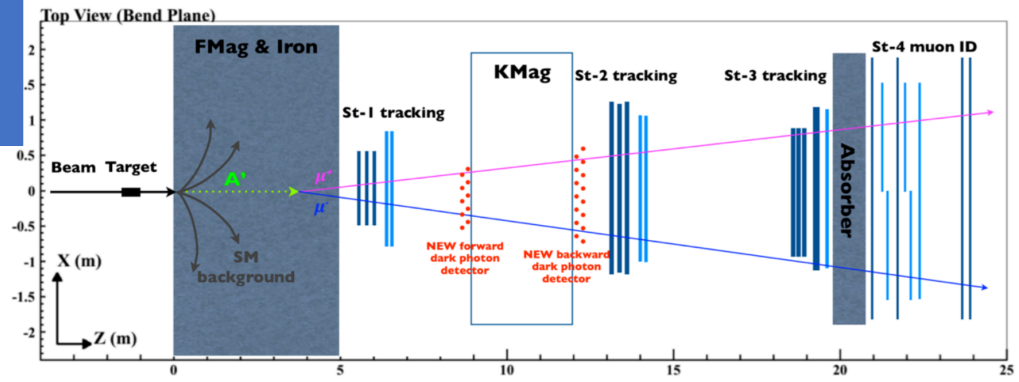
Proposal for a Dedicated Dark Sector Physics Search in SeaQuest at the Fermilab Intensity Frontier

06/22/2018

Proposal for a Dedicated Dark Sector Physics Program at SeaQuest

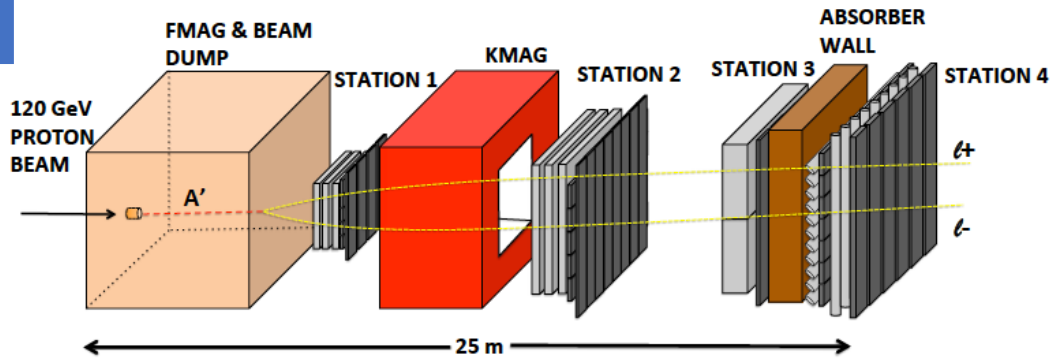
- 2019-2021: Parasitic Dark Sector physics program with E1039
  - **Attract and build up HEP groups in SeaQuest**
    - Carry out DP physics program with dimuons: dark photon, dark Higgs etc.
    - EMCal refurbishment and preparation for integration at Fermilab, 2018-2021
  - **New HEP members develop SeaQuest detector expertise for the future experiment operation and data analysis**
    - Also help E1039 operation and maintenance of spectrometer and DAQ
  - **Transition into HEP DP program after E1039**
    - Develop new proposals, seek HEP DOE/NSF and other external fund
    - Parasitic data taking with E1039 for DP search, further explore new opportunities
    - Develop online/offline analysis, study DAQ and triggers capability for future DP experiment
    - Background study, test small prototype in SeaQuest, w/ minimal impact on E1039
  - **E1039 2-year data taking: summer 2019 – summer 2021**
- 2022-2024: first dedicated dark sector physics run @NM4
  - Install EMCal for electron and hadrons ID, explore new phase space below dimuon mass (200MeV)
  - Further develop dark sector physics program
  - Possible NP parasitic physics program under discussion
  - POT = a few 10^{18}
- 2024-2025: major detector upgrade during the long shutdown
  - Upgrade tracking chambers
  - Add di-photon capability with preshower detectors
  - Add tracking station-0 near target, more shielding
  - Possible PID with TOF etc
  - And more
- 2026-2030+: high luminosity dark sector physics program
  - Full physics program with upgrade detectors, POT =10^{19}~10^{20}
  - Carry out an extensive (SHiP-like) HEP experimental program at NM4
  - Possible NP parasitic physics program under discussion (~US EIC physics era)

PAC endorsement is essential
1) attract new members;
2) start EMCal work at Fermilab in 2018



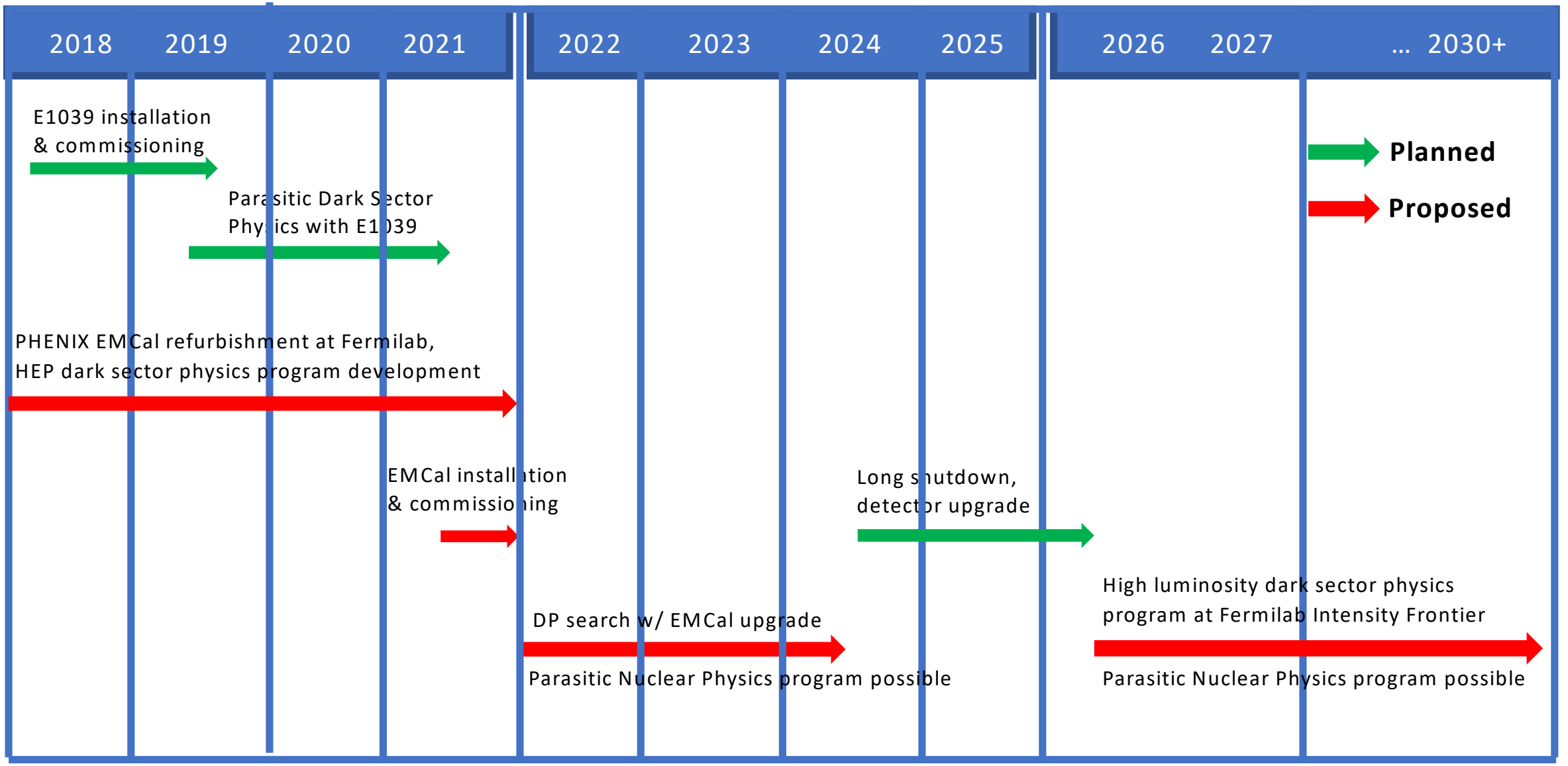
SeaQuest in 2017 with displaced dark photon trigger

