

# ***DarkQuest and the $(g-2)_\mu$ anomaly***

David Sperka  
(Boston University)

On Behalf of the DarkQuest Collaboration

June 22<sup>nd</sup> 2021

# DarkQuest Collaboration



## Experimentalists:

- BU: Zeynep Demiragli, David Sperka, Zijie Wan, Caspian Chaharom, Luke Saunders, Mariia Kharchenkov
- FNAL: Nhan Tran, Cristina Mantilla Suarez, Yongbin Feng
- JHU: Petar Maksimovic, Amitav Mitra
- LANL: Ming Liu, Kun Liu
- MIT: Phil Harris, Duc Hoang Noah Paladino, Sebastian Rotella
- SLAC: Omar Moreno, Tim Nelson

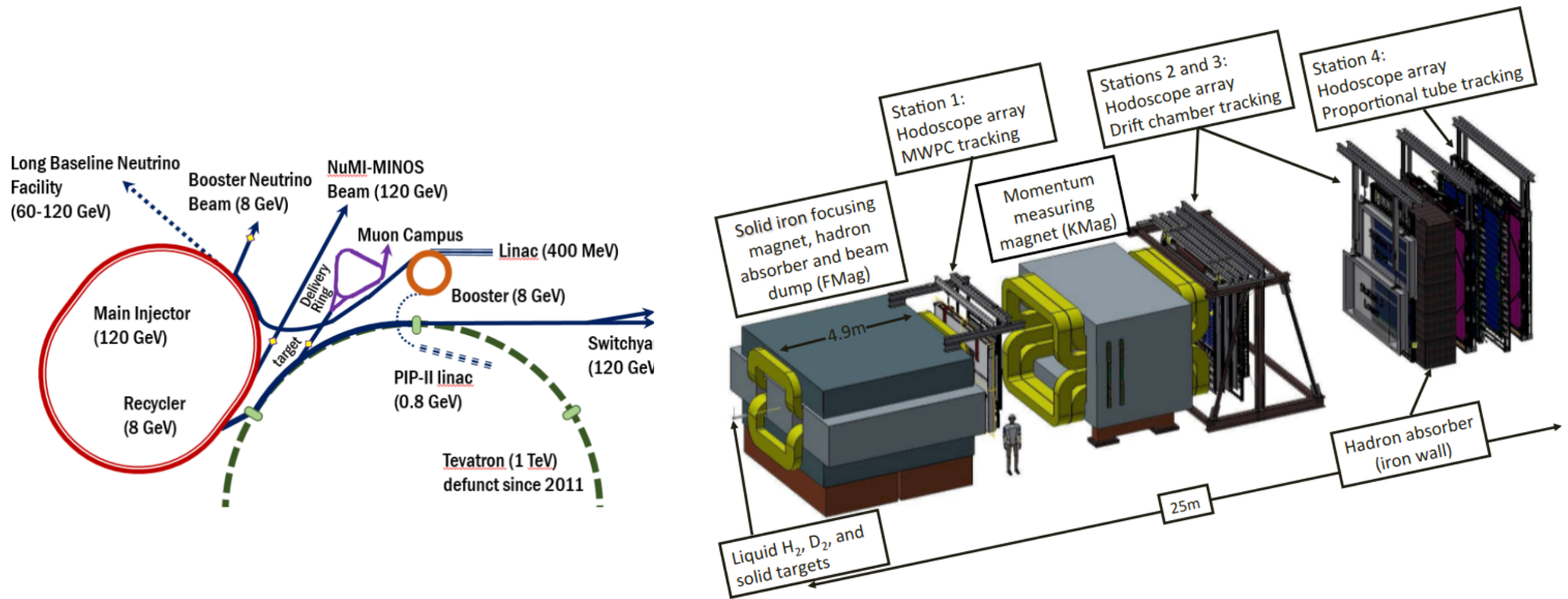
## Theorists:

- FNAL: Nikita Blinov, Yu-Dai Tsai
- NYU: Asher Berlin
- Pitt: Brian Batell, Mudit Rai
- UCSC: Stefania Gori

- Strong team of both Experimentalists and Theorists
- Regular meetings for more than a year
- Establishing strong connection with current SpinQuest collaboration
- **More welcome to join the effort!**

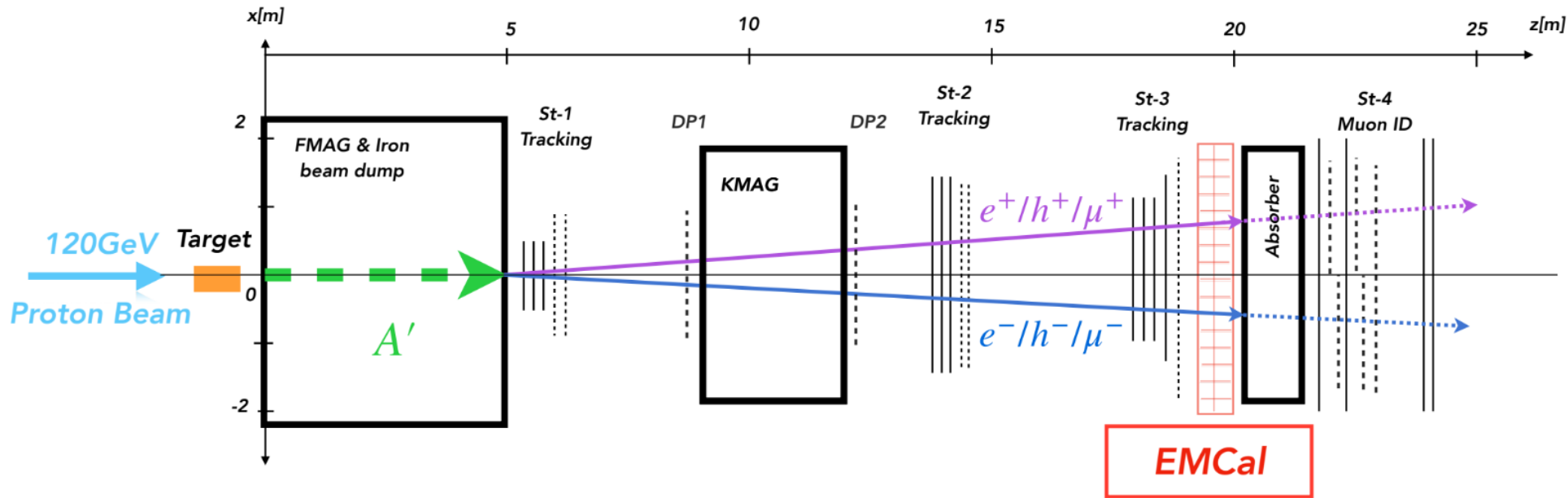


# SpinQuest Experiment



- Uses 120 GeV high-intensity proton beam from the Fermilab Accelerator Complex  
→ Expect  $1e18$  POT in a 2 year parasitic run, and  $1e20$  POT after the upgrade
- Spectrometer has 5m thick Fmag (1.8T) as the beam dump and absorber, hollow KMag (0.4T) for tracking, and 4 stations of drift chambers (tracking) and scintillator hodoscopes (triggering)
- Specialized liquid and solid targets to measure the Drell-Yan process for studying the Transverse Momentum Dependent PDFs inside the proton

# DarkQuest Concept



- DarkQuest upgrades the spectrometer with one Electromagnetic calorimeter (EMCal) sector (Pb-scintillator from PHENIX Experiment, 2mx4m)
  - Identify and trigger on electrons, photons, and hadrons; reject muon background
- Opens possibility to search for wide range of dark sector particles

