HPS Overview

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HPS Review

SLAC, January 19, 2019

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Thomas Jefferson National Accelerator Facility

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Outline

- Dark matter and portals to hidden sector
- HPS in Hall-B at Jefferson Lab
- What next for 2015/2016 data analysis
- Status of HPS MC
- First production run in about 7 month
- Status of the tracker and trigger upgrades
- Couple of other comments
- Summary

Dark Sector

Dark Matter and portals to Hidden Sector

The astrophysical evidence for Dark Matter is compelling, but so far, there's no proof DM has been produced in particle physics experiments, interacted with sensitive detectors, or been seen annihilating or decaying.

Minimal models:

- Scaler Higgs portal: $\underbrace{(H'H)}_{\text{SM}}\underbrace{(\lambda S^2 + AS)}_{\text{HS}} + \ldots$

Paspelov, Ritz, Phys. Let. B671, 391 (2009)
Arkani-Hamed et al. PRD 79 015014 (2009)

Requires scaler singlet ***S***, mixing with the Higgs - $\lambda \sim \frac{m_s}{M_W} \sim small$

- Neutrino portal: $y_{ij} L_i H N_j + \ldots$

Requires singlet fermions, N_j, can lead to the generation of observable neutrino masses and neutrino oscillation phenomenology, the mixing angle $\theta^2 \sim \frac{m_\upsilon}{M_R} \sim small$ for $M_R \sim O(GeV)$

- Vector (photon) portal: $\frac{\varepsilon}{2} F'_{\mu\upsilon} F^{\mu\upsilon}$

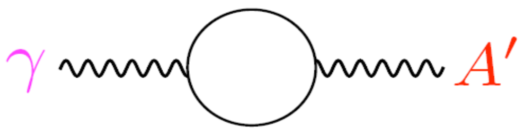
Requires HS has effective $U(1)_d$, the force carrier $(A', \varphi \ldots)$ mixes with SM photon (if light, < GeV) or Z (if m ~ M_W). The coupling of charged matter to new, dark photon, *q=ε e*

The Vector "Portal" – $U(1)_d$

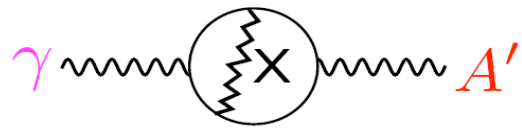
The simplest case, a heavy particle that is charged under EM charge and DM charge, and couples to the Standard Model photon through the kinetic mixing.

B. Holdom, Phys. Lett. B 166, 196 (1986).

Coupling



$$\epsilon \sim 10^{-4} - 10^{-2}$$



$$\epsilon \sim 10^{-5} - 10^{-3}$$

(if SM unifies in a GUT)

$$\varepsilon^2 = \frac{\alpha'}{\alpha}$$

α is the fine-structure constant

Mass – less constrained

If $U(1)_d$ breaking is driven by a scalar, there is a lower bound on the mass from two loop effects

$$m_{A'}^2 \approx \varepsilon^2 \left(\frac{\alpha_d}{4\pi}\right) m_W^2$$

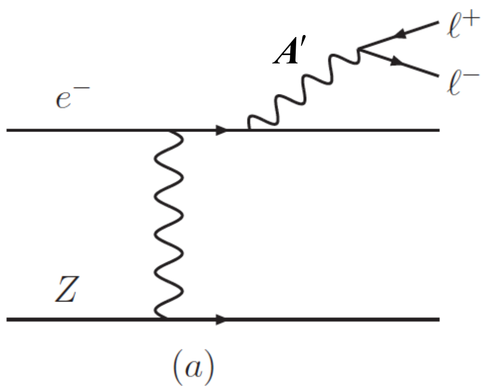
Additional effect arises in supersymmetric theories

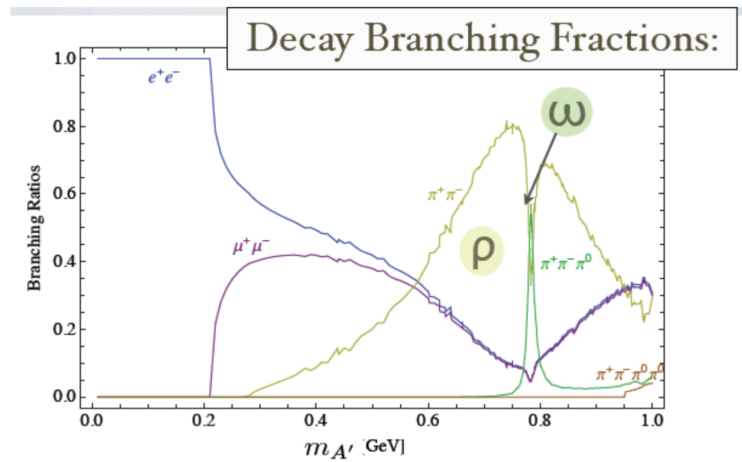
$$m_{A'}^2 \approx \varepsilon \sqrt{\alpha \alpha_d}\, m_W^2$$

$$m_{A'} \approx MeV - GeV$$

Where and how to search for dark photons

A′ can be electroproduced the same way as radiative tridents in the fixed target experiments and can decay to SM particles (*J.D. Bjorken, R. Essig, P. Schuster, and N. Toro, Phys. Rev. D80, 2009, 075018*)

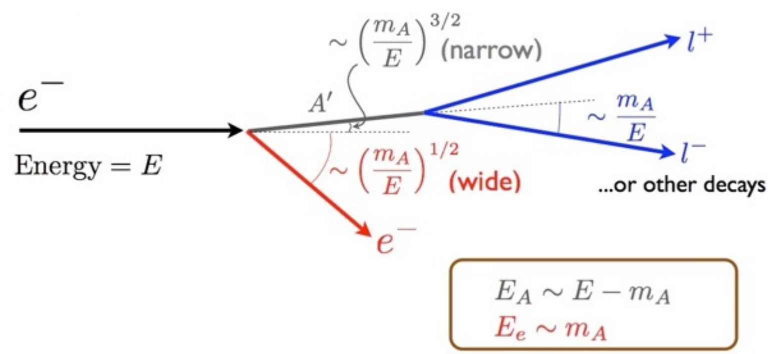




Kinematics is very different from massless photon bremsstrahlung, the heavier product takes most of the beam energy.

$$\frac{d\sigma}{dx} \propto \frac{\alpha^3}{\pi} \frac{\epsilon^2}{m_e^2 \cdot x + m_A^2 (1-x)/x}$$