PAC endorsement is essential to develop this program



SeaQuest in 2021+ with EMCal upgrade

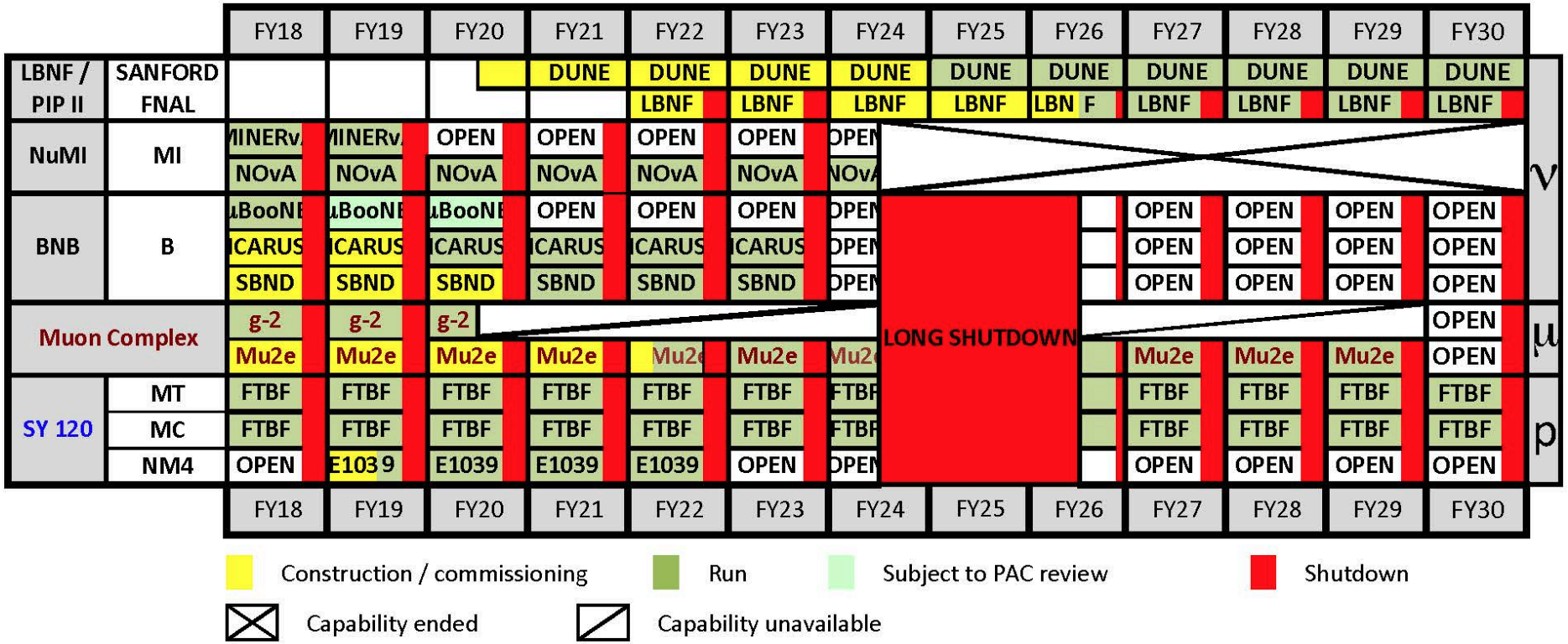
Dark Sector Physics Search Program at Fermilab SeaQuest



Fermilab Long Range Plan

Fermilab Program Planning 5-April-18

LONG-RANGE PLAN



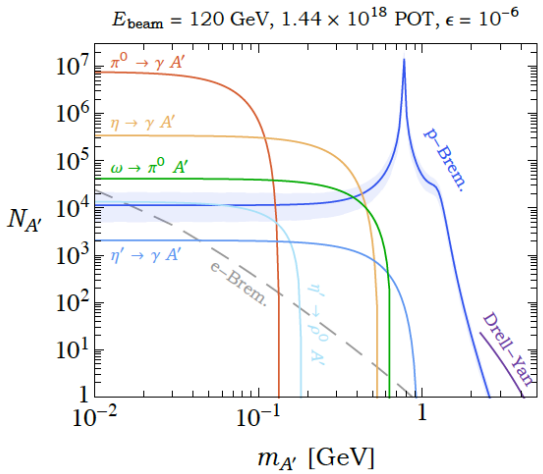
NOTES:
1. Mu2e estimates 4 year running starts mid-FY22 after 18 months commissioning. Assume, with contingency, 5.5 years data taking.
2. DUNE: 1st 10kT detector module commissioned in FY24. Runs without beam FY25 to mid-FY26.
3. NOvA runs as long as possible [in the spirit of PAC Nov 2017].
4. Assume NuMI in nubar mode through FY19 - facilitates 12E20 POT for MINERvA [PAC Nov 2017]. Assumption may need revision.
5. Assume g-2 completed before Mu2e commissioning start mid-FY20. Very tight. Needs scrutiny.
6. Assume E1039 fully approved & commissioned by mid-FY19.
   Experiment estimates 2 yrs run. Add 1 yr contingency. [Stage 1 approval PAC June 2013, update July 2017]
7. FY19 and FY20 MicroBooNE running subject to future PAC review [PAC July 2017].

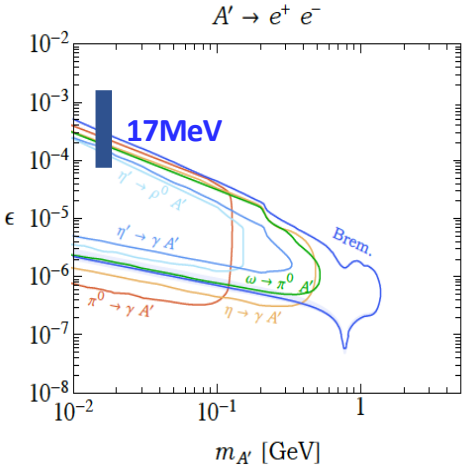
Money Plots (I)
to include all other experimental searches up to year ~2025+

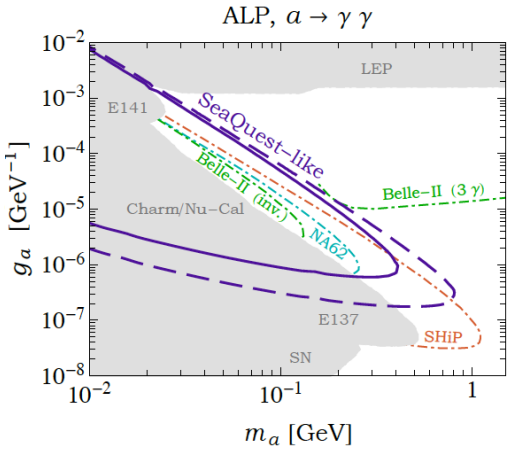
Phase space covered by SeaQuest:
2019 ~2021 – dimuon channel (POT = 10^18)
2022-2024 – add di-electron (POT = 10^18)
2026 – 2030+ --- all channels (POT > 10^19)

SeaQuest dark photon coverage:
- Dimuons (current capability)
- Di-electrons (w/ EMCal upgrade)

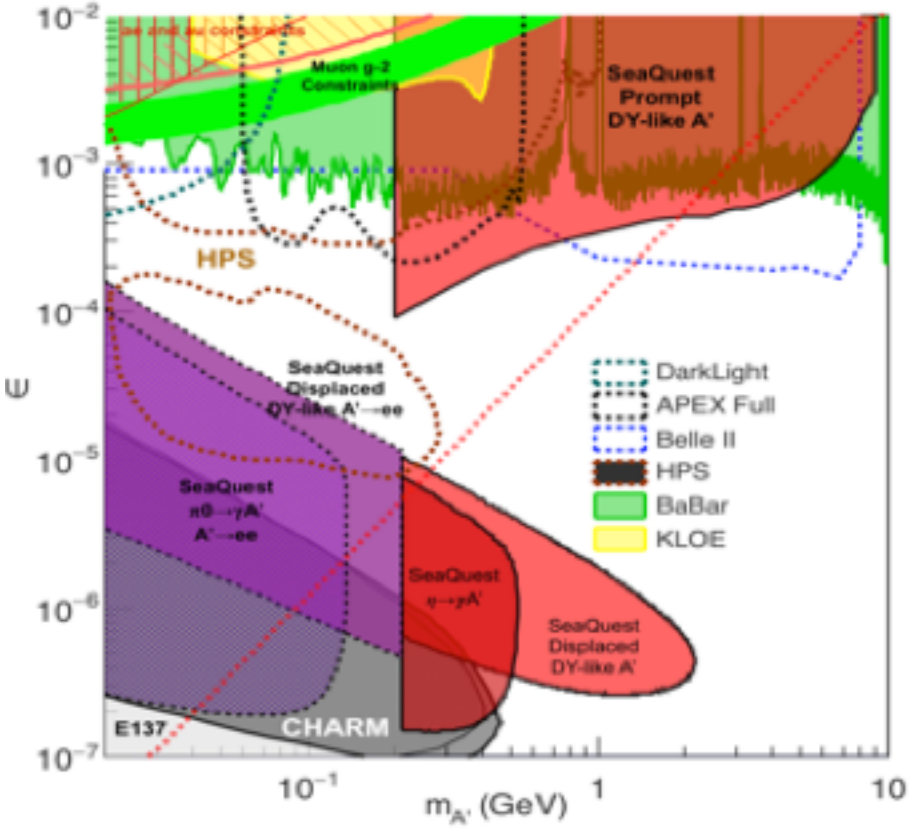
Detailed SeaQuest coverage in various production channels with di-electrons and di-photons



