The Heavy Photon Search Experiment

Omar Moreno
on Behalf of the Heavy Photon Search Collaboration

Santa Cruz Institute for Particle Physics
University of California, Santa Cruz
omoreno1@ucsc.edu

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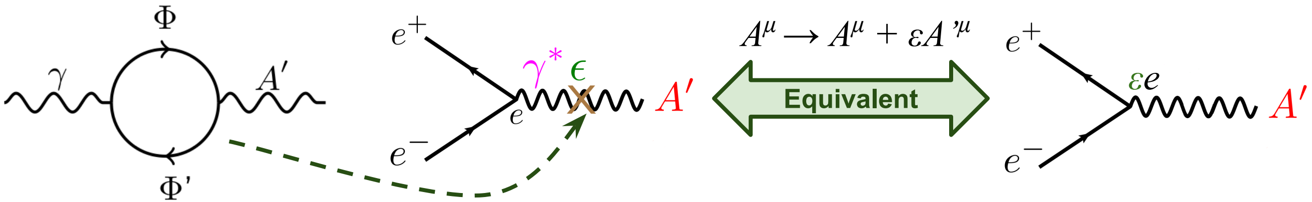
What is a "Dark Photon"?

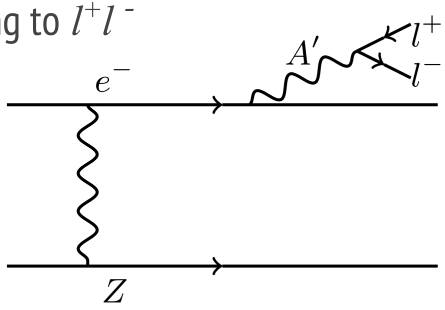
- Consider a theory in which nature contains an additional Abelian gauge symmetry, $U(1)_D$
  Holdom, Phys. Lett. B166, 1986

$$\mathcal{L} = \mathcal{L}_{\mathsf{SM}} + \frac{\varepsilon}{2} F^{Y,\mu\nu} F'_{\mu\nu} + \frac{1}{4} F'^{\mu\nu} F'_{\mu\nu} + m^2_{A'} A'^{\mu} A'_{\mu}$$

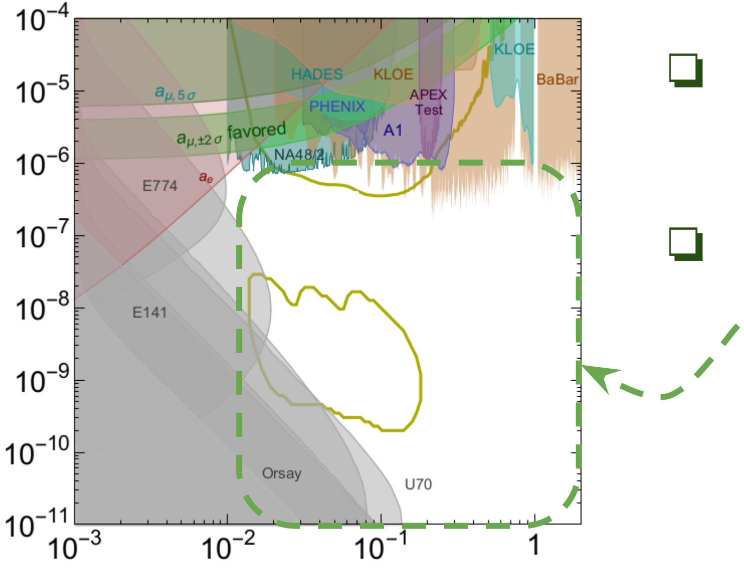
- This gives rise to a **kinetic mixing** term where the photon mixes with a new gauge boson ("dark/heavy photon" or A') through the interactions of massive fields $\longrightarrow$ induces a weak coupling to electric charge



- Since dark photons couple to electric charge, they will be produced through a process analogous to bremsstrahlung off heavy targets subsequently decaying to l^+l^-

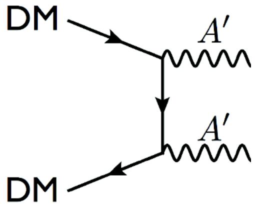


Where Do You Search for a Dark Photon?

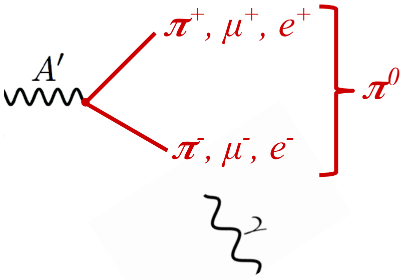


Present limits

- Lack of signals at LHC and direct detection experiments implies thinking of other type of DM, possibly light, which is compatible with dark photons
- New astrophysical anomalies (INTEGRAL, GC) can be explained by a light Dark Matter (~GeV) candidate decaying to an MeV - GeV A' (ε^2 ~ 10^{-6} - 10^{-12})



Arkani-Hamed et. al., Pospelov, Ritz, Finkbeiner + Weiner, Nomura + Thaler



Hooper, Weiner, Xue

Fixed target with e- beam
APEX test run (JLab), Mainz (A1)

