Direct Search for Dark Photons with the SeaQuest Spectrometer

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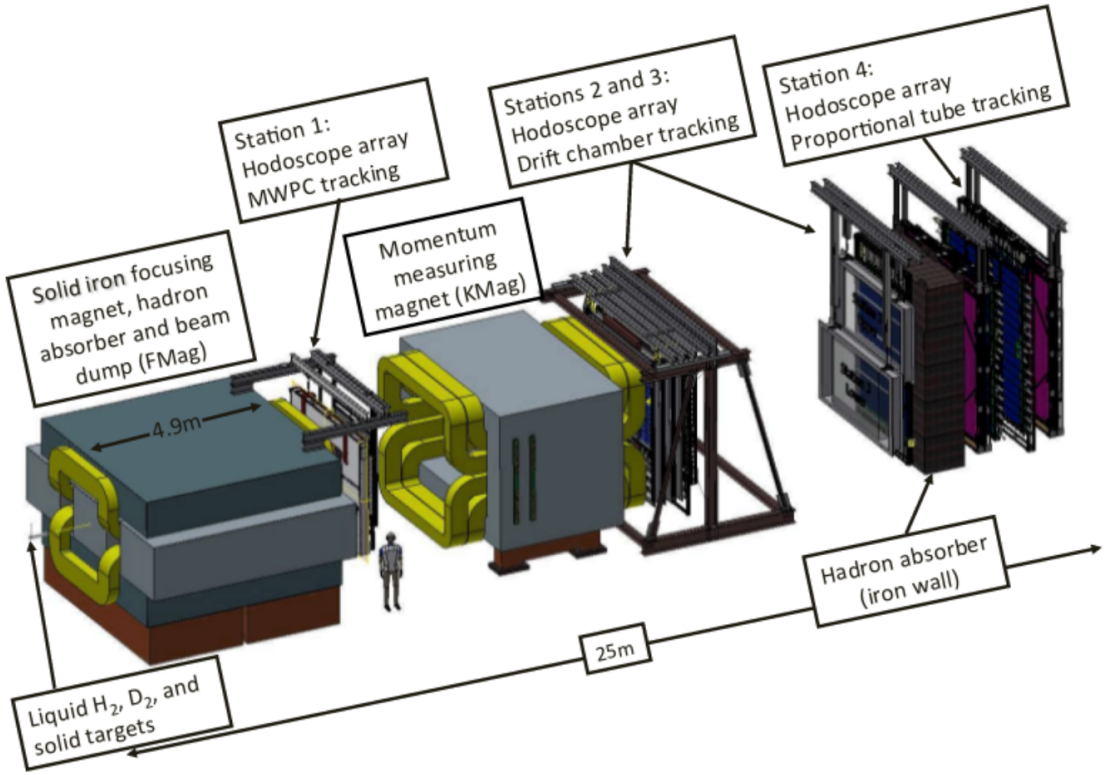
SeaQuest Collaboration

The SeaQuest facility

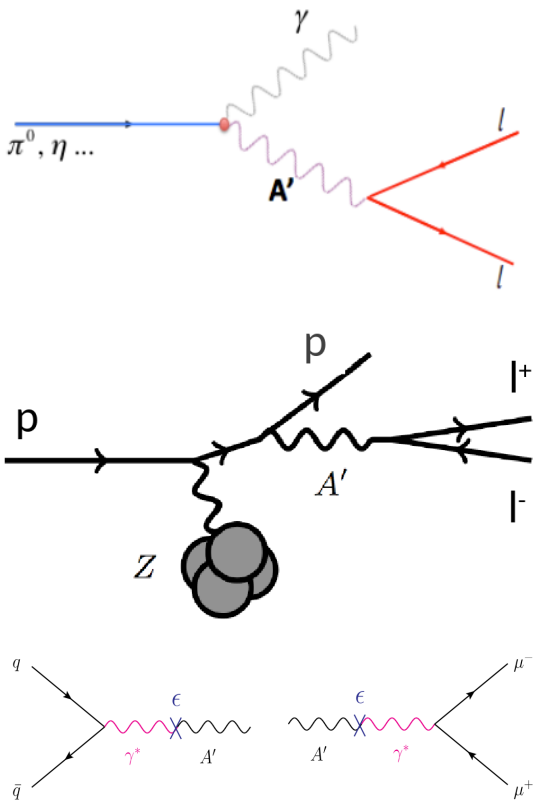
- Fixed-target muon spectrometer, Fermilab 120 GeV proton beam
- Primary program: Drell-Yan measurements of sea quark distributions
  - E906 (unpolarized targets, 2012–2017), E1039 (polarized targets, 2019–2020)
- Parasitic searches for dark photons approved 2015 (E1067)

