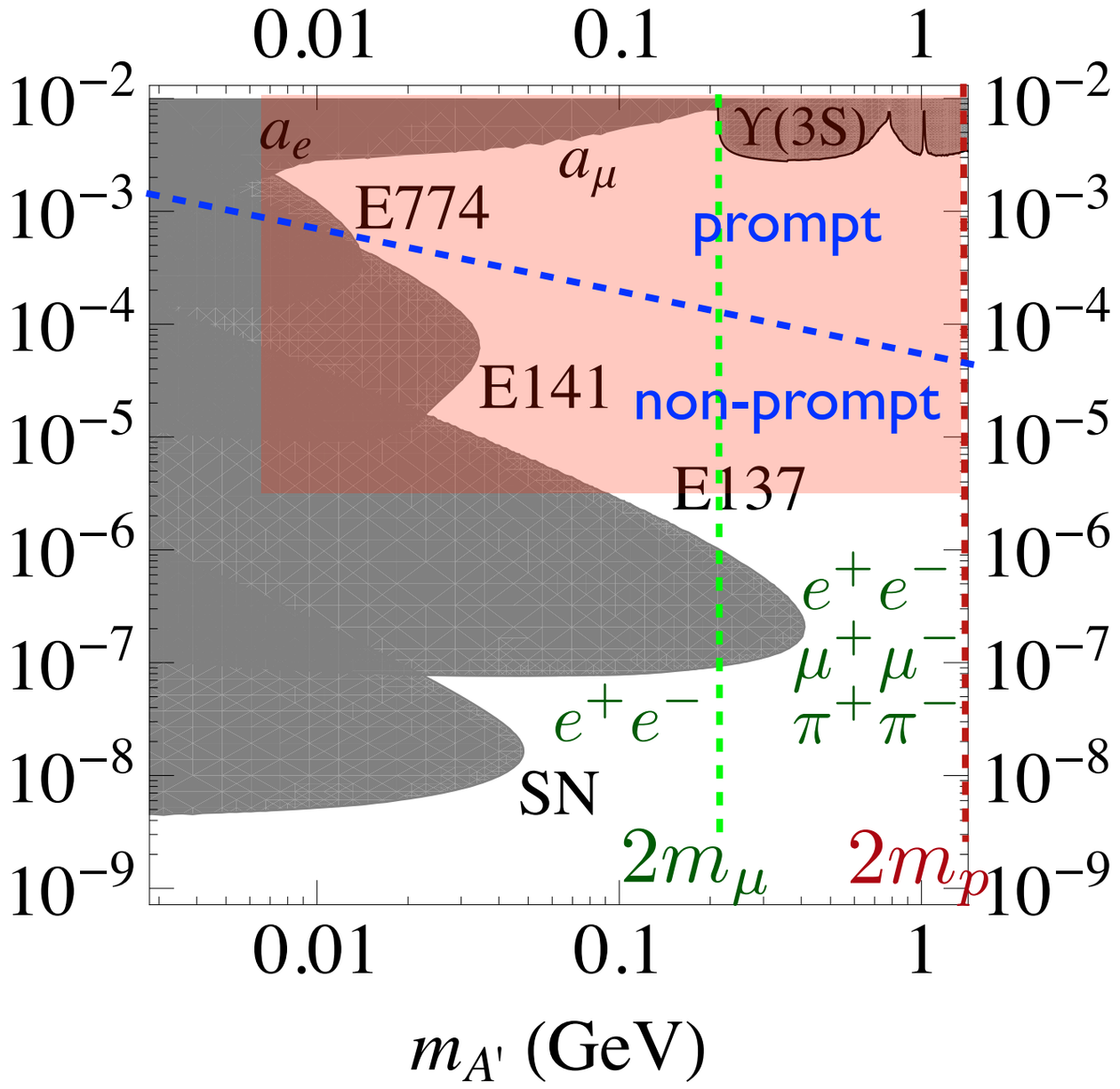
- A′ decay products decay in shield (lifetime too small)
- not enough luminosity (cross-section too small)

Requires New Experiments

In simple models, expect:

- $\epsilon \sim 10^{-5} - 10^{-2}$
- $m_{A'} \sim \sqrt{\epsilon} M_W \sim \mathrm{MeV} - \mathrm{GeV}$ for Higgs-like U(1)′ breaking.