Fixed target with p beam
Fermilab

Beam dump experiments
E774, E141, u70, Orsay

Annihilation
BABAR, BELLE, KLOE

Meson decay
KLOE, BES-3, WASA-COSY, NA48/2 (CERN SPS), PHENIX

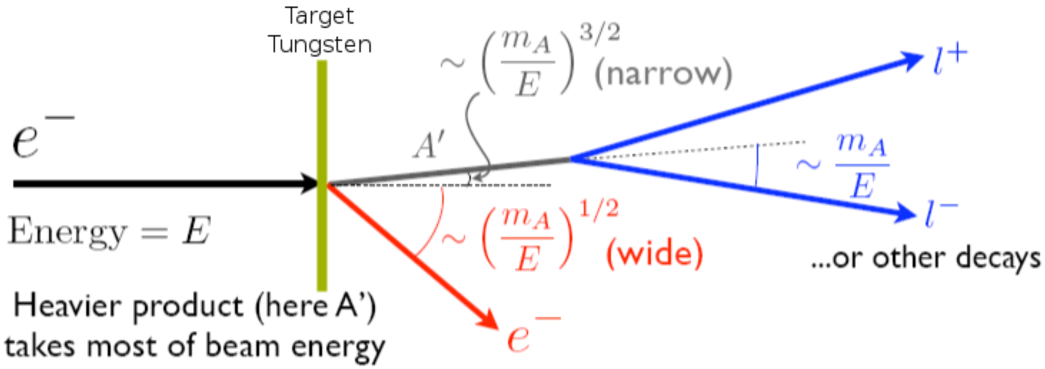
A' Fixed Target Kinematics

PHYSICAL REVIEW D **80,** 075018 (2009)

New fixed-target experiments to search for dark gauge forces

James D. Bjorken,[1] Rouven Essig,[1] Philip Schuster,[1] and Natalia Toro[2]
[1]*Theory Group, SLAC National Accelerator Laboratory, Menlo Park, California 94025, USA*
[2]*Theory Group, Stanford University, Stanford, California 94305, USA*
(Received 20 July 2009; published 28 October 2009)

Fixed-target experiments are ideally suited for discovering new MeV–GeV mass $U(1)$ gauge bosons through their kinetic mixing with the photon. In this paper, we identify the production and decay

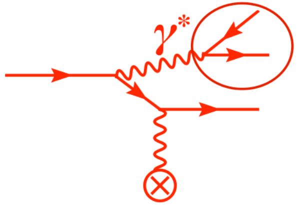


- Even though A' particles are produced by a process analogous to ordinary photon bremsstrahlung, the rate and kinematics differ in several key ways
  - The A' productions cross section is suppressed relative to photon bremsstrahlung by a factor of $m_e^2 \varepsilon^2 / m_{A'}^2$
  - The A' is produced very forward → opening angle of its decay products is $\sim m_{A'}/E_{beam}$
  - The A' will take most of the incident beam energy
  - Long lived A' will have a displaced vertex → Will help cut down prompt backgrounds

A' Fixed Target Backgrounds

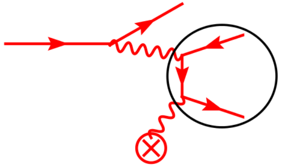
Two physics backgrounds collectively known as "tridents"

Radiative

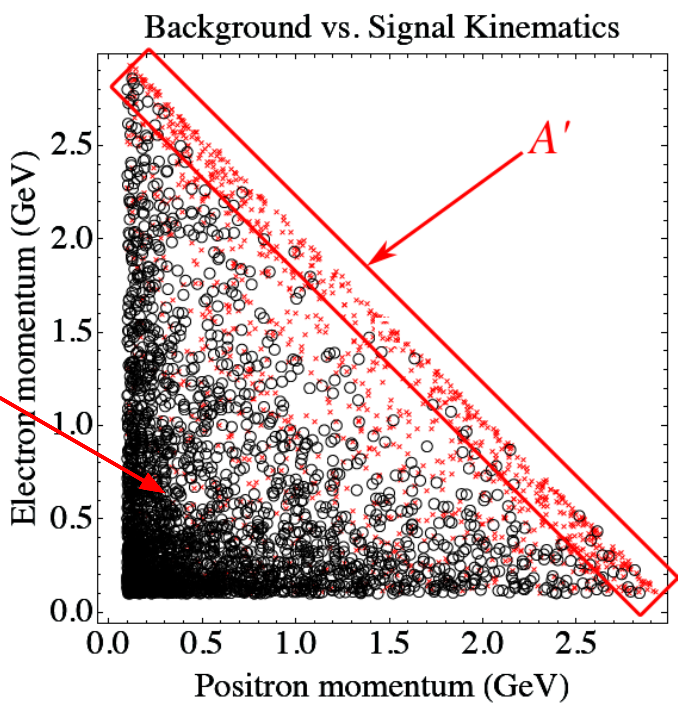


Irreducible.
Kinematically identical to A'.

Bethe-Heitler



Dominant but is also kinematically distinct to the *A'*. Even after kinematic cuts, Bethe-Heitler dominates.