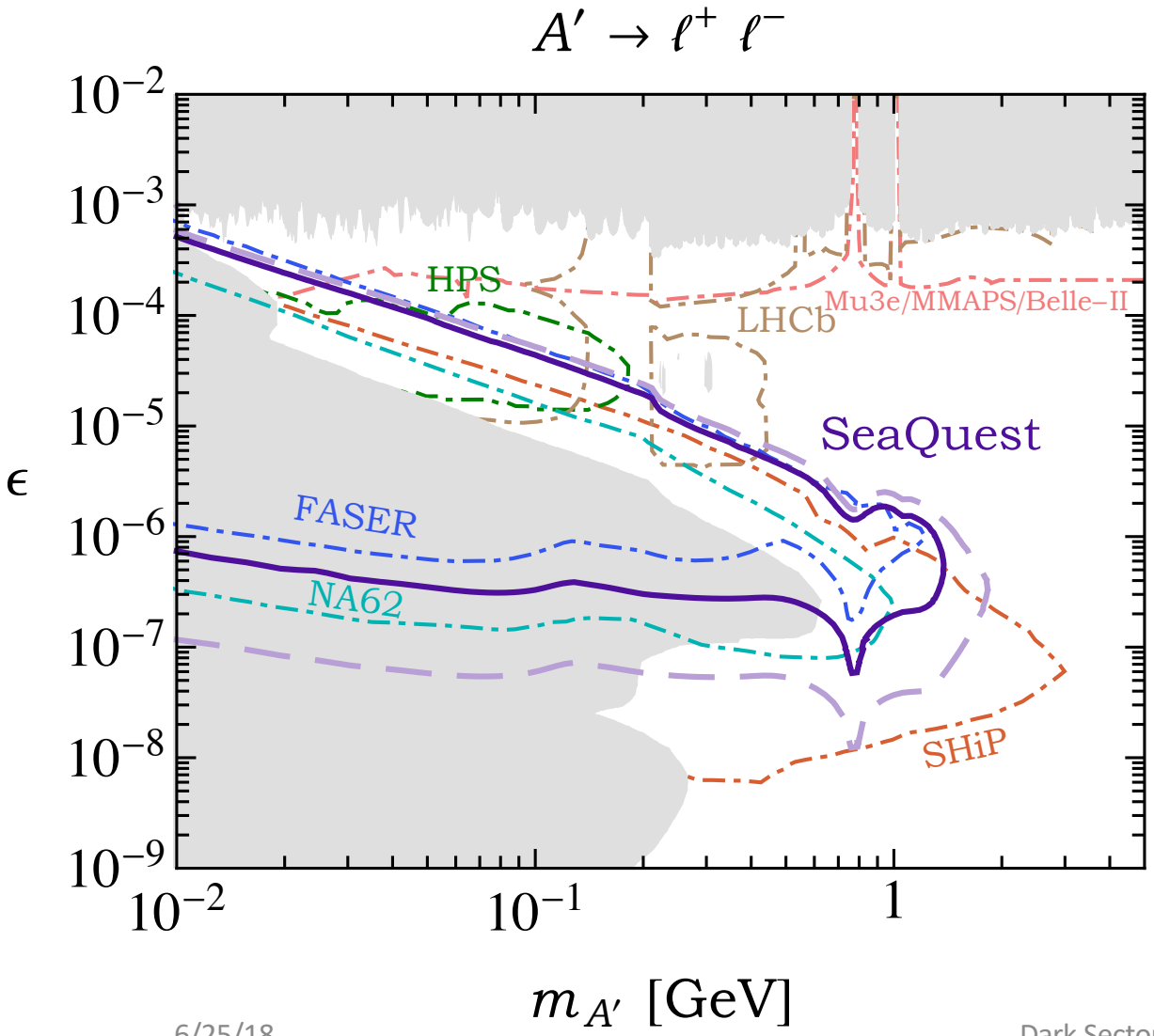


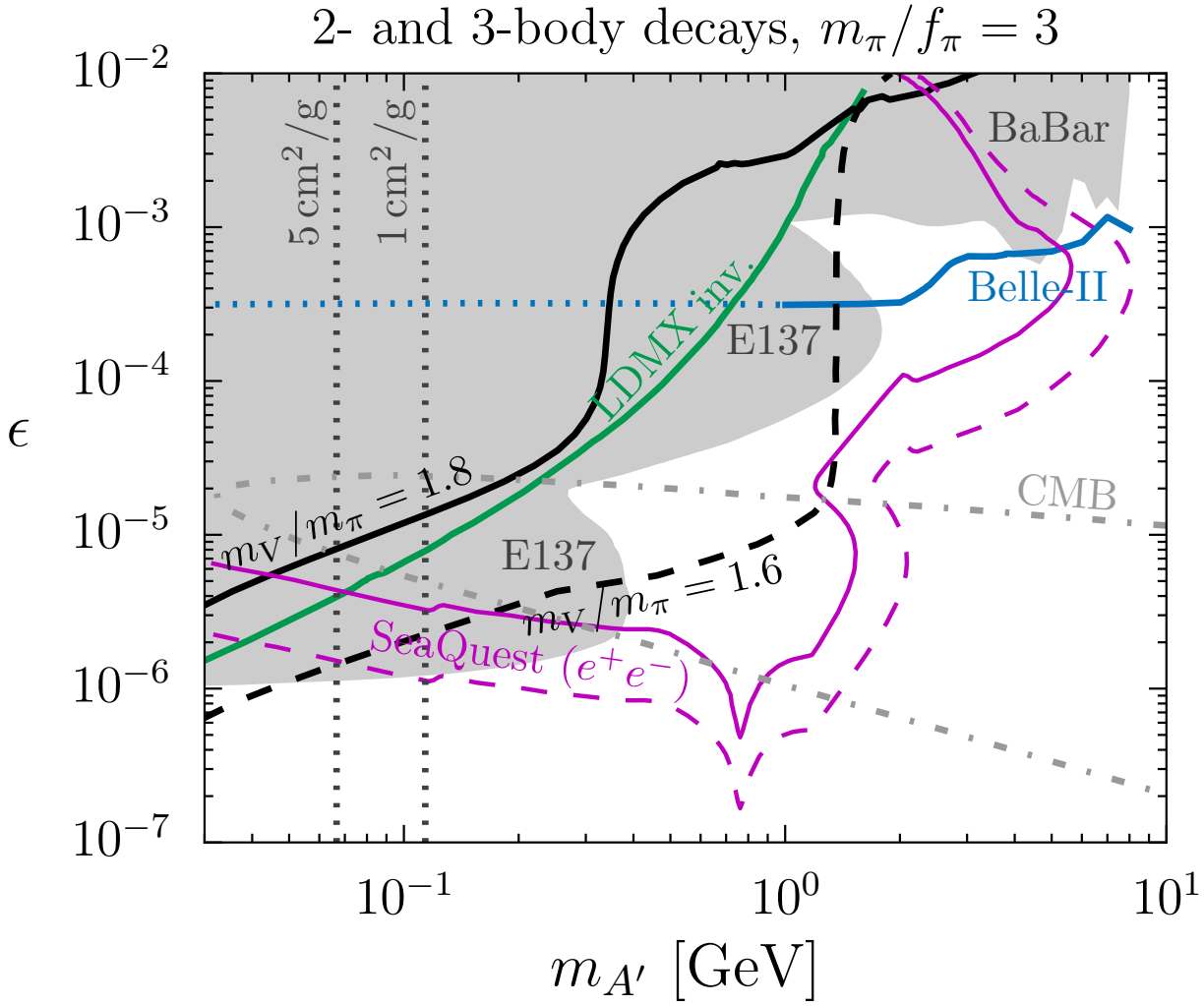


arXiv:1804.00661



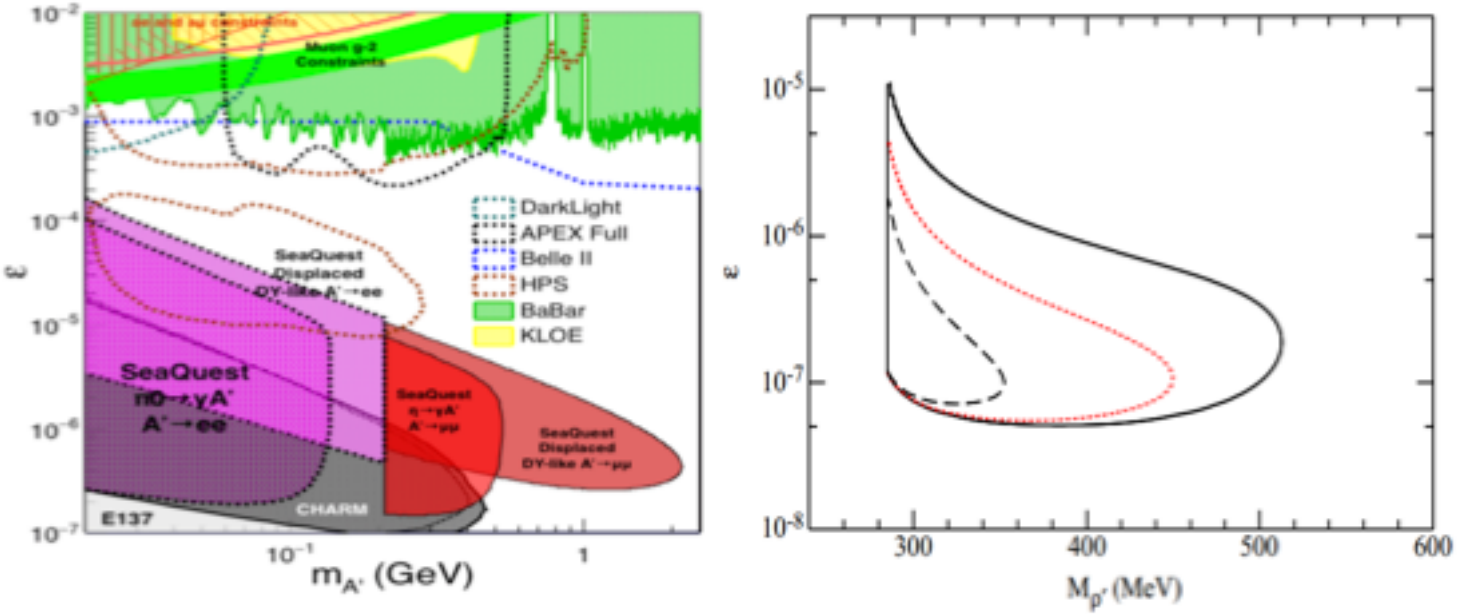
Money Plots (II) - with all Future Projections