$$x = \frac{E_A}{E}$$



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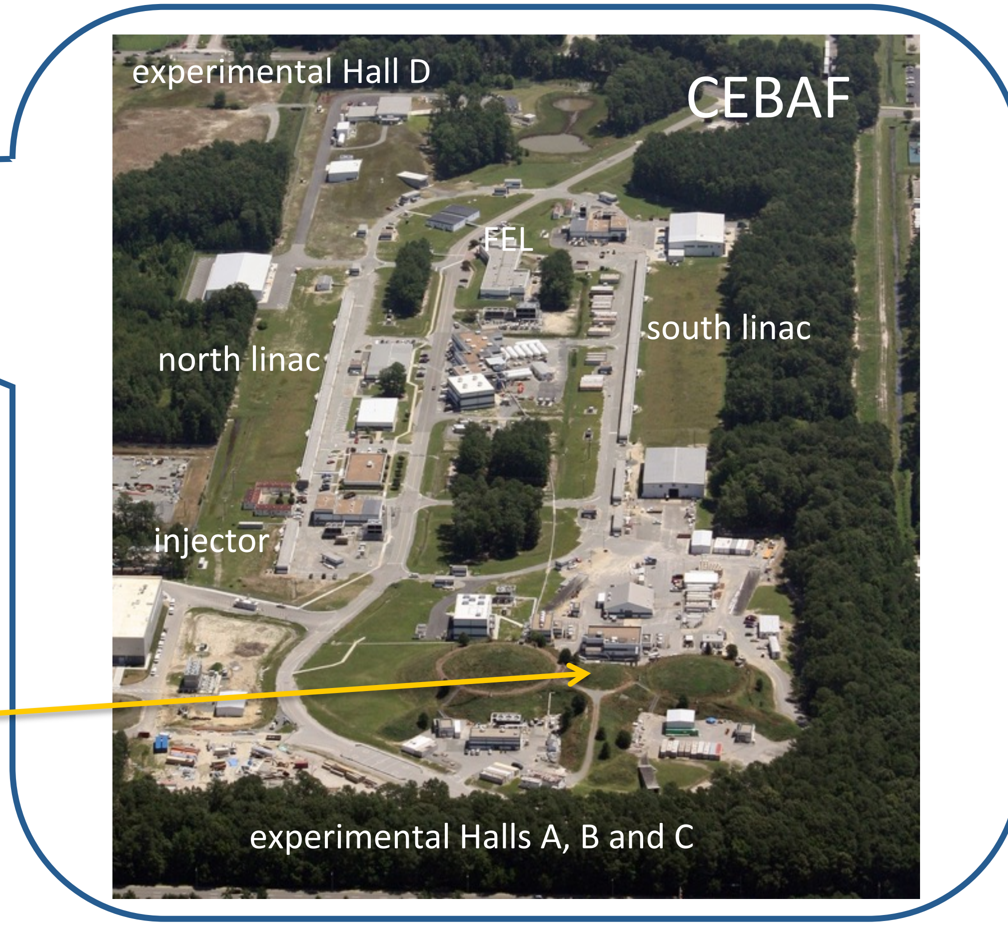
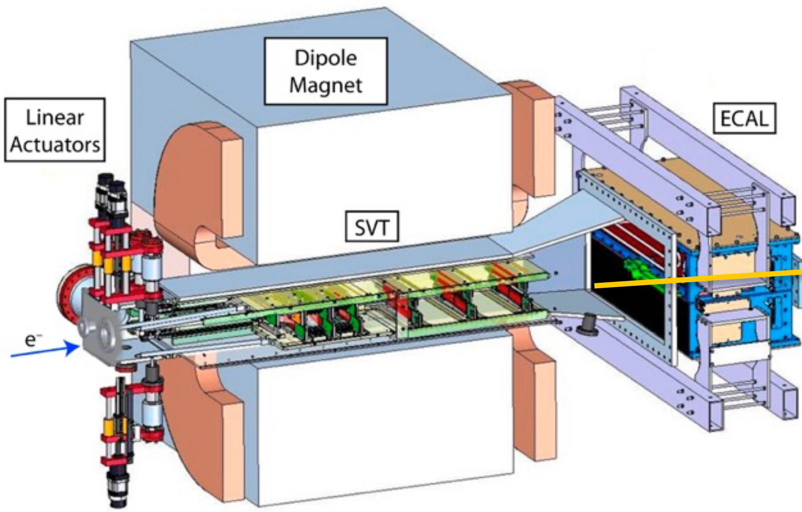
Heavy Photon Search experiment at JLAB





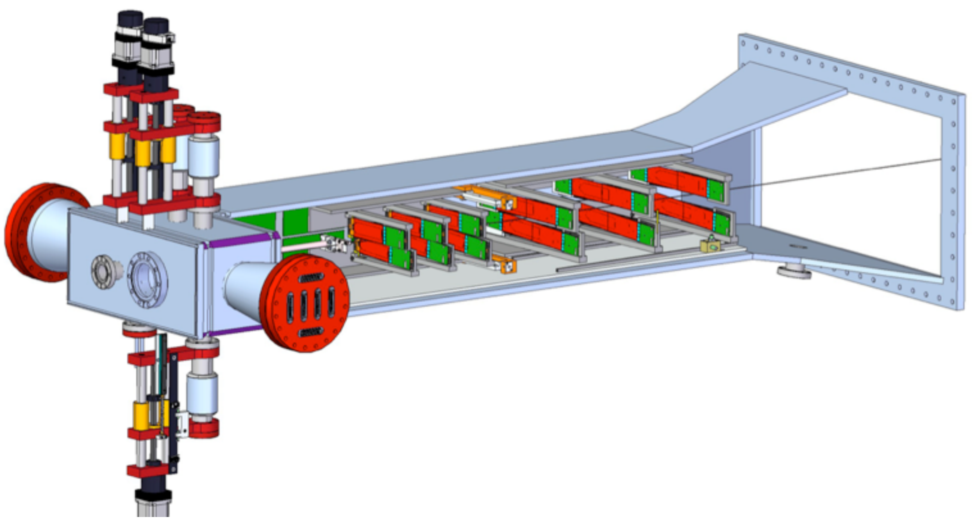
HPS searches for hidden sector gauge bosons ("heavy photons") in a unique region of parameter space by exploiting both separated vertex and invariant mass signatures.

HPS apparatus - SVT

Precise measurements of momentum and production vertex of charged particles

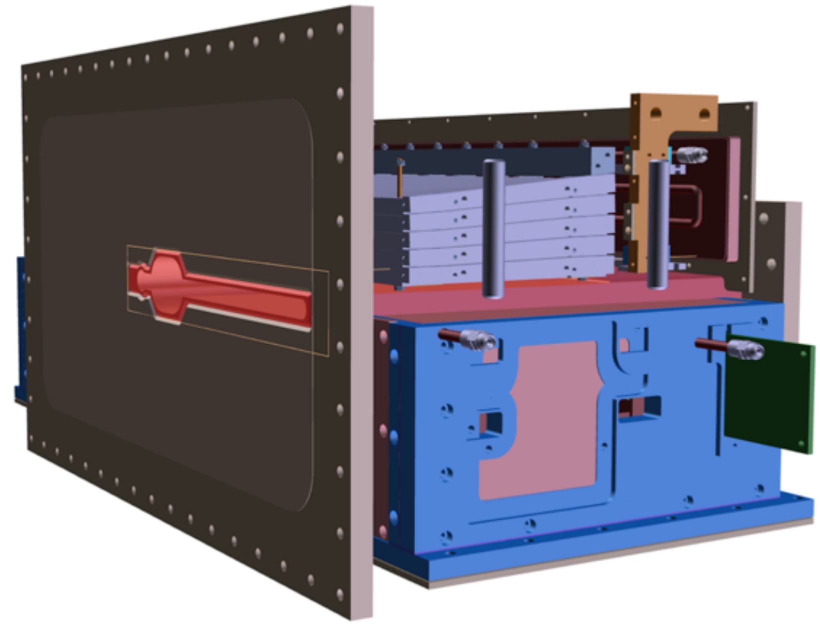
- Will be installed in the vacuum inside the analyzing magnet
- First layer is located at **10 cm** from the target, the silicon in the first layer is only **0.5 mm** from the center of the beam
- First 3-layers are retractable
- Silicon will be actively cooled to remove heat and retard radiation damage
- The sensors have 60(30) μm readout (sense) pitch (hit position resolution ~6 μm)
- The sensors are read out continuously at 40 MHz using the APV25 chip

