DarkQuest - Searching for light dark matter at Fermilab's Proton Fixed-Target Experiment

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for the DarkQuest Team

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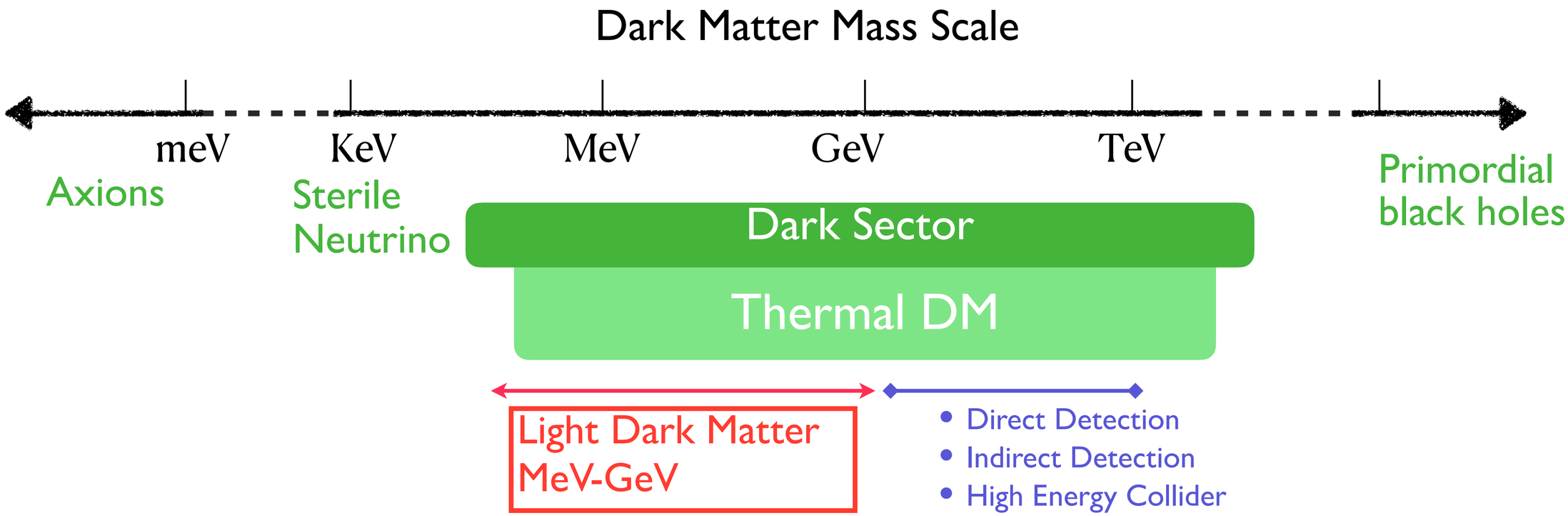
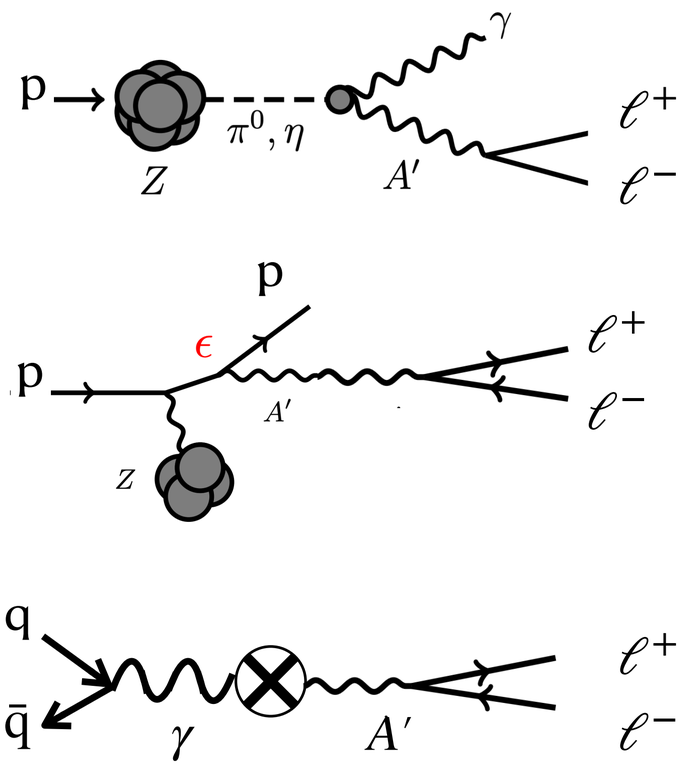
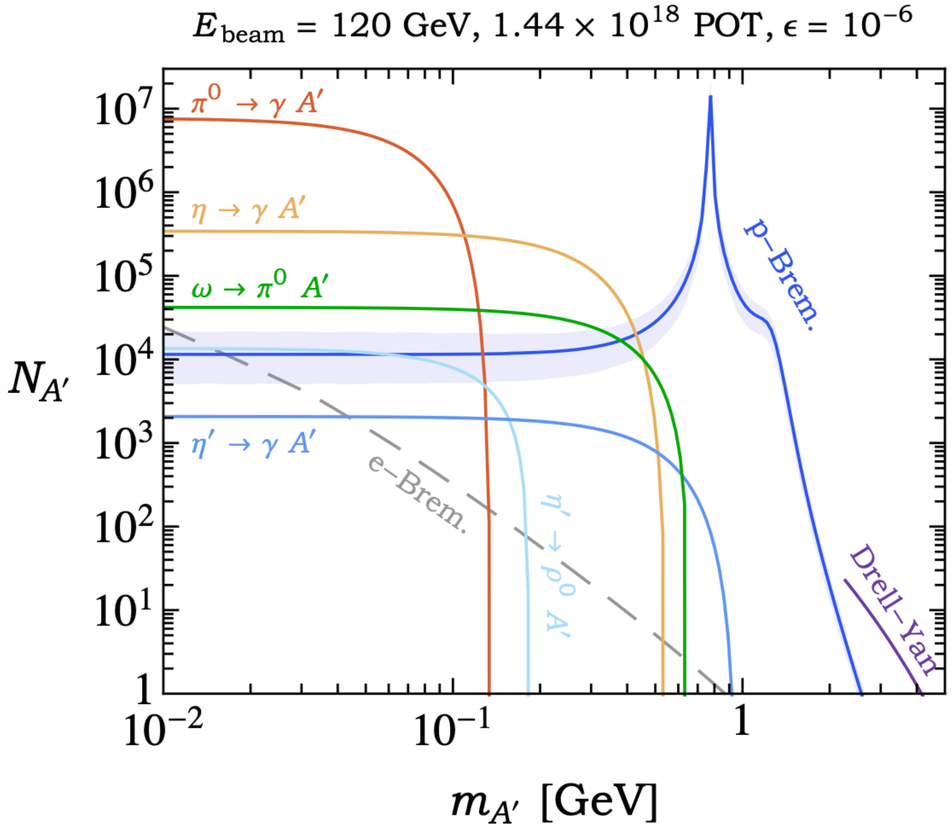
Physics Motivation



- Dark Sectors provide the DM candidates, and can also address many other open problems in particle physics (baryogenesis, strong CP problem, neutrino masses, hierarchy problem, etc)
- High-intensity accelerators and fixed-target experiments provide an ideal environment to probe dark sector physics in MeV-GeV range