Supporting Slides

Physics goals and recent accomplishments



- LOI of dark matter search in dimuon channel was presented to PAC in June 2015. Obtained very positive feedbacks.
- A phase-II of EMCal and possibly HCal upgrade was also mentioned. PAC suggested we submit a new proposal based on the results obtained from the phase-I study
- The detector proposed in the phase-I was successfully installed and accumulated one week worth of data before E906 shuts down in July 2017
- We will continue to take the dimuon data parasitically with E1039

Fermilab

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July 15, 2015

Ming Liu
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Los Alamos, NM 87545

Dear Ming,

Thank you very much for your presentation: "P-1067 *LOI: Direct Search for Dark Photon and Dark Higgs*" at the June meeting of the Fermilab Physics Advisory Committee (PAC). The Committee explicitly mentioned its appreciation of the carefully prepared presentations for this meeting.

Future initiatives were an important topic at the meeting. Excerpts on your LOI from the PAC report are attached. As you can see, the committee "*… recognizes the exciting opportunity brought by P1067 to search directly for a dark photon and dark Higgs in high-energy proton□nucleus collisions using existing SeaQuest Spectrometer.*" The PAC noted that in the LOI the collaboration requests approval for inclusion of the new elements in the detector needed to make a dark sector trigger, and approval of parasitic data collection during E-1039 running. The committee "*… believes that P-1067 offers exciting physics prospects and recommends the Laboratory to grant these modest requests.*" The PAC also suggests "*A proposal for a dedicated experiment, or a parasitic experiment with electron and hadron calorimeters, should be based on the results obtained with this first phase.*"

I accept the PAC recommendations, and wish you good luck in implementing a dark sector trigger.

Sincerely,

Nigel S. Lockyer
Director of Fermilab

cc: D. Bortoletto, G. Bock, P. Reimer, J. Shank, S. Geer, P. McBride, D. Geesaman, J. Lykken, T. Meyer, A. Stone

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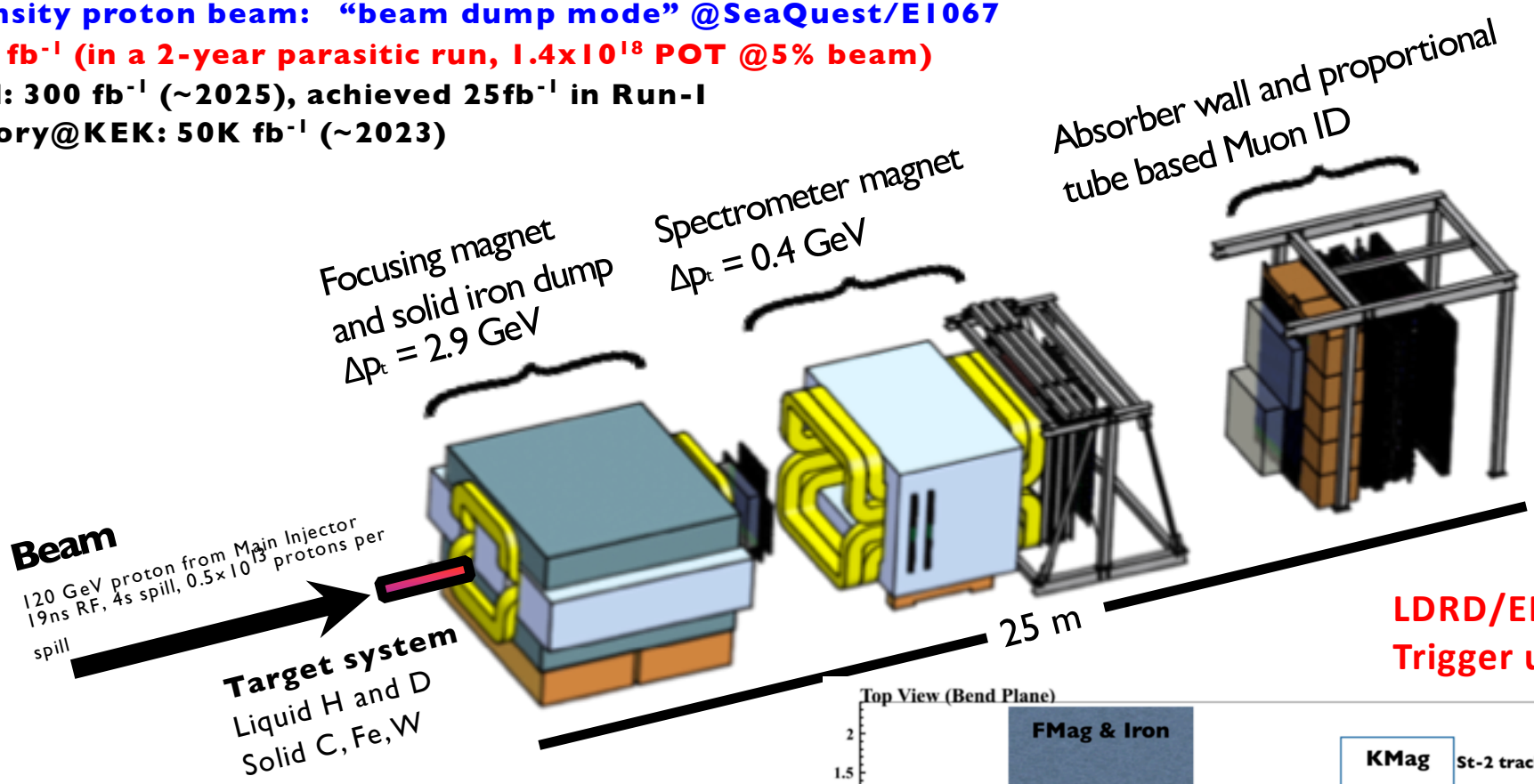
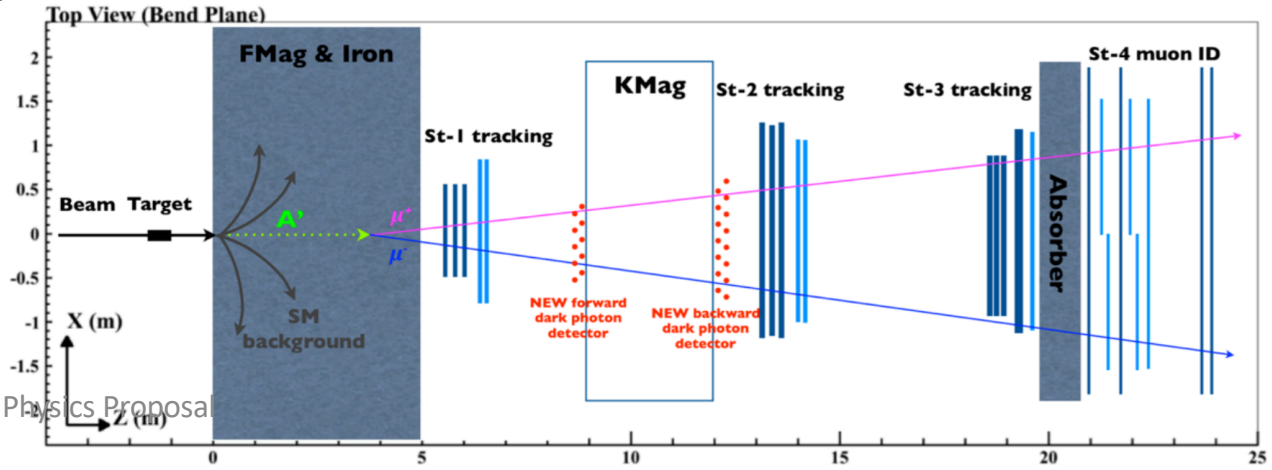
SeaQuest at the Intensity Frontier at Fermilab

High intensity proton beam: "beam dump mode" @SeaQuest/E1067

- **35,000 fb^{-1} (in a 2-year parasitic run, 1.4x10^{18} POT @5% beam)**
- **LHC-II: 300 fb^{-1} (~2025), achieved 25fb^{-1} in Run-I**
- **B-factory@KEK: 50K fb^{-1} (~2023)**