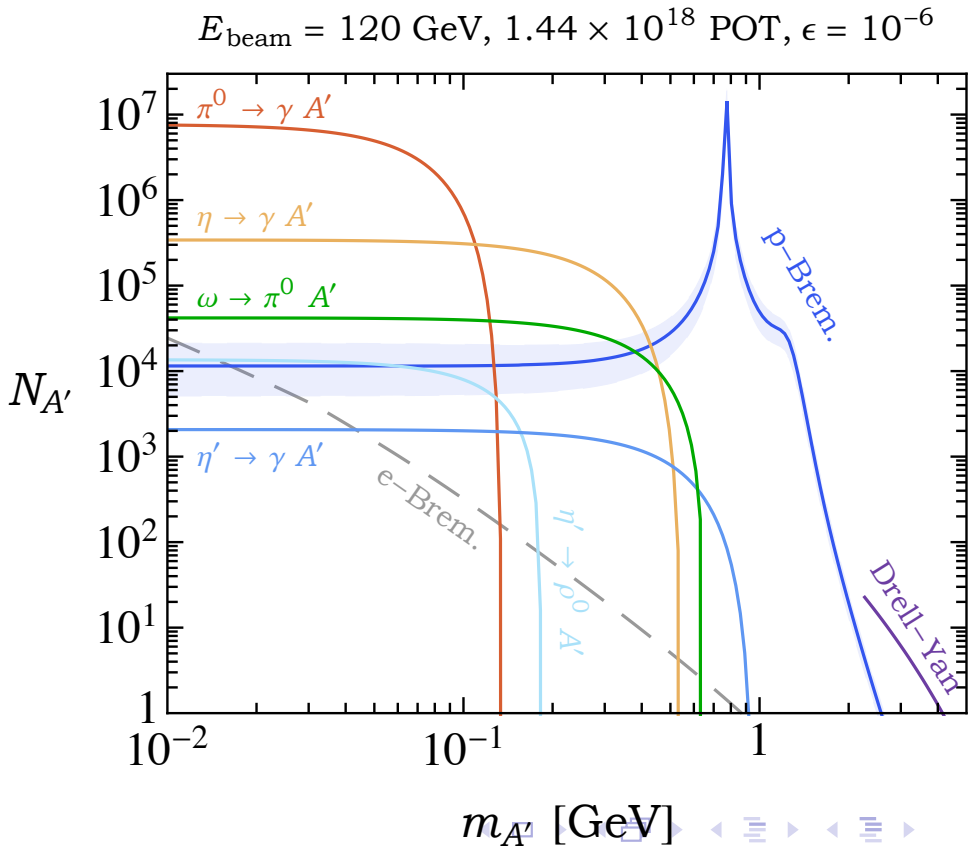


arXiv:1706.09990

Production and signatures at SeaQuest

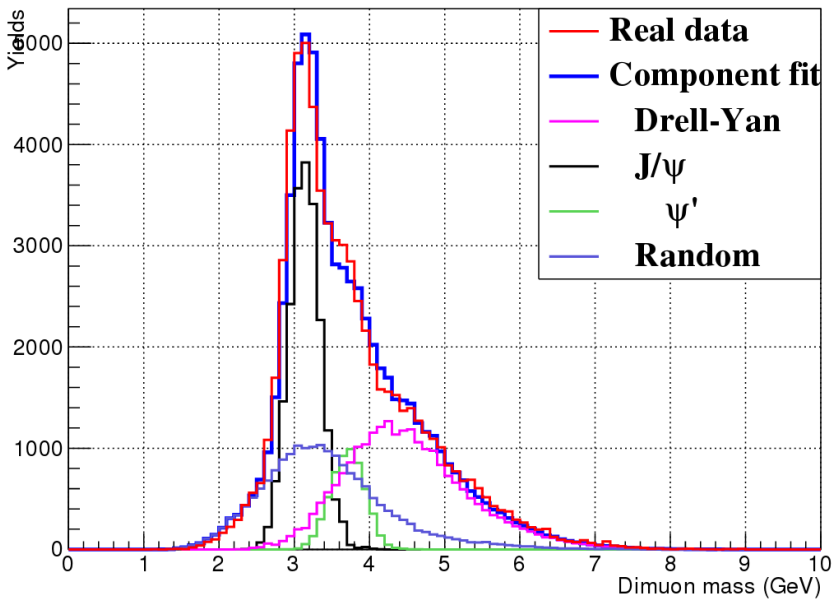
- Three dominant production mechanisms: meson decay, proton bremsstrahlung, Drell-Yan (yields from arXiv:1804.00661)
- Prompt $A' \to \mu^+\mu^-$: bump-hunt
- Displaced $A' \to \mu^+\mu^-$: background suppressed by vertexing
- Displaced $A' \to e^+e^-$: background absorbed in dump



