Dark photons at SeaQuest

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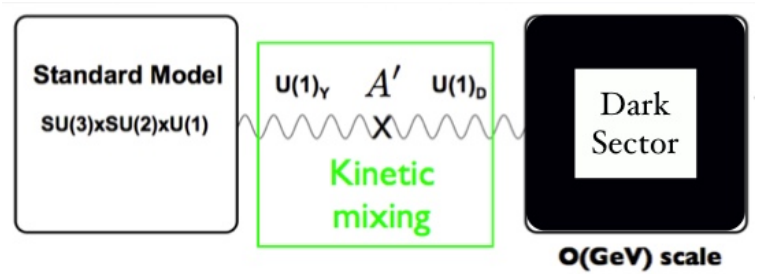
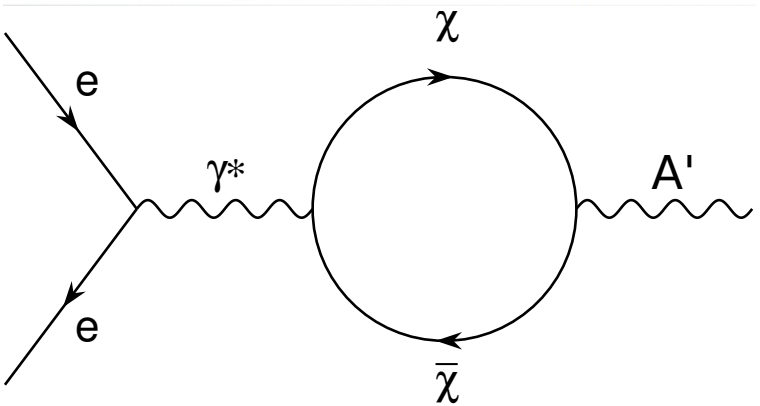
What is the dark photon?

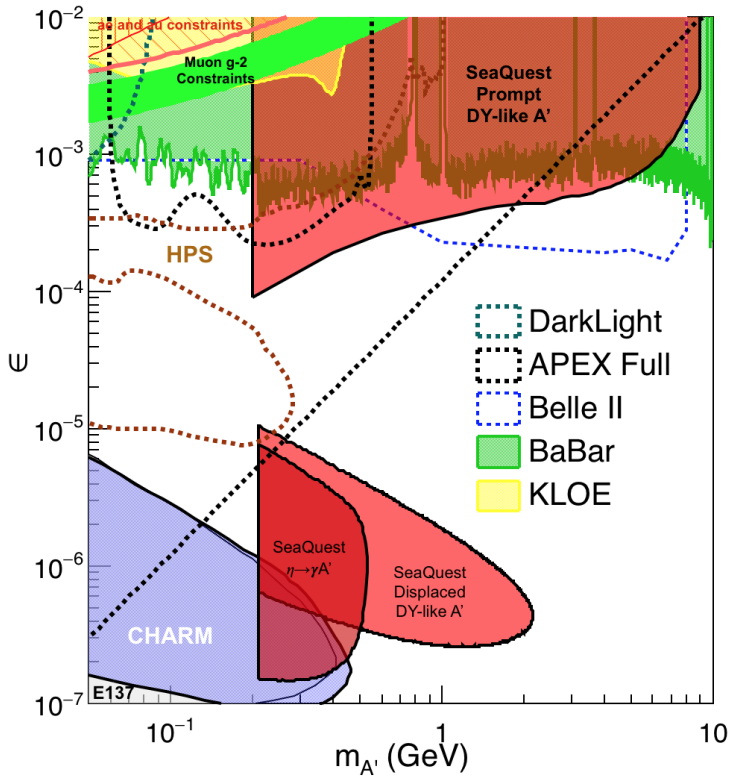
- "Dark sector" emerging as a picture of dark matter that is compatible with light dark matter, and allows for self-scattering, collisional excitation, annihilation
  - Standard Model forces don't couple to the dark sector, dark forces don't couple to Standard Model matter
  - "Portals" create weak effective couplings between the sectors
- Vector portal: dark mediator is a massive $U(1)$ boson (heavy photon)
  - Kinetic mixing with the photon $\rightarrow$ weak coupling to electric charge