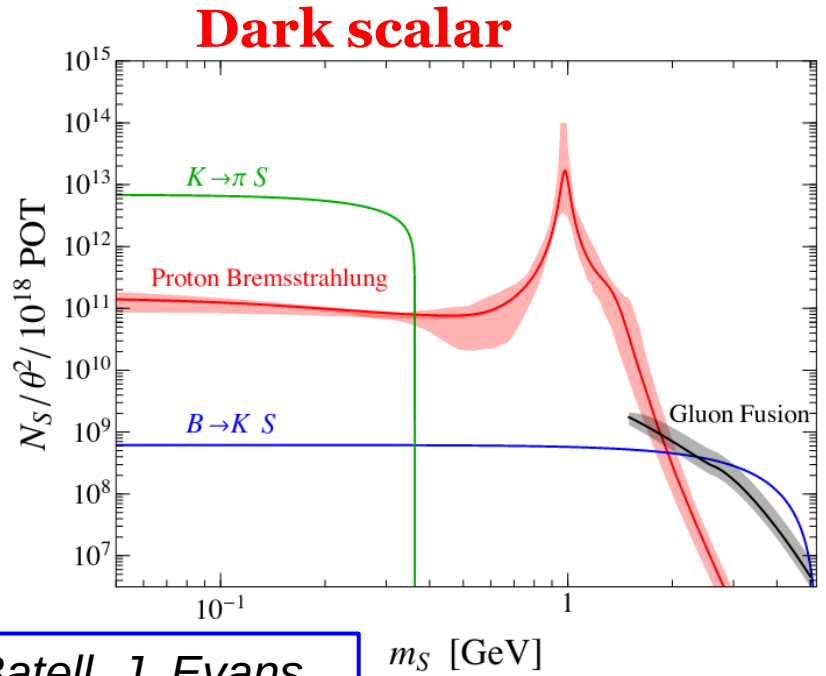
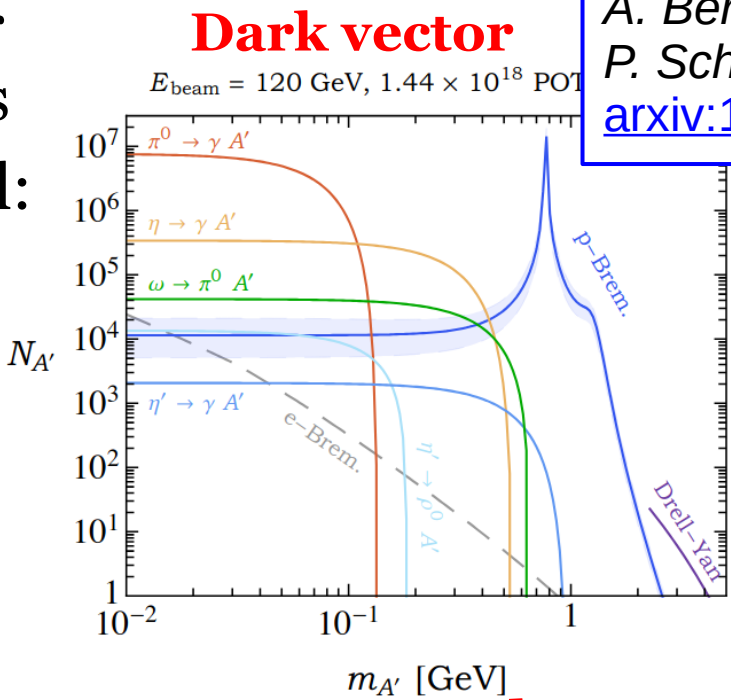




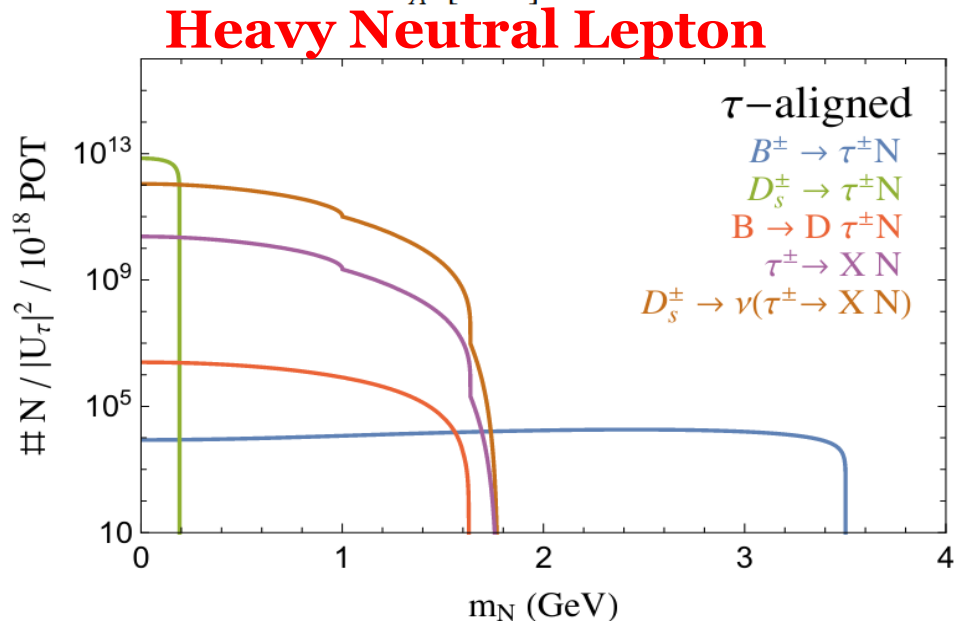
# Dark Sector Particle Production

- Copious production of dark sector particles in variety of BSM models
- Mechanism depends on the model:
  - Proton bremsstrahlung, meson decay, tau decay

A. Berlin, S. Gori,  
P. Schuster, N. Toro  
[arxiv:1804.00661](https://arxiv.org/abs/1804.00661)



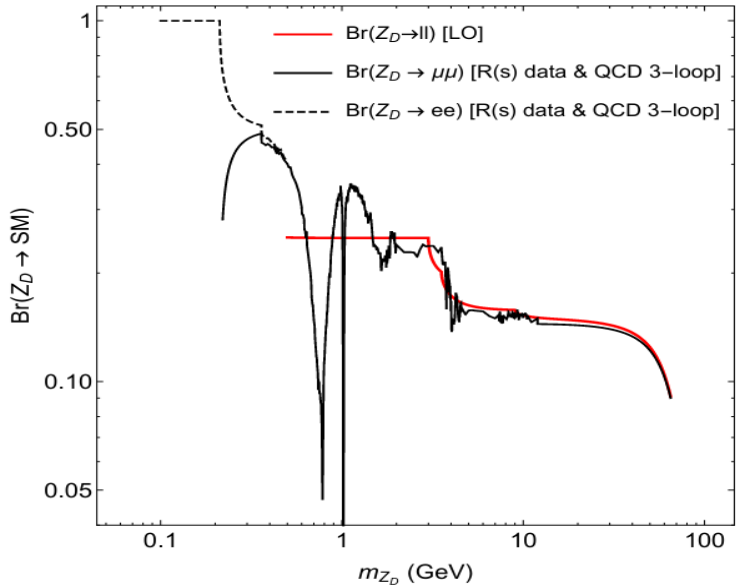
B. Batell, J. Evans,  
S. Gori, M. Rai  
[arxiv:2008.08108](https://arxiv.org/abs/2008.08108)



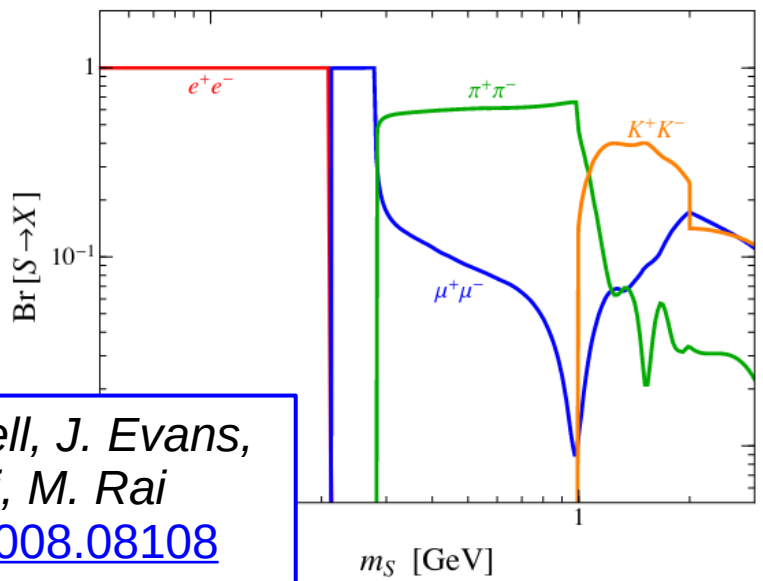
# Dark Sector Particle Decays

- Wide variety of possible decay modes, often involving electrons or charged hadrons
- Long-lived neutral Kaon decays, e.g.  $K_L^0 \rightarrow \pi^\pm e^\mp \nu$ , are important backgrounds that can be suppressed with the EMcal

