

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

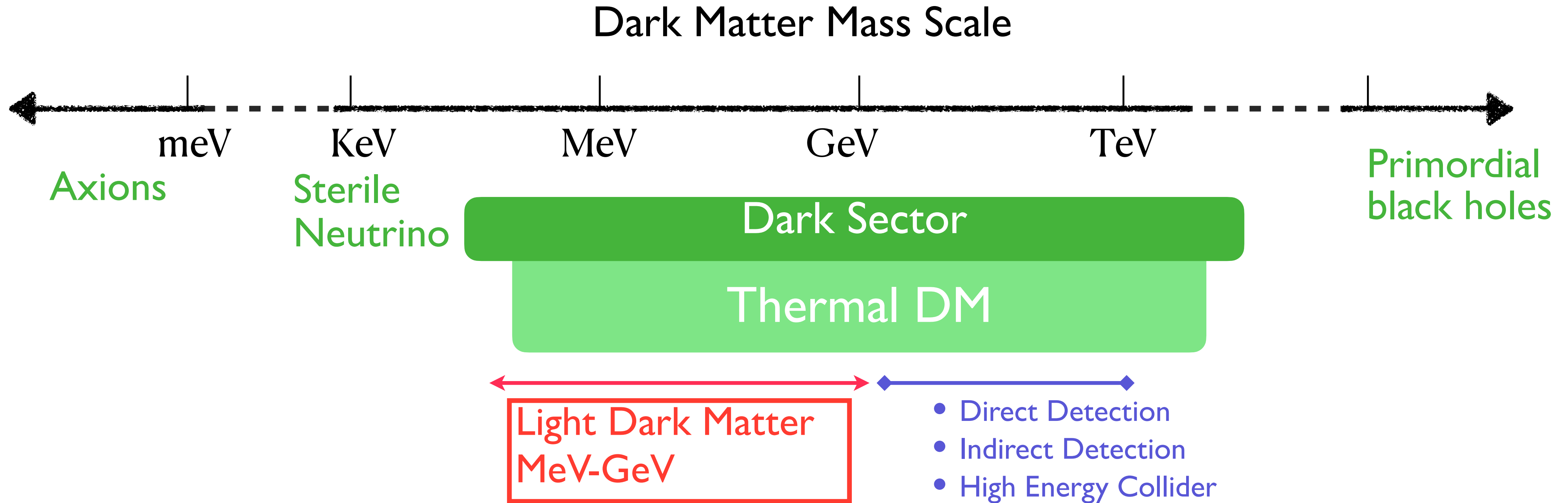
Yongbin Feng (Fermilab)