Signal Processes: Dark Photon Example

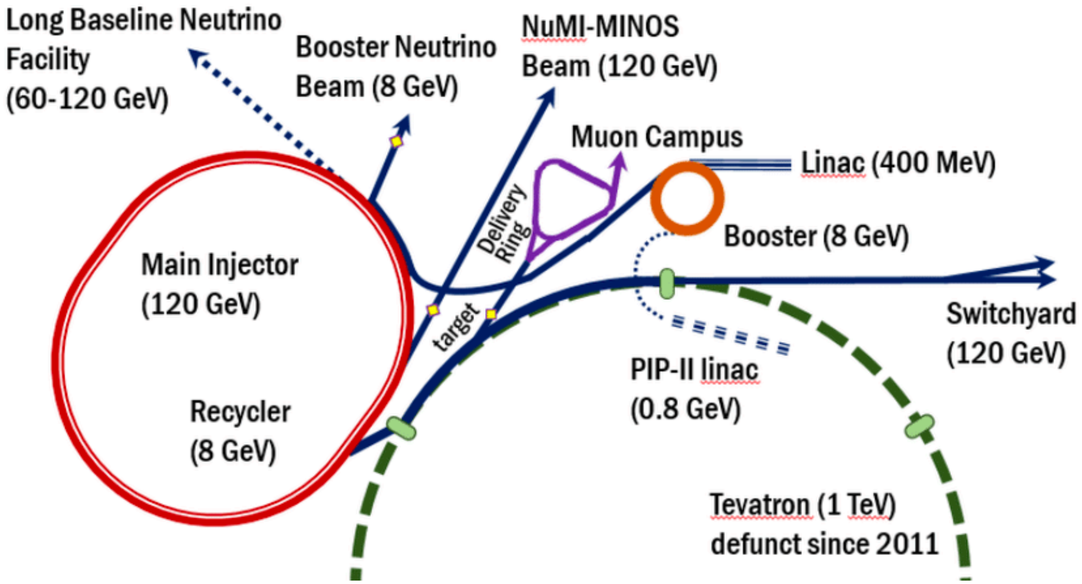


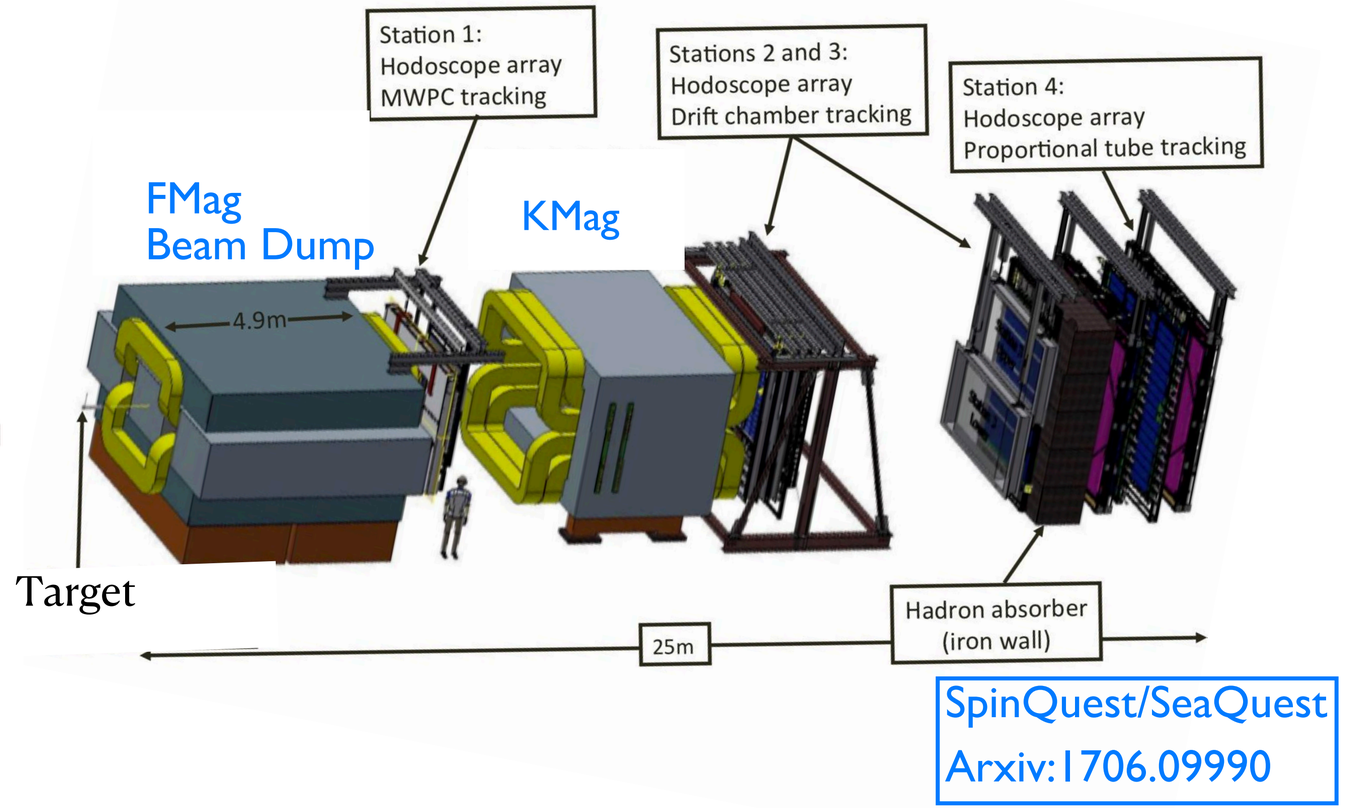


A.Berlin, S.Gori, P.Schuster, N.Toro
Arxiv:1804.00661

- For proton fixed-target beam dump experiment, three dominant signal production mechanisms: meson decay, proton bremsstrahlung, and Drell-Yan process
- Larger production rates with proton beams compared with electron beams