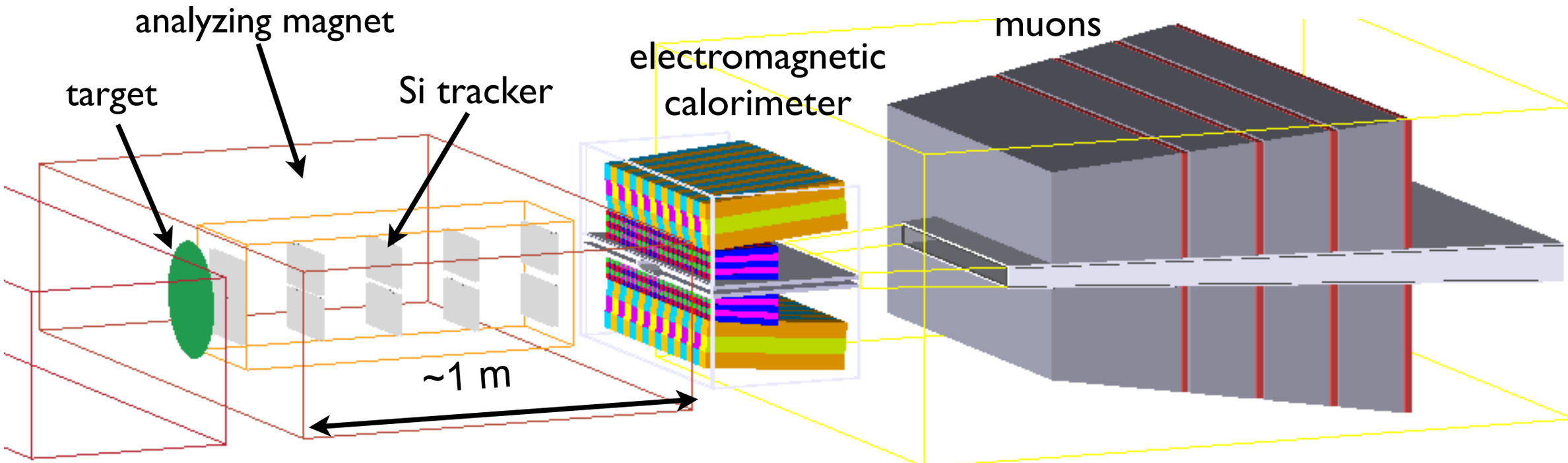
Interesting region not easily explored!



(H)eavy (P)hoton (S)earch Experimental Concept

Sensitivity in this region relies upon abilities to *precisely*...

- determine invariant mass of A′ decay products (estimate momentum vectors)
- distinguish A′ decay vertexes as non-prompt (extrapolate tracks to origin)