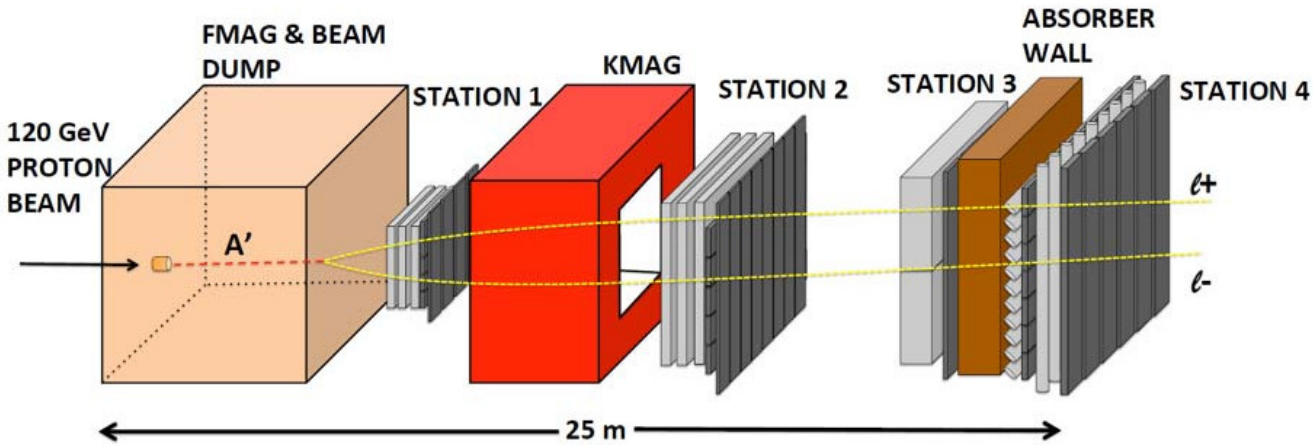


SeaQuest searches for dark photons

- Dimuons in main SeaQuest dataset
  - Bump-hunt at high mass (ongoing effort)
- Dimuon displaced-vertex trigger
  - Commissioned 2017
- Dielectron trigger
  - EMCal for electron PID (proposals in preparation)