for the DarkQuest Team

PHENO 2022, Pittsburg, PA, USA

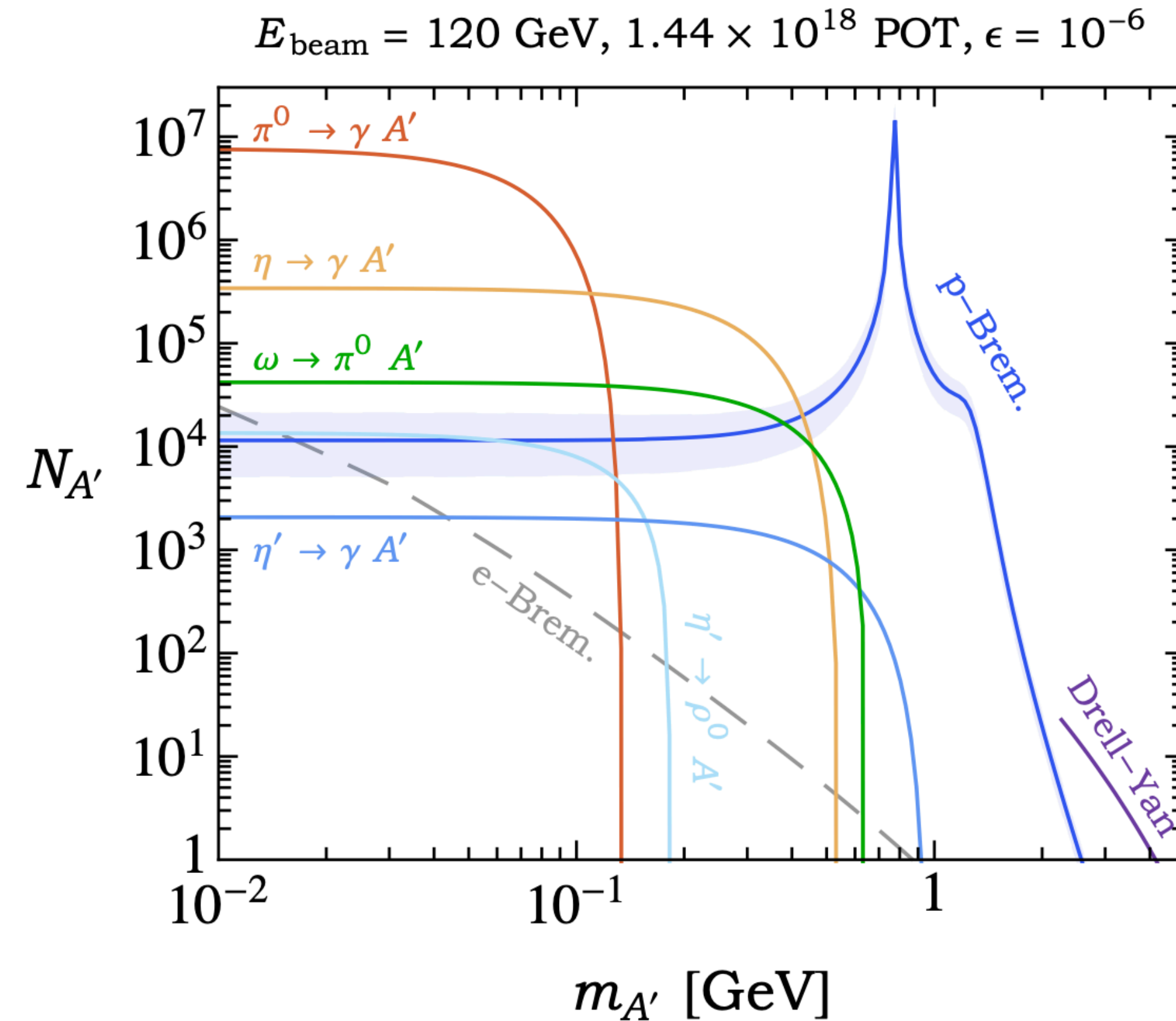
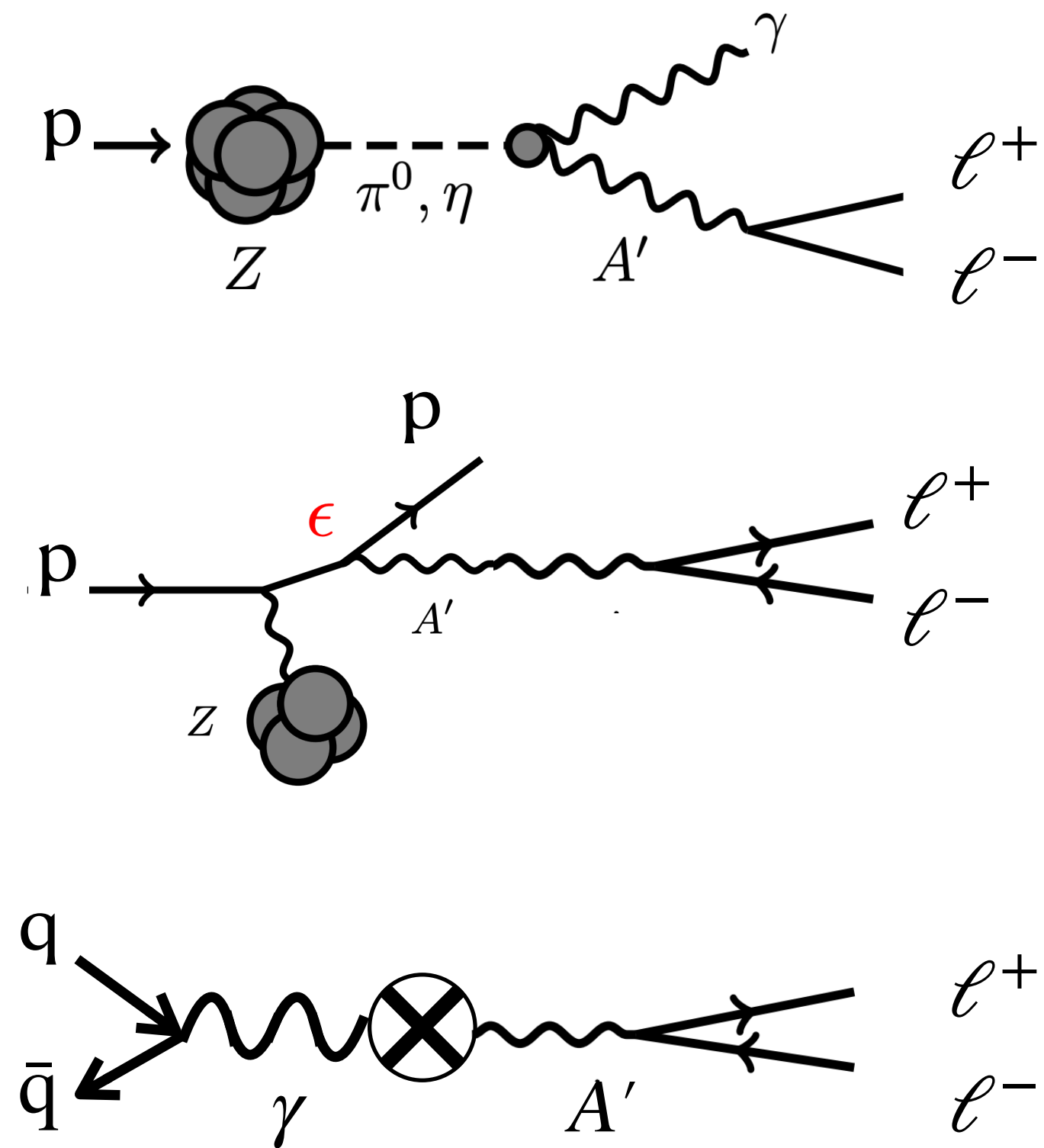
May 9th, 2022