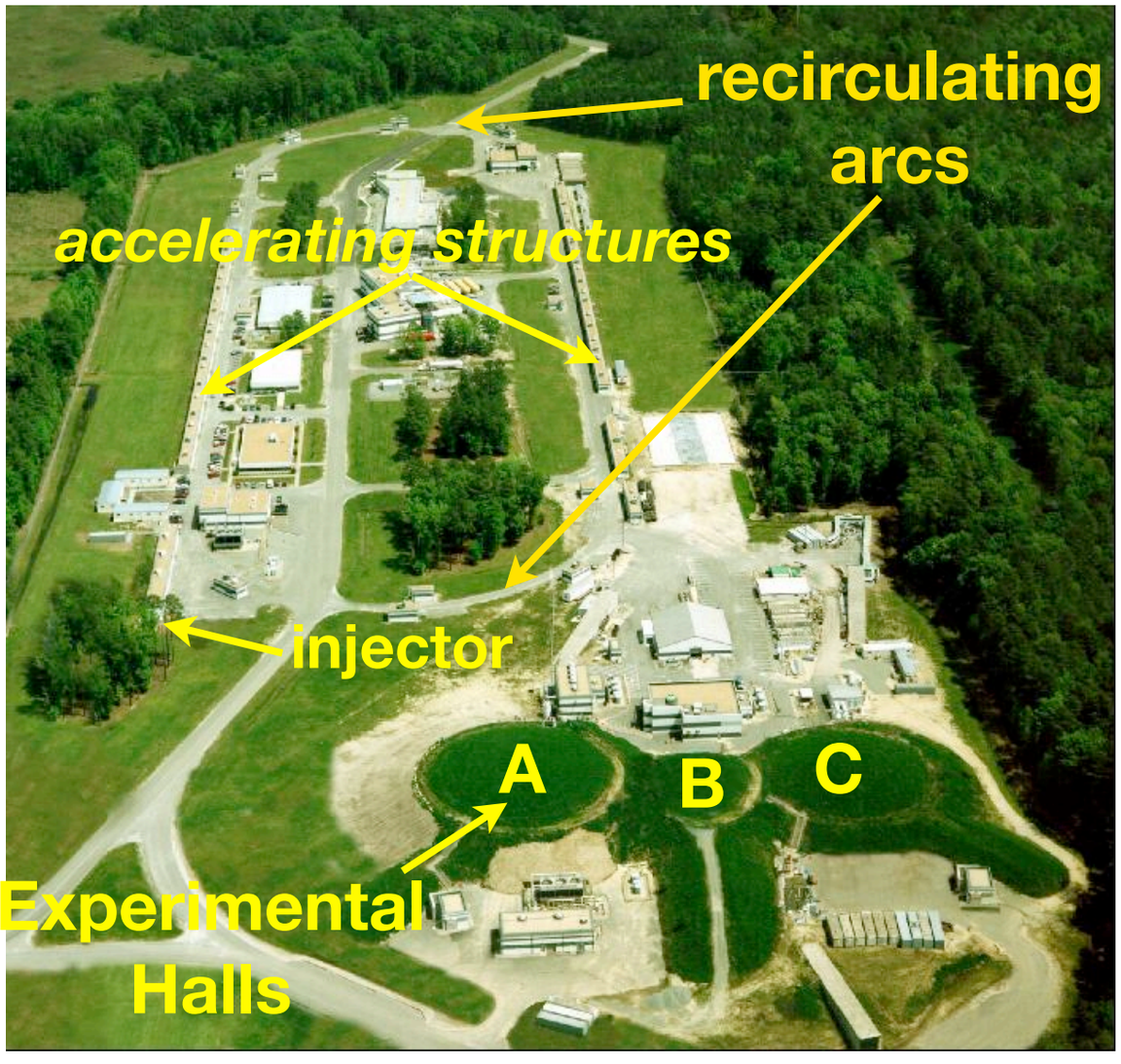


[SLAC]

CEBAF at JLab

Simultaneous delivery of electron beams at different energies and intensities in three experimental halls.

- $E_{\text{beam}} = n \times 1.1$ GeV, n≤5 (5.5 GeV Max)
- $I_{\text{beam}} < 100\ \mu$A (A&C), <800 nA (B)
- 2 ns bunch separation: short integration time reduces ~DC backgrounds
- energy upgrade complete in 2014:
  $E_{\text{beam}} = n \times 2.2$ GeV, n≤5 (11 GeV max)



Ideal for this experiment.