## Dark vector

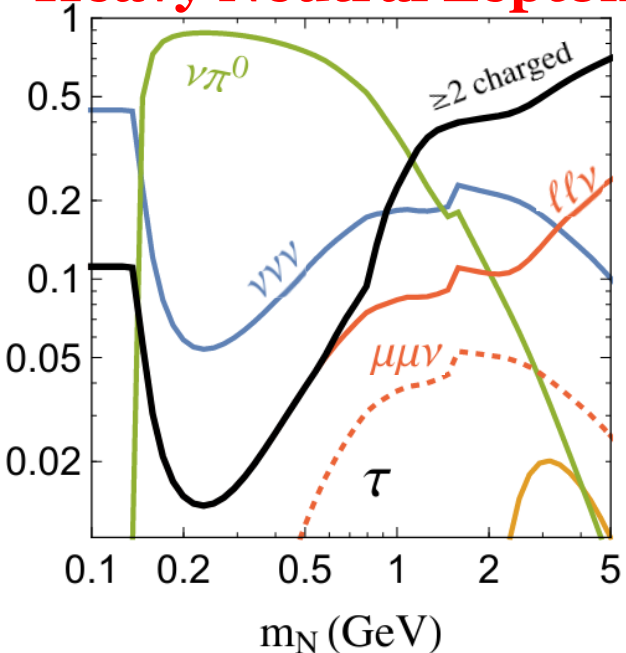


## Dark scalar



B. Batell, J. Evans,  
S. Gori, M. Rai  
[arxiv:2008.08108](https://arxiv.org/abs/2008.08108)

## Heavy Neutral Lepton

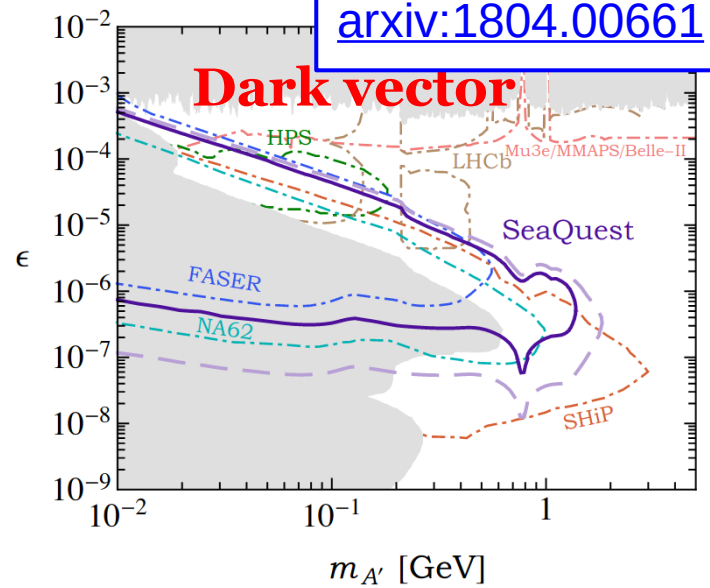




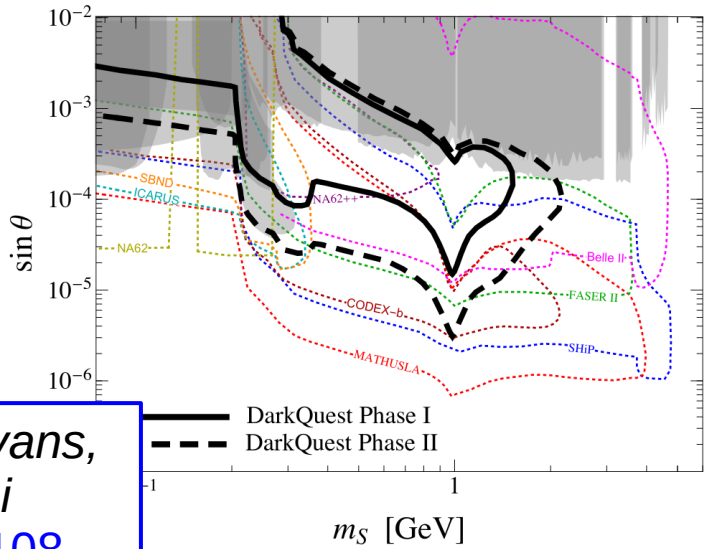
# Dark Sector Sensitivity Projections

- Comparable or better limits compared to other experiments for low cost (~\$500k) and short time scale (start ~2023)
- Estimated bounds for different intensity scenarios and decay regions:
  - 5m–6m: After FMAG and before station 1.
  - 5m–9m: After FMAG and before KMAG.
  - 5m–12m: After FMAG and before the end of KMAG

A. Berlin, S. Gori,  
P. Schuster, N. Toro  
[arxiv:1804.00661](https://arxiv.org/abs/1804.00661)

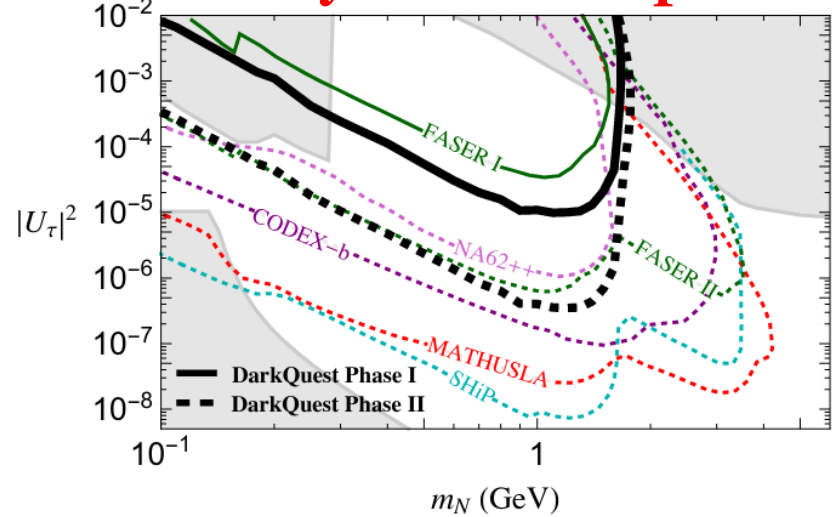


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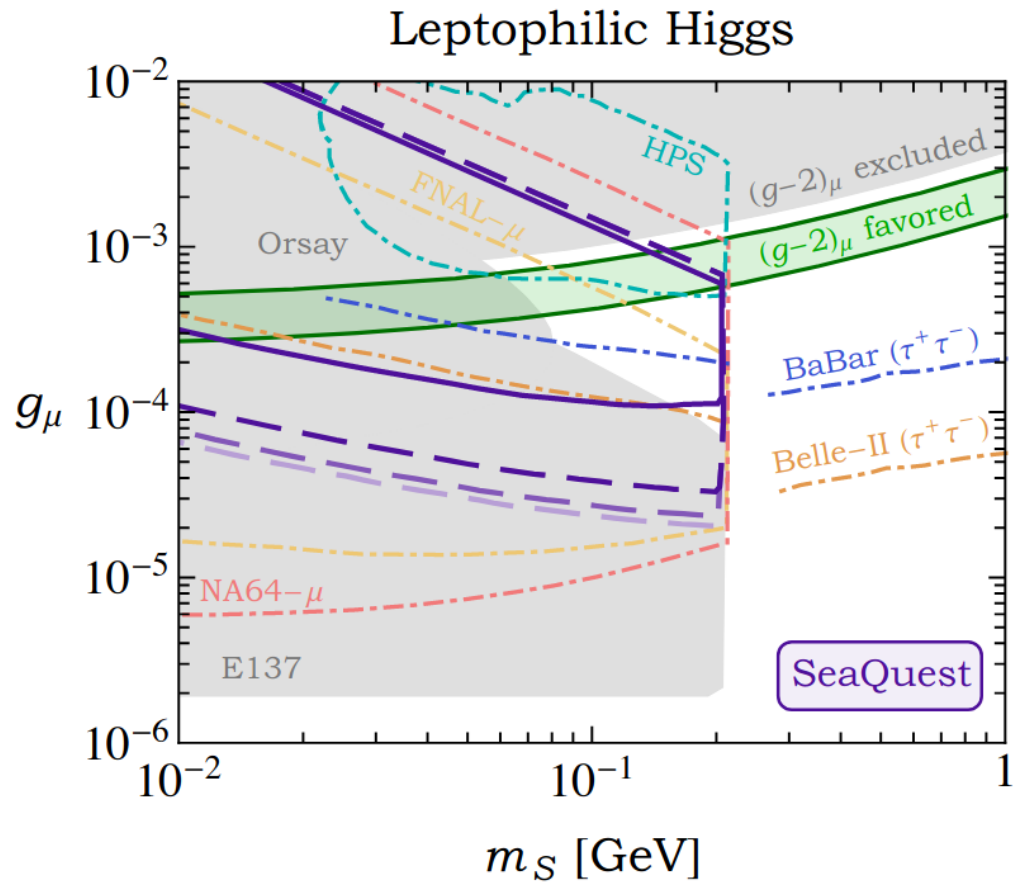
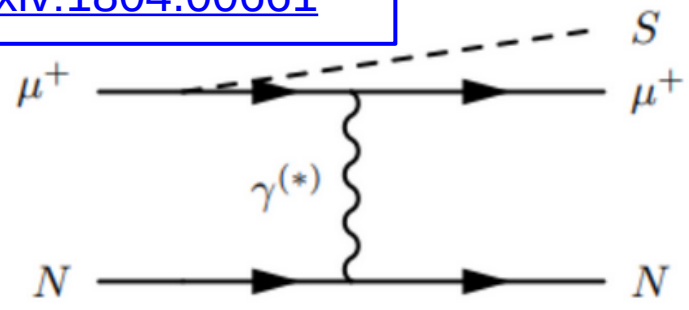
# Leptophilic Scalars