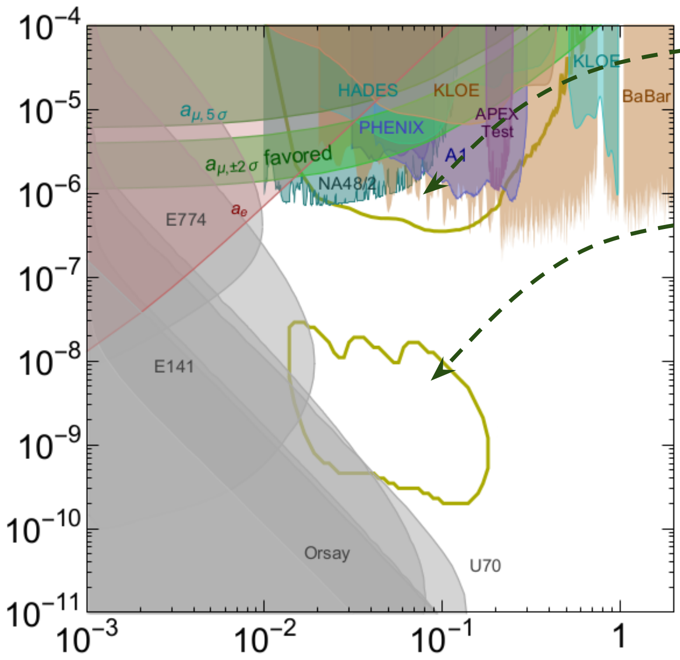


Beam Backgrounds

- Coulomb scattering in the target
- Secondary particle production: bremsstrahlung and delta-rays
- Pair conversion of bremsstrahlung photon

HPS Design Considerations

Maximizing the acceptance to low mass A' decays and precise vertexing requires placement of the detector as close to the beam as possible



Bump Hunt

Requires good mass (momentum) resolution to fight high backgrounds

Displaced Vertex + Bump Hunt

Distinguishing A' decay vertices as Non-prompt requires good vertex resolution

- ❑ Both will require a tracking system and magnet that are placed as close to the target as possible
- ❑ Mass and vertex resolution will be dominated by multiple scattering so tracker material needs to be minimized

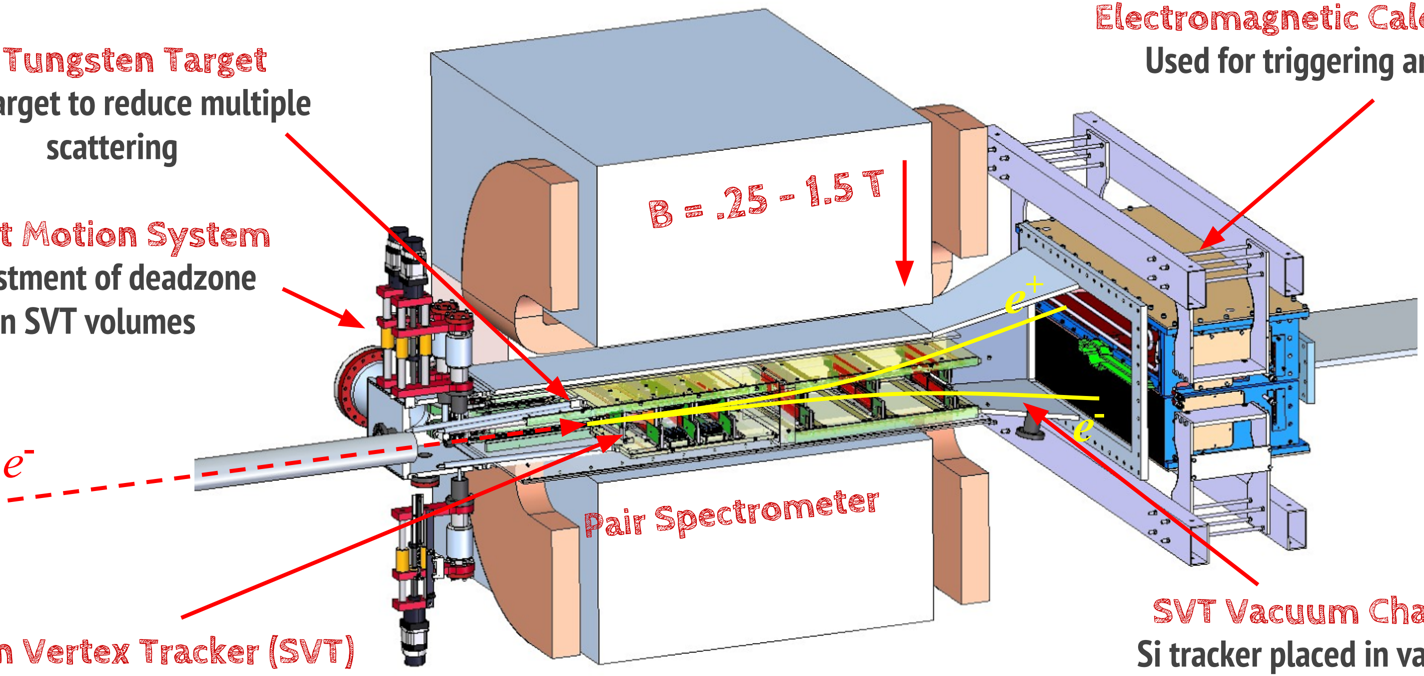
Small coupling ⟶ small cross section ⟶ requires high intensity beam