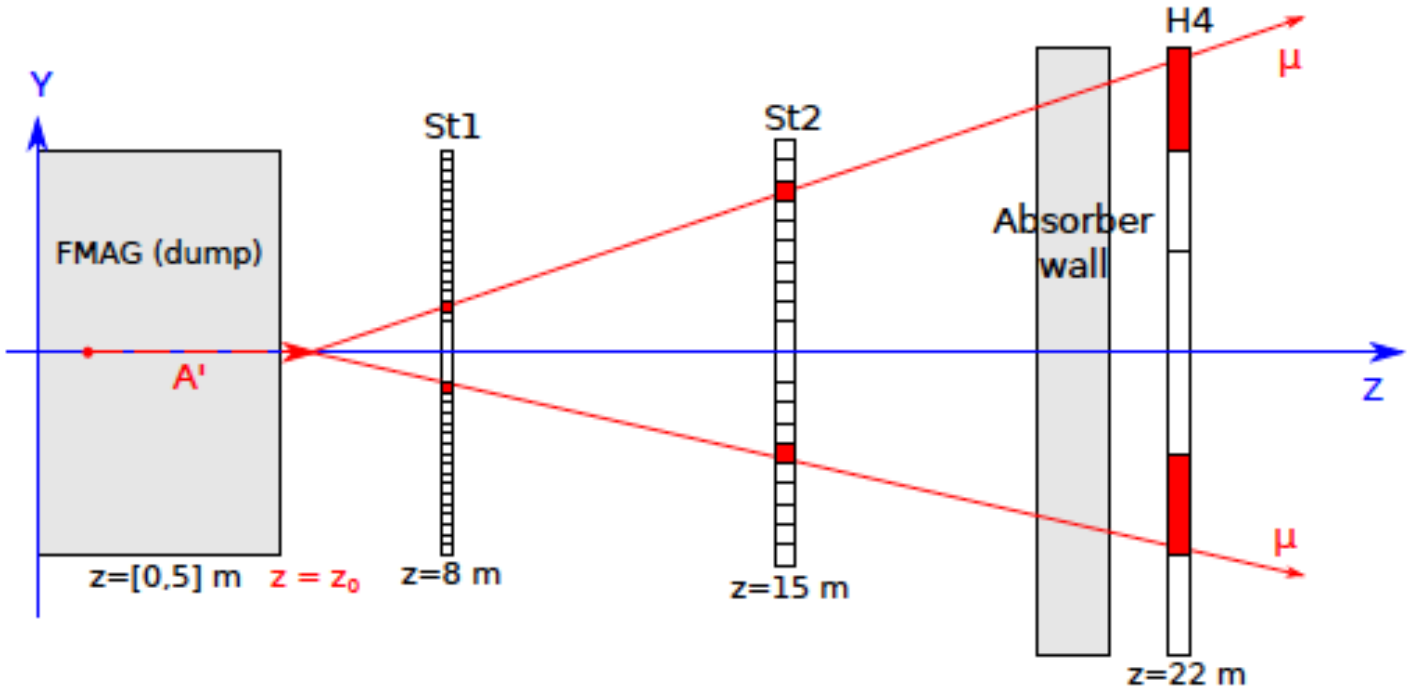
LDRD/ER: 2016-2018
Trigger upgrade, parasitic runs



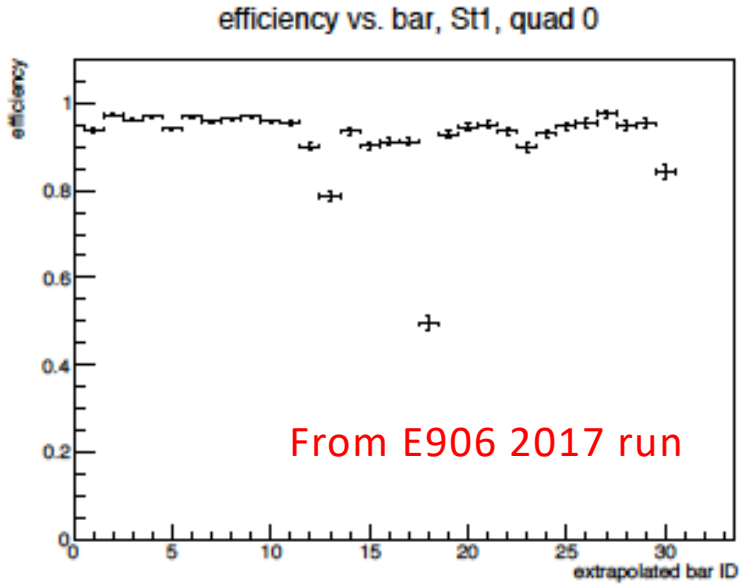
- Beam dump mode: p+Fe collisions! Target ~ 10%λ_I
- Parasitic run with other fixed target experiments, E906/E1039

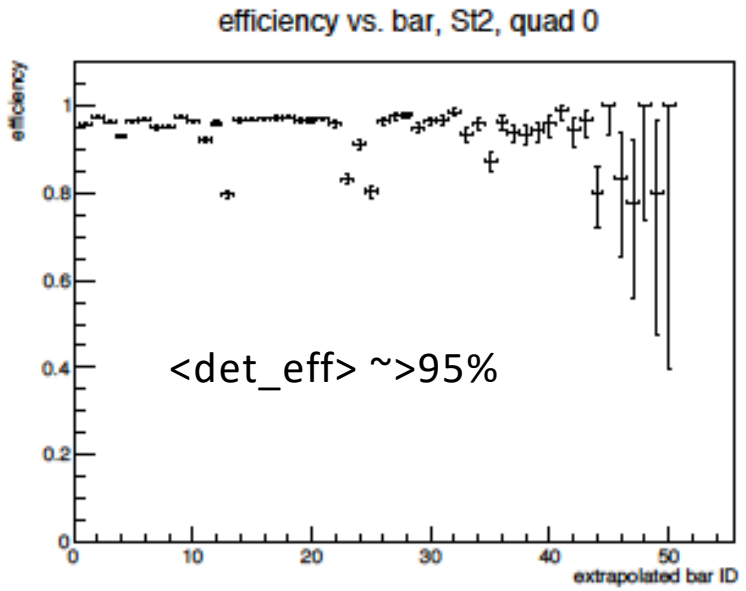
Displaced Dark Photon Trigger Detectors Work Well!

-Detector and trigger system installed and commissioned during the last SeaQuest/E906 run in 2017
- Physics analysis in progress