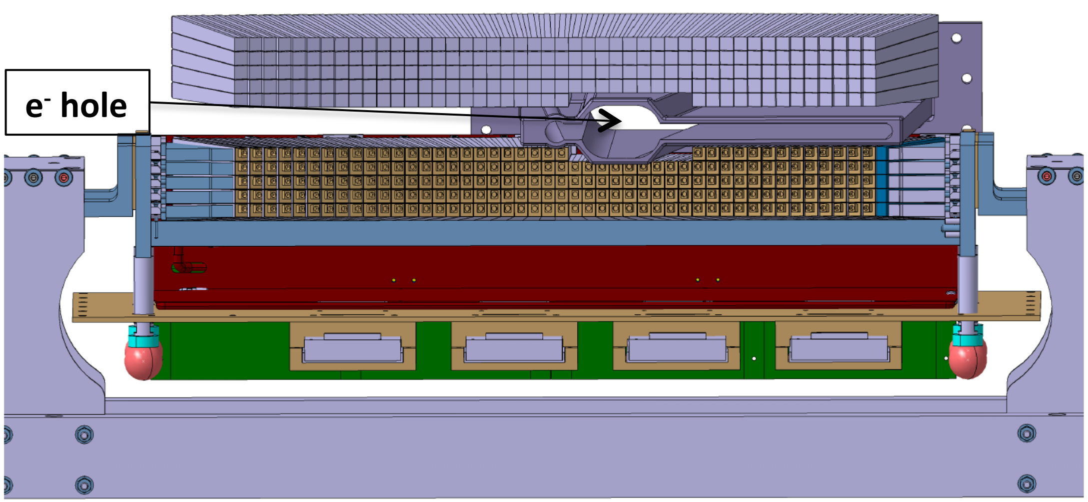
Layer number	1	2	3	4	5	6
nominal z, from target (cm)	10	20	30	50	70	90
Stereo Angle (mrad)	100	100	100	50	50	50
Bend-plane resolution (μm)	≈ 60	≈ 60	≈ 60	≈ 120	≈ 120	≈ 120
Non-bend resolution (μm)	≈ 6	≈ 6	≈ 6	≈ 6	≈ 6	≈ 6
Number of sensors	4	4	4	8	8	8
Nominal dead zone in y (mm)	± 1.5	± 3.0	± 4.5	± 7.5	± 10.5	± 13.5
Module power consumption (W)	6.9	6.9	6.9	13.8	13.8	13.8

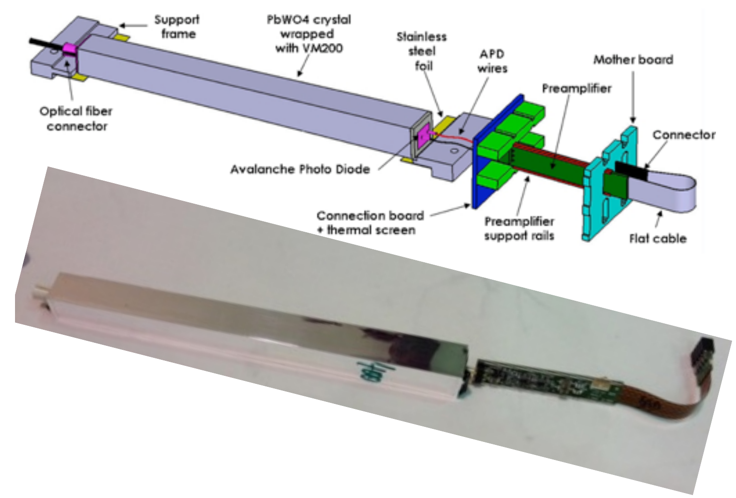


HPS apparatus - ECal

- Lead-tungstate calorimeter with 442 16 cm long crystals (1.3x.1.3 cm^2 cross section) with APD readout (Hamamatsu S8664-55)
- In each half, crystals are arranged in rectangular formation in 5 layers, 4 layers have 46 crystals and the one closest to the beam has 37 crystals
- Modules are located inside the thermal enclosure with temperature stability <1^{o}C
- Expected energy resolution $\sigma/E \approx 4.5\%/\sqrt{E}$