Experimental Setup: SpinQuest

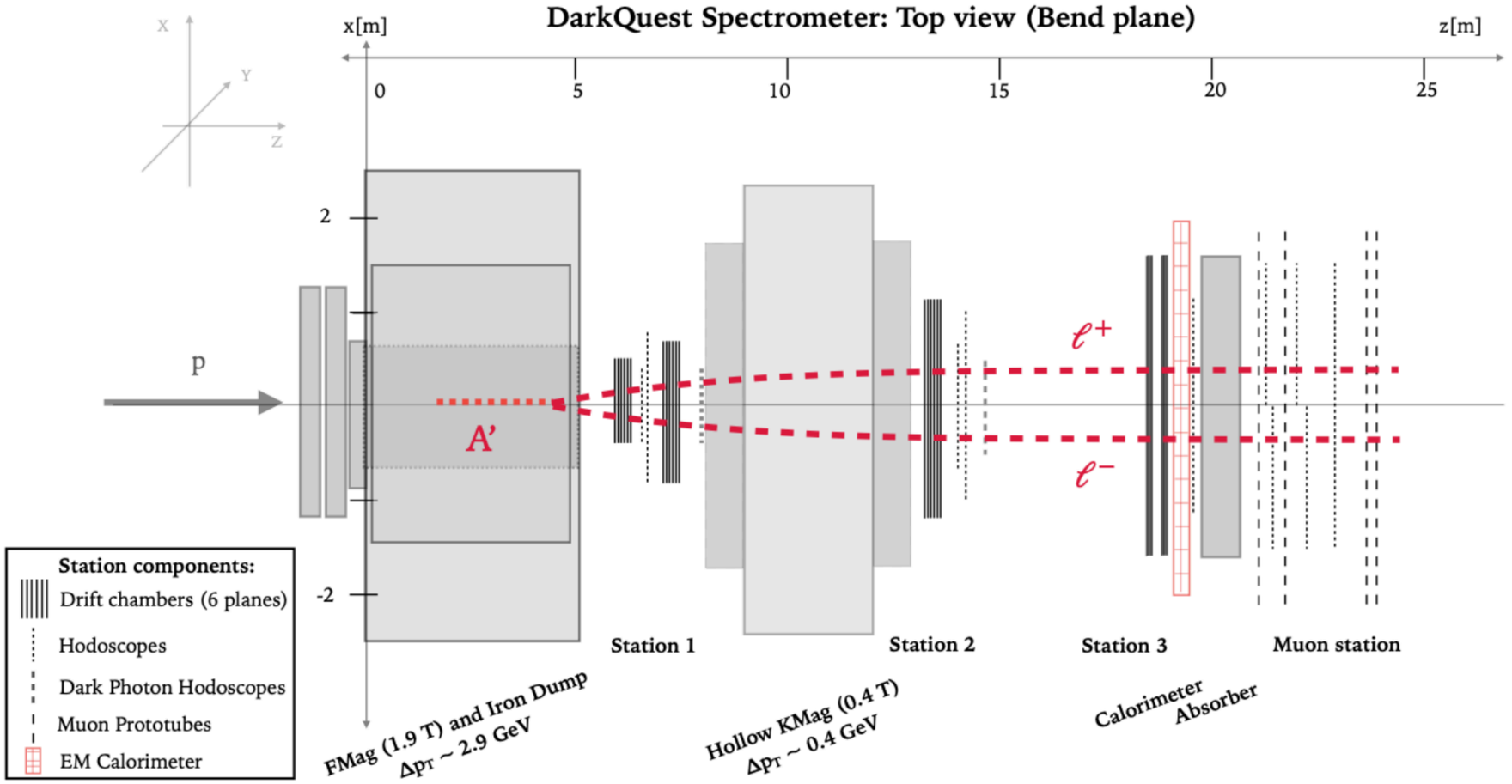




SpinQuest/SeaQuest
Arxiv:1706.09990

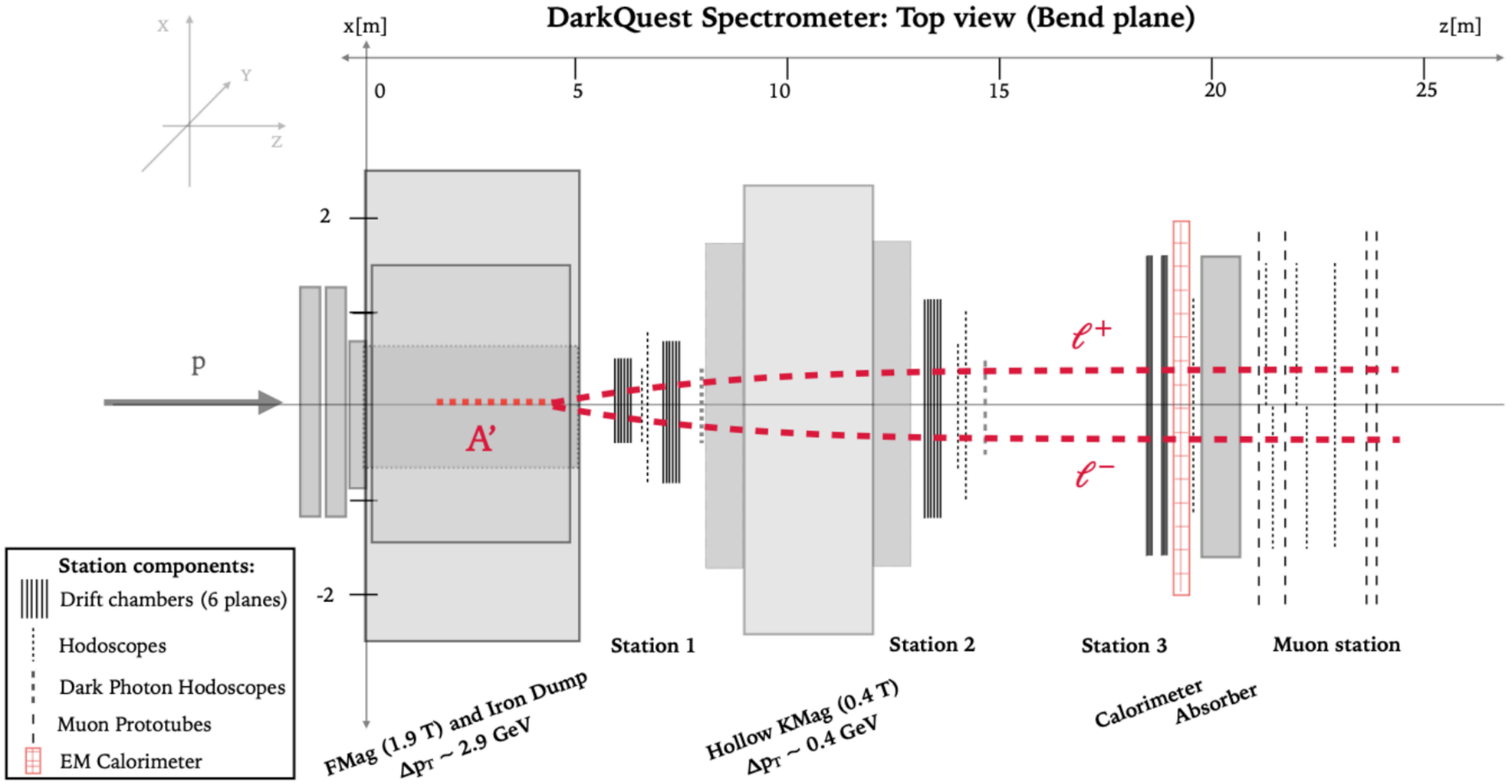
- 120 GeV high-intensity proton beam from the Fermilab Accelerator Complex
  - Expect 10^{18} Protons on target (POT) in a 2-year parasitic run, and 10^{20} POT after the PIP-II accelerator upgrade
- SpinQuest spectrometer 5m thick FMag as the beam dump and absorber; hollow KMag for tracking; and 4 stations of drift chambers (tracking) and scintillator hodoscopes (triggering)
  - Measuring the Drell-Yan process for studying the Transverse Momentum Dependent PDFs (TMDs) inside the proton

Experimental Setup: DarkQuest



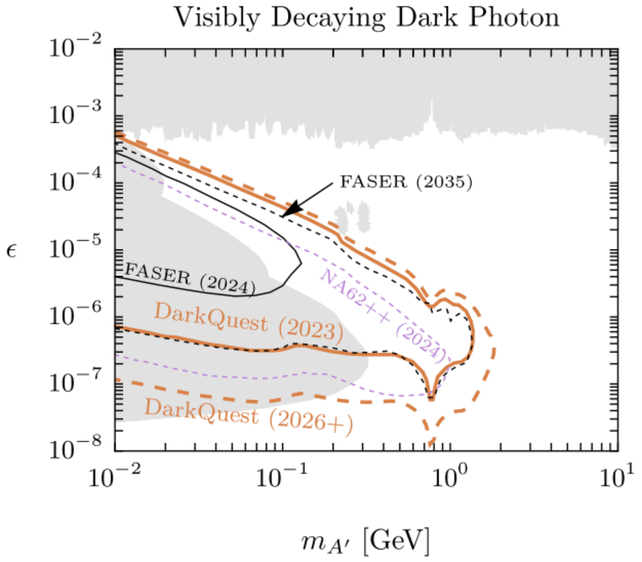
- Make full use of the existing SpinQuest spectrometer
- Upgrade with one Electromagnetic calorimeter (EMCal) sector (2mx4m, from PHENIX Experiment):
  - Provide access to electron and photon final states. Broaden the coverage to lower masses below $2m_\mu$
  - Provide more sensitivity by rejecting muon and hadron backgrounds