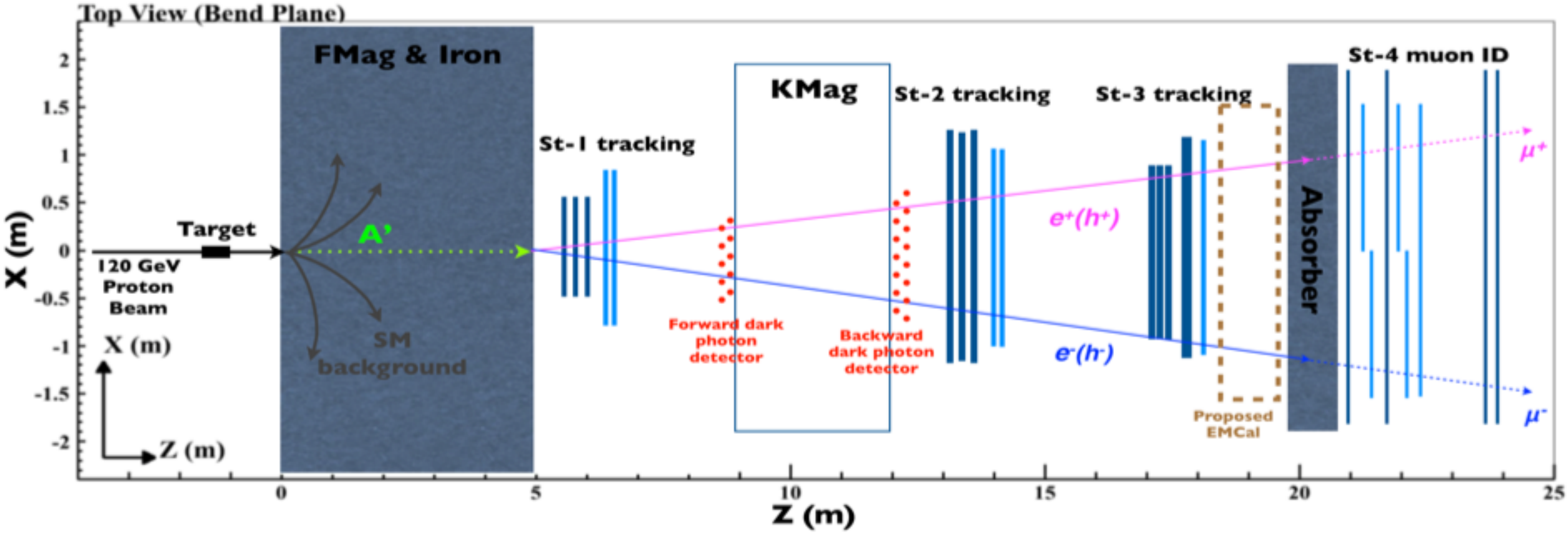
Schematic of displaced dimuon trigger





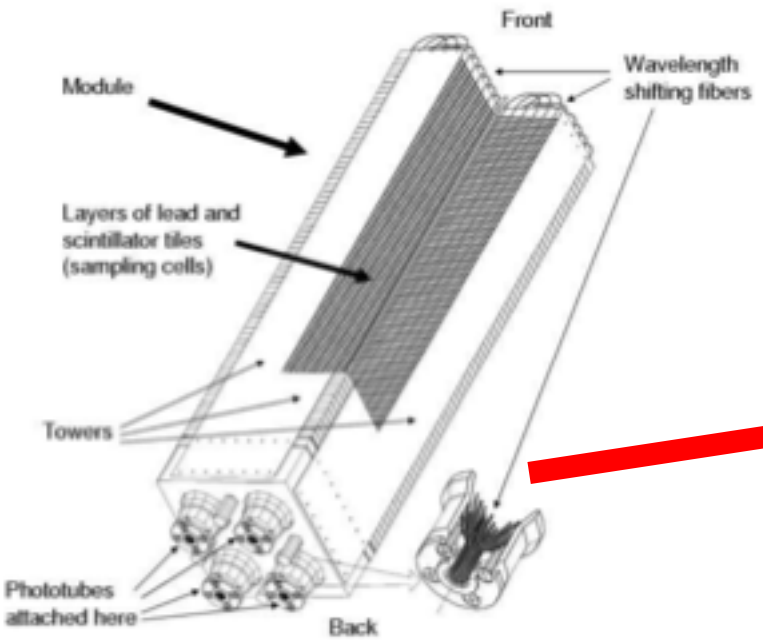
EMCal Upgrade in 2021

An EMCal detector recycled from PHENIX at RHIC



Details of PHENIX EMCal

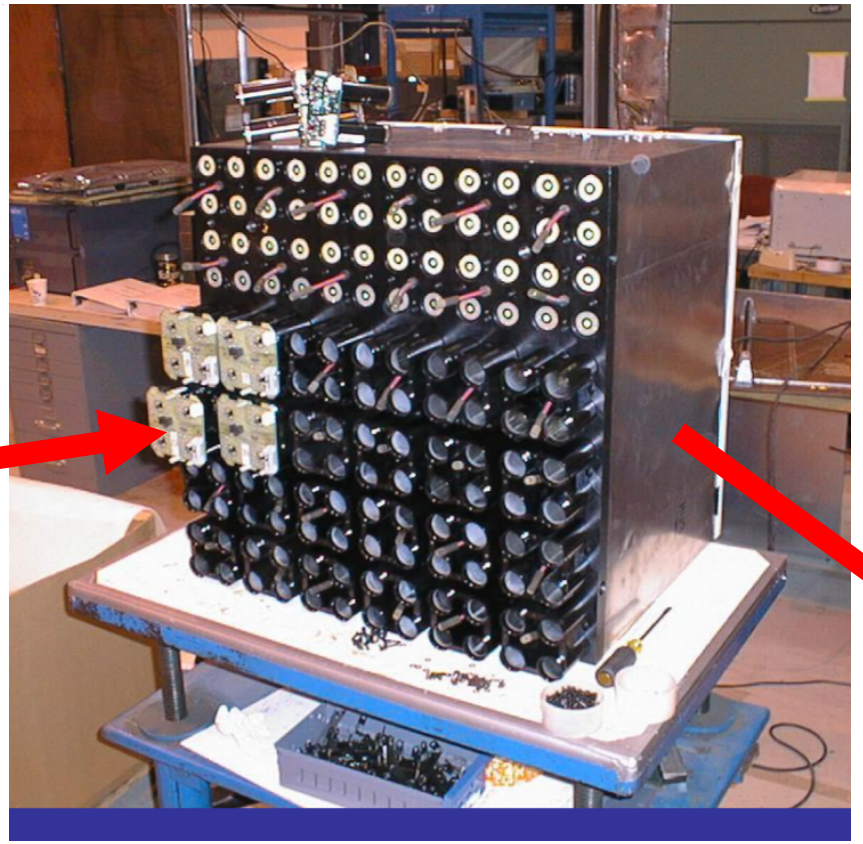
(we will get 2 sectors)



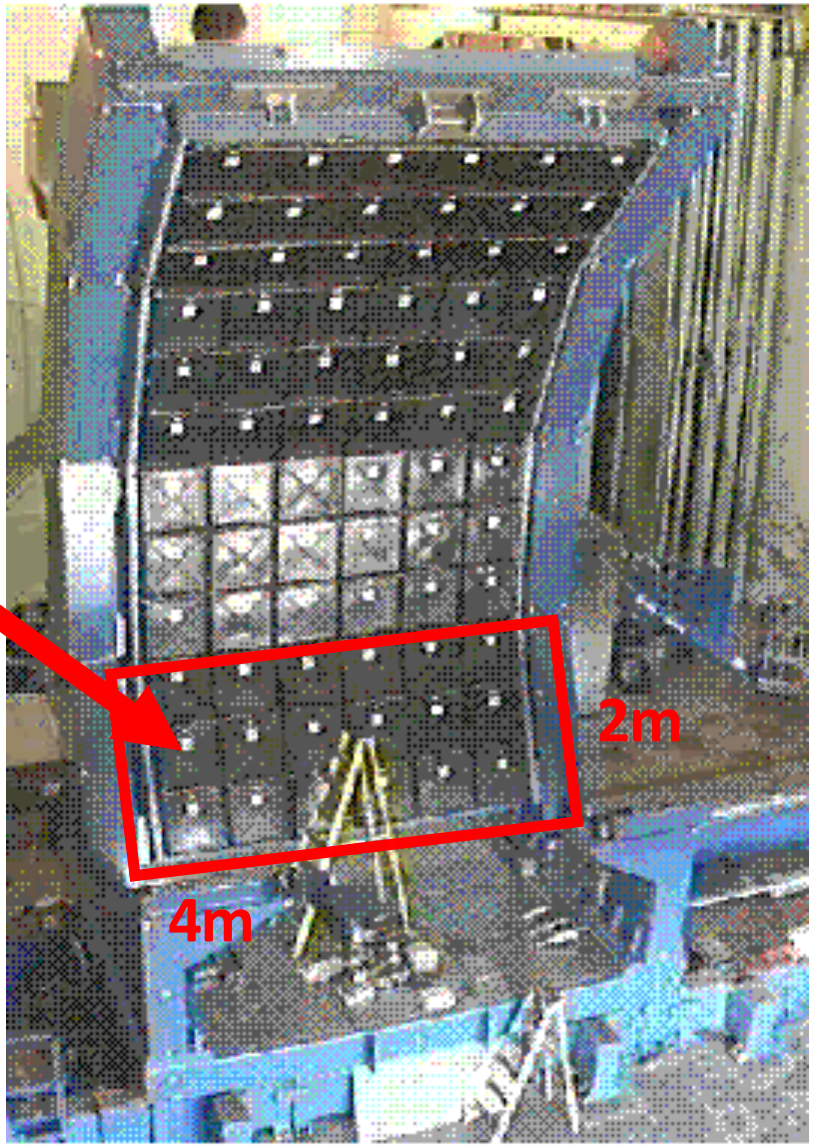
- Shashlik-type Pb scintilator
- 1 tower is 5.52*5.52*33 cm^3
- 4 towers make a module

Total # of readout channels if gang 4-"PMTs":

36 x 3 x 6 = 648 (2592)



- 6x6 modules make a super module
- 3x6 supermodules make a sector
- 1 sector covers 2x4 m^2, weights about 22t(std)



Proposed EMCal Work and Possible Timeline

2018: ship EMCal to Fermilab for initial testing and evaluation

2019-2020: refurbishment and readout integration

Summer 2021: installation in SeaQuest

Data taking: 2021+

Bring in new HEP collaborators to work on EMCal upgrade and also other detector upgrade activities

Immediate goal:

- Ship the detector from BNL to Fermilab in summer 2018, ready for refurbishment and testing
- Identify onsite space at Fermilab with crane support and basic utilities for the EMCal test work