HPS Reach Estimates

E_{beam} = 6.6 (2.2) GeV

I_{beam} = 450 (200) nA

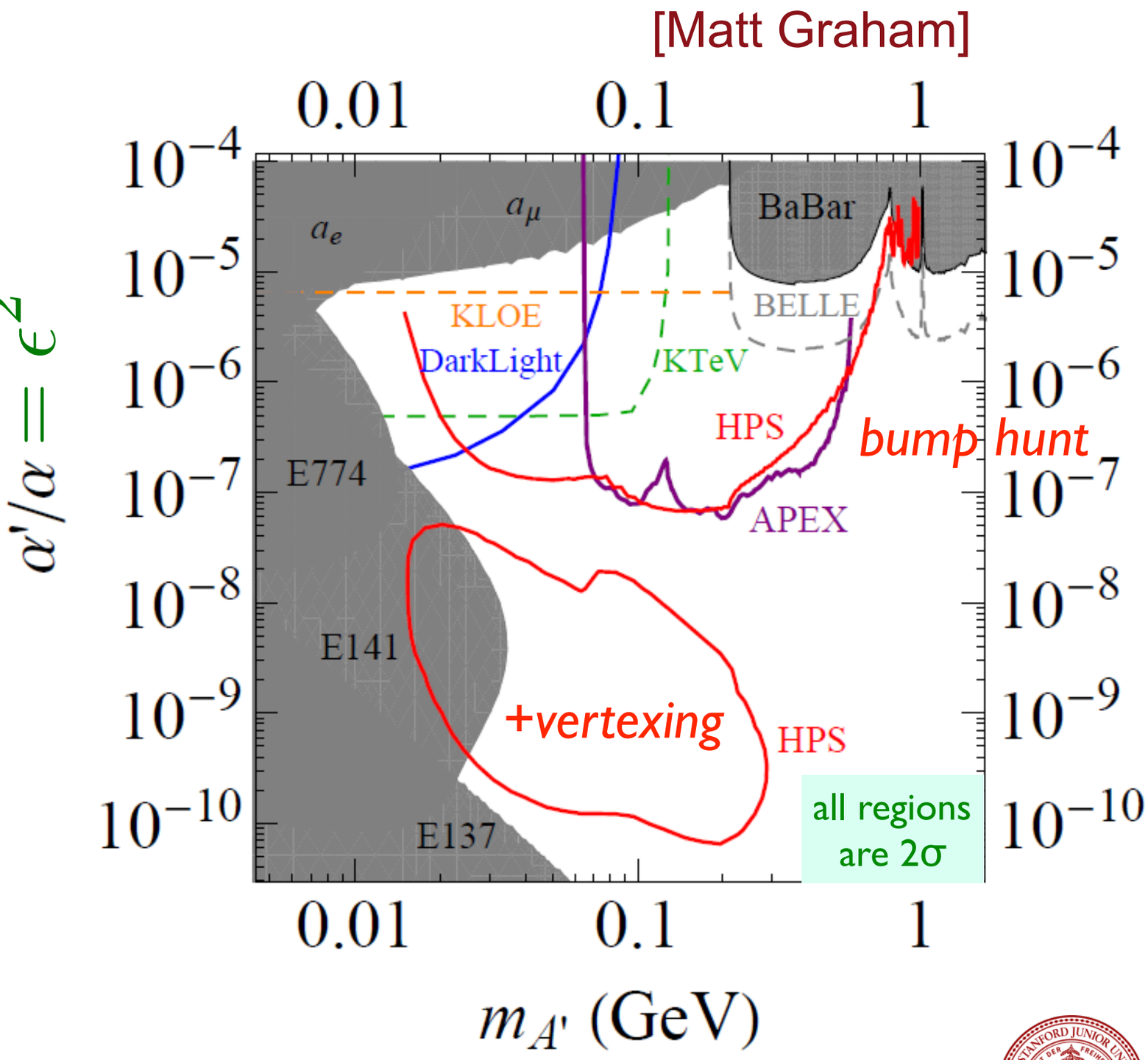
Target = 0.25 (0.125) %X_0 W

Time = 3 months each

APEX: "A-prime Experiment"
$m(e^+e^-)$ bump-hunt using JLab Hall A two-arm spectrometer.

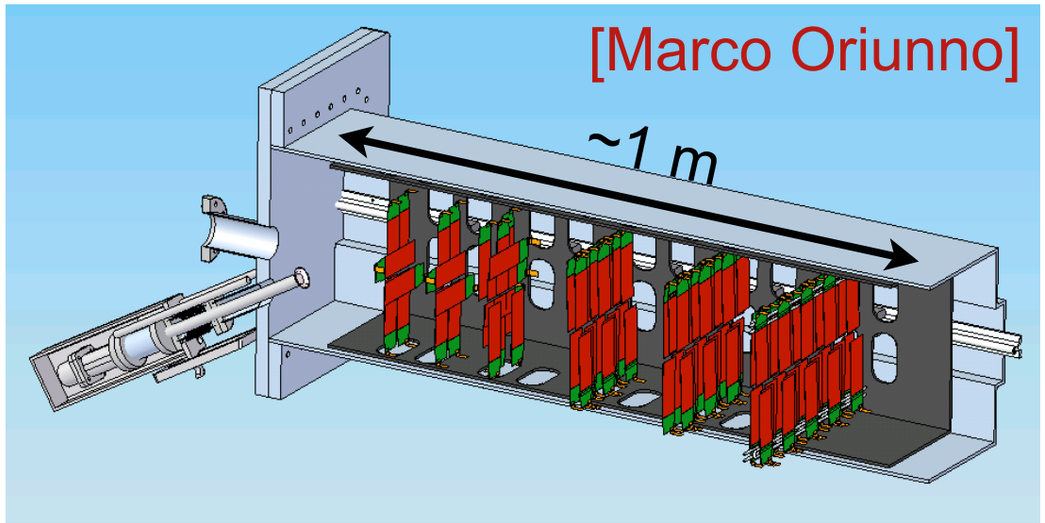
DarkLight:
full kinematic reconstruction using JLab FEL and H-gas target