A. Berlin, S. Gori,  
 P. Schuster, N. Toro  
[arxiv:1804.00661](https://arxiv.org/abs/1804.00661)

- Large secondary production of muons from pion/Kaon decays makes DarkQuest also a muon beam dump experiment
- One model which can resolve  $(g-2)_\mu$  is a leptophilic scalar

$$-\mathcal{L} \supset g_\mu \sum_{\ell=e,\mu,\tau} \frac{m_\ell}{m_\mu} S \bar{\ell} \ell$$

- For  $m_S < 2m_\mu$ , dominant decay mode is  $e^+e^-$ , and decay is displaced  
 →  $BR(S \rightarrow \gamma\gamma)$  typically  $< 10\%$
- DarkQuest can cover most of the parameter space below  $2m_\mu$





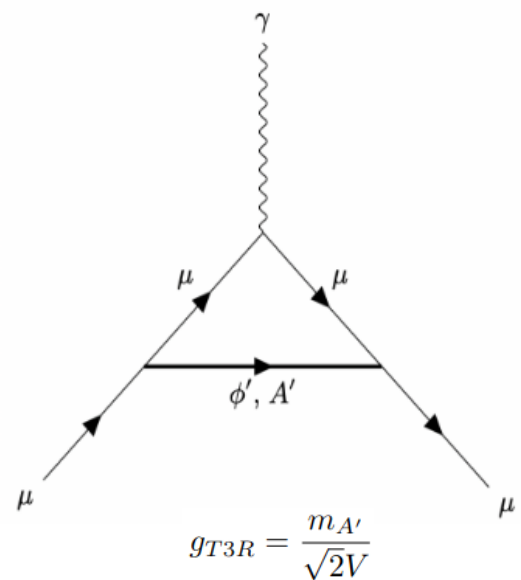
# Explaining $(g-2)_\mu$ and $R_K$

B. Dutta, S. Ghosh,  
P. Huang, J. Kumar  
[arxiv:2105.07655](https://arxiv.org/abs/2105.07655)

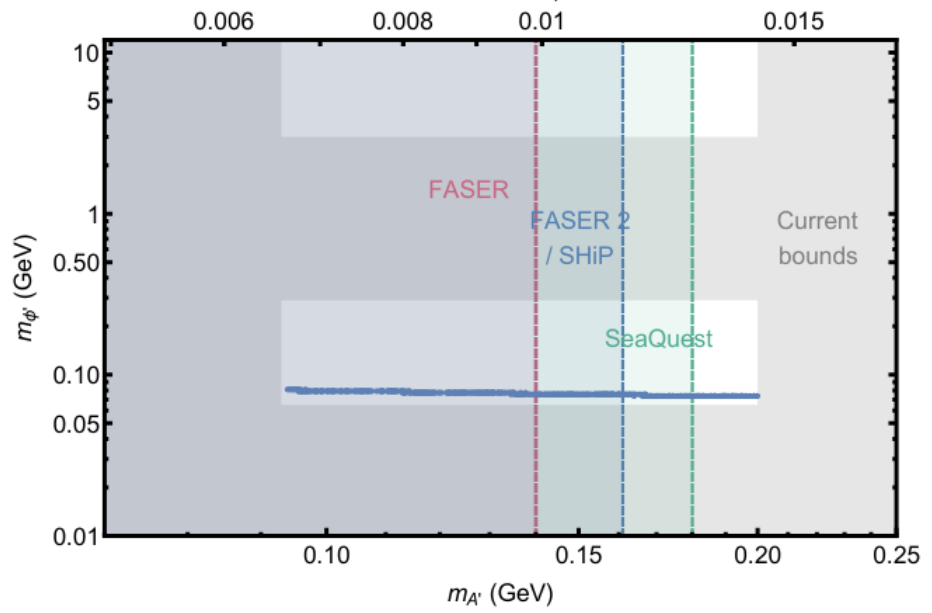
- New gauge group  $U(1)_{T_{3R}}$  that couples to right-handed  $\mu, \nu, u$  and  $d$
- Symmetry broken by a dark Higgs, both particles contribute to  $(g-2)_\mu$  and their contributions largely cancel
- Dark photon decay to  $e^+e^-$  generated by one-loop kinetic mixing

$$\epsilon \sim (m_{A'}/\sqrt{2}V) \sqrt{\alpha_{em}/4\pi^3}$$

- A narrow region exists that can explain both anomalies and can also be uniquely probed by DarkQuest (advantage from shorter baseline)

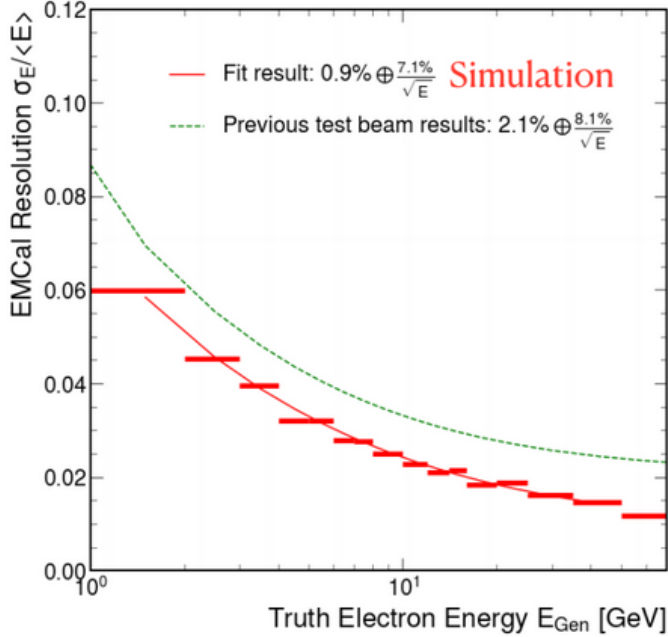
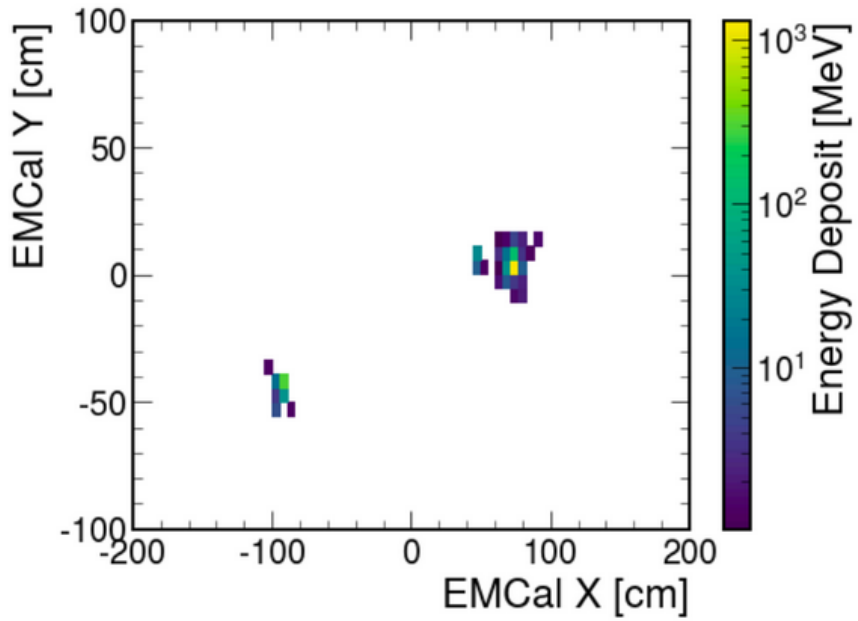
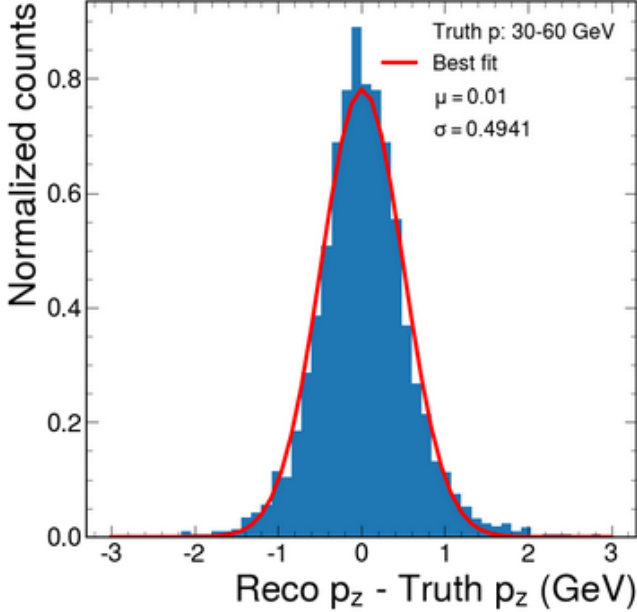