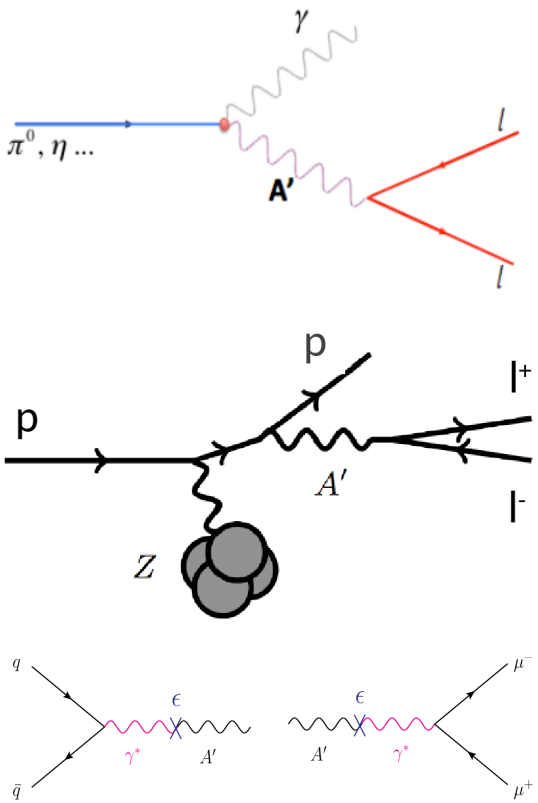
Parameter space

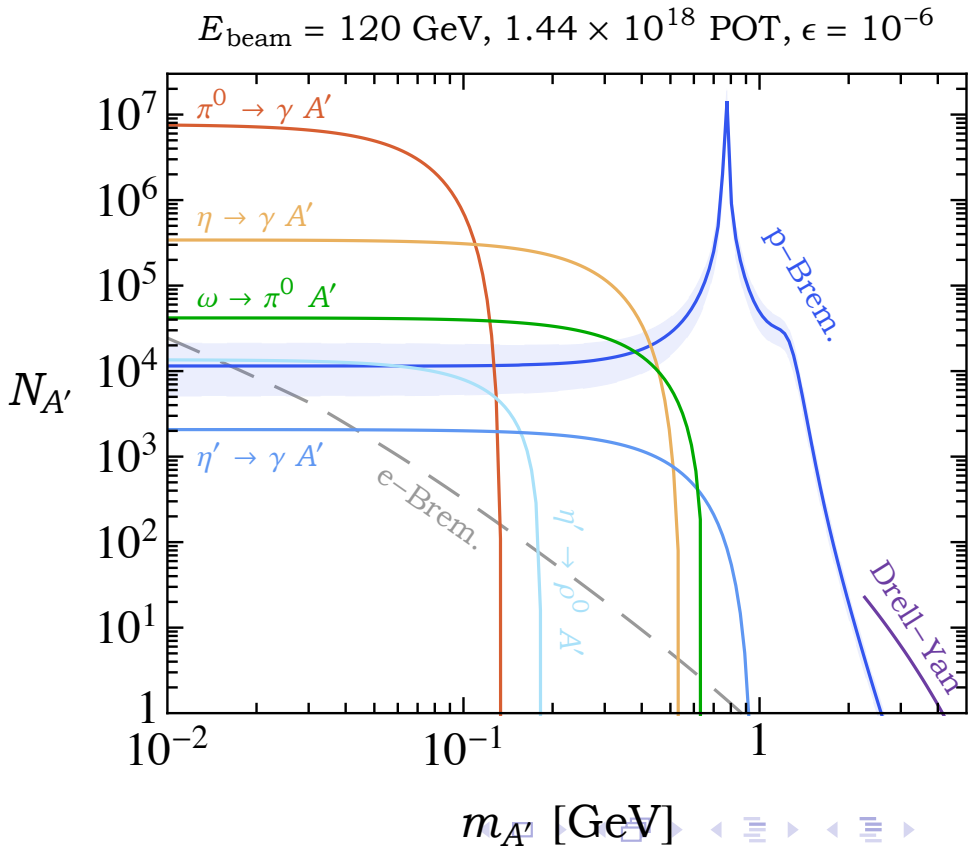
- Two relevant parameters: mass $m_{A'}$, coupling strength $\epsilon = \sqrt{\alpha'/\alpha}$
  - Coupling strength governs production from, and decay to, Standard Model matter
  - Favored region is $m_{A'}$ MeV—GeV, $\epsilon > 10^{-6}$
- Broad search space (few strongly favored regions in either mass or coupling)
  - The dark photon is not the dark matter; cosmology is mostly sensitive to α_D, the DM$-A'$ coupling
- Mass hierarchy: dark photon decays visibly if $m_{A'} < 2m_\chi$, invisibly if $m_{A'} > 2m_\chi$
  - SeaQuest is sensitive to visible decays



Production and signatures at SeaQuest

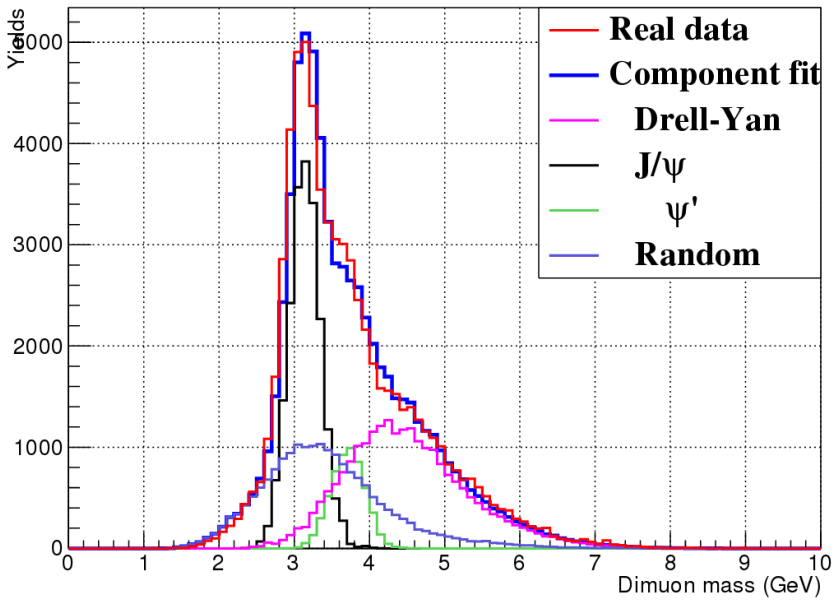
- Three dominant production mechanisms: meson decay, proton bremsstrahlung, Drell-Yan (yields from arXiv:1804.00661)
- Prompt $A' \to \mu^+\mu^-$: bump-hunt
- Displaced $A' \to \mu^+\mu^-$: background suppressed by vertexing
- Displaced $A' \to e^+e^-$: background absorbed in dump