[Matt Graham]

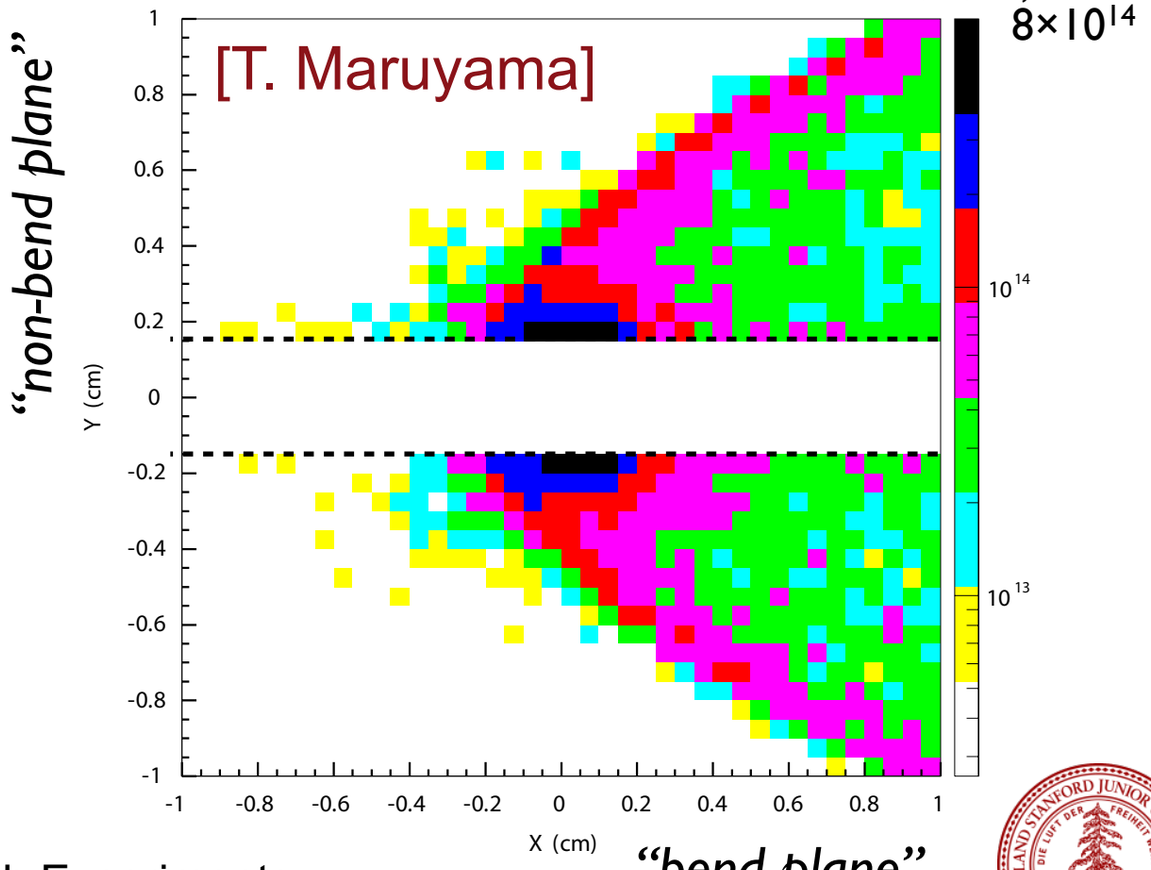


Small Apparatus, Big Technical Challenges

- Small beamspots / thin targets
  - rotating target foils (< 10 μm W)
- Mass and vertex resolution
  - low-mass construction (CF composites)
- Occupancies and radiation
  - robust Si sensors (D∅ Run IIb) with fast readout (CMS APV25 ASIC)
  - movability / replaceability of Si planes
  - operation in vacuum
- Large acceptance / 10^{-7} vertex purity
  - sensor layout optimized with extensive simulation (org.lcsim)
- High-rate environment
  - fast DAQ, trigger, data processing