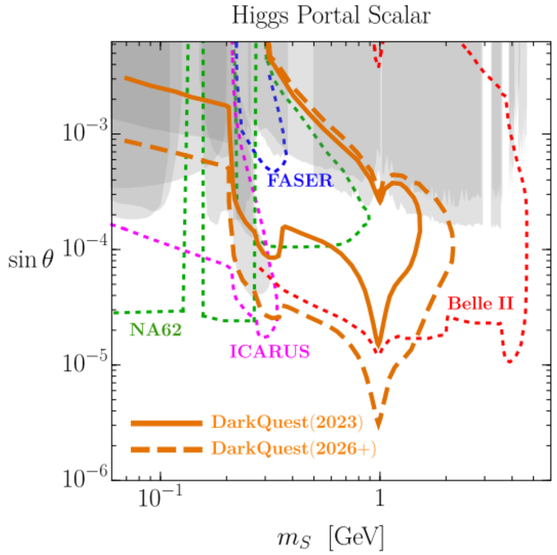
Why DarkQuest

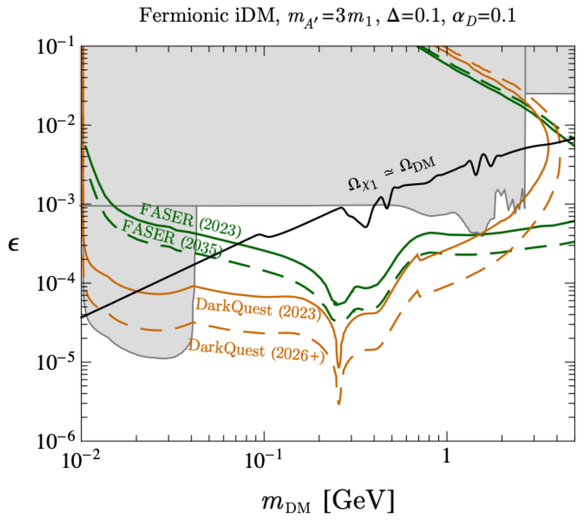


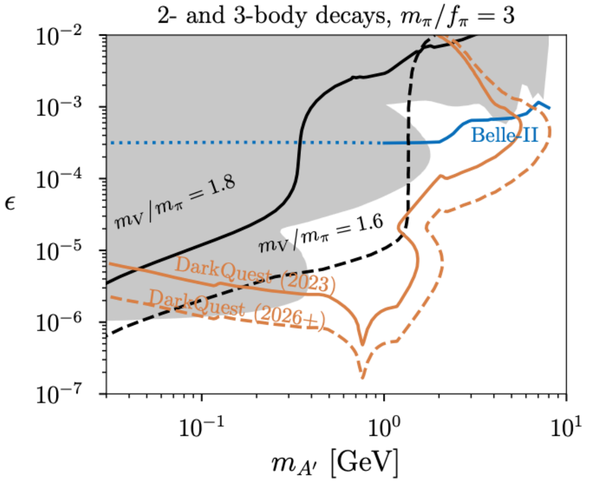
- Large dark sector production cross section with 120GeV high-intensity proton beam
- Compact geometry and relatively short displacement baseline ($\mathcal{O}(m)$) to cover unique and broad phase space:
  - KMag and 3-4 tracking layers provide good momentum measurement
  - Scintillator hodoscopes + EMCal to trigger on signals
  - EMCal opens up new final states distinct from large muon backgrounds
- Most of the experimental components already exist, very low cost

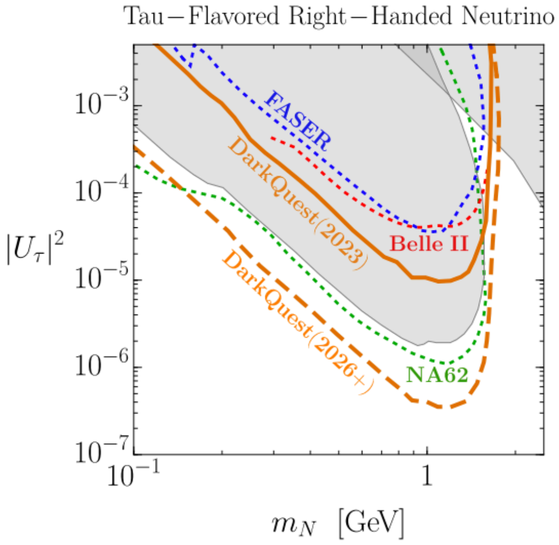
Broad Sensitivity Coverage

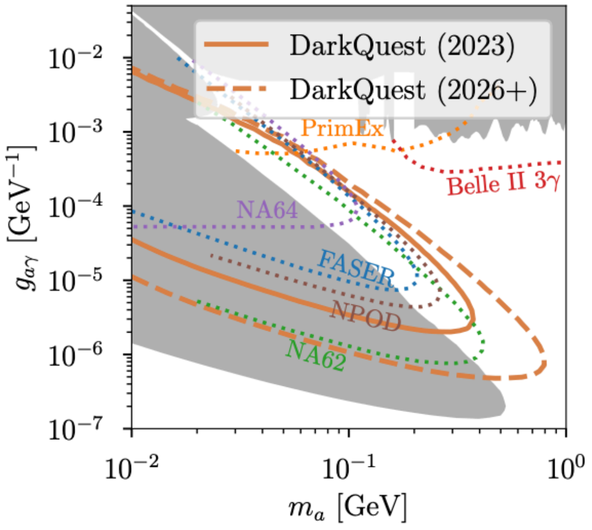






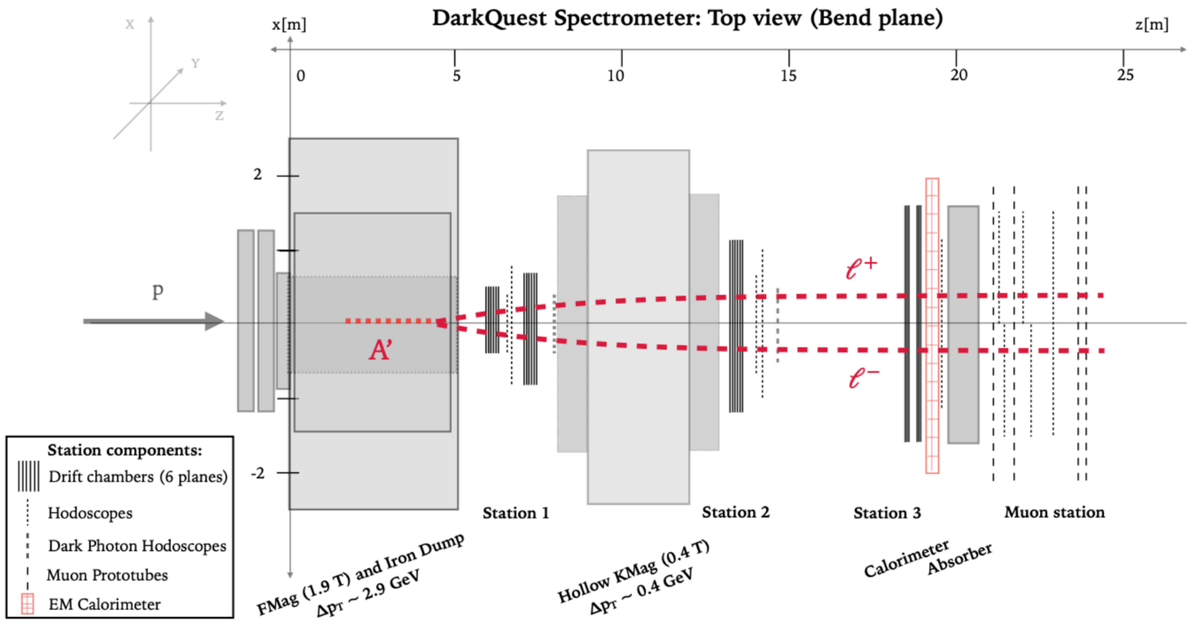


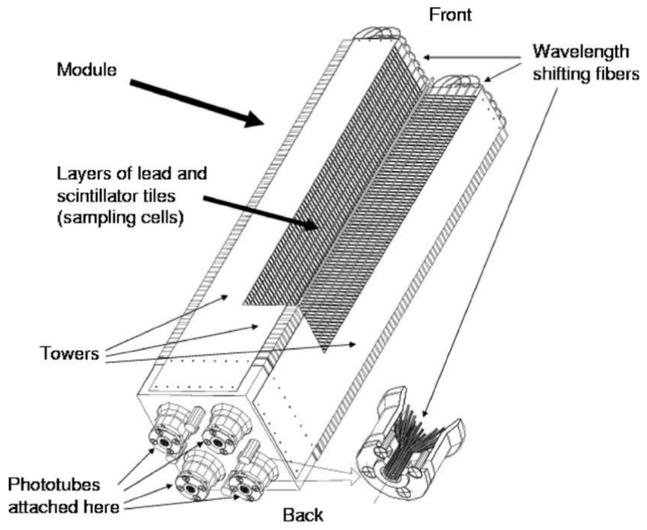




- Broad coverage to different theory models, e.g.,
  - Berlin, Gori, Schuster, & Toro, Arxiv.1804.00661
  - Batell, Evans, Gori, & Rai, Arxiv.200808108
  - Berlin, Blinov, Gori, Schuster, Toro, Arxiv.1801.05805