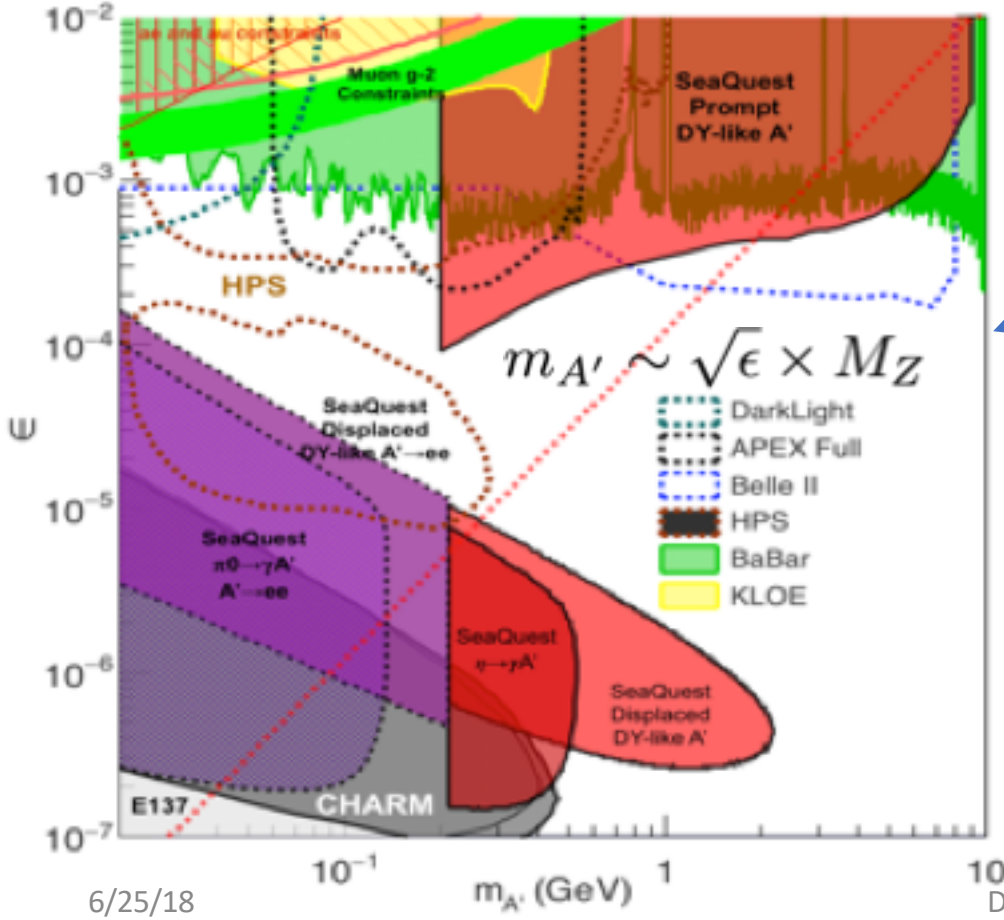
Ultimate goal:

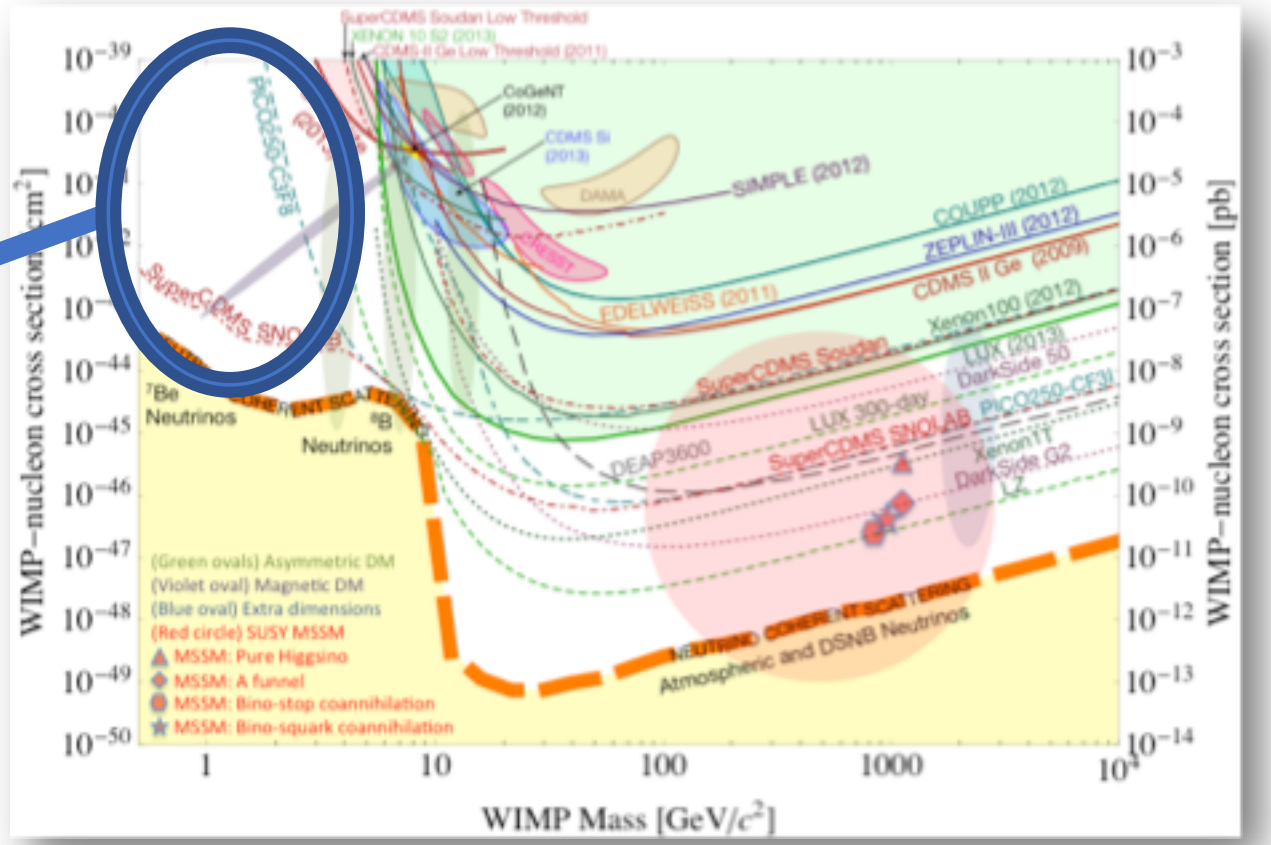
- Have the full detector ready for installation by the end of E1039
- Install the detector during the summer shutdown in 2021, after the E1039 completion; commissioning in later part of 2021
- Ready for dedicated HEP DP physics run early 2022