Layer 1 e^- exposure



SLAC and HPS Are an Ideal Fit

- *HPS fits into SLAC vision as center for dark matter / dark energy*
  - Fermi has provided key physics motivation
  - BaBar, E137, E141 currently yield best constraints
  - SLAC theorists proposed HPS concept [Essig, Schuster*, Toro*]

*now at Perimeter Institute

- *SLAC expertise is critical*
  - beamline, target, magnet, vacuum systems [Field, Moffeit, Walz, Odian]
  - radiation-tolerant silicon detector systems [Nelson, Oriunno, Kenney]
  - high bandwidth electronics and DAQ [Haller, Herbst]
  - high-volume data handling [Neal]
  - simulation, reconstruction, analysis [Graham, Maruyama, Partridge, Jaros]
  - *Small experiment ideal for Stanford students/SLAC postdocs*

➡*SLAC group is one focus of a very strong collaboration*

➡*JLab is the other: we are newcomers there!*

HPS: A (truly) Brief History

18 months!

- June 2009: Paper by SLAC/Stanford theorists: http://arxiv.org/abs/0906.0580
- Aug. 2009: HPS concept presented at Dark Forces Workshop
- *Nov. 2009: HPS members sign APEX proposal*
- Jan. 2010: HPS concept pitched to Hall B, *encouraged to make proposal*
- Jan. - July 2010: APEX test run approved, SLAC designs/builds target and participates in data taking
- Jun. 2010: SLAC electron review: *high marks for HPS in Sep. report*
- Sep. 2010: HPS Proposal presented to JLab management, *well received*
- Dec. 2010: Revised HPS Proposal submitted to JLab PAC

  https://confluence.slac.stanford.edu/display/hpsg/Heavy+Photon+Search+Experiment

- *Jan. 2011: PAC meeting at JLab. DOE presence anticipated.*

HPS Technical Progress

DOE support (~$300K) has allowed development work for proposal:

- Software
  - Development of simulation for background estimates (Stanford student)
  - Development of detailed simulation/reconstruction for tracking/vertexing in org.lcsim framework (SLAC postdoc)
- DAQ
  - APV25 DAQ test stand from CMS set up in lab (Stanford student)
  - Tracker readout board currently in layout
  - Design of hybrids beginning in January (based upon CMS designs)
- Mechanical
  - Design for tracker planes, support and cooling has begun
  - Design for target underway

HPS Schedule and Cost

- Schedule
  - CEBAF upgrade to 12 GeV: no beam from mid-2012 to 2014.
  - No significant time on floor before upgrade: *main HPS run in 12 GeV era*
  - We are proposing a short test run before the upgrade to study backgrounds, occupancies, and trigger; and gain invaluable experience running at CEBAF.
- Cost: $500K (test run) + $1.9M (full expt.) = $2.4M
  - FNAL donating Si detectors
  - JLab donating much of ECal including electronics and DAQ
  - Collaborators planning NSF MRI for ECal and Muon systems
- *Recommendation of PAC after January meeting is critical.*
- DOE to act on PAC recommendations in March: *decision point for funding of test run.*

Summary

- HPS physics is at a nexus of core interests at SLAC
  - Opportunity for SLAC to seize a central role in dark photon story
  - HPS also has potential to discover true muonium: http://arxiv.org/abs/0904.2225 [Brodsky]
- Technical challenges of HPS suit SLAC strengths
- Major strategic risks being mitigated by careful planning
  - Participation in APEX addresses inexperience at JLab
  - Test run proposal advances development through CEBAF shutdown
  - Hastening to exploit opportunity: Mainz/DESY also pursuing experiments
- *Decisions in next few months are critical to the future of HPS*

*We are working fervently to ensure that this future is **dark**!*