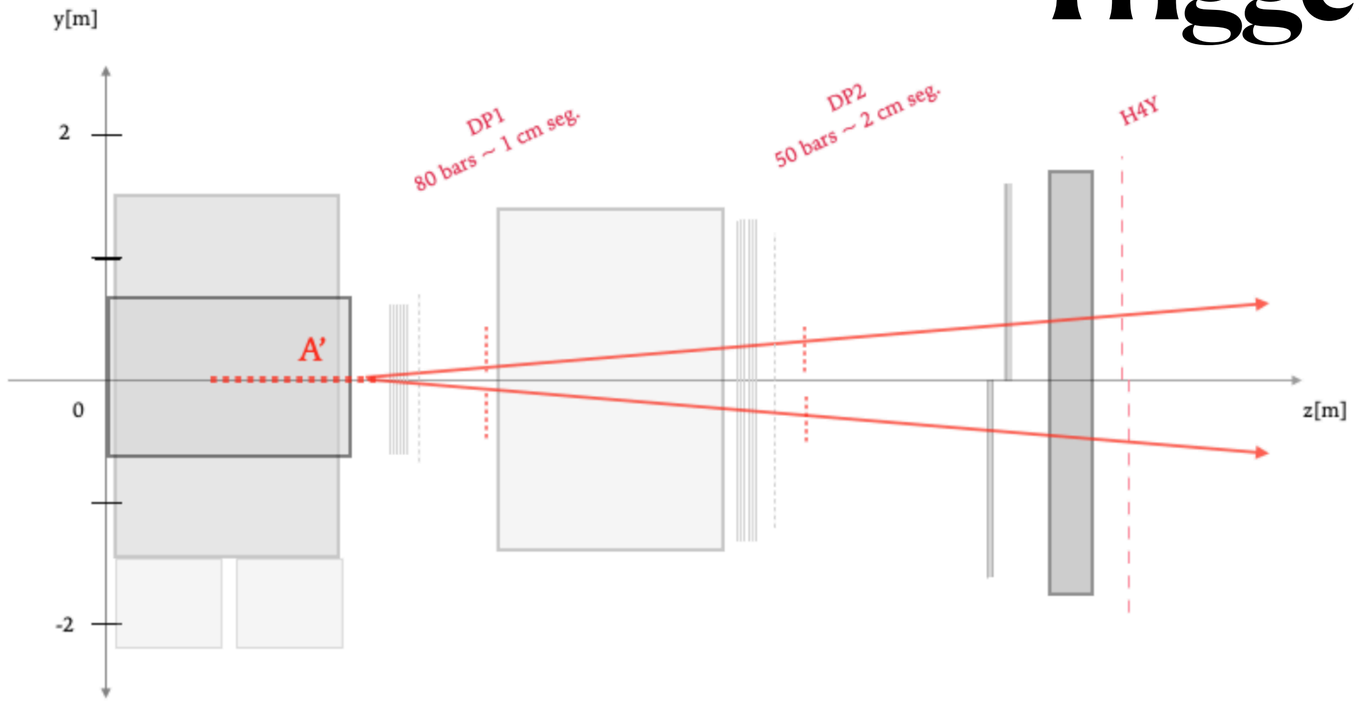
Spectrometer Upgrade

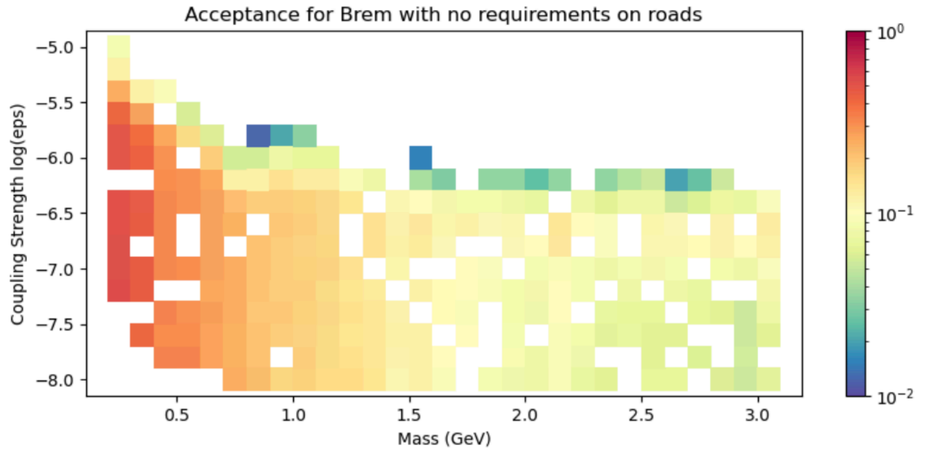




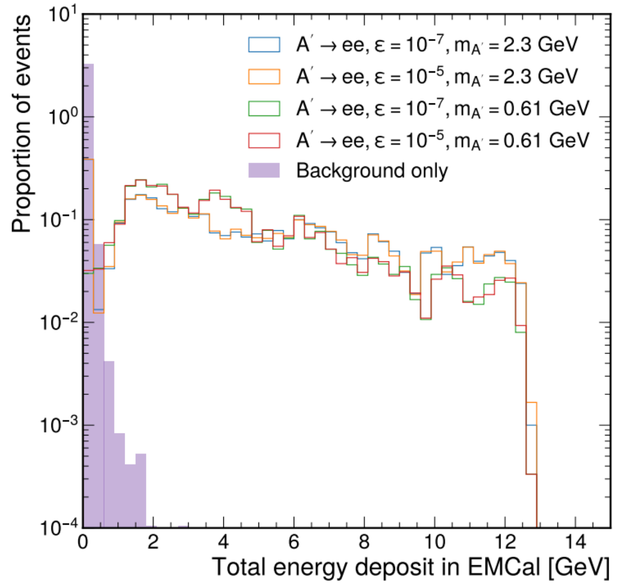
- EMCal integration into the spectrometer:
  - Developments of the readout and trigger system ongoing
  - Currently in possession of a few cells to explore SiPM readouts
- Additional proportional tubes from HyperCP experiment - can be installed before KMag to improve the tracking