- ❑ High occupancy will require fast readout and trigger system

The HPS Apparatus

$\sim 10^{-3}$ X_0 Tungsten Target
Thin target to reduce multiple scattering

Linear Shift Motion System
Allows adjustment of deadzone between SVT volumes



Electromagnetic Calorimeter
Used for triggering and particle ID

Silicon Vertex Tracker (SVT)
Used for precise momentum and vertex determination

SVT Vacuum Chamber
Si tracker placed in vacuum in order to avoid backgrounds due to beam-gas interactions

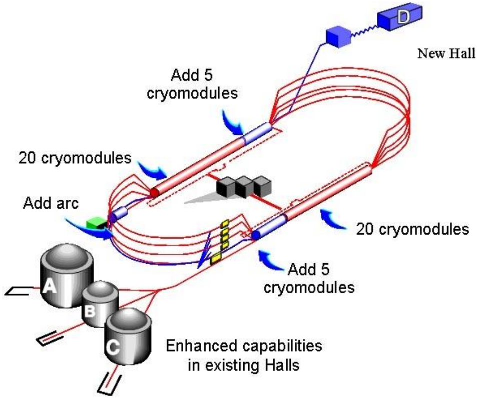
SVT + ECal DAQ capable of 50 kHz

Continuous Electron Beam Accelerator Facility

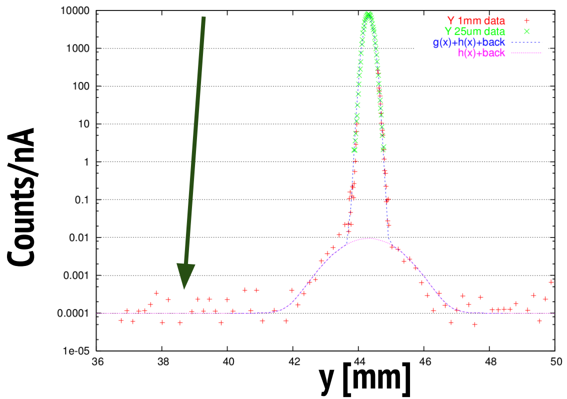
Simultaneous delivery of **intense** electron beams of different energies to four experimental halls.

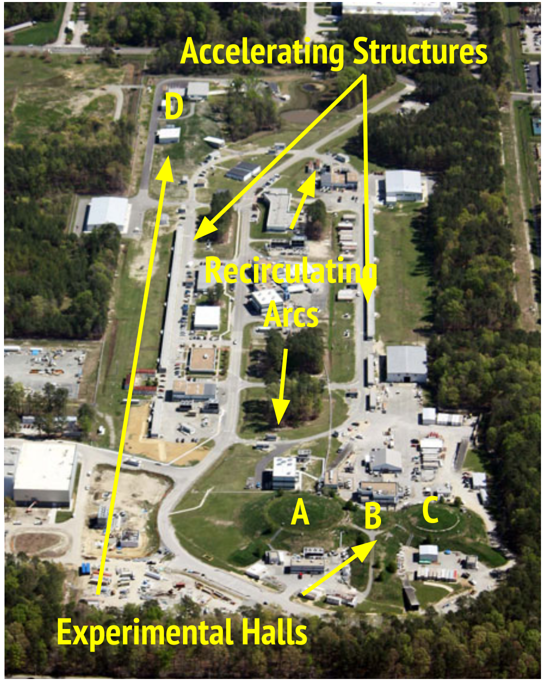
- Hall **A**, **C**: I_{beam} < 100 μA, Hall **D**: I_{beam} < 90 μA, Hall **B**: I_{beam} < 800 nA
- With energy upgrade, E_{beam} = n x 2.2 GeV, n < 6 up to a maximum of 11 GeV (12 GeV for Hall D)
- Beam delivery is nearly continuous → 2 ns bunch structure
- Capable of providing small beam spot with small tails which will help improve vertexin

HPS will run in experimental Hall B at a beam energy ranging from 1.1 - 4.4 GeV and current of 50 nA to 200 nA