Dark Photon/Higgs Search at Beam Dump Experiments @Fermilab

SeaQuest/E1067 search for **low mass dark particles**:
- mass =1 MeV – 10GeV

- WIMP search – mass > 10GeV,
- Needs low mass coverage, mass < 10GeV



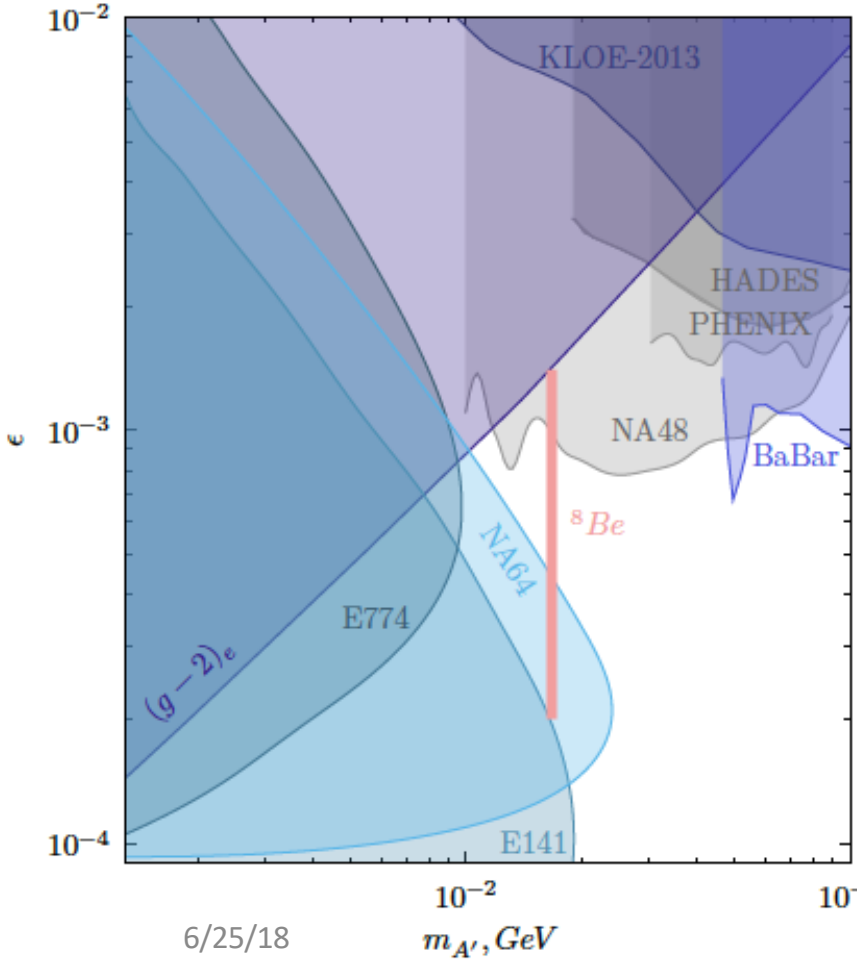


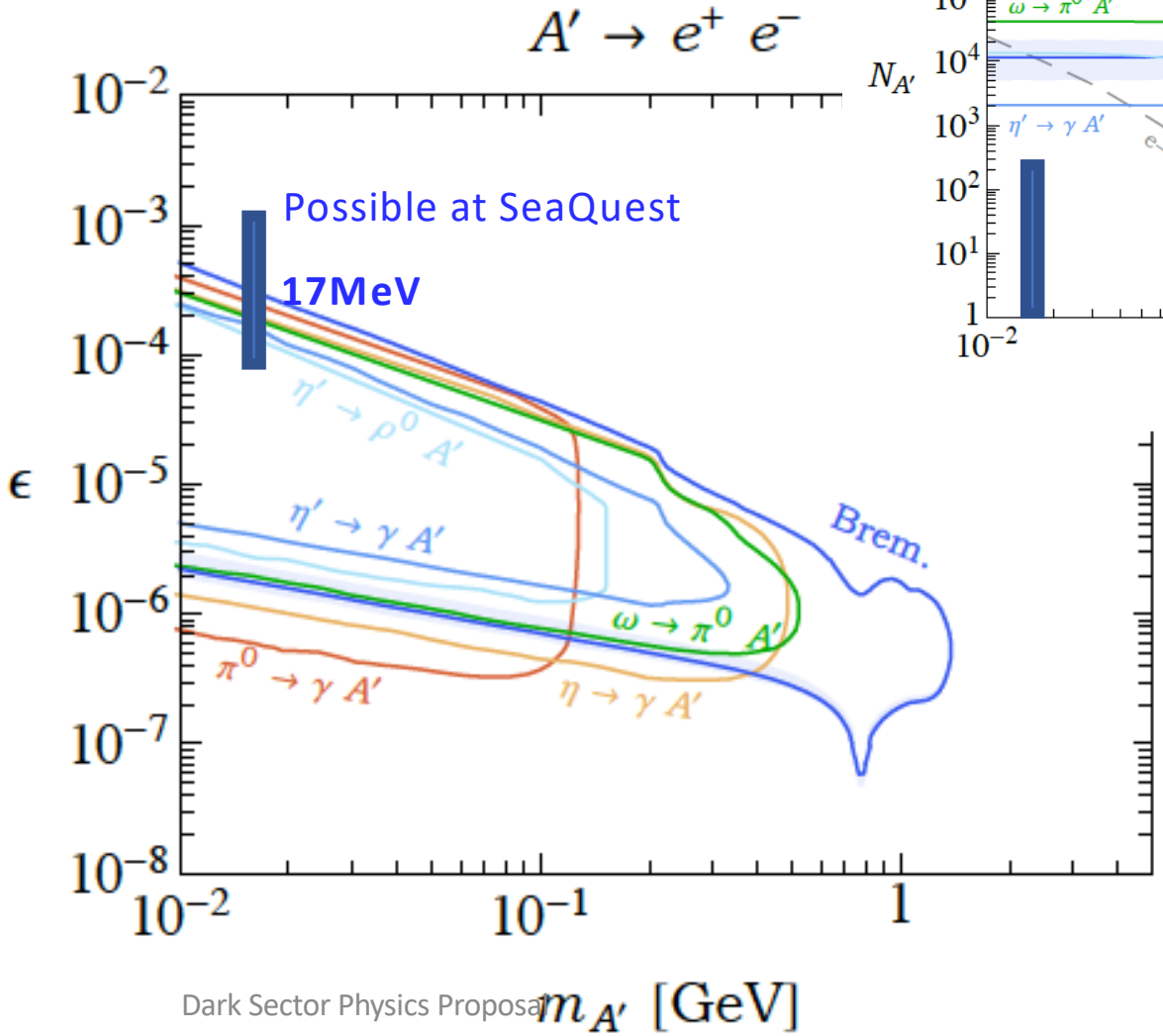
CIPANP18 – Update on Physics

- 17 MeV dark photon candidate

A possible way to access larger coupling, by using shorter "FMag", drill a longer hole inside the FMAG – background could increase

NA64, arXiv:1803.07748





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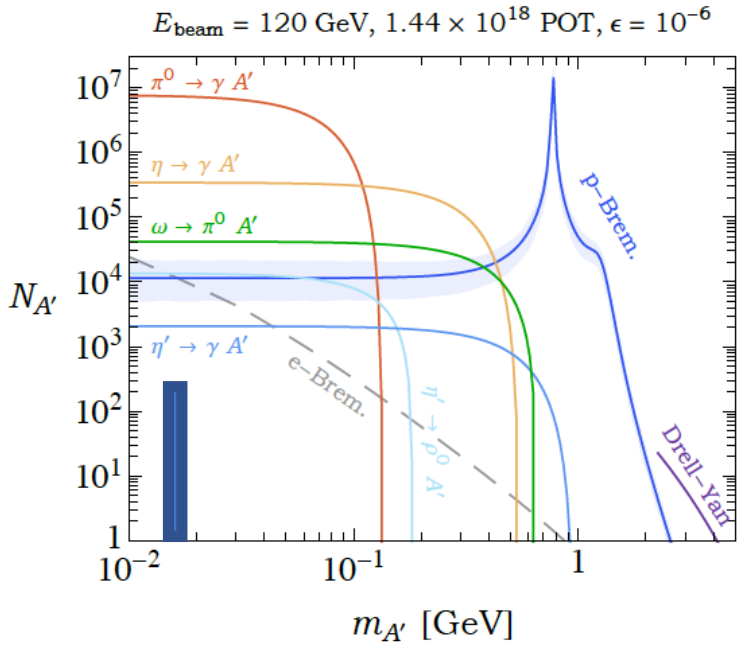

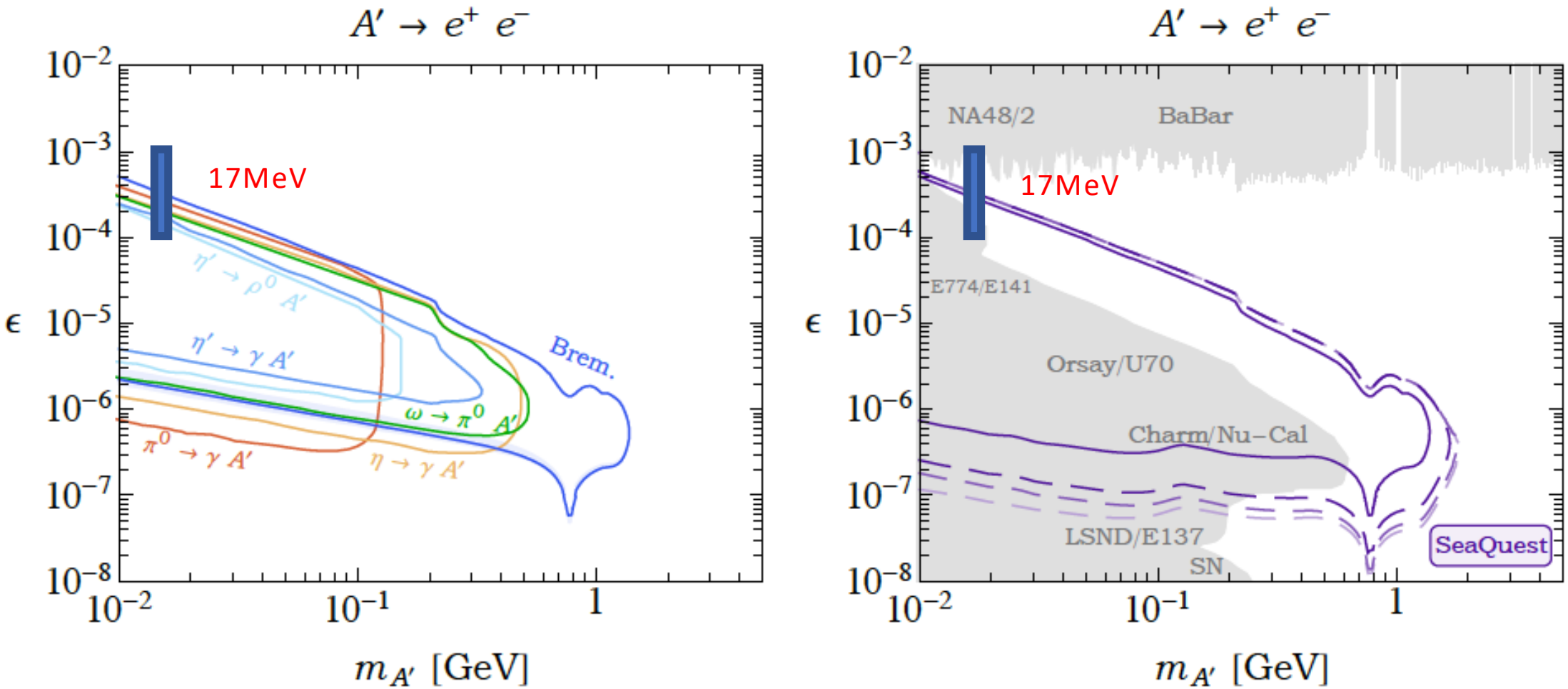

Figure 5. **Left panel**: The projected Phase I SeaQuest sensitivity to the dark photon parameter space using the 5 m – 6 m fiducial decay region. The various contours correspond to 10 dielectron signal events for dark photons produced from meson ($\pi^0, \eta, \eta', \omega$) decays and proton Bremsstrahlung. The blue shaded region represents the theoretical uncertainty in computing the Bremsstrahlung rate (see text for details). **Right panel**: Seaquest sensitivity to displaced dark photons at Phase I (solid purple) and Phase II (dashed purple), corresponding to 10 signal events. For Phase I, we conservatively fix the fiducial decay region to 5 m – 6 m. For Phase II, moving from darker to lighter contours corresponds to the fiducial decay regions of 5 m – 6 m, 5 m – 9 m, and 5 m – 12 m, respectively. The gray region denotes parameter space that is already excluded by past experiments [1, 2].