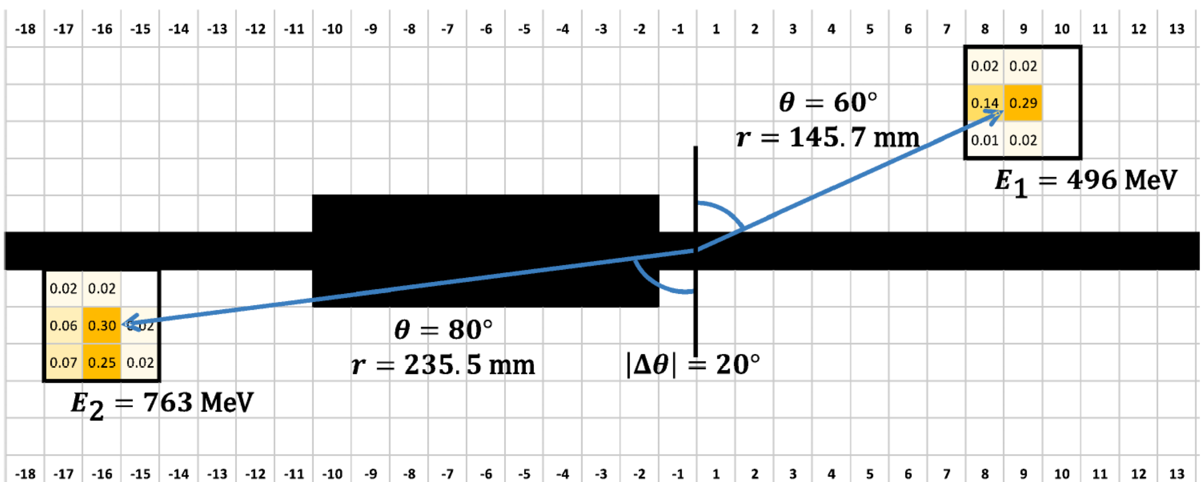






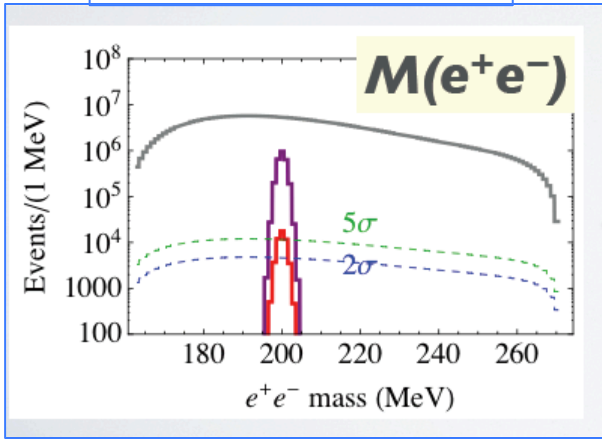
DAQ and the trigger

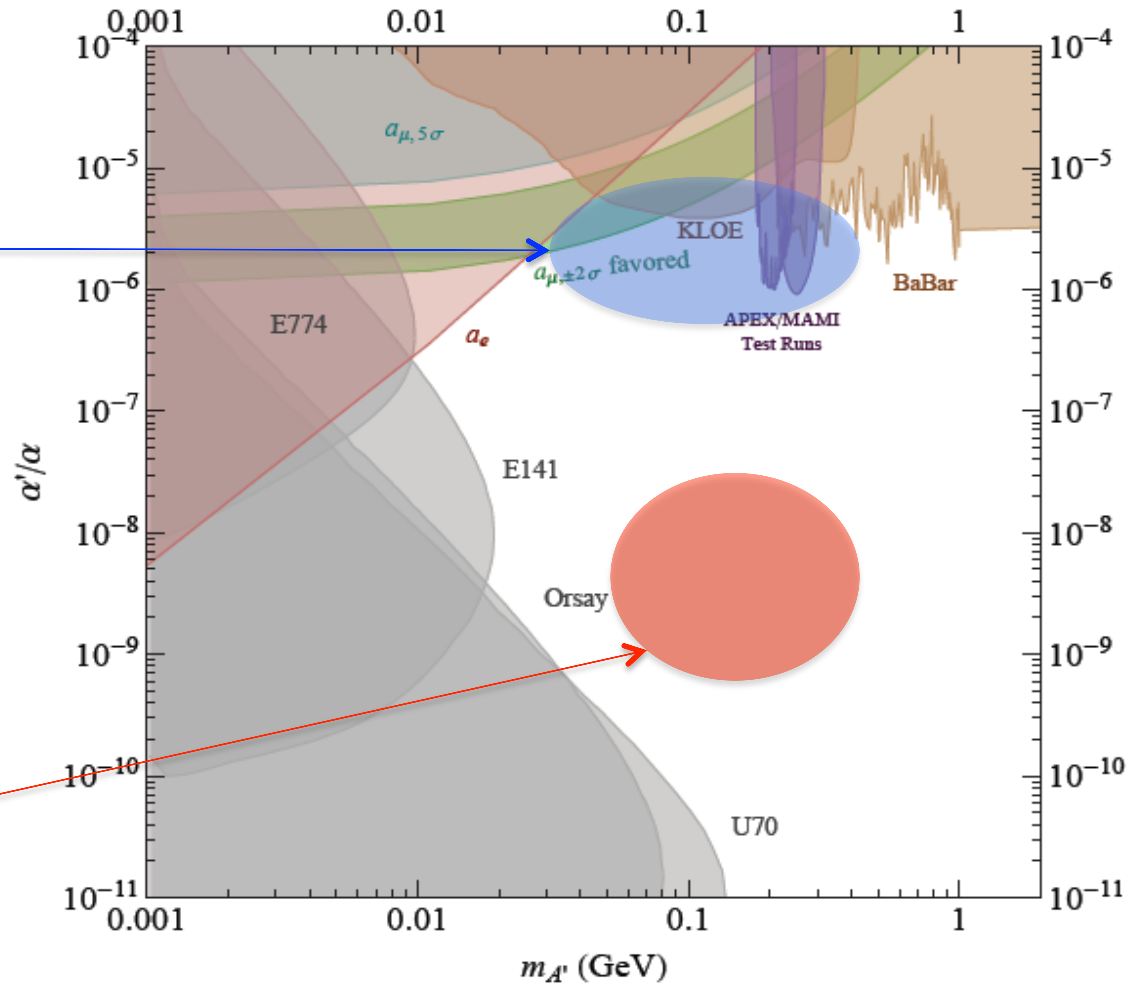
- Two DAQ architectures, ATCA for SVT (SLAC) and VXS-FADC250 for ECal (JLAB)
- JLAB CODA DAQ software for trigger and readout
- Trigger is defined by clusters in ECal and based on JLAB FADC250
- The analog signal from each Ecal channel is continuously sampled by the FADC every 4 ns.
- Modules with energy above threshold are processed for the trigger.
- Pulse height, spatial and timing information from each crystal are available for the trigger decision
- Energy and position cuts are applied to define cluster pair trigger.



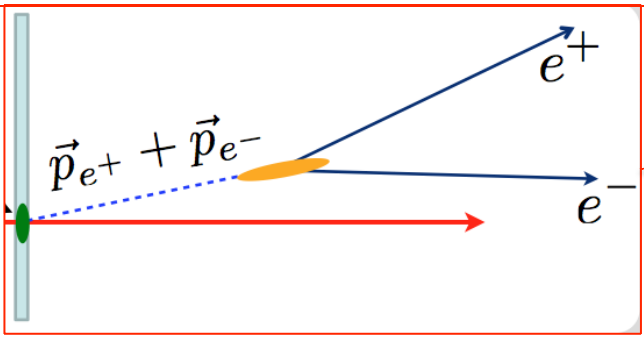
Heavy Photon Search strategies

Resonance search





Displaced decay vertex search



HPS evolution

January 2011

Proposal: PR12-11-006 **Scientific Rating:** Unrated

Recommendation: C2, i.e. the PAC conditionally approves this proposal contingent on the success of the test run. It feels that the test run should be carried out as early as possible (ideally before the 6 GeV shutdown), so that the full experiment can be carried out in a timely manner.

June 2012

Proposal: C12-11-006 Scientific Rating: A
Recommendation: C1 Conditionally Approved

between the measured rates and the simulations. Although there is still a substantial amount of work needed to get from this first test run to a full operation of the experiment, the view from the PAC is that the experiment should be promoted to the next level: Conditional Approval 1, which does not require a return to the PAC, but leaves it to the laboratory management to conduct a technical review of the experiment and to schedule beam

April 2014

Dear John and Stepan,
Thank you for submitting the document we requested regarding your response to the July 2013 DOE review of HPS and updating your run plans. We have studied your document and are generally pleased with the efforts you are making to address the comments from the review panel. The full rate test of electronics and DAQ is still to come, but we would like to involve personnel from the JLab experimental physics division to review and monitor your progress in this area. Rolf and Volker will be in contact with you about this.

Nevertheless, we agree that HPS has sufficiently satisfied the requirements to remove the C1 conditional approval. With the concurrence of the Lab Director, Hugh Montgomery, (see below) we will grant HPS full approval for the engineering run currently envisioned for FY15. Approval for future running beyond this engineering run will be contingent on successful demonstrated performance of the HPS apparatus during the engineering run.

We look forward to working with you to successfully realize the potential of the HPS experiment.
Best regards,
Bob

2015-2016 *Engineering runs at 1.1 GeV and 2.3 GeV (used only 15 PAC days)*

July 2016 *Fully Approved for full 180 PAC days (165 PAC days remains to run)*

June 2019 *Run I – 31.5 PAC days*

?? 202* *Run II*

?? 204* *Run Run Run*

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Our achievements since the first proposal

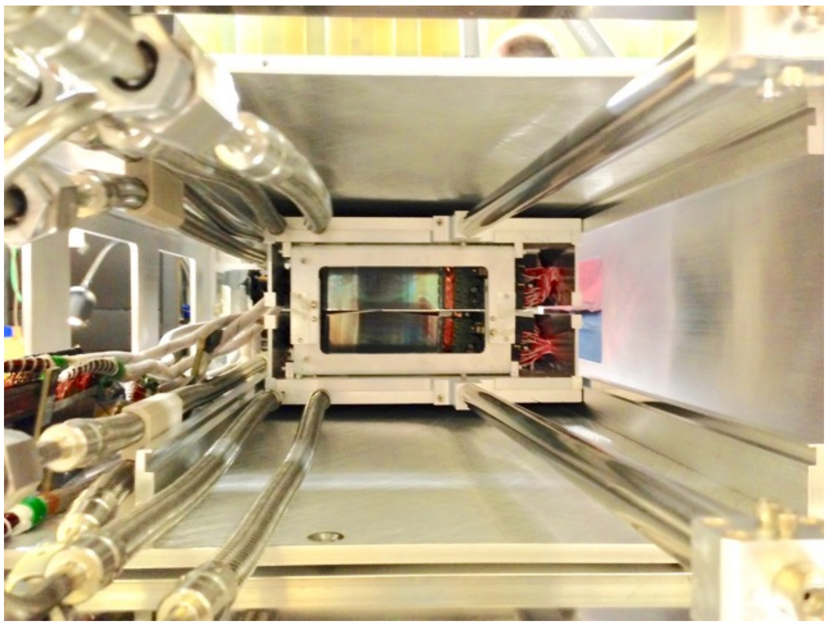
- HPS has been presented to JLAB PAC twice, PAC37 (C2) and PAC39 (C1)
- Successfully passed two DOE reviews for funding, March 2011 (got funded for the test apparatus) and July 2013 (has been fully funded)
- Built a test setup and run with photon beam in 2012,
- Built the full apparatus in 2013-2014, completed JLAB readiness reviews in 2014, ERR and ARR, and has been approved for engineering run
- Successfully completed two engineering runs, in 2015/2016 with 1.1/2,3 GeV beams
- Published three technical papers:
  - *"The Heavy Photon Search test detector"*, NIM **A777** (2015) – based on the 2012 test run with photon beam
  - "*The HPS Electromagnetic Calorimeter*", NIM **A854** (2017) – based on the engineering runs
  - "*The Heavy Photon Search beamline and its performance*", NIM **A859** (2017) – based on the engineering runs