Trigger

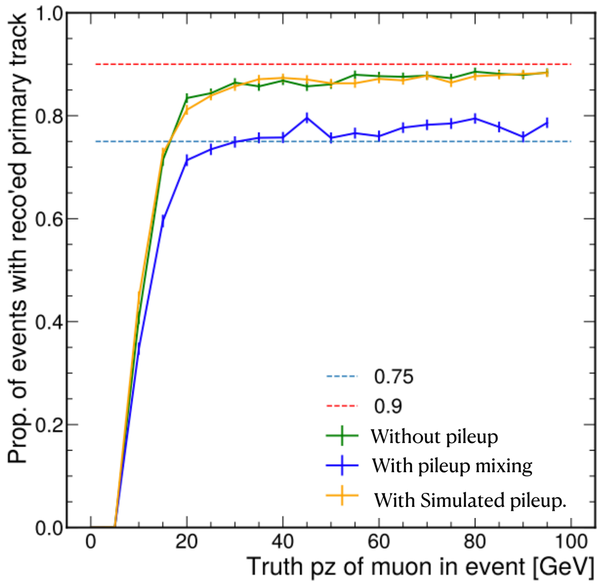


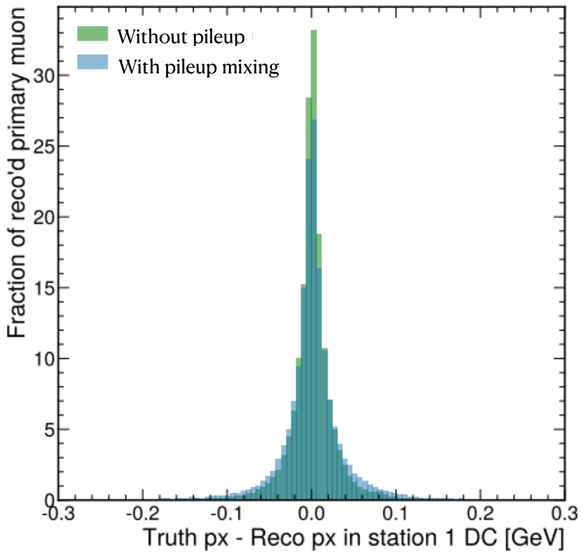


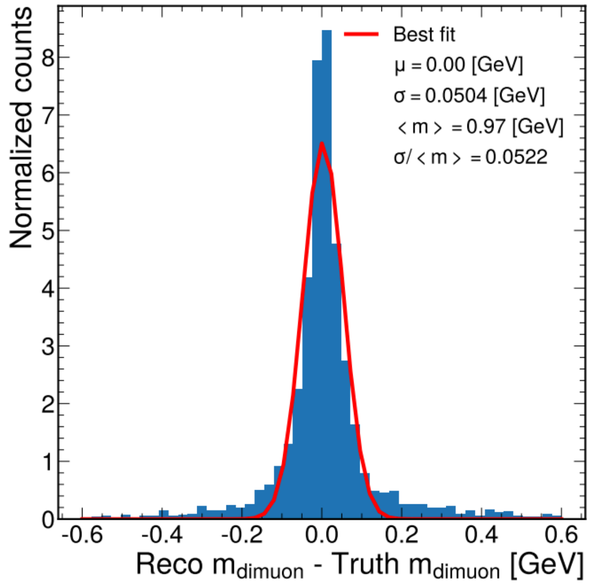
- Exploring newly installed Dark Photon trigger:
  - Large improvements on the displaced signals compared with the existing standard hodoscope triggers
  - Working on the trigger design and the implementations
- Include EMCal information in the trigger system
  - Good separation of electron/photon signals out of hadron and muon backgrounds

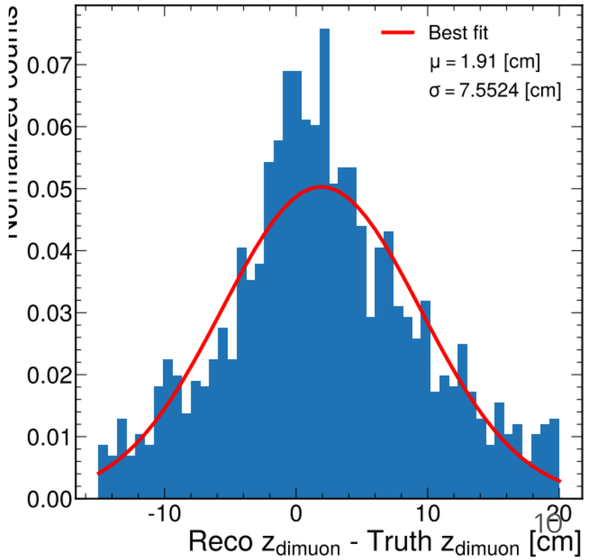


Tracking and Vertexing



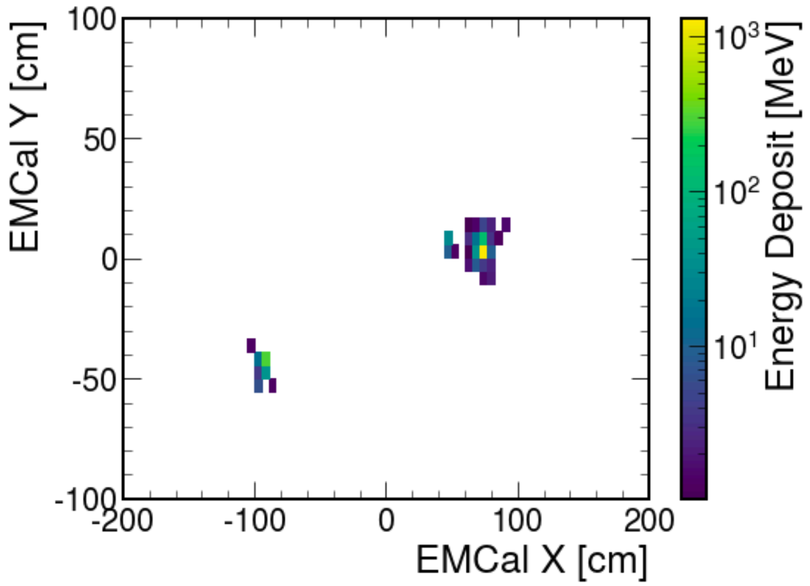


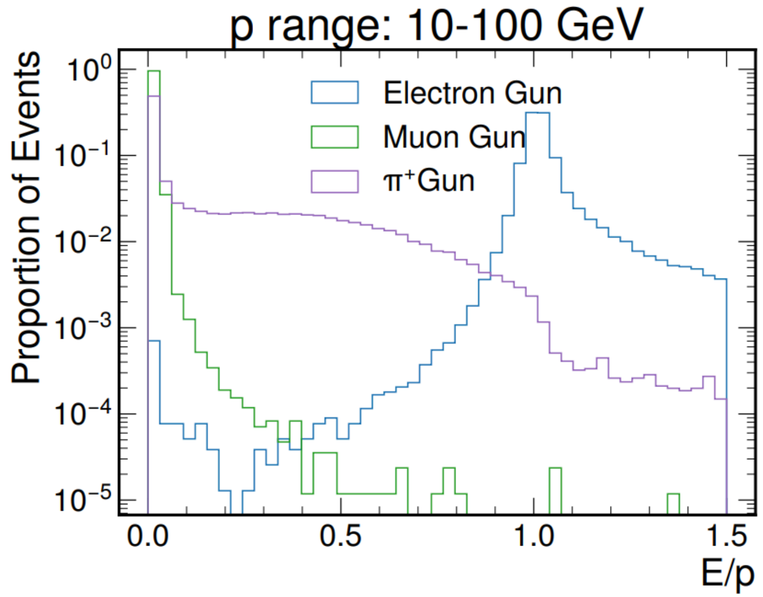




- Improved tracking and vertaxing for displaced tracks and vertices based on the existing SpinQuest code:
  - Better resolution for tracks and vertices compared with prompt DY signals because of the less impact from the FMag in the front.
  - 75% track reconstruction efficiency for high momentum particles; 5% mass resolution, 5-10cm Z resolution for dark photons decaying after FMag