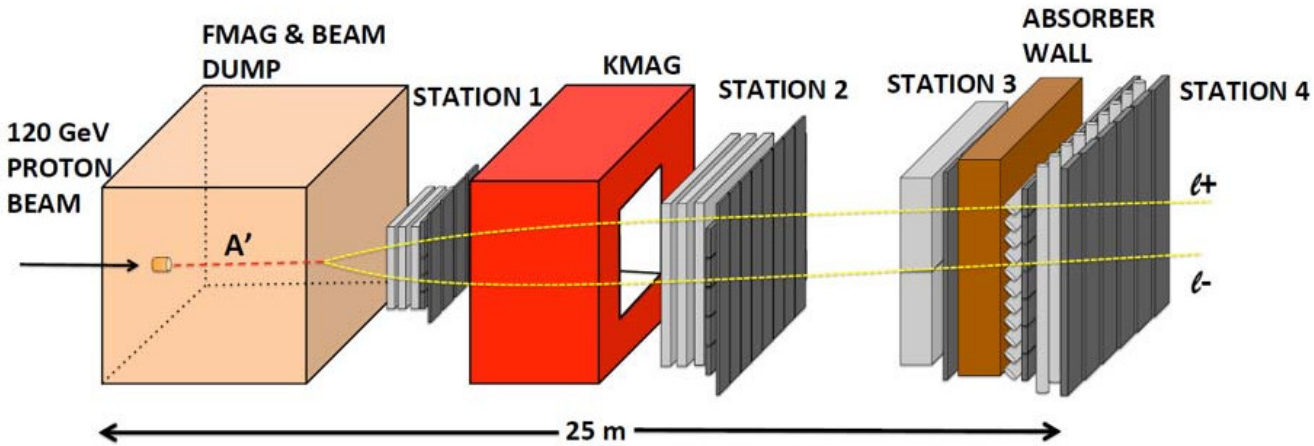




SeaQuest searches for dark photons

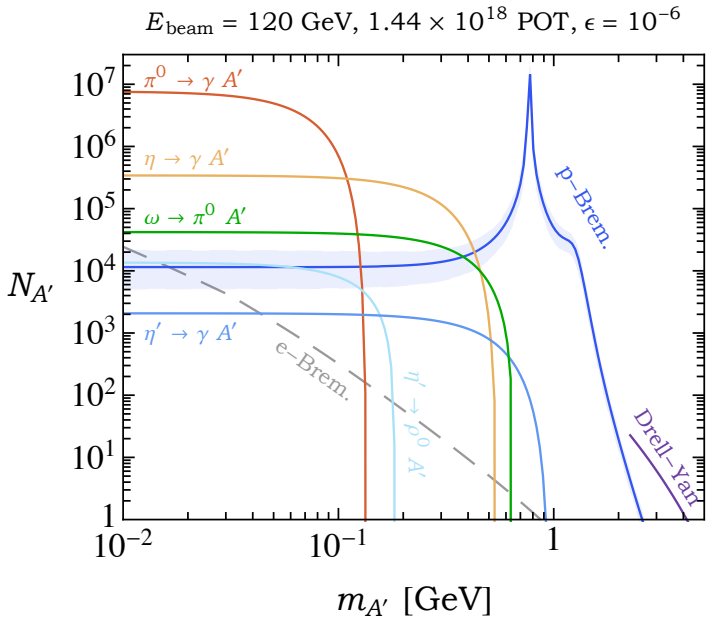
- Dimuons in main SeaQuest dataset
  - Bump-hunt at high mass (ongoing effort)
- Dimuon displaced-vertex trigger
  - Commissioned 2017
- Dielectron trigger
  - EMCal for electron PID (proposals in preparation)

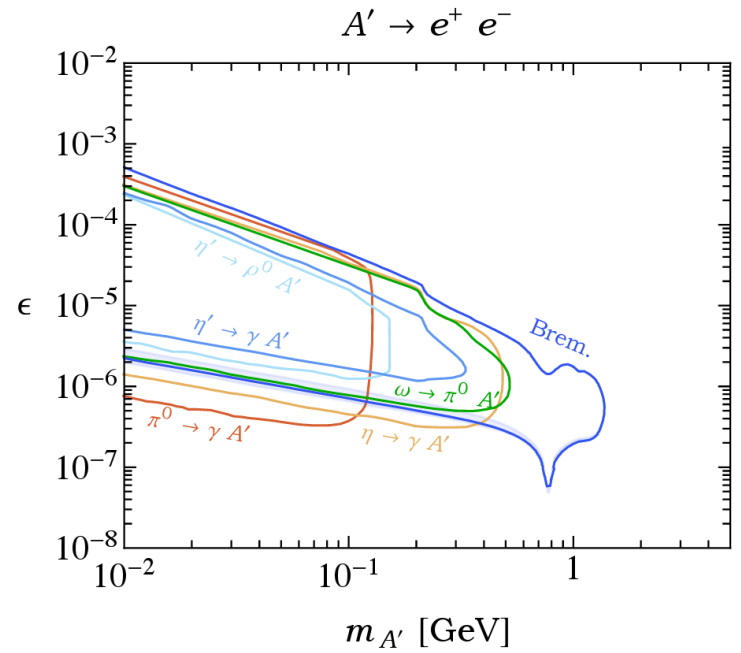




Why SeaQuest?