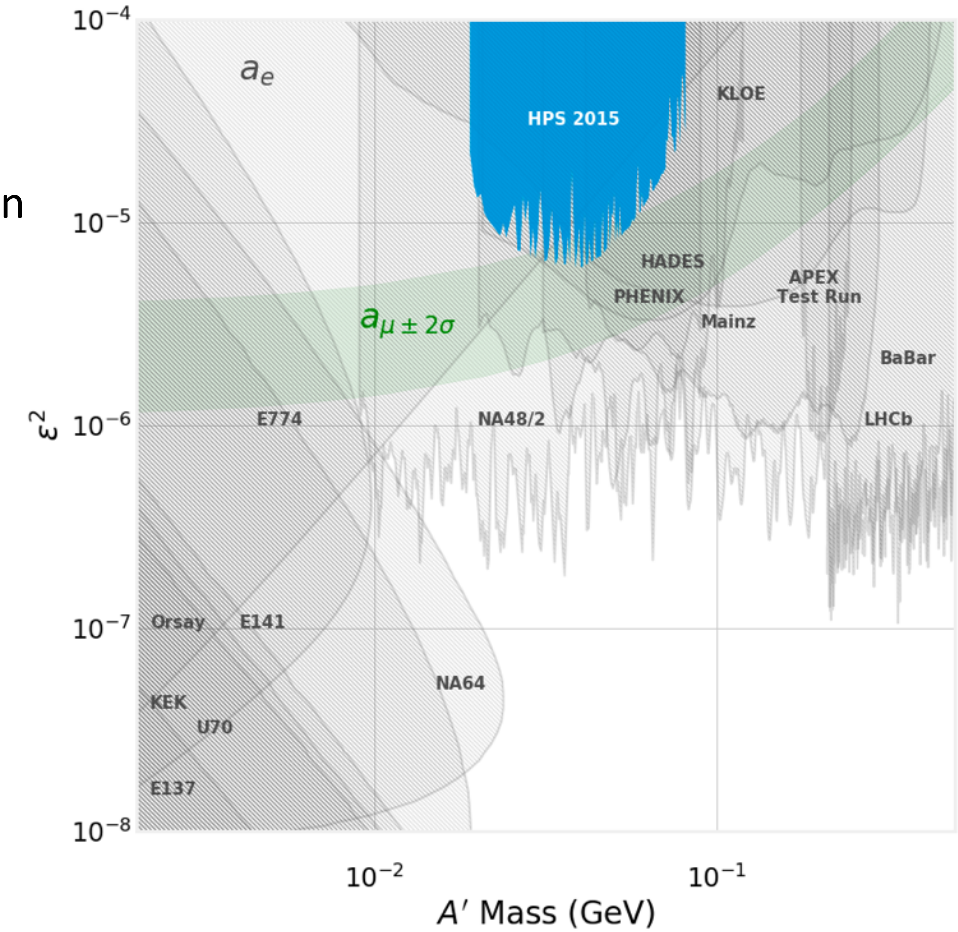
  One physics paper:
  - *"Search for a Dark Photon in Electro-Produced e^+e^- Pairs with the Heavy Photon Search Experiment at Jlab"*, Phys.Rev. D**98**, 091101(R)

  A ICHEP proceedings:
  - "*The Heavy Photon Search beamline and its performance*", NIM **A859** (2017) – based on the engineering runs
- Working towards for one more publication from the engineering run, combining resonance (2016) and displaced vertex (2015/16) search results.

First physics publication

- Paper has been accepted for publication as Rapid Communication in Physical Review D (email from 10/10/2018)
  - article was posted on arxive 7/30/2018
- Article has been selected to be a PRD Editors' Suggestion and will be featured on the new Physical Review D homepage





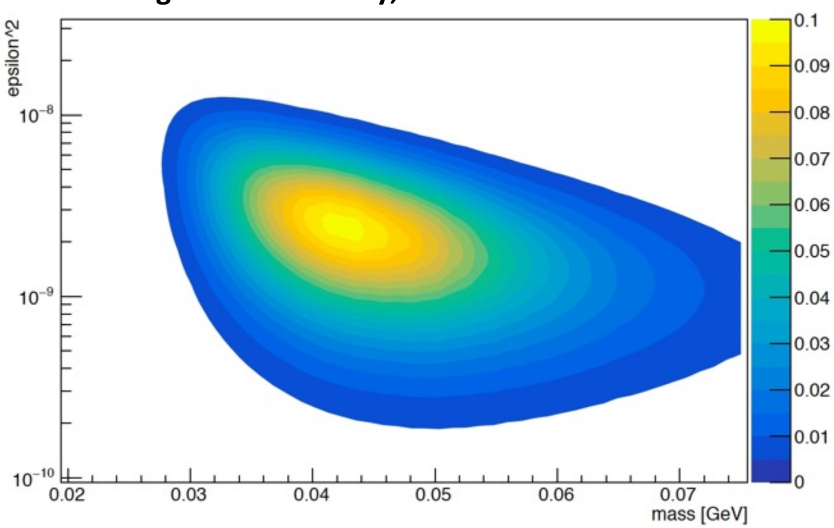
Kudos to Omar for shepherding the process and of course for our first physics results. Many thanks to the whole analysis team for a great work!

More good news on publication

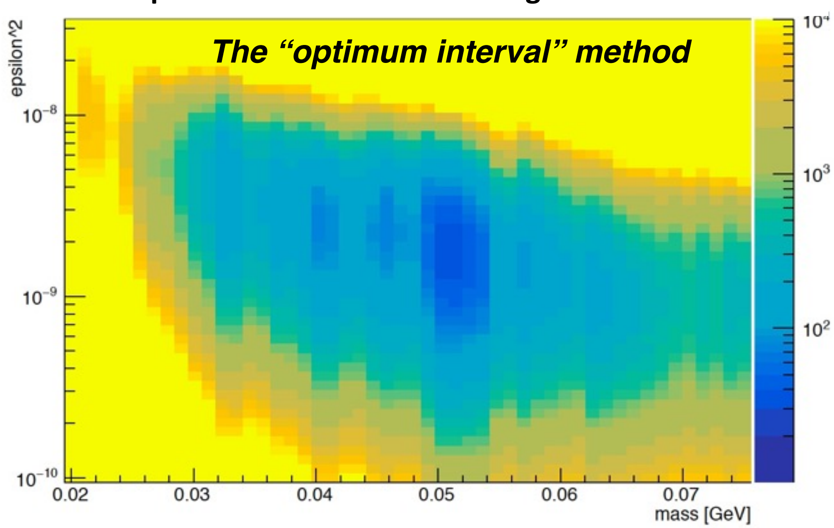
- Omar and Matt S. presented resonance and displaced vertex search results from 2015 run at ICHEP, 4-11 July 2018, Seoul, South Korea. Joined contribution from two presentations has been submitted for proceeding and is on arXiv:1812.02169[hep-ex] with author list of the PRD paper
- A search for displaced dark photon decays did not rule out any territory but resulted in a reliable analysis procedure that will probe new, unexplored parameter space with future, higher luminosity runs.