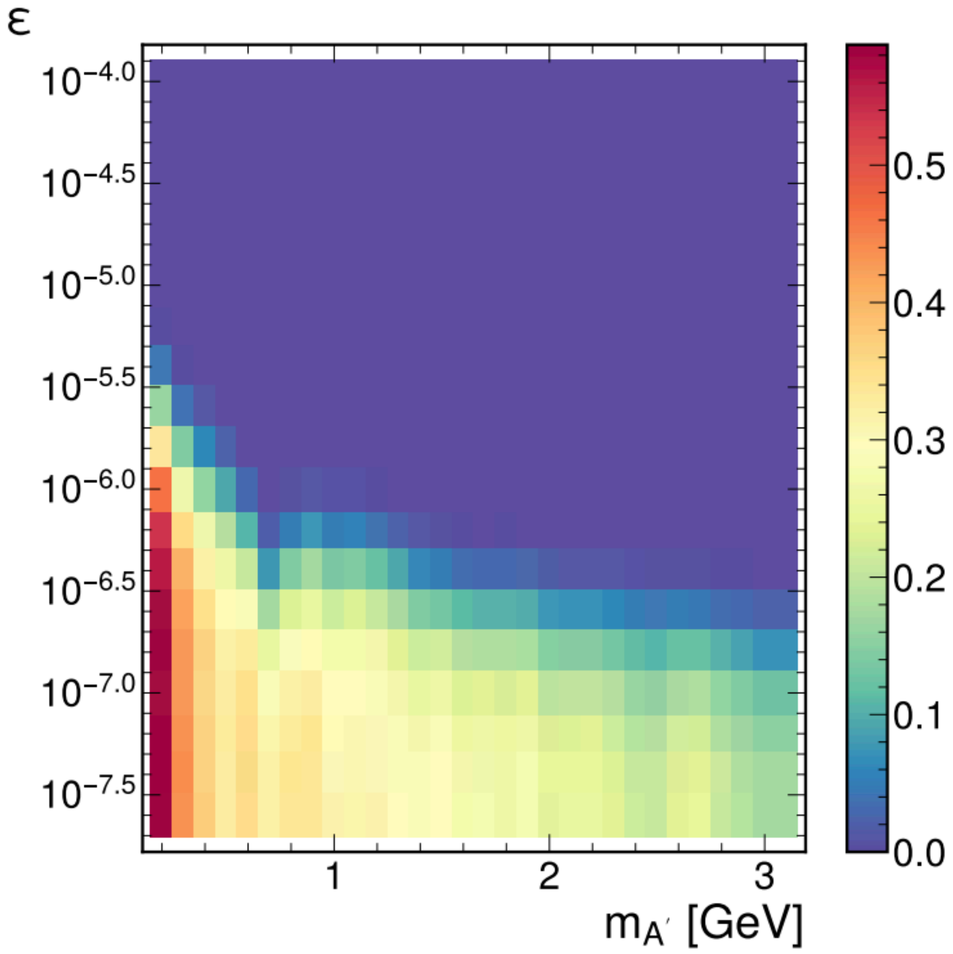
Particle Identification





- Well-separated electron showers in the EMCal
- Working on Particle ID based on the combination of tracking and EMCal information

Signal Acceptance



- Dark photon signal acceptance as a function of coupling and masses
  - Only includes the muon channel; working on understanding the electron channel
- Simulation and study of the hadron and muon backgrounds ongoing.

Collaboration

- A strong team assembled of both experimentalists and theorists; having regular meetings for more than two years

- Integration with the Snowmass project; have one Snowmass paper on this: https://arxiv.org/pdf/2203.08322.pdf
- We are establishing strong connections with the current SpinQuest collaboration, testing and installing upgrades, taking data, and performing analysis
- Welcome to join the effort! Contact us if interested! (yfeng@fnal.gov ntran@fnal.gov)

DarkQuest: A dark sector upgrade to SpinQuest at the 120 GeV Fermilab Main Injector

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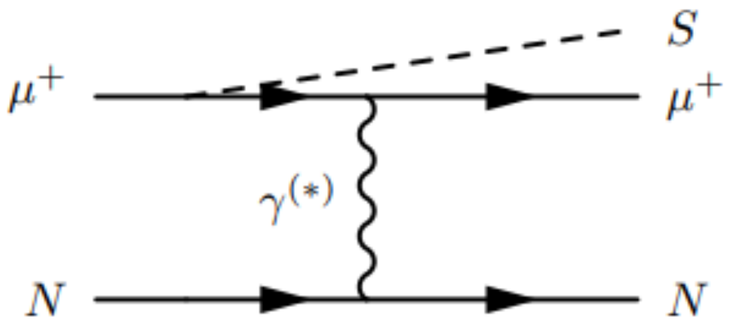
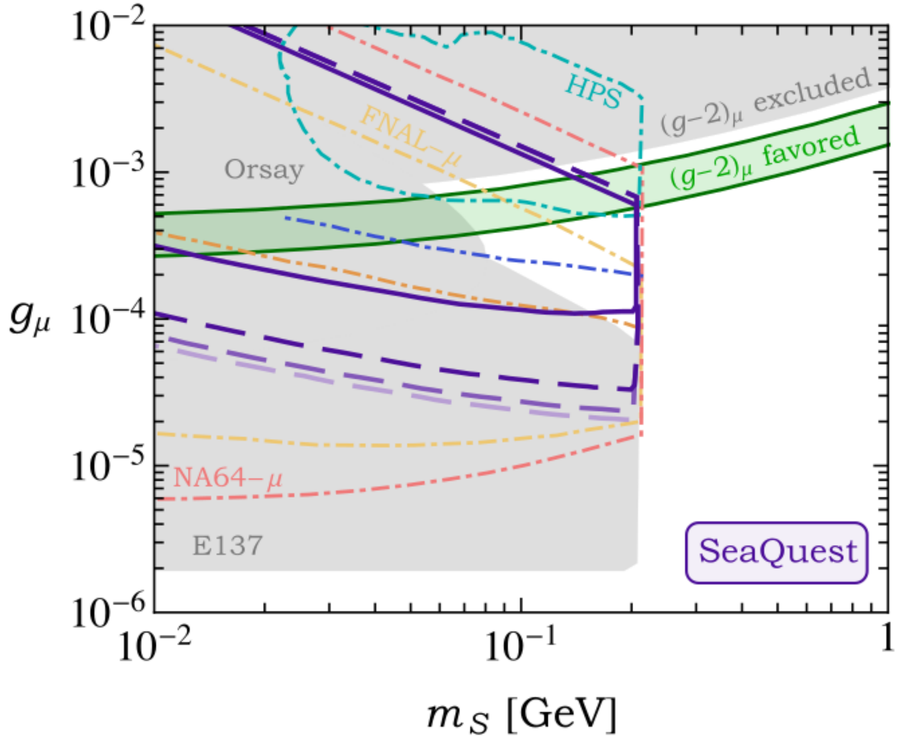
Summary

- DarkQuest is a high-intensity proton beam-dump experiment, which makes use of current SpinQuest experiment, with the upgraded EMCal from sPHENIX experiment
- DarkQuest offers a low-cost and near-term opportunity to uncover a broad range of MeV-GeV dark sectors
- Planned timeline: SpinQuest run (~2022) and aim to start dark sector exploration in 2023-2024!
- A lot of electronics design, simulation, and reconstruction studies ongoing; welcome to join the efforts! (yfeng@fnal.gov, ntran@fnal.gov)