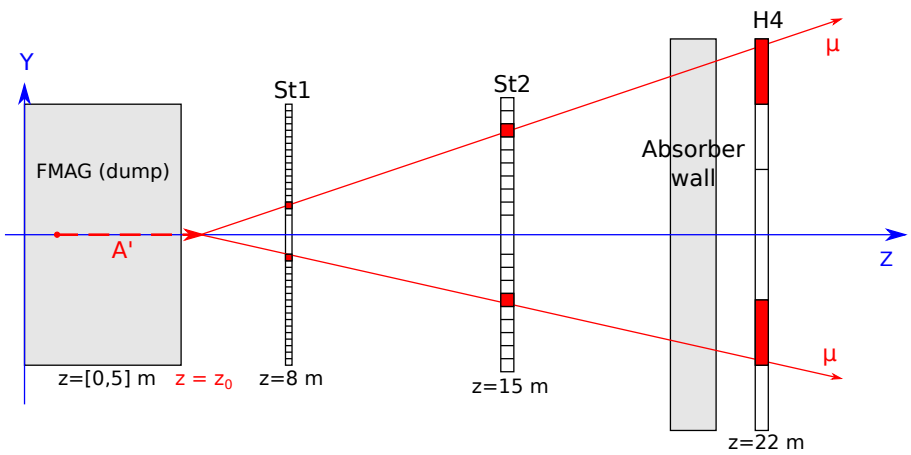
- Most fixed-target dark photon experiments have thin targets or thick beam dumps (100s of meters)
- SeaQuest has:
  - Thin dump, just thick enough to absorb beam backgrounds
  - High beam energy (boosts the A', so $\gamma c\tau$ gets through the dump)
  - Proton beam: many production channels and wide mass coverage

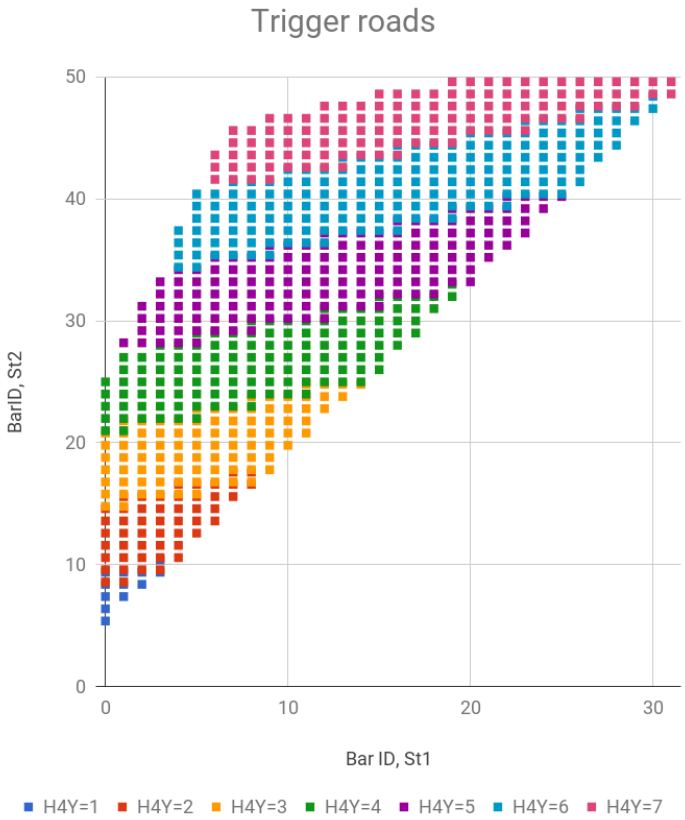




Trigger logic

- 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 roads
- L2: two-out-of-four coincidence between opposite-sign quadrants
- In 2017, we wired this to NIM2