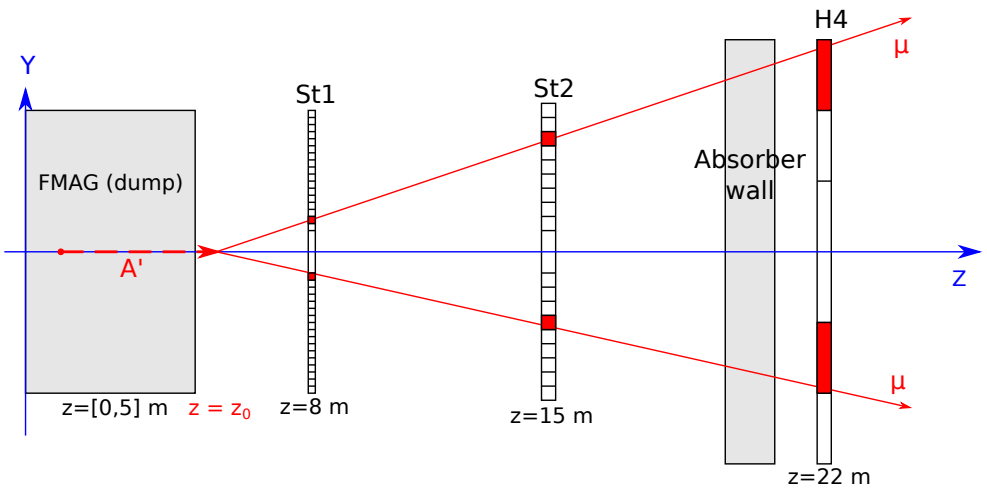


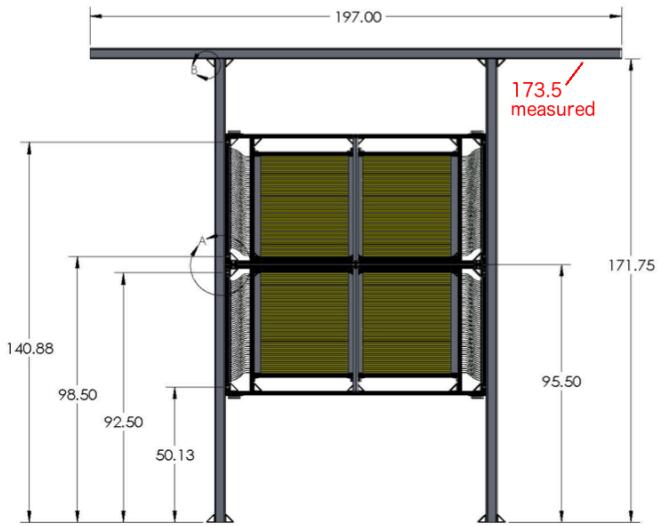
E906 preliminary



Displaced vertex trigger

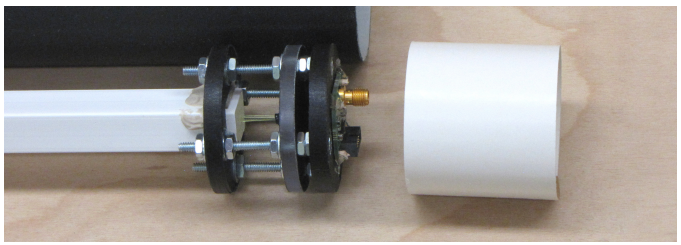
- Two new fine-grained scintillator hodoscopes measure track Y
- Existing station 4 paddles are used for muon ID
- FPGA trigger extrapolates tracks to the beam plane and fires on pairs of tracks with large Z





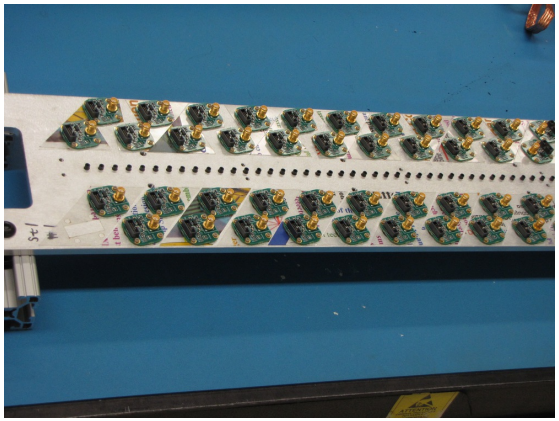
Trigger hodoscopes

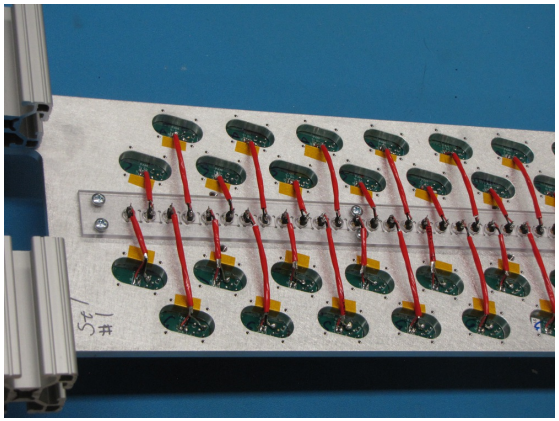
- Extruded scintillator bars detect charged particles, wavelength-shifting fibers collect light and transport it to SiPMs
- Each station is split into quadrants; active area has a beam gap of $|y| > 7.5$ cm but minimal gap in x
- Station 1: $z = 8$ m, 1 cm segmentation, 80 bars/quadrant
- Station 2: $z = 15$ m, 2 cm segmentation, 50 bars/quadrant