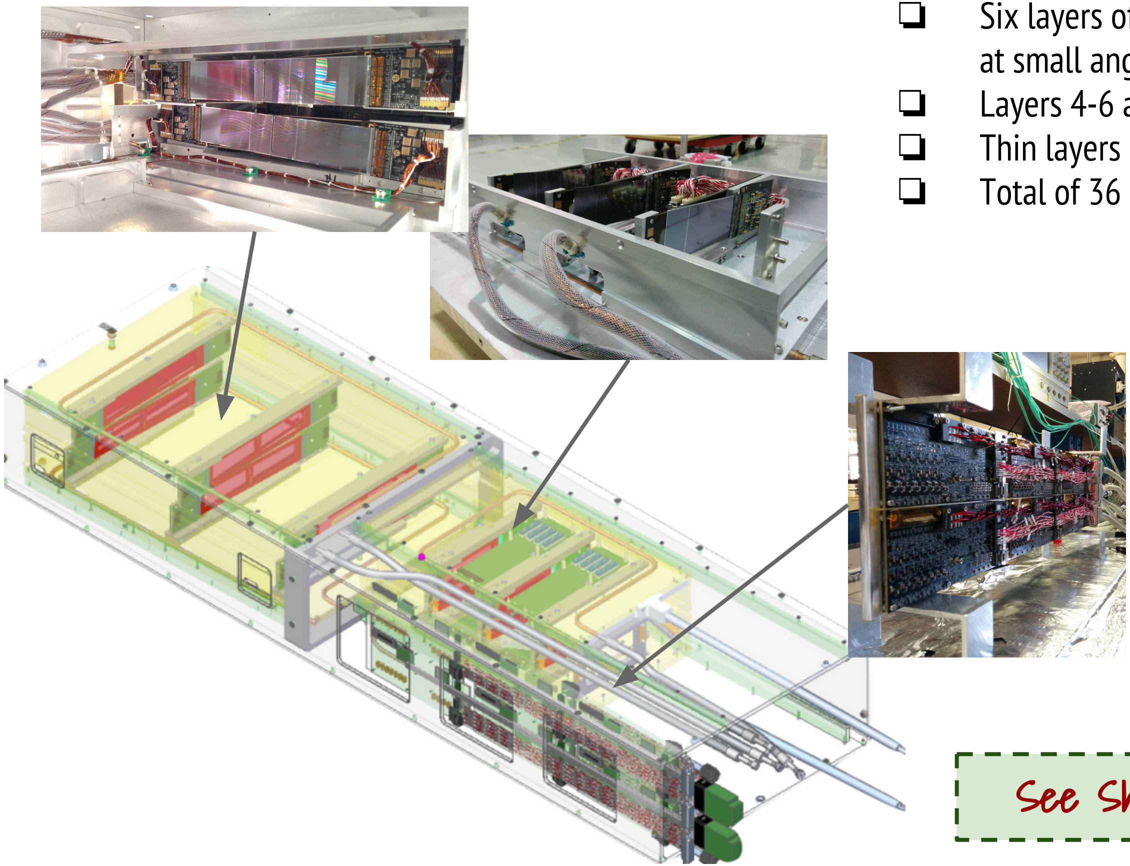


Beam halo/tails 10^{-7}





Silicon Vertex Tracker

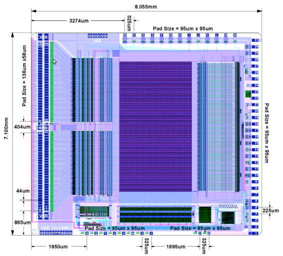


Design

- ❏ Six layers of pairs of Si microstrip sensors ⟶ One axial and the other at small angle stereo (50 or 100 mrad)
- ❏ Layers 4-6 are double width in order to match calorimeter acceptance
- ❏ Thin layers in order to reduce multiple scattering (0.7%X_0/layer)
- ❏ Total of 36 sensors and 23004 channels

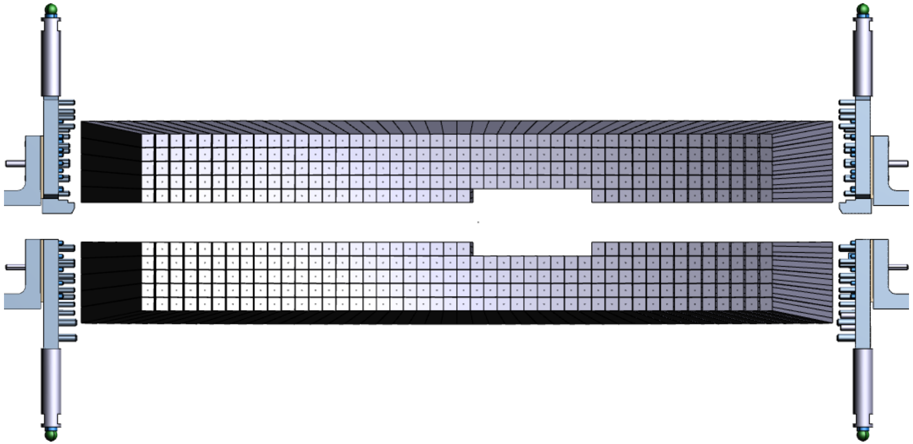
Readout

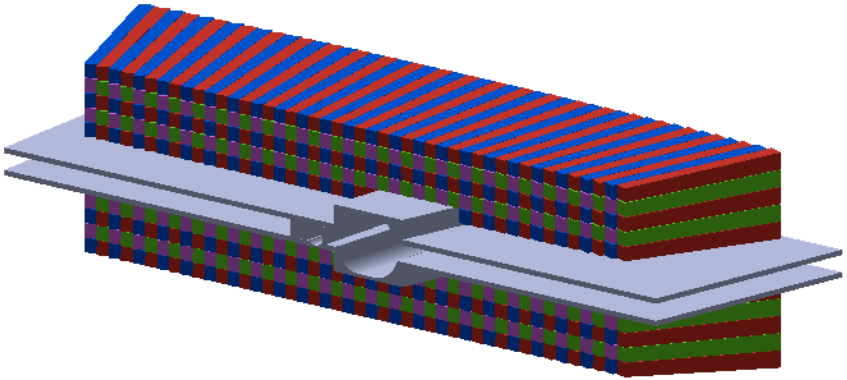
- ❏ Makes use of APV25 readout chip
- ❏ 40 MHz six sample readout helps achieve a 2 ns t0 resolution and fight pileup
- ❏ Low noise ⟶ S/N > 25
- ❏ High radiation tolerance