Thanks to Holly, Matt S. and the whole analysis group.

Maximum detectable A' after z-cut with 2015 integrated luminosity, 1165 nb^{-1}



The 90% confidence limit for zero background requires us to have an expected number of A' events greater than 2.3



Limitations of the engineering run detector reach and reclaiming the full reach with upgraded detector

- Comparing the engineering run data with the new, improved simulations several key reasons for overestimated the reach in the original proposal has been identified:
  1. Electron hole in the ECal was not taken into account resulting to **x2** higher detection efficiency for pairs
  2. Acceptance vs. decay length was assumed to be the same as for prompt decays, that overestimated integrated rate for long-lived A' by **x2**
  3. The original MC was giving **x1.5** higher yield due to incorrect nuclear form-factor

  These amounted to a total loss in pairs rates in data compared to the earlier estimate – **x6**
- With proposed detector/trigger upgrades, original reach will be restored:
  1. A single-arm positron trigger will eliminate losses due to ECal electron hole. Such trigger requires a scintillation hodoscope in front of ECal to veto bremsstrahlung photons that scatter to the positron side of the calorimeter. The overall gain for pairs rate detected in the tracking will increase by **x2**
  2. The SVT Upgrade:
     - Adding one more layer 5 cm downstream of the target, L0, will improve vertex resolution by about factor two, increasing integrated detection efficiency by **x2+** and
     - Moving L2 and L3 closer to beam to boost acceptance for long lived A' by anther **x 1.5**
- These upgrades, together with longer running, 4 PAC weeks, will regain most of the original HPS reach for displaced vertex search.

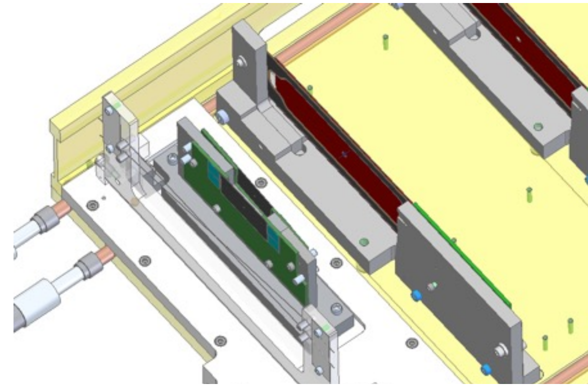
First production run

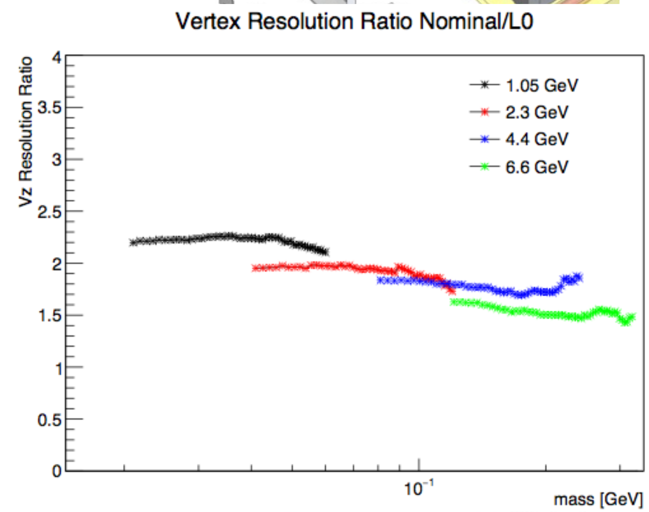
- HPS is scheduled to run for 63 days (31.75 PAC days) in summer of 2019, June 10 to August 11
- CEBAF will be configured for low energy operations, 0.9 GeV/pass
- Beam energy for HPS at 5th pass is expected to be 4.55 GeV, beam bunch frequency 499 MHz
- Detector will be ready with upgraded detector: SVT with L0, scintillation hodoscope and a new single-arm trigger – the upgrades absolutely necessary for the success, to reclaim originally proposed reach
- HPS may face some challenges for smooth running. A parity experiment in Hall-A will run in parallel to HPS in Hall-B. Parity experiments have very stringent requirements for the beam quality and polarization, and require very high current beams (70 μA)
- The CLAS12 spring run ends on April 7. Hall-B will be ready for HPS installation starting the week of April 15 − must remove some of the CLAS12 detectors and beam pipes before HPS can go in.

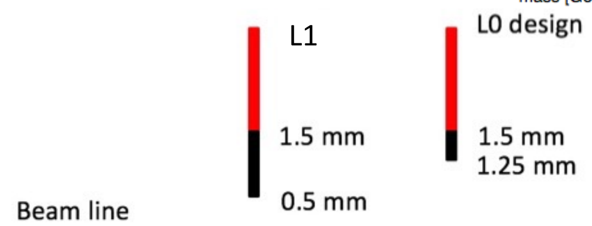
SVT Upgrade

- A new silicon layer, thinner and closer to the target improves vertex resolution ~2x.
- More technically aggressive than current SVT: special sensor processing and even closer to beam.
- It is possible, and potentially advantageous, to replace current L1 with new Layer 0 modules:
  - less dead material to convert WABs
  - active area can be closer to beam, improving angular acceptance for long-lived signal events
  - enables lower occupancies and improved pattern recognition
  - sacrifices only a small amount of recoil acceptance

Details in Tim Nelson's talk



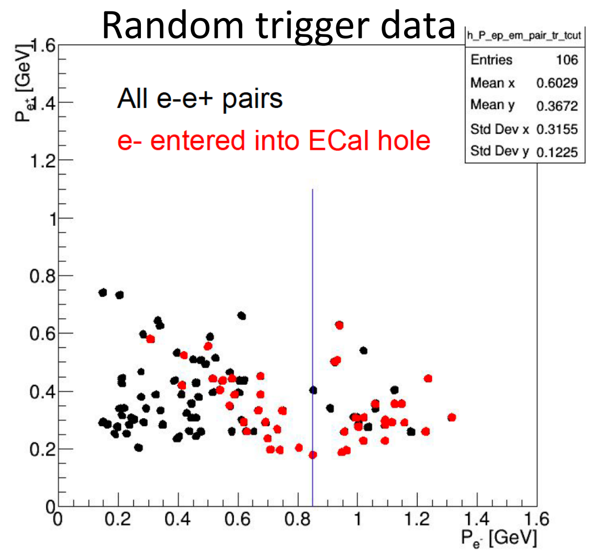




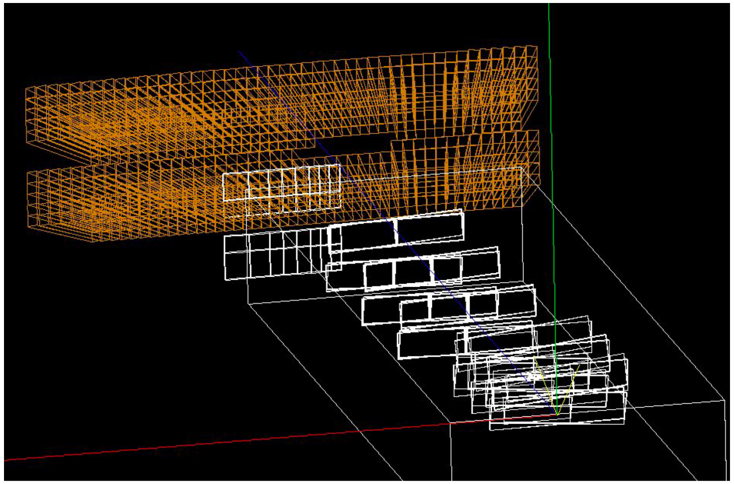
Important change for suppressing scatters