Readout and services

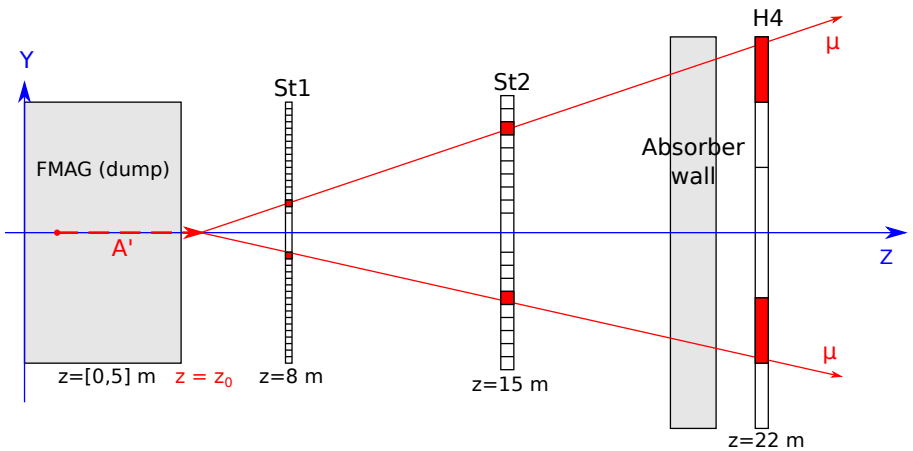
- Power supplies provide independent control of every SiPM bias voltage
- Postage-stamp preamps read out the SiPMs and send signals to discriminators
- Discriminators fan out to TDCs (readout) and CAEN V1495 FPGA boards (trigger)

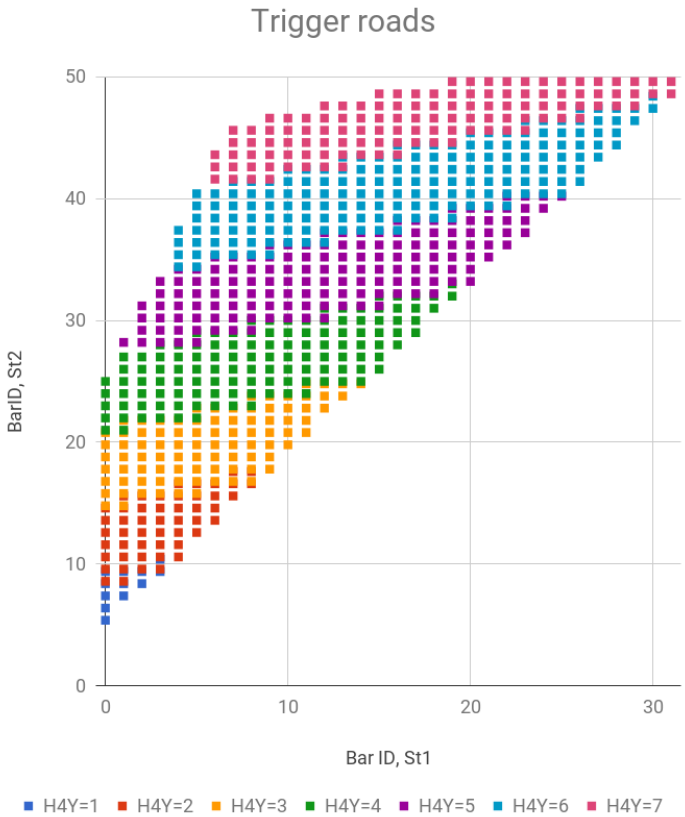




Trigger logic

- Two levels: identify displaced tracks, trigger on pairs
- L1: three-way coincidence within each quadrant
  - Identify displaced tracks ($z_0 \in [400, 650]$ cm) in each quadrant using hit patterns ("roads")
- L2: two-out-of-four coincidence between opposite-sign quadrants