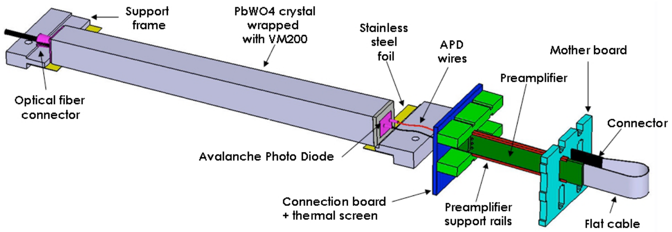
See Sho Uemura's talk for details

Electromagnetic Calorimeter





- Comprised of 442 PbW04 crystals
- FADC readout at 250 MHz → allows for a narrow trigger window (8ns)
- FPGA based trigger selection (Two clusters along with some constraints on their energy and geometry) reduces background trigger rate from 3 MHz to 27 kHz
- Trigger and DAQ capable of a rate > 50 kHz



See Holly Vance's talk for details

HPS Experimental Reach

Spring of 2015

1 Week @ 1.1 GeV

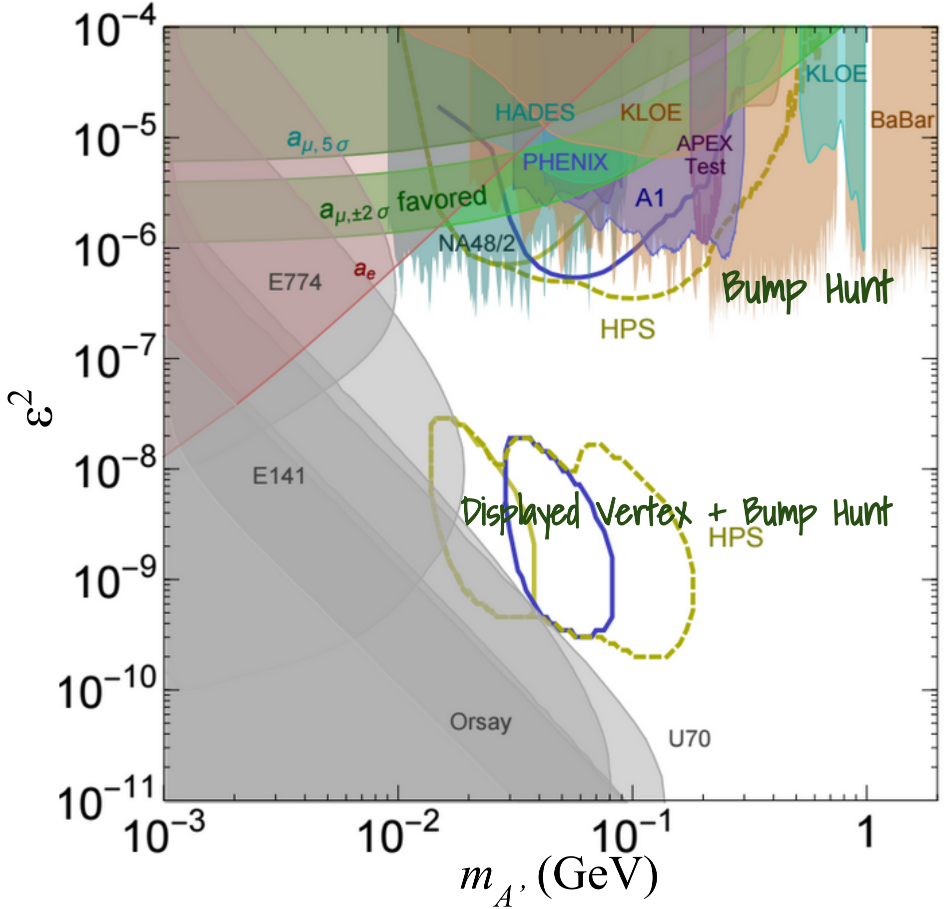
Fall of 2015

1 Week @ 2.2 GeV

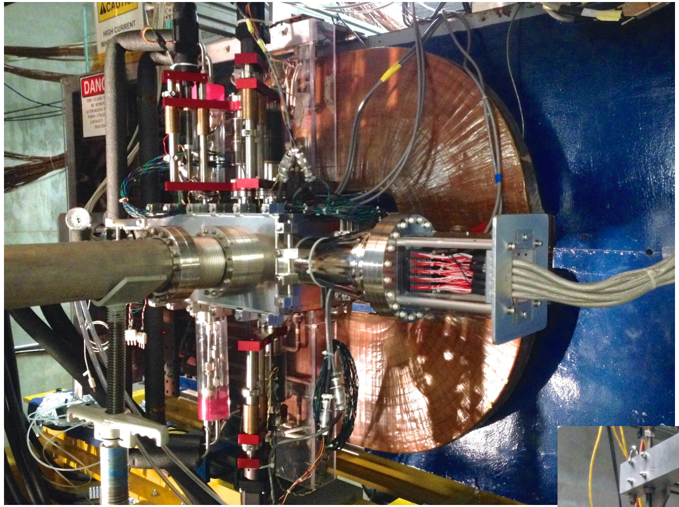
Beyond…

2 Weeks @ 4.4 GeV

Running at other energies also possible

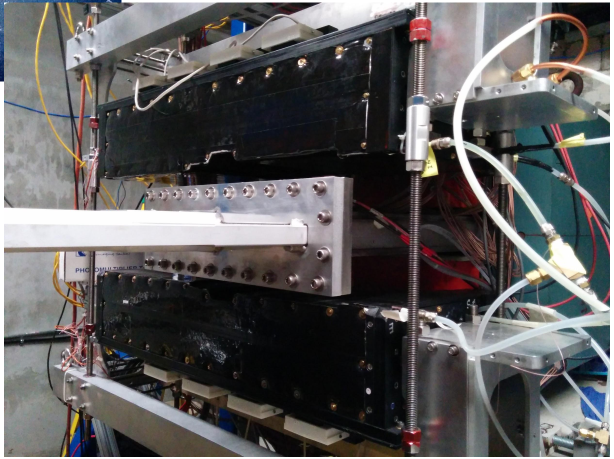


Current Status



- Installation of the ECal was completed in Fall in time for a December commissioning run
- Installation of the SVT was completed in February 2015.
- Both systems have been commissioned and are ready for electrons

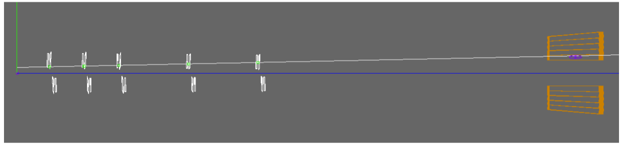
1.1 GeV beam expected any day now!



Test Run

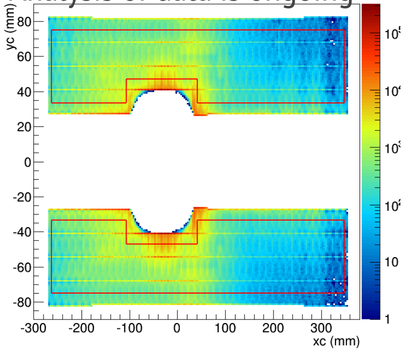
Demonstrated HPS is ready for electrons!