Trigger upgrade – scintillation hodoscope

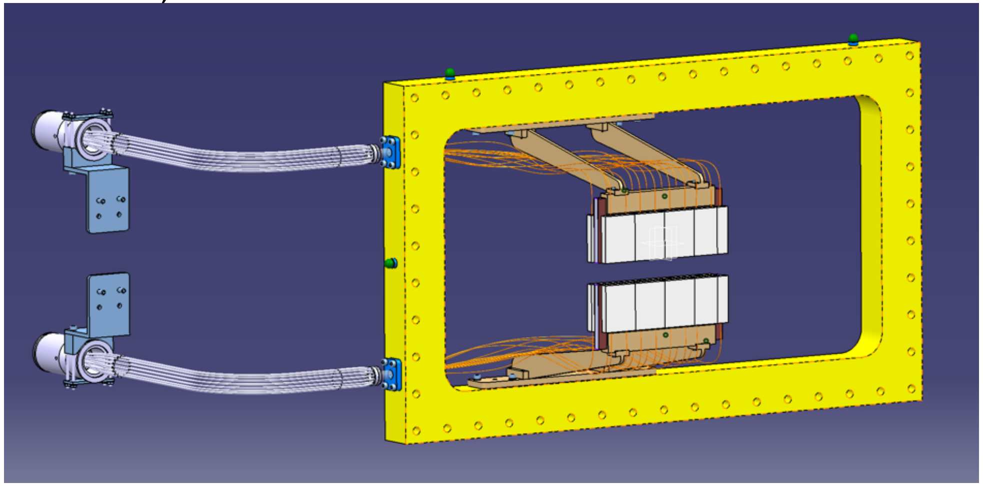
- Cluster pair trigger worked well, efficiency >95%, DAQ rates ~20 kHz at LT≈95%
- But, more than ½ of the recorded triggers were from ($e^-\gamma$) pairs and the half of the (e^+e^-) pairs where e^- scatters in the ECal electron hole were lost in the trigger, although they could have been reconstructed by the tracking system
- A single arm, positron trigger will resolve both issues



Scintillation counter on the "positron" side to veto photons in the trigger

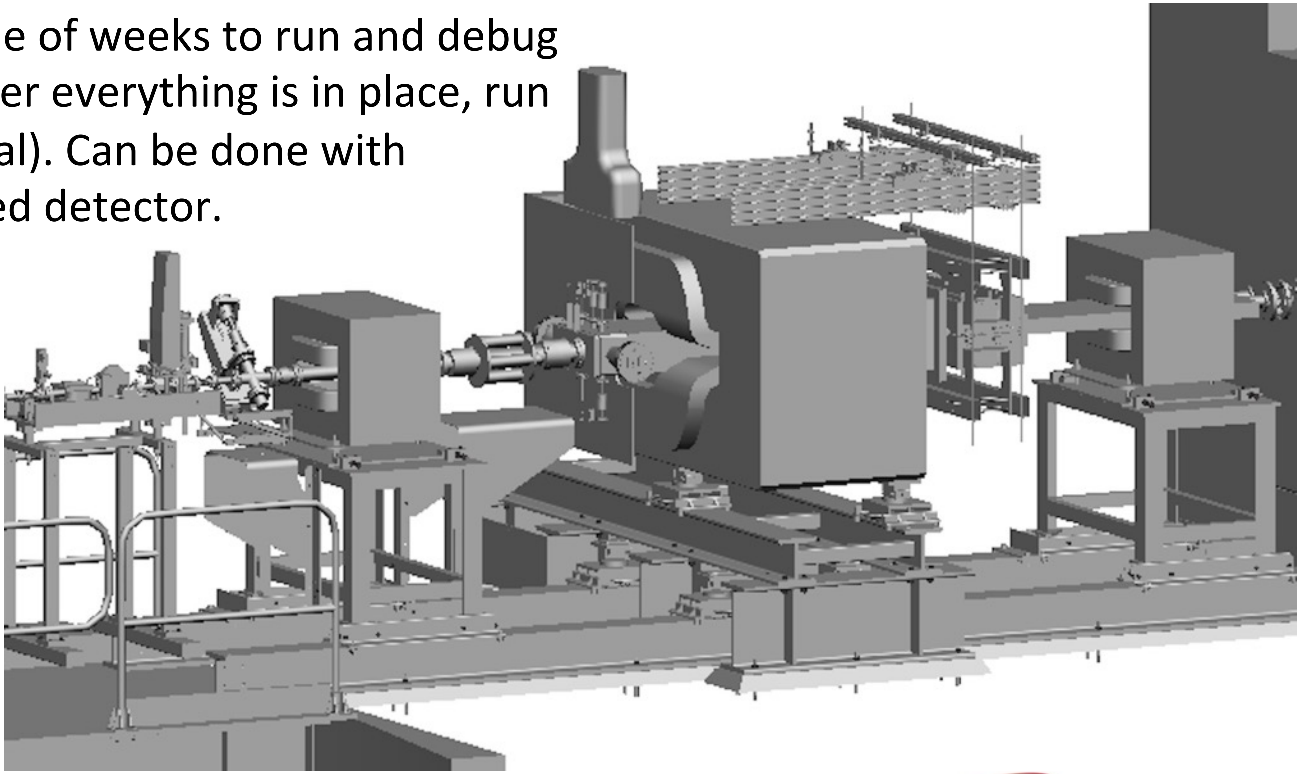


Scintillation hodoscope: double layer of scintillator strips for each half, with WLS fibers and maPMT readout