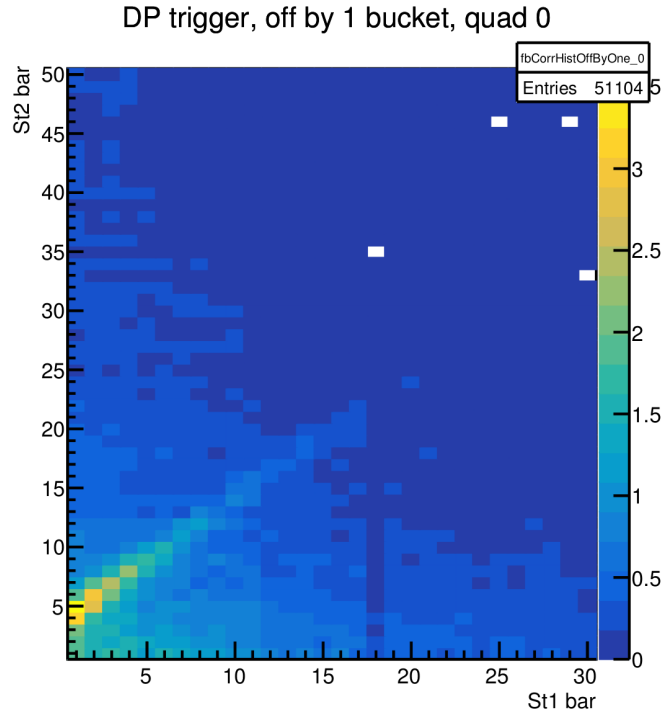


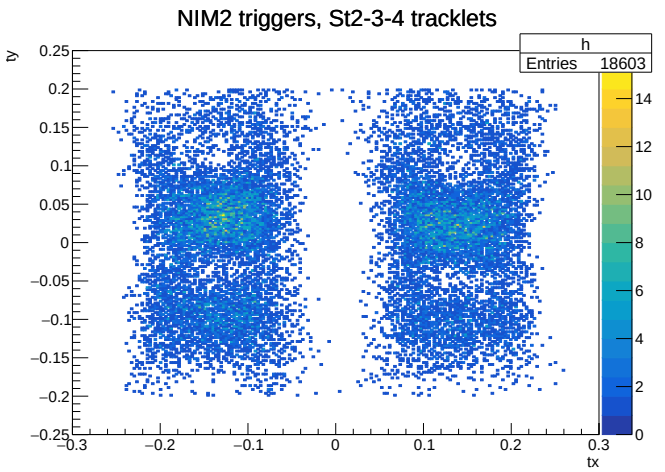
Installation and commissioning

- Trigger hodoscopes installed 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 summer shutdown

Trigger performance in 2017 data

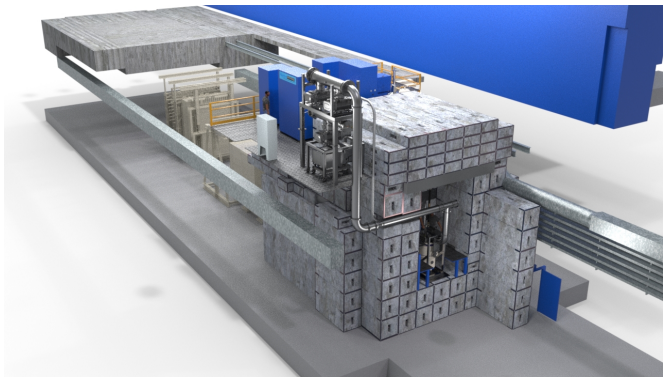
- Displaced-vertex trigger is 150 ns late relative to the event (cabling mistake during commissioning)
- Damage report: lost all hits in DC0 (120 ns drift time) and ∼50% of hits in other chambers
- We can make straight tracks in stations 2–4 and try to assess backgrounds in the non-bend view
  - Problem: 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

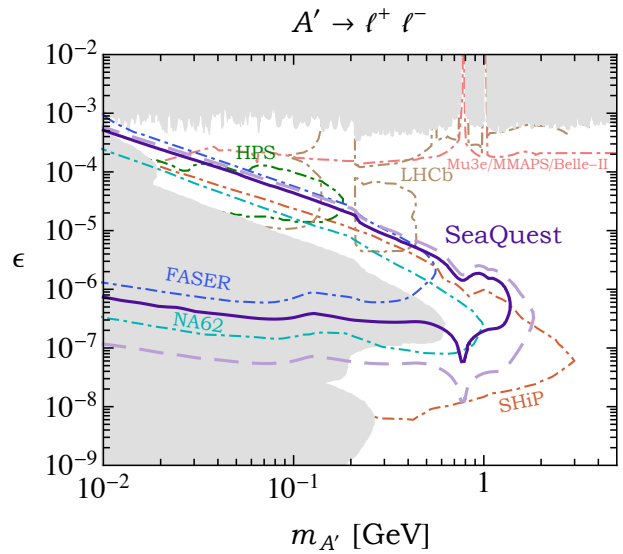




Schedule and prospects

- Updated reach estimates soon
  - Realistic trigger geometry and acceptance
- Displaced-vertex trigger will be ready to go when beam arrives at SeaQuest
  - Bad channels will be fixed, trigger logic will be recommissioned
- Possible PID upgrade (using recycled PHENIX EMCal) will add sensitivity to dielectron decay channel and other new physics (SIMPs, iDM)





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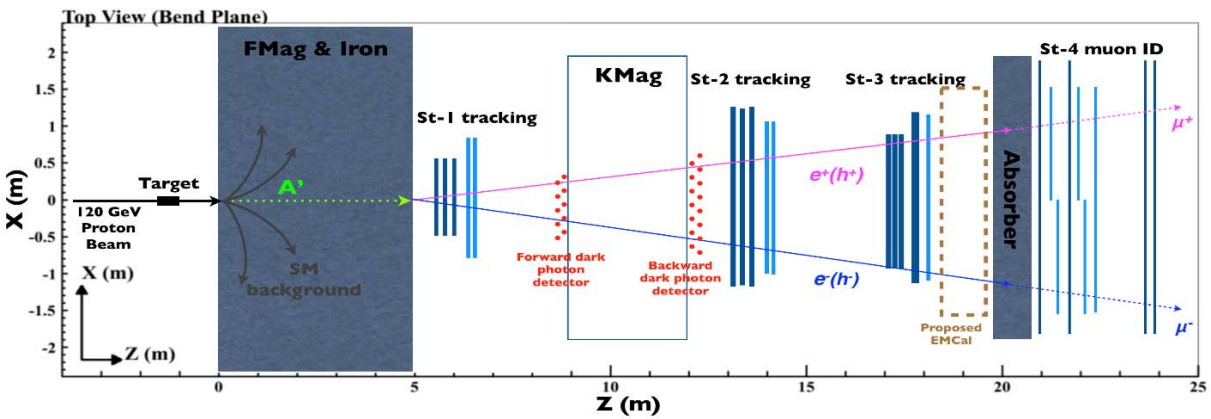
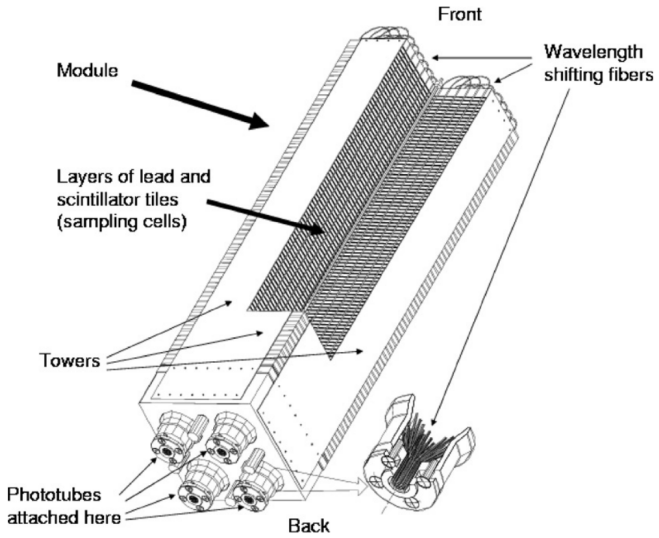
EMCal upgrade