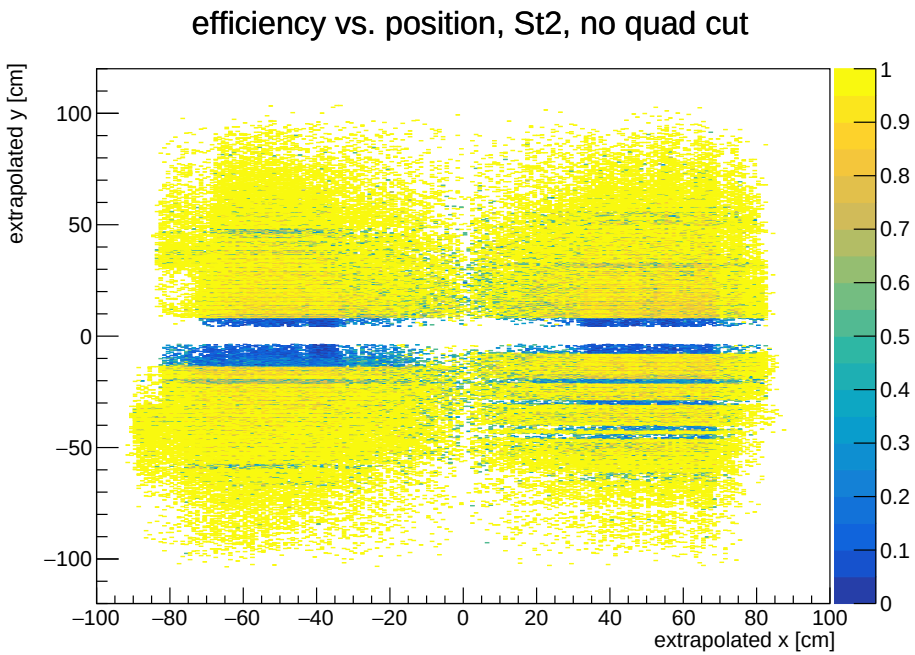


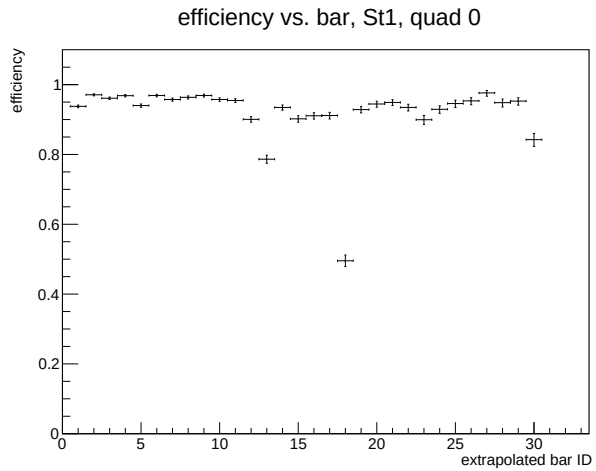
Installation and commissioning

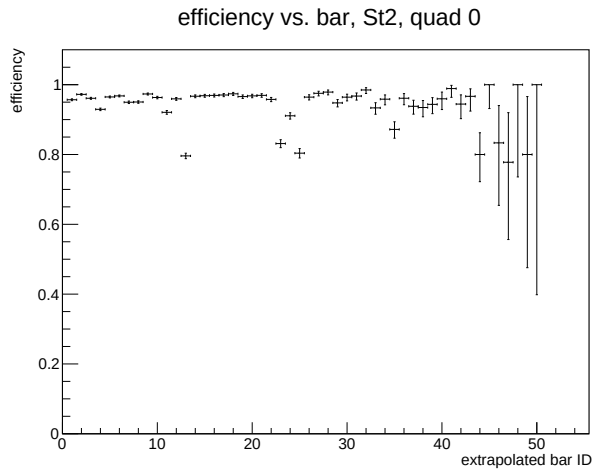
- Trigger hodoscopes installed on the SeaQuest beamline spring 2017
- Displaced vertex trigger rate is $\sim$5% of the SeaQuest Drell-Yan trigger, acceptable for parasitic running
- 5 days of good data taken with the displaced vertex trigger before accelerator shutdown: 8×10^{15} live protons on target
- Expect O(10^{18}) POT over the next two years, parasitic with new SeaQuest polarized target run

Detector performance

- Efficiencies ∼95% excepting ∼10% bad channels
- Inefficiency: bar gaps
- Bad channels: inconsistent optical coupling (will fix)