$$g_{T_{3R}} = \frac{m_{A'}}{\sqrt{2}V}$$



# Ongoing Simulation/Software Studies

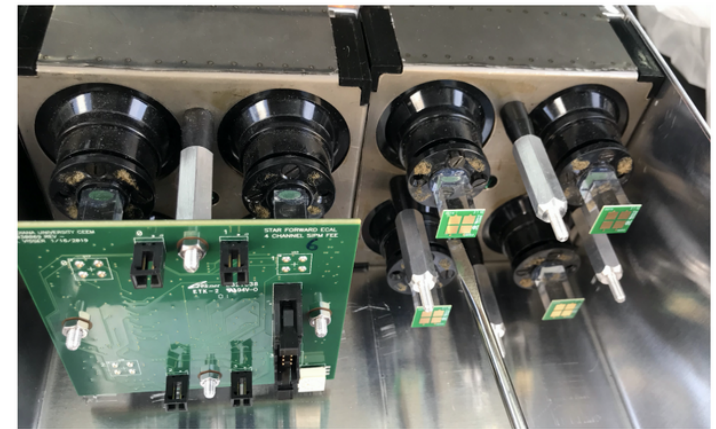
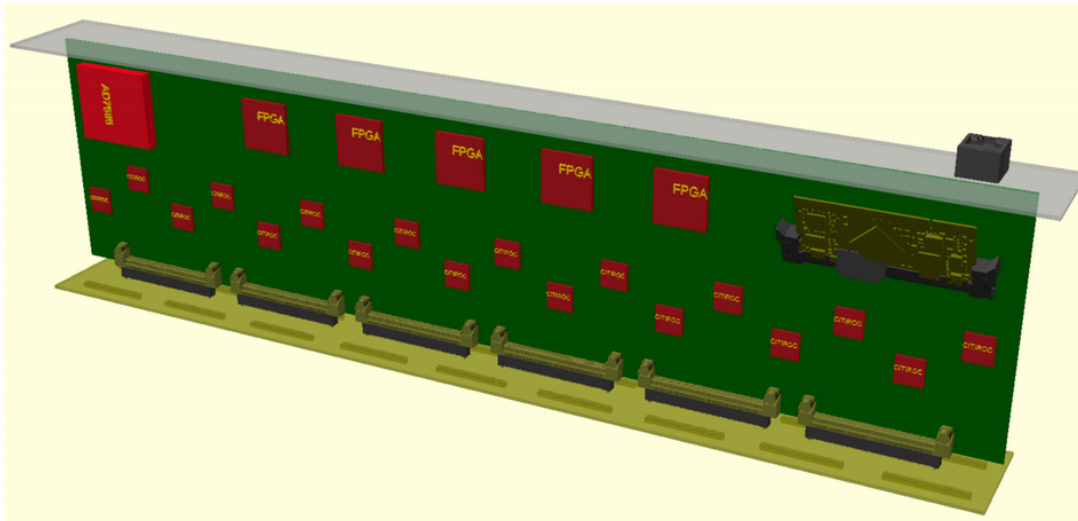
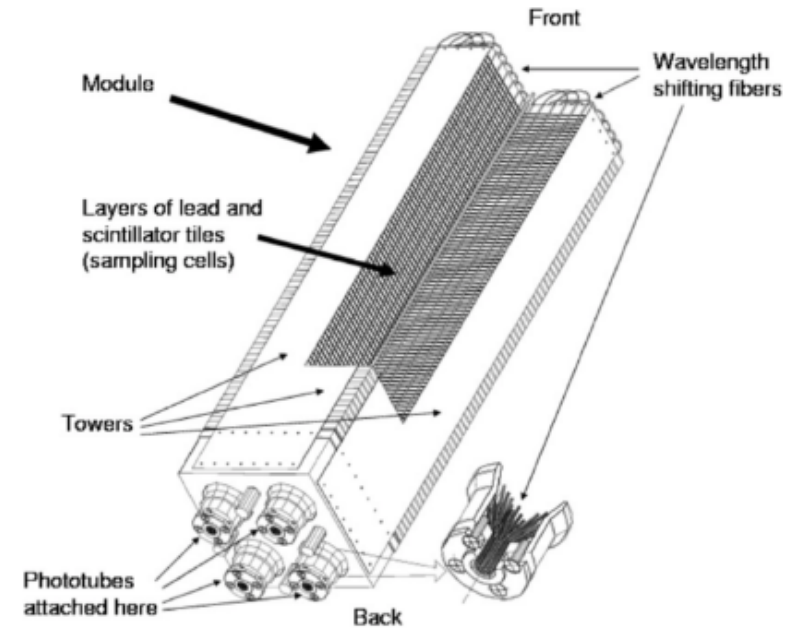
- Commissioning displaced tracking using full SpinQuest simulation and reconstruction framework
  - First step for a dimuon search
- Integrating EMCal in to detector simulation, validating performance and developing reconstruction





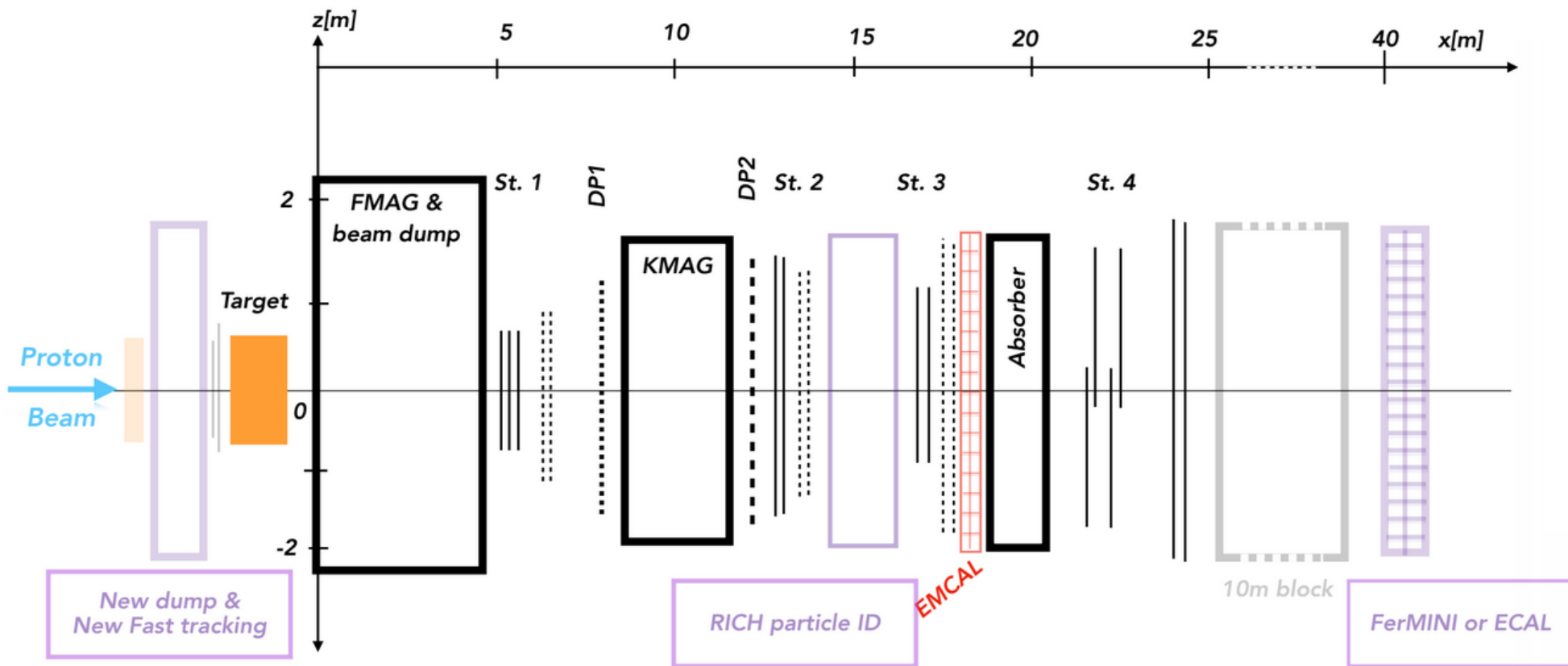
# Ongoing Hardware Studies

- PHENIX EMCAL PMTs to be replaced with new SiPMs
- Engineering discussions started on how to most quickly and efficiently develop new readout electronics
  - Could make use of existing designs, e.g. the one being developed at BU for EMPHATIC