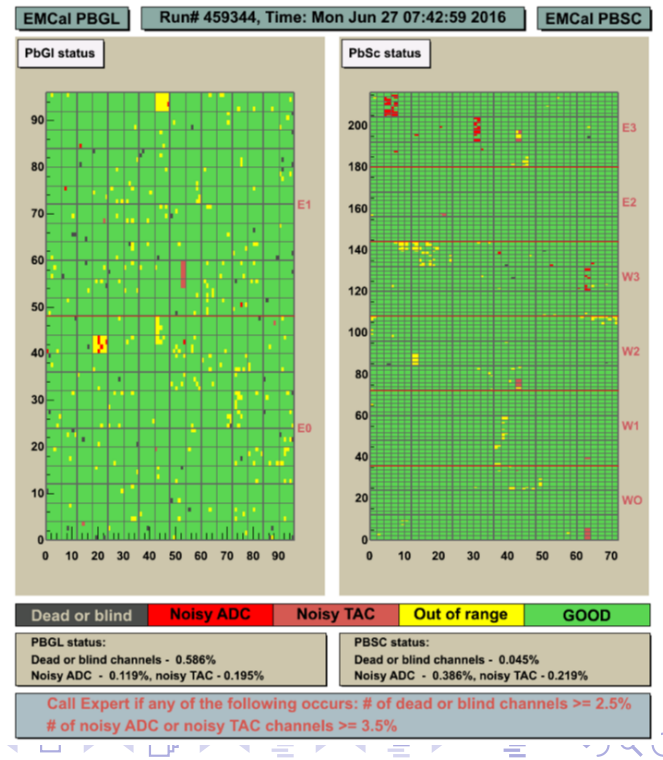
- One PHENIX EMCal sector: 2×4 m^2 wall of Pb-scintillator shashlyks
- Between St-3 and the absorber wall
- Simple energy threshold can trigger on non-MIP particles
- Track matching enables electron ID (reject $K_L^0 \to \pi^{\pm} e^{\mp} \nu_e$ mis-ID background)



EMCal upgrade — hardware

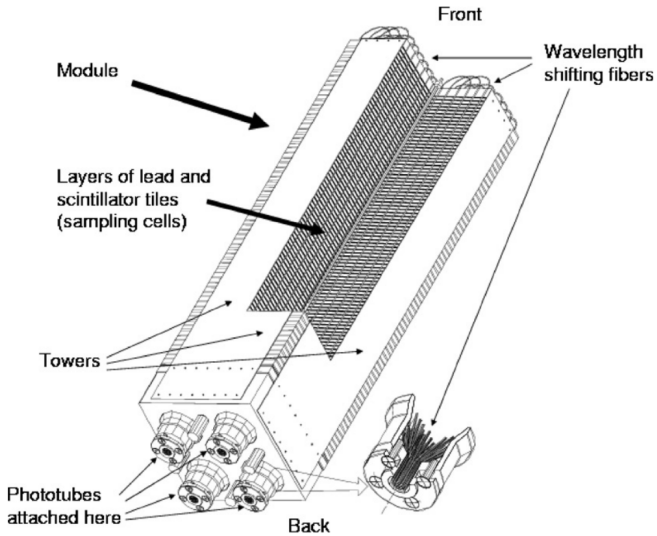
- The two best sectors have been transferred (on paper) to LANL
- We have the full PHENIX readout system; investigating whether it can be directly reused for SeaQuest
  - Time structure (10 MHz vs. 53 MHz) is the main concern
  - Alternative: STAR is developing a readout system with the same modules
- HV uses LeCroy mainframes, will be loaned by BNL
- LV used custom PHENIX supplies which are gone, looking at other options
- Monitoring system: fibers and splitters are in place, probably use an LED light source in place of laser