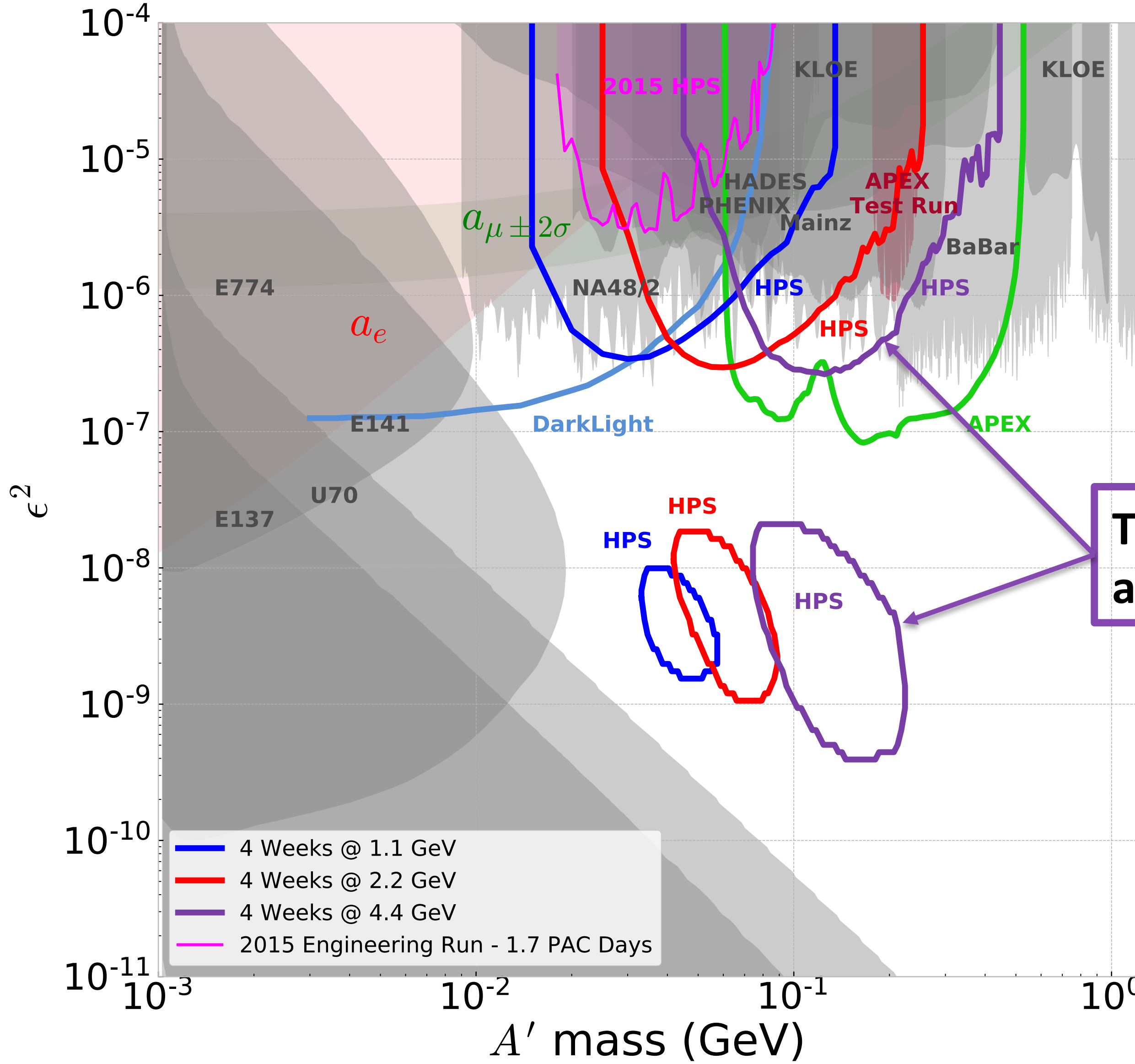


HPS installation

- During the CLAS12 operations, HPS was dismounted and moved off the beam line
- Installation of the HPS must be well planned, there are dependences in the sequence of detector installation. Staged approach may be needed, depending on the progress of upgrades
- With everything ready, the whole installation is a ~2 weeks effort
- Will need couple of weeks to run and debug DAQ/trigger after everything is in place, run calibrations (Ecal). Can be done with partially installed detector.



Expected reach with upgrades



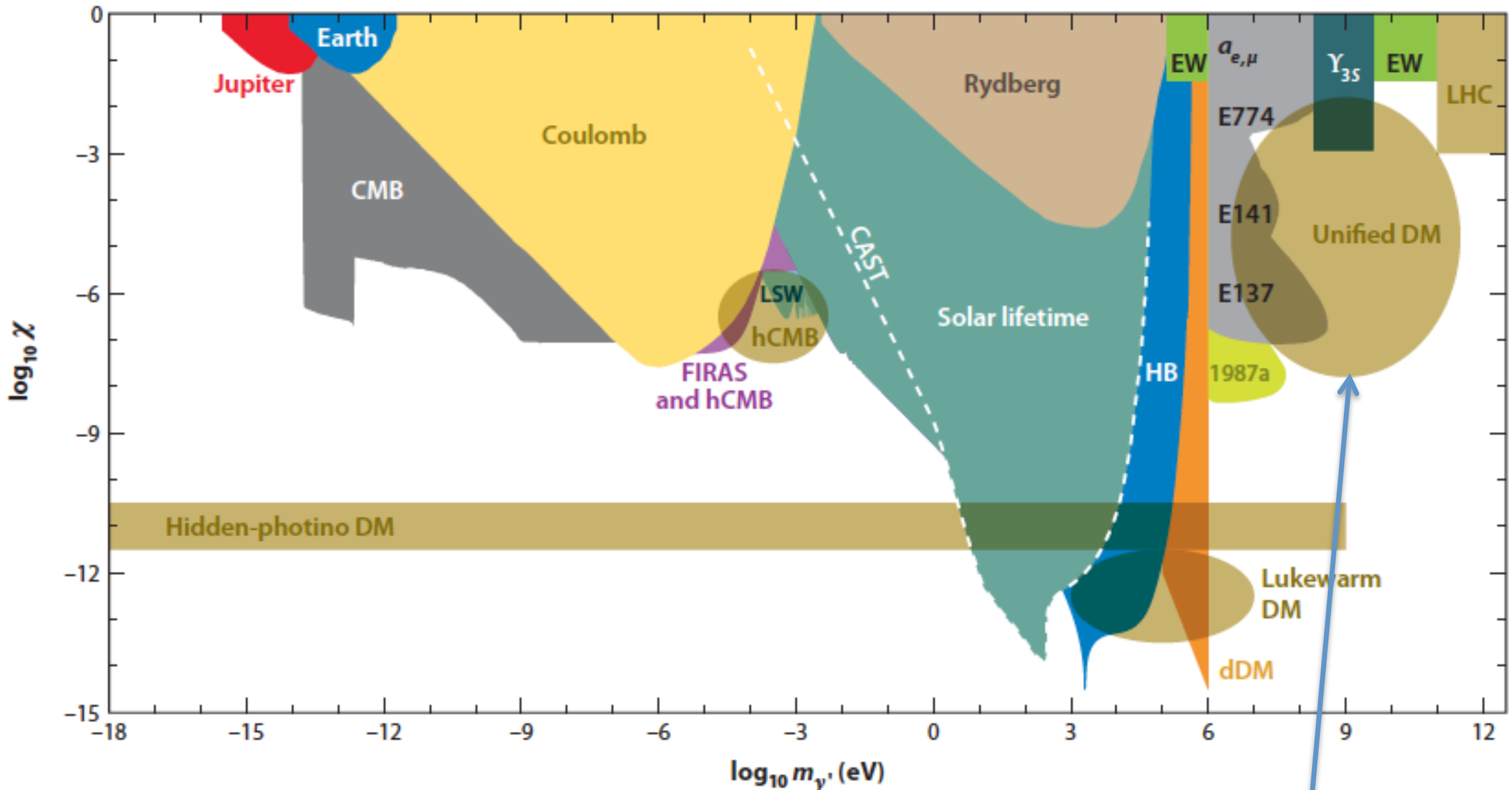
The 28 PAC days at 4.4 GeV

Summary

- Dark photons
- HPS
- Publication
- Upgrade
- **The highest priority for HPS is completion of the upgrades and get ready for the first production run − need start on simulations to define , June-August 2019**
- there are exciting new physics targets for HPS. After summer run, >134 PAC days still on the books to be defended

Backups

Parameter space for LDMP



Jaeckel and Ringwald, Annu. Rev. Nucl. Part. Sci. 2010.60:405-437

Hidden sector photons

Jeopardy

- The process of Jeopardy will begin with the PAC meeting in 2019, first with proposals in Halls A and C approved in 2006-2007 that have not been (fully) run or scheduled
- The process will continue ~4 years, PAC will be considering both new proposals and resubmitted Jeopardy proposals
- In 2020, the Jeopardy process will be applied to the presently approved Hall B program
- Each run group that has not been scheduled to **complete** yet (in 2020) will be considered for Jeopardy
- Hall B jeopardy might include the current Run Groups A, B, C, D, E, G, H, I (note: includes HPS as run group I), but of course it depends on the actual run schedule in the next 5 years
- It is likely that HPS will have to go in front of the PAC to defend remaining approved beam time, ~134 days after summer run!