# LongQuest

Y. Tsai, P. deNiverville, M. Liu  
[arxiv:1908.07525](https://arxiv.org/abs/1908.07525)



- Possible further upgrades of DarkQuest: “LongQuest” to further extend coverage and sensitivity
- Adding PID detector, new dump and fast tracking, and /or second ECAL,

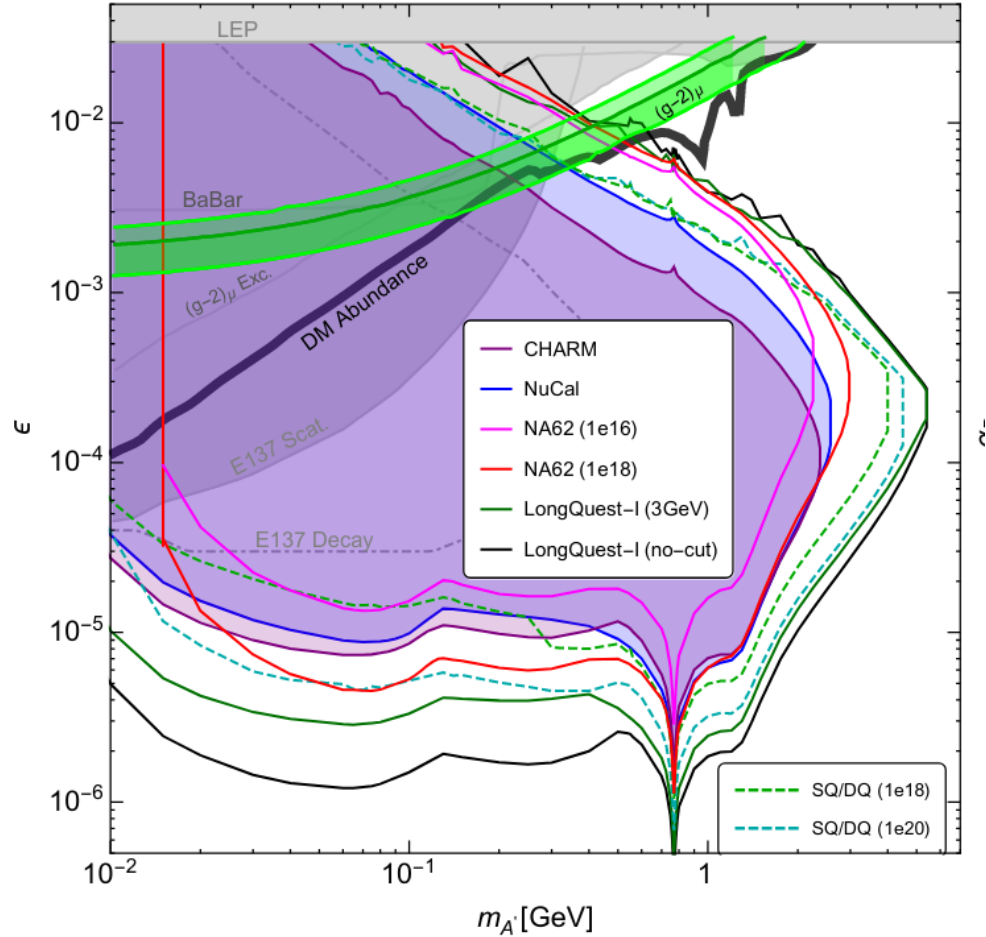


# IDM for $(g-2)_\mu$ with LongQuest

- Inelastic Dark Matter models can accommodate  $(g-2)_\mu$  and DM relic abundance
- Evades existing constraints due to a semi-visible decay

$$A' \rightarrow \chi_2 \chi_1 \rightarrow e^+ e^- \chi_1 \chi_1$$

- Kick from Kmag lowers acceptance in  $(g-2)_\mu$  region, and  $K_L^0$  backgrounds concerning
  - RICH Detector to discriminate  $e^+/\pi^+$ ;
  - Turn off Kmag
- Results in competitive sensitivity compared to NA62



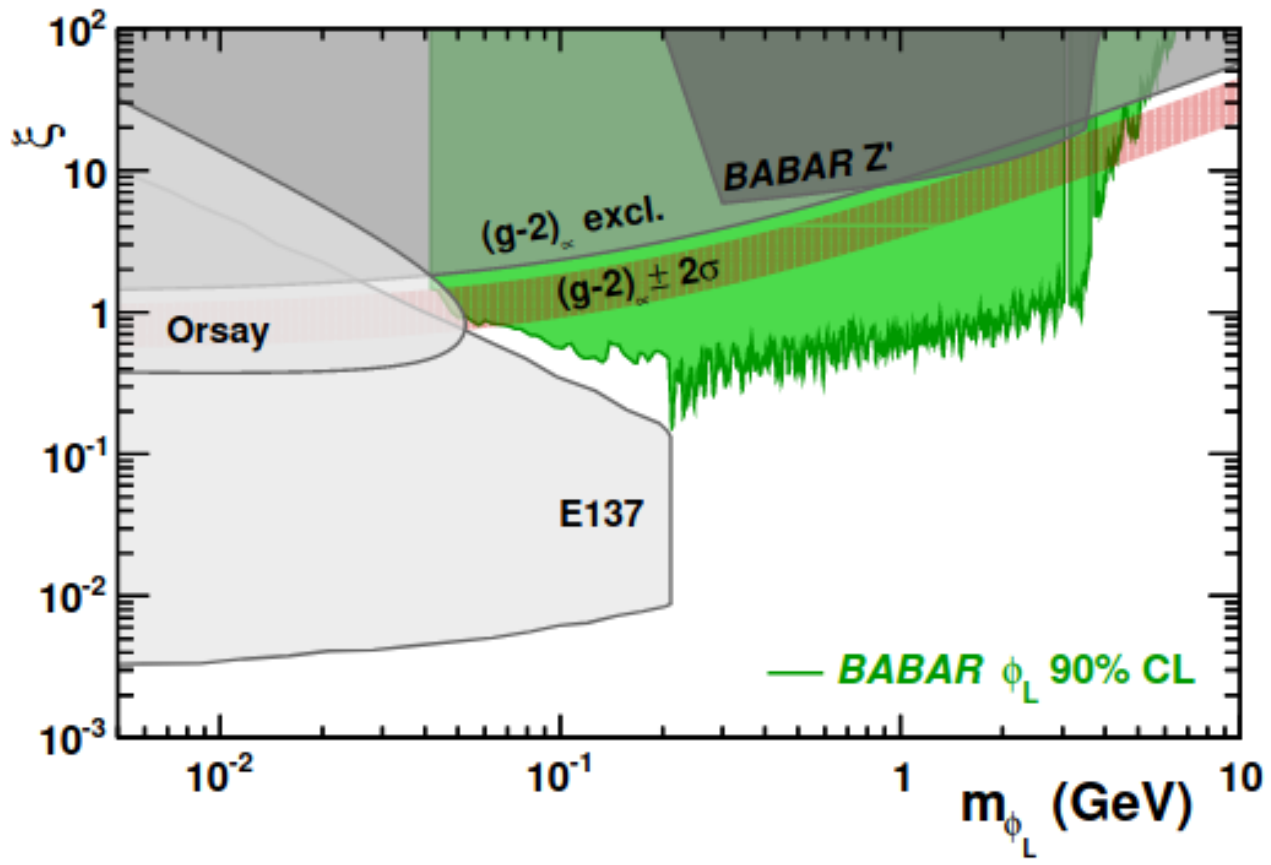
Y. Tsai, P. deNiverville, M. Liu  
[arxiv:1908.07525](https://arxiv.org/abs/1908.07525)

# Summary

- **DarkQuest is a low cost, short timescale proposal to probe a wide variety of Dark Sector scenarios**
  - Cost of EMCAL upgrade only ~\$500k
  - Planned timeline: SpinQuest run (2022) and DarkQuest aiming to start from Fall2023
- **DarkQuest can probe multiple scenarios that explain  $(g-2)_\mu$** 
  - Further upgrades (“LongQuest”) provide better sensitivity
- **A lot of activity ongoing to develop electronics design, detector simulation, particle reconstruction**
  - Stay Tuned!!!