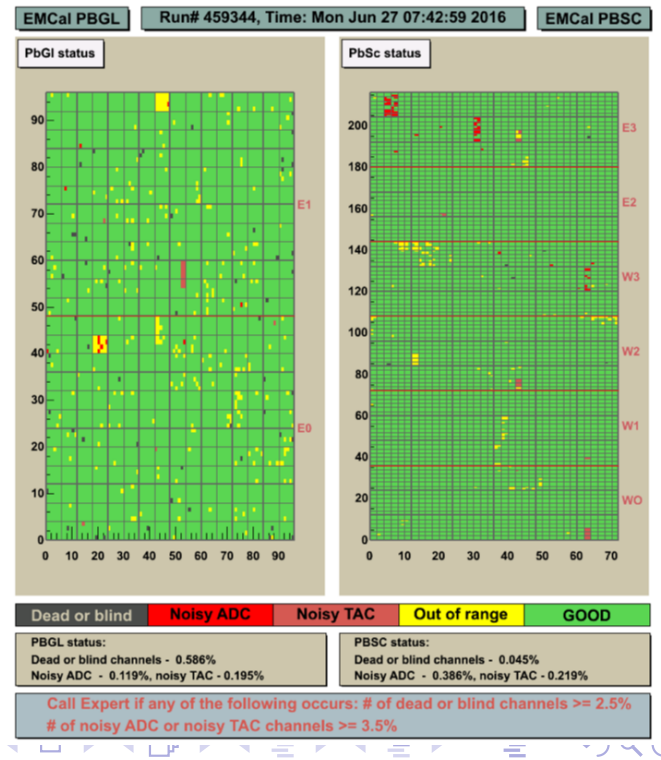




EMCal plan

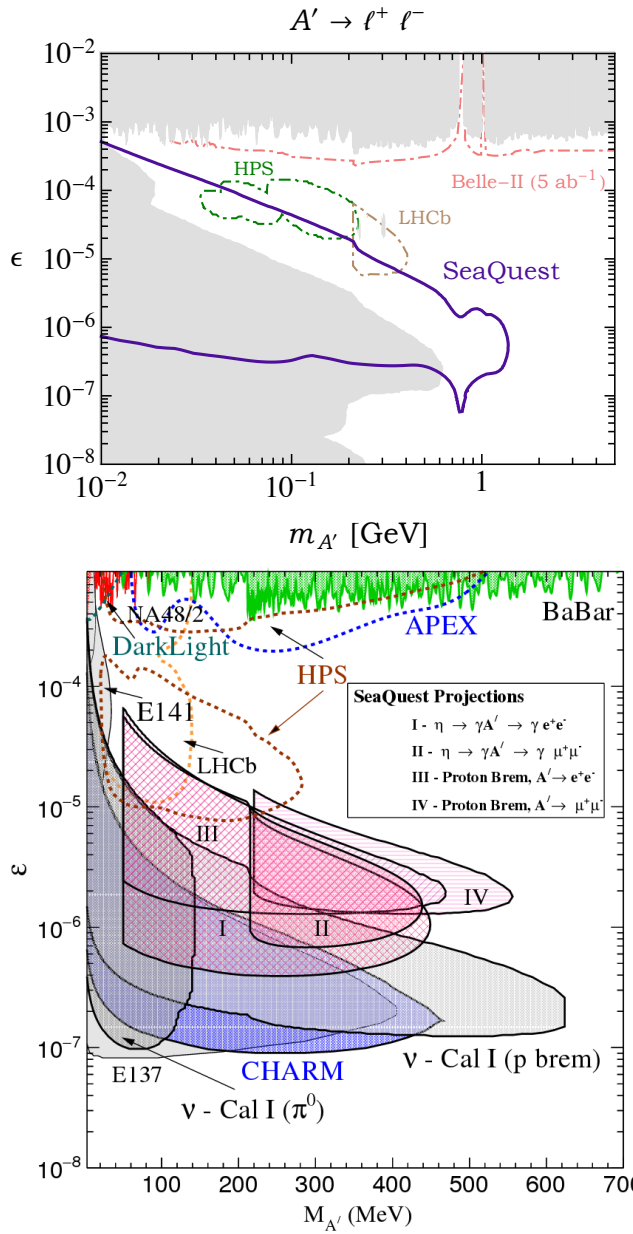
- EMCal proposal being discussed with Fermilab PAC
- Gathering collaborators: theorists, detector groups (PHENIX EMCal, STAR+sPHENIX forward upgrades)
- The sectors are ready to be shipped next month to the DØ assembly area
- Hope to be ready to install during the 2019 summer shutdown