Back Up

Why DarkQuest: Connection with (g-2) Anomaly

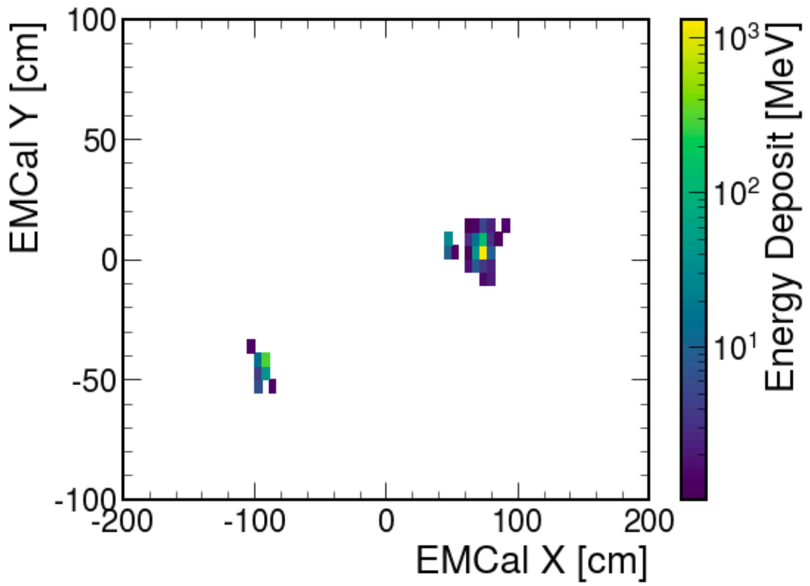


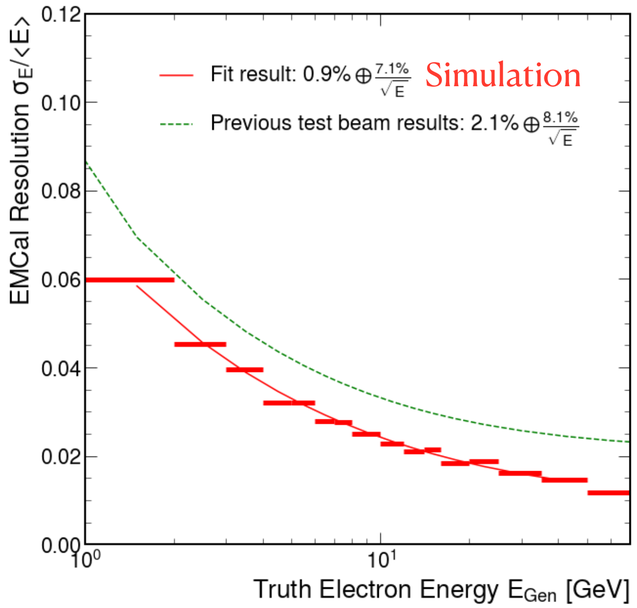


A.Berlin, S.Gori, P.Schuster, N.Toro Arxiv:1804.00661

- Large flux of secondary muons from pion decays traversing a thick target, which makes DarkQuest a muon beam dump experiment
- Search for displaced decays of light muon-coupled mediators

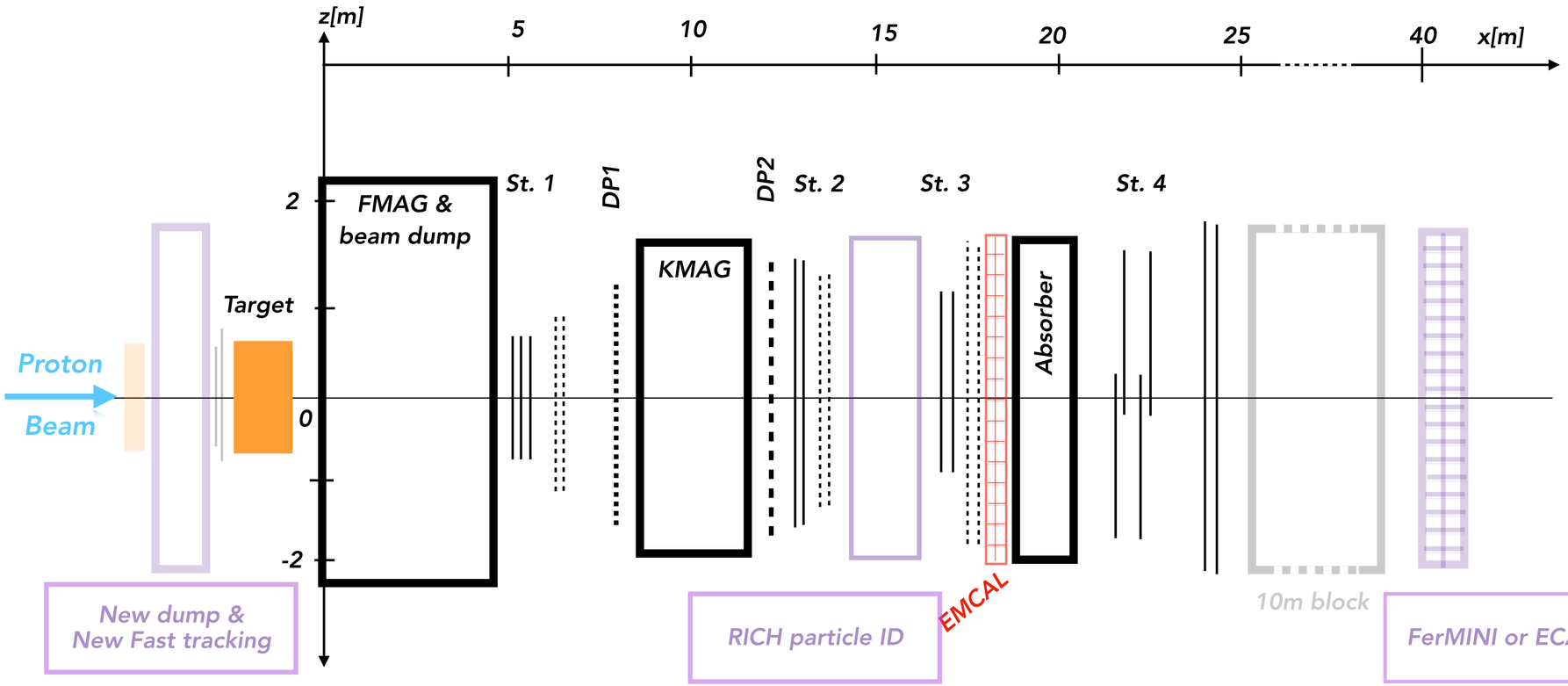
Ongoing Studies: EMCal Simulations

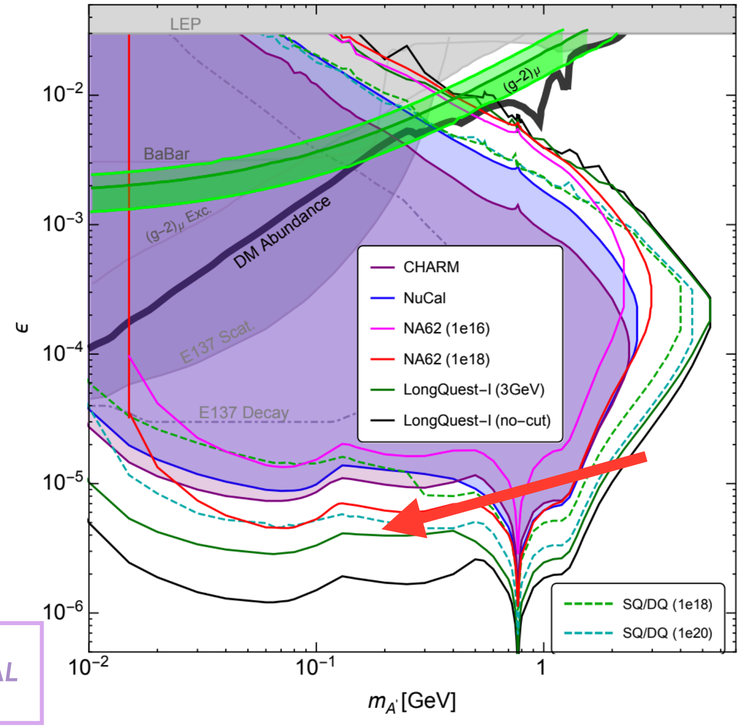




- Integrate the EMCal into the SpinQuest simulation framework; validate the performance and study the reconstructions
- Left plot is one example event display of two electron showers in the EMCal
- Right plot shows the agreement of the resolutions between the simulation (red) and the previous test beam results

Future Upgrade: DarkQuest -> LongQuest





Y. Tsai, P. deNiverville, M. Liu
Arxiv:1908.07525

- Future upgrades of DarkQuest - LongQuest: adding particle ID detector, new dump and new fast tracking, and ECAL, to further extend the coverage and sensitivity; explore this for Snowmass