# Backup

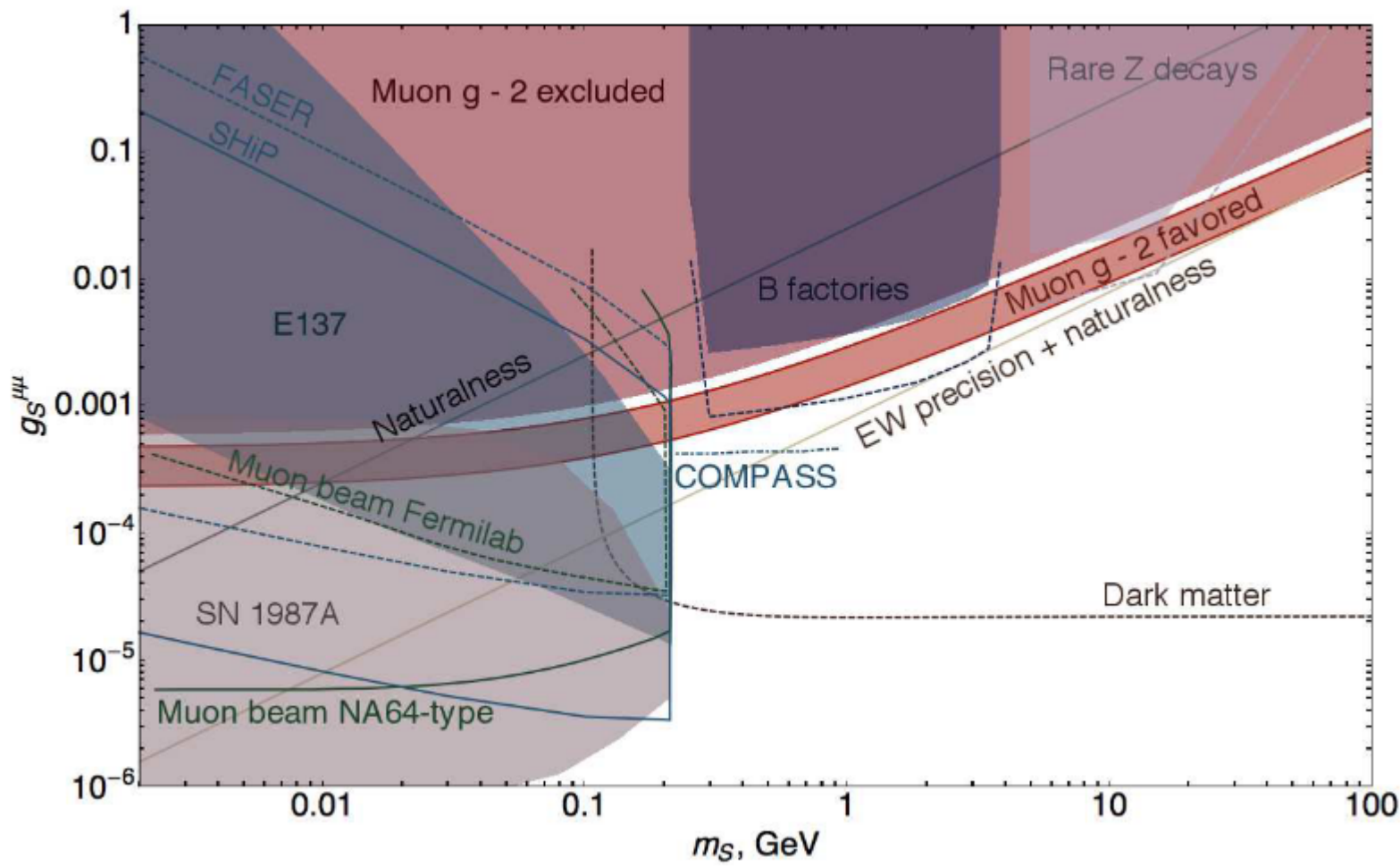
# Leptophilic Scalar constraints by BaBar



[arxiv:2005.01885](https://arxiv.org/abs/2005.01885)