Y-Z view of a track



December 2014 Run

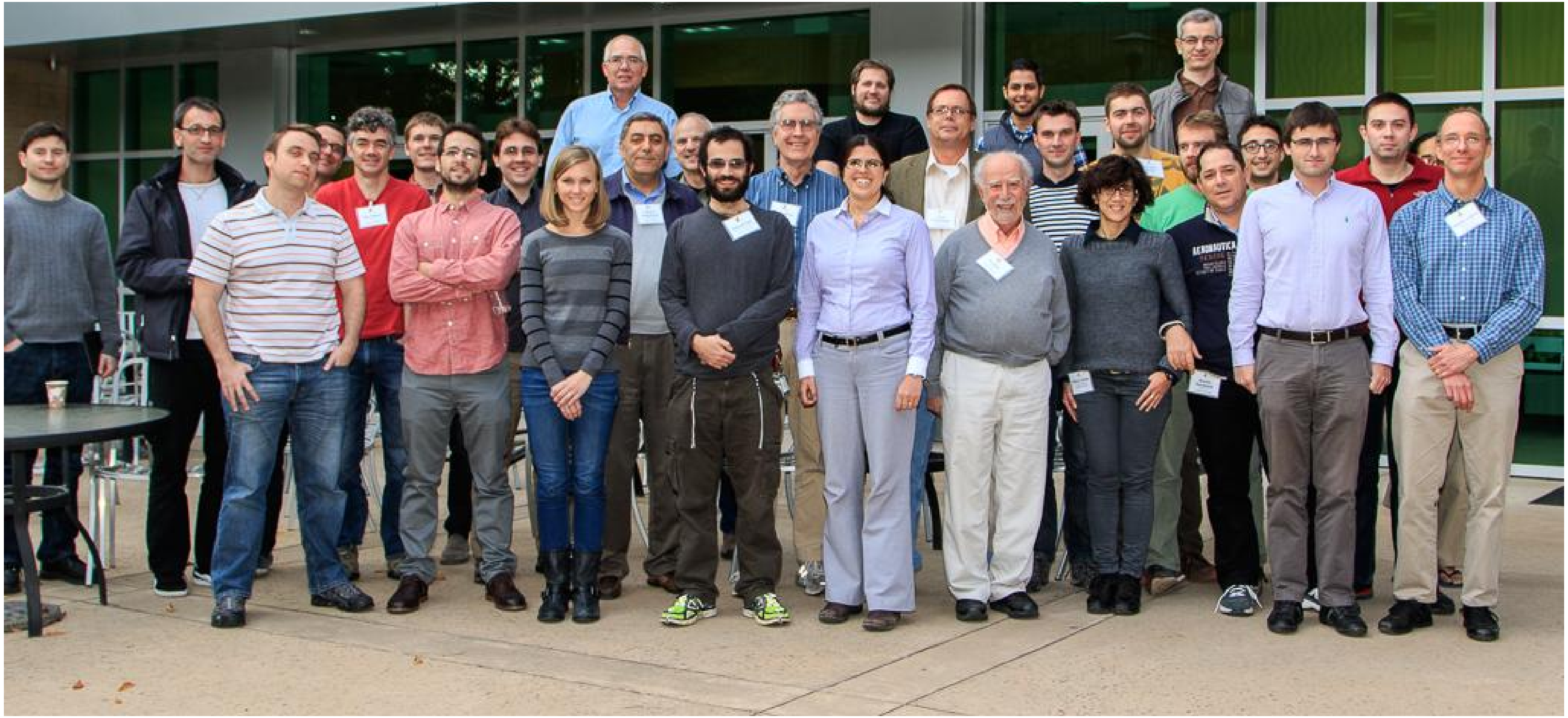
Analysis of data is ongoing



See Nathan Baltzell's talk for details

HPS Collaboration

SLAC P. Hansson Adrian, C. Field, N. Graf, R. Herbst, J. Jarros, T. Maruyama, J. McCormick, K. Moffeit, T. Nelson, A. Odian, M. Oriunno, B. Reese, S. Uemura UCSC A. Grillo, V. Fadeyev, O. Moreno FNAL W. Cooper JLab N. Baltzell. S. Boyarinov, V. Burket, C. Cuevas, A. Deur, H. Egiyan. A. Freyberger, F.X. Girod, V. Kubarovsky, B. Raydo, Y. Sharabian. S. Stepanyan, M. Ungaro. B. Woitsekhowski Stony Brook R. Essig INFN Genova M. Battaglieri, A. Celentano, R. DeVita, M. Osipenko ODU S. Bueltmann. G. Kalicy. H. Vance, L. Weinstein INFN Torino D. Calvo. A. Filippi INFN Sassari M. Carpinelli, V. Sipala Orsay G. Charles, R. Dupre, M. Guidal, C. Munoz-Camacho, S. Niccolai, A. Simonyan INFN U. Rome L. Colaneri, A. D'Angelop, A. Rizzo YerPhI