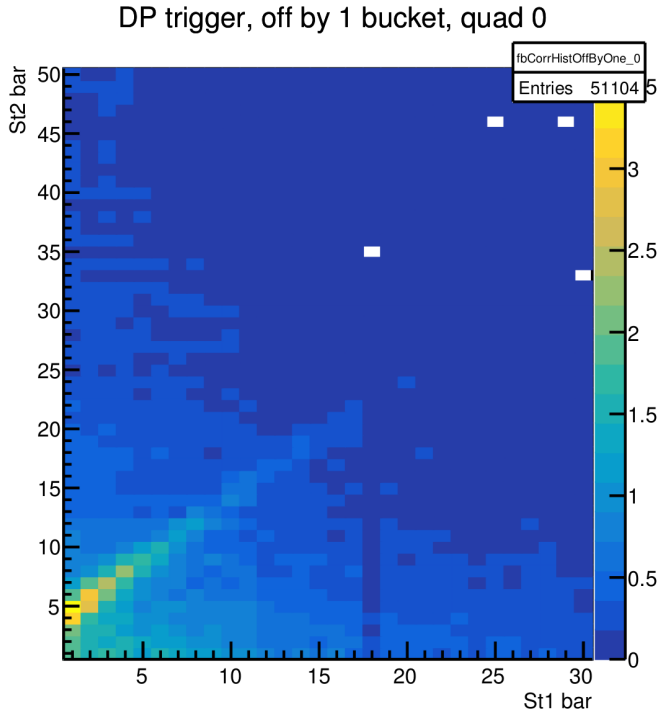






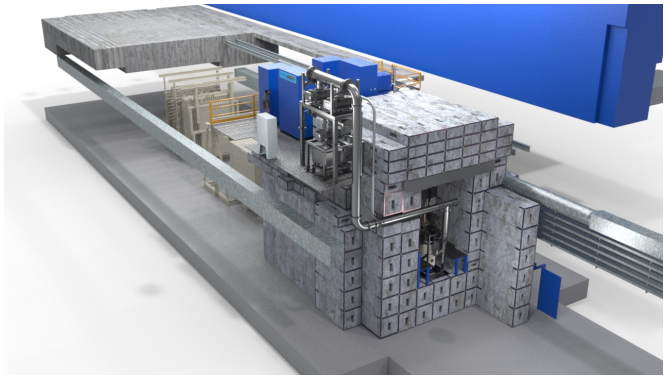
Trigger performance in 2017 data

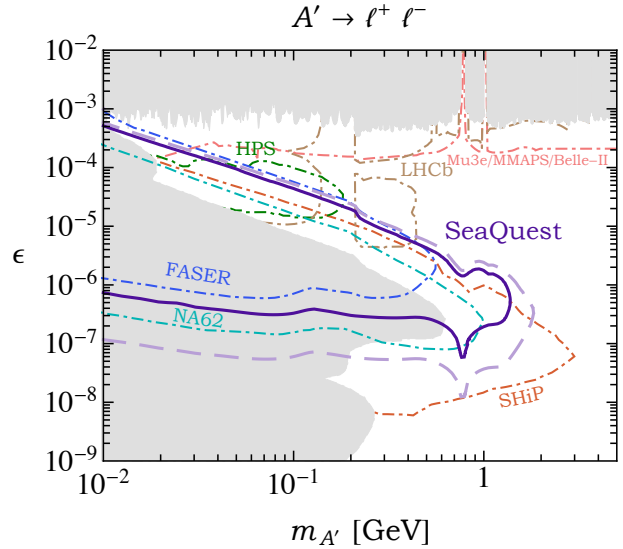
- Displaced-vertex trigger is 150 ns late relative to the event (cabling mistake during commissioning)
- Damage report: lost all hits in station 1 drift chamber (120 ns drift time) and $\sim$50% of hits in other drift chambers
- We can make straight tracks in stations 2–4 and try to assess backgrounds in the non-bend view
  - Problem: very bad (and angle-dependent) tracking efficiency
- We can look at hodoscope hit information (not in time relative to events that fired the displaced-vertex trigger) to understand trigger backgrounds
  - May allow us to optimize the trigger criteria



Schedule and prospects

- Updated reach estimates soon
  - Realistic trigger geometry and acceptance
- SeaQuest will run with polarized target (E1039) for two years: displaced-vertex dark photon search will run parasitically
  - Displaced-vertex trigger will be ready to go when beam is available
- Possible PID upgrade (using recycled PHENIX EMCal) will add sensitivity to dielectron decay channel and other new physics (SIMPs, iDM)





arXiv:1804.00661

EMCal upgrade

- One PHENIX EMCal sector: 2×4 m^2 wall of Pb-scintillator shashlyks
- Refurbish the readout: replace PMTs with SiPMs, new readout electronics
- Simple energy threshold can trigger on non-MIP particles
- Track matching enables electron ID