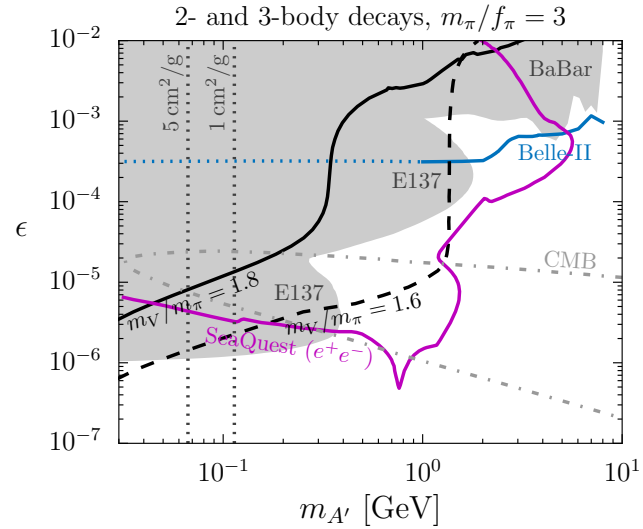
EMCal reach

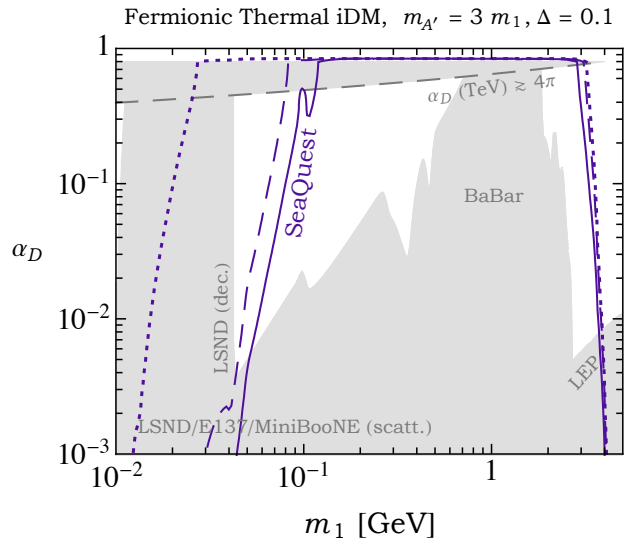
- SeaQuest with EMCal could access a big chunk of the parameter space
  - Plot shows expected reach from other experiments by 2021 (before LHCb run 3)
- Lots of interest in the dark sectors community
  - SeaQuest+EMCal note: arXiv:1804.00661 (compare to arXiv:1509.00050 from Gardner+Holt+Tadepalli)
  - Working with theorists to converge on expected performance



Other DM models: iDM, SIMPs

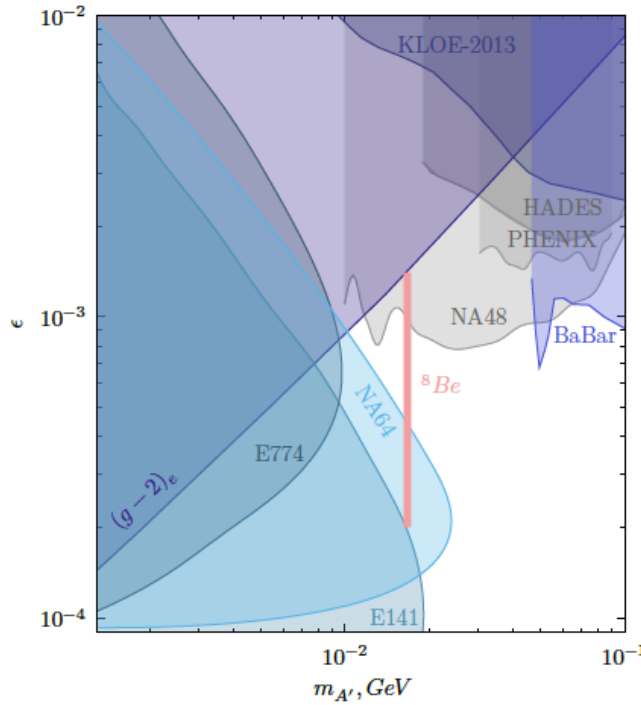
- More complicated (“rich”) dark sectors with similar signatures
  - SeaQuest has an advantage over other experiments since it is relatively insensitive to production kinematics
- SIMPs (strongly interacting dark matter)
  - arXiv:1801.05805
- iDM (inelastic dark matter)
  - arXiv:1804.00661

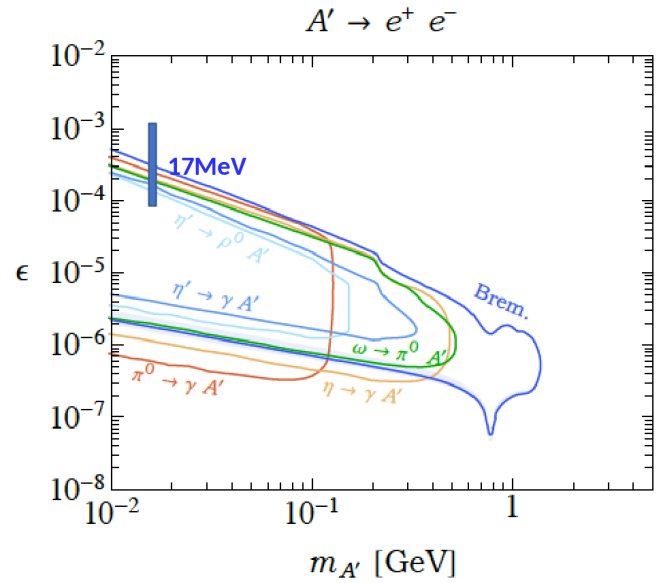




Beryllium-8 anomaly

- Anomaly in $p + {}^{7}\mathrm{Li} \rightarrow {}^{8}\mathrm{Be}^{*} \rightarrow {}^{8}\mathrm{Be} + e^{+}e^{-}$ could be explained by a dark photon-like particle with mass $\sim$17 MeV
  - Caveats: a vanilla dark photon is ruled out in this region, some model-building is needed (arXiv:1608.03591)





Leptophilic scalar

- One possible solution to the muon $g-2$ anomaly: leptophilic scalar (Higgs-like coupling to leptons)
  - Relevant area of the dark photon parameter space has been covered
- Radiated by muons inside the beam dump, decays to dielectron