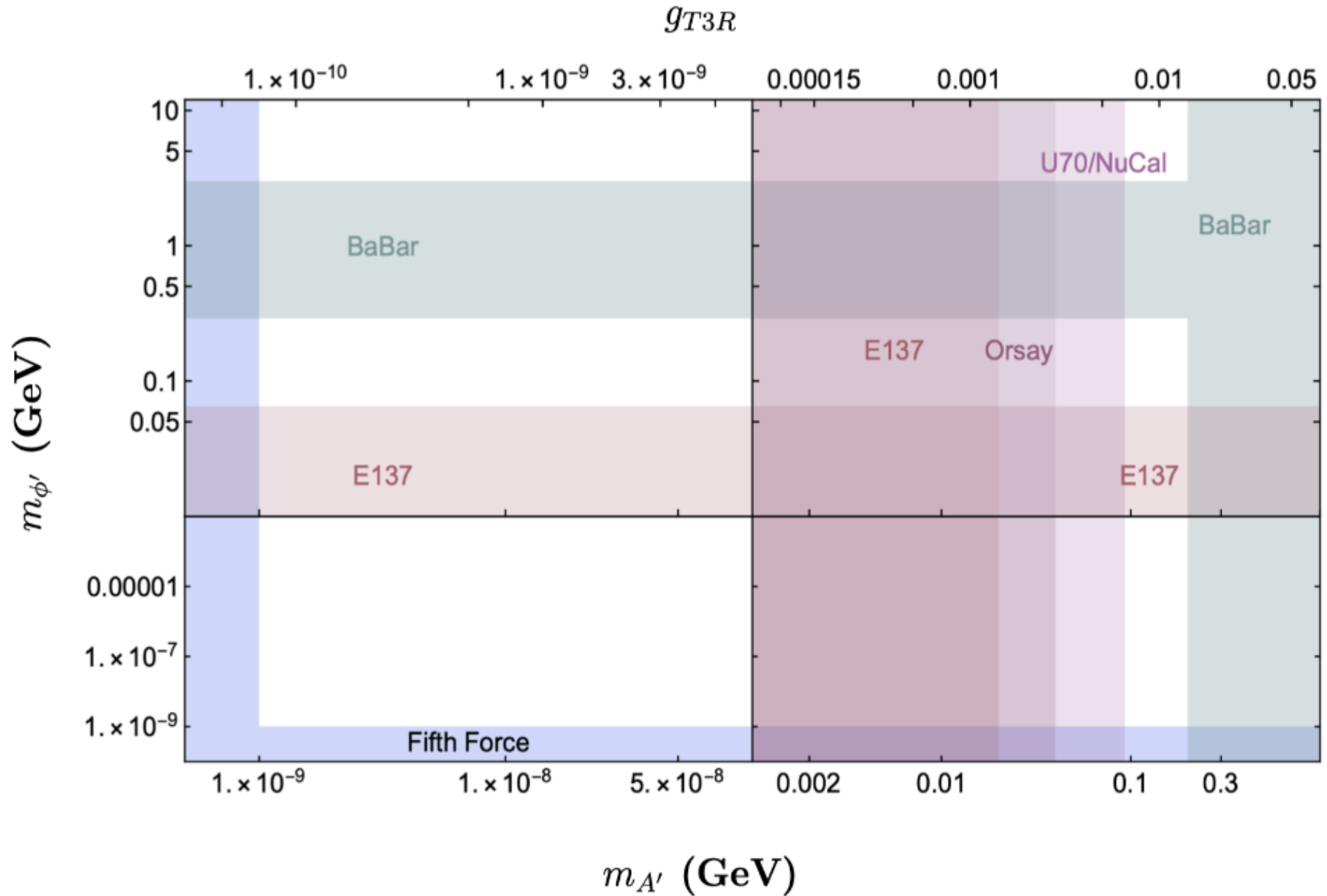


# Muon-philic Scalar constraints



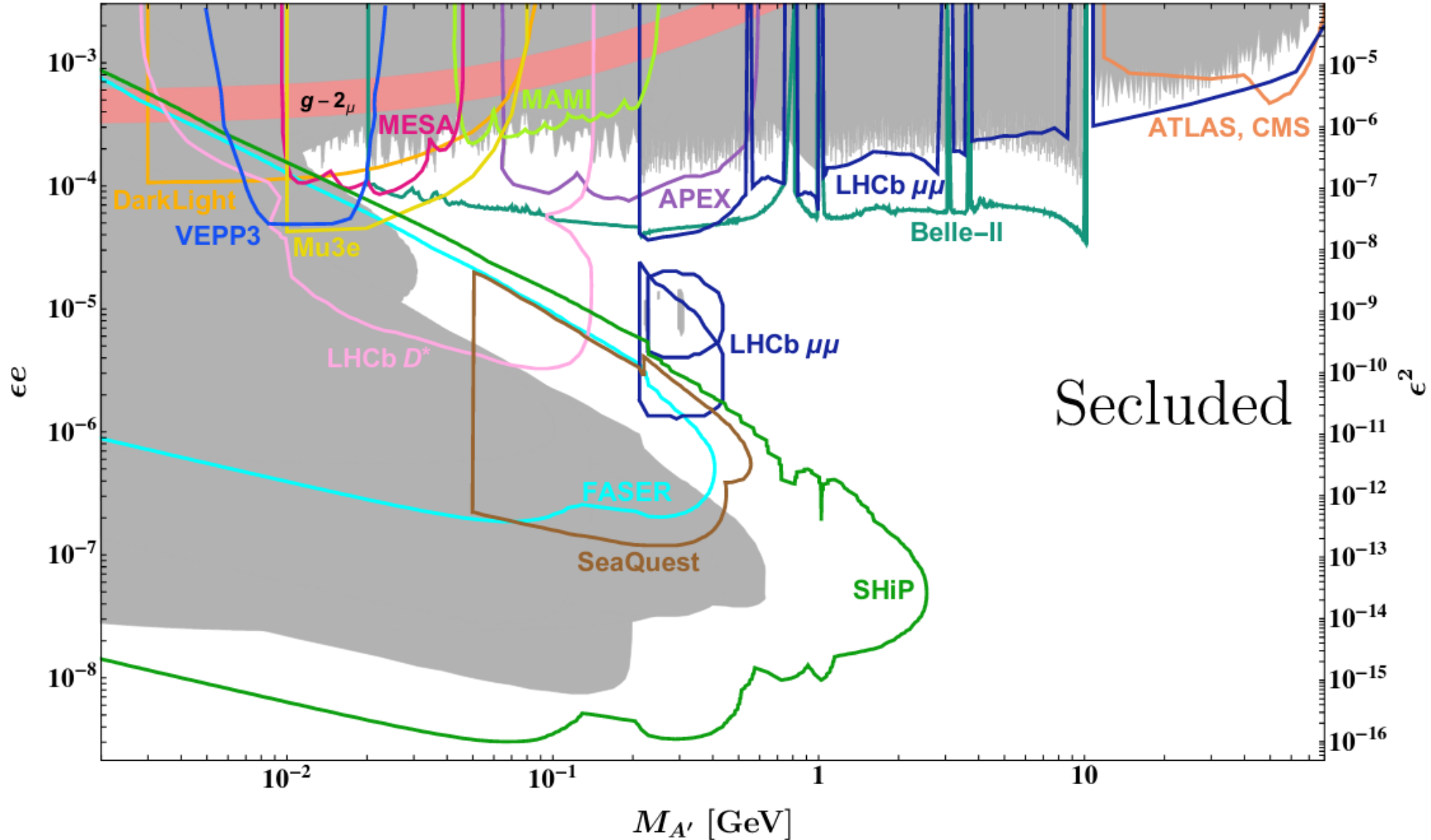
[arxiv:1712.10022](https://arxiv.org/abs/1712.10022)

# $U(1)_{T3R}$

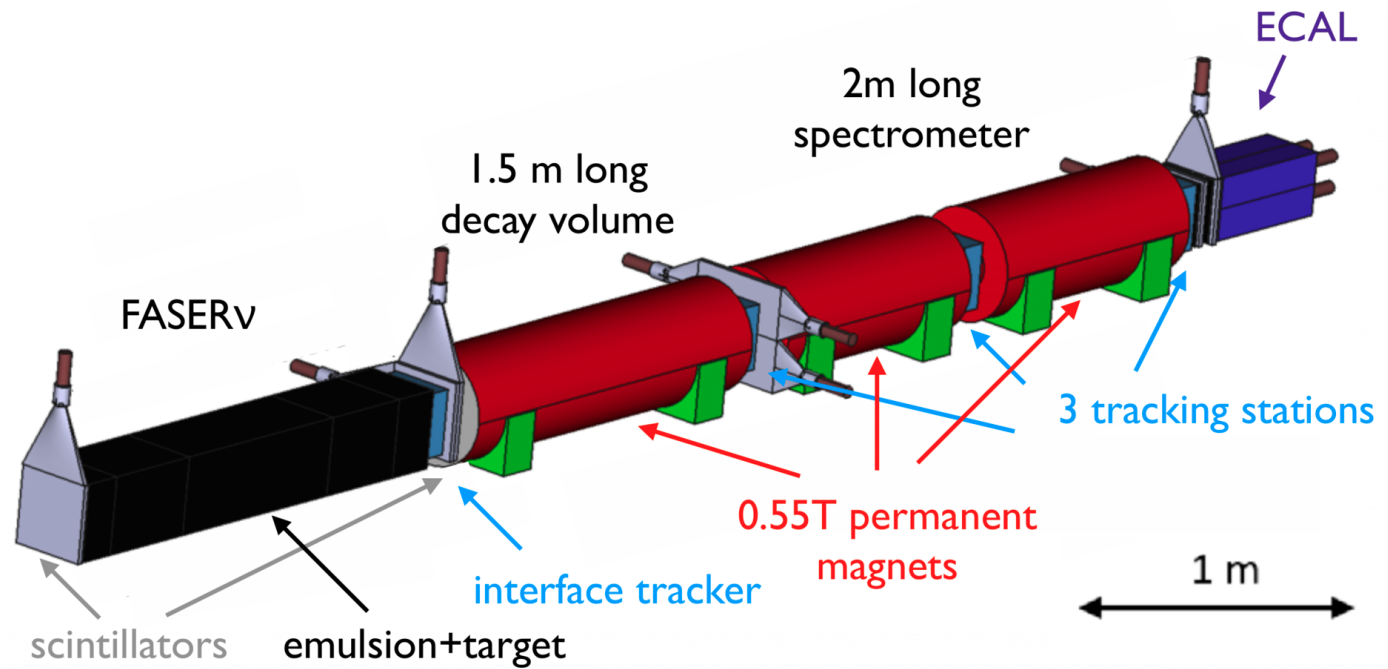
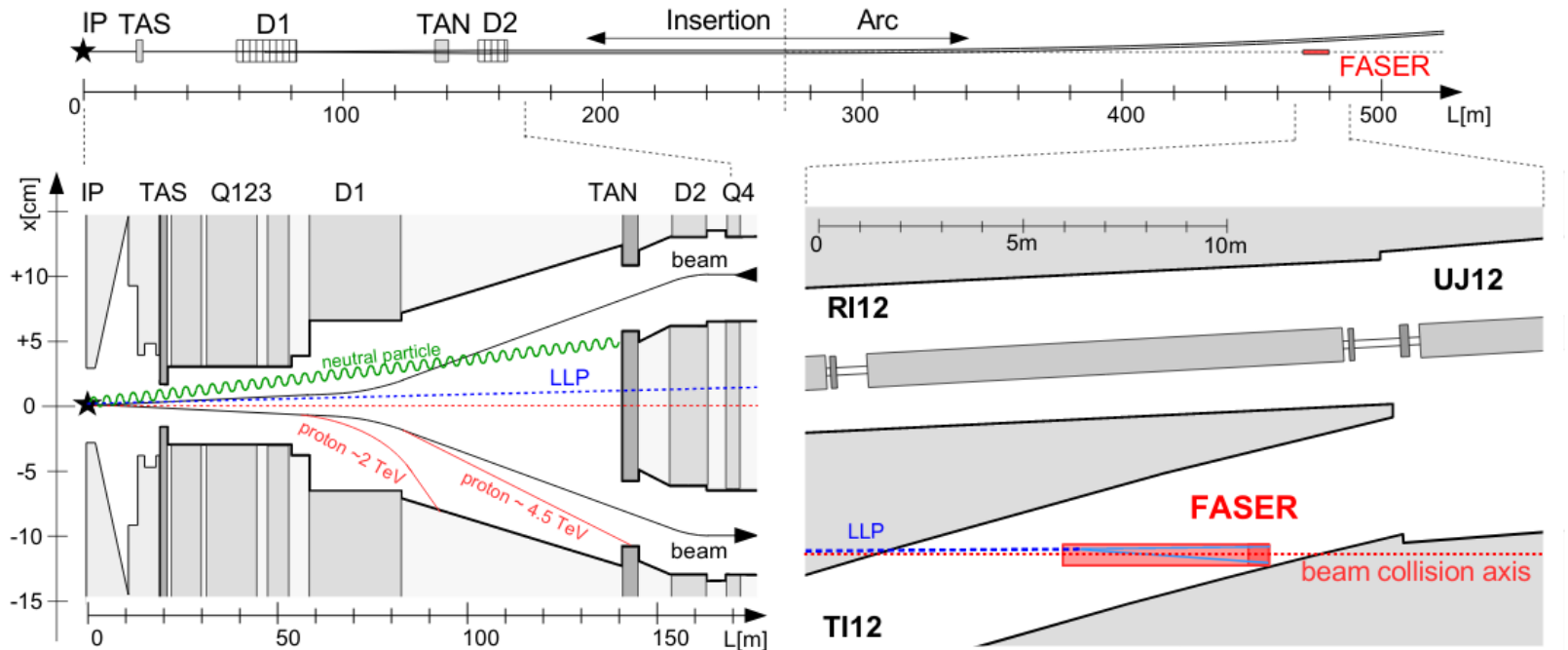


# Sensitivity Projections for Dark Photons

*Bauer, Foldenauer, Jaeckel [arxiv:1803.05466](https://arxiv.org/abs/1803.05466)*



# Faser





# SHIP