N. Dashyan. N. Gevorgyan, H. Voskanyan NFN Catania M. De Napoli. E. Leonora, N. Randazzo CEA-Saclay M. Garcon William and Mary K. Griffioen, S. Paul UNH M. Holtrop, K. McCarty, R. Paremuzyan Glasgow K. Livingston, B. McKinnon, D. Sokhan, Perimeter Institute P. Schuster, N. Toro INFN Sassari V. Sipala



Stay Tuned

Tracking and Vertexing for the Heavy Photon Search

Sho Uemura

Heavy Photon Search Commissioning Run and Performance of the Electromagnetic Calorimeter

Holly Szumila-Vance

Results from the HPS Commissioning Run

Nathan Baltzell

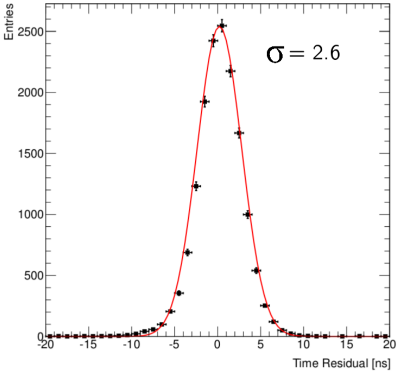
Back Up

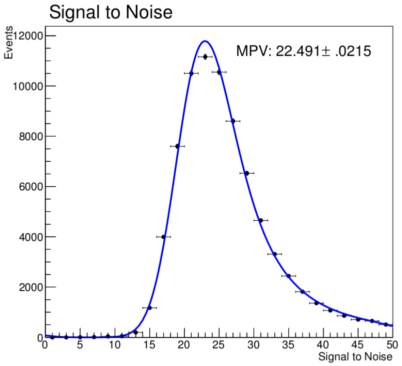
Test Run Results

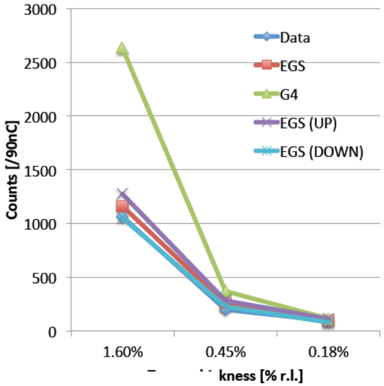
Demonstrated HPS is ready for electrons!

98% of 12780 SVT channels were operational
t0 resolution was found 2.6 ns
SVT aligned to within 300 um

Signal to noise ~23
Hit efficiencies > 99%
Trigger rates are well understood







Y-Z view of a track