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

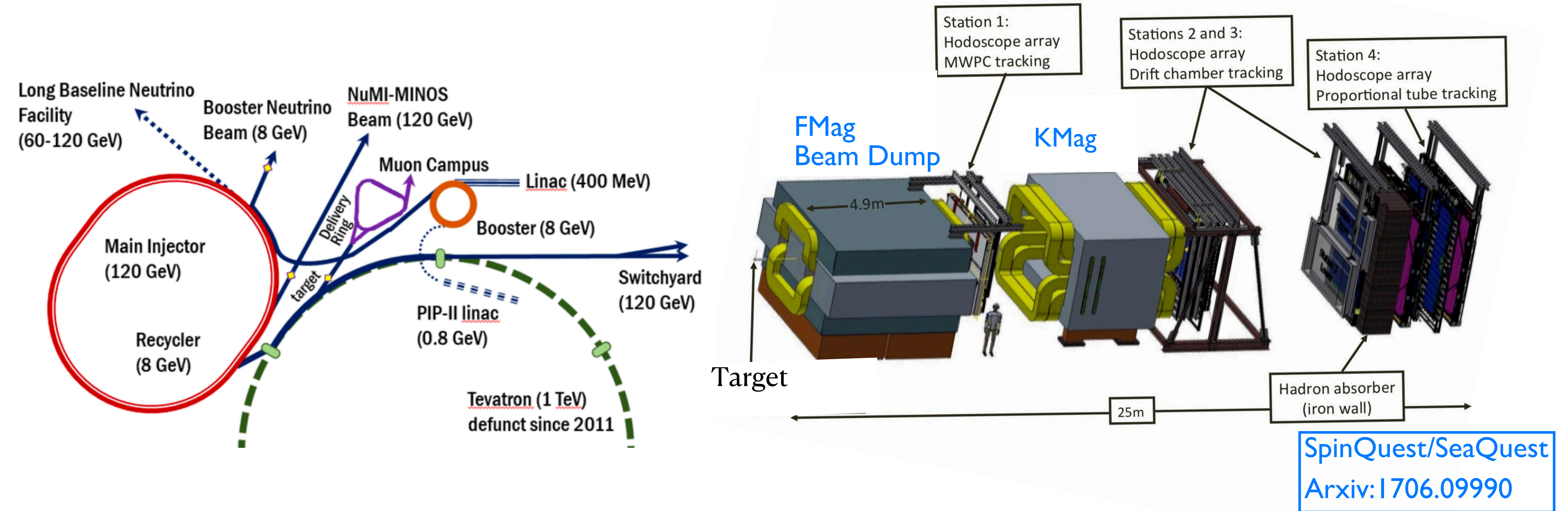
Signal Processes: Dark Photon Example



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

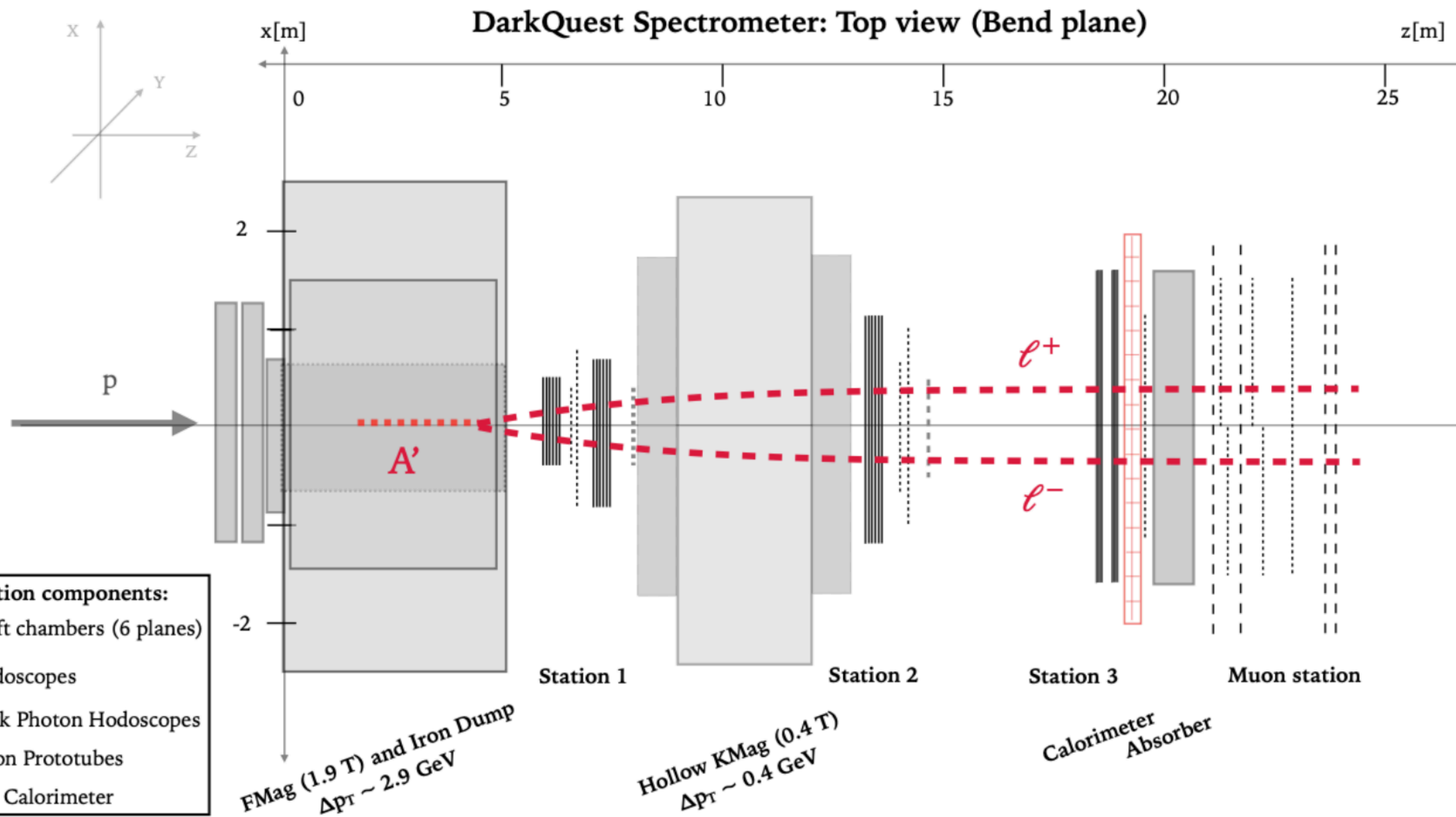
- For proton fixed-target beam dump experiment, three dominant signal production mechanisms: meson decay, proton bremsstrahlung, and Drell-Yan process
- Larger production rates with proton beams compared with electron beams

Experimental Setup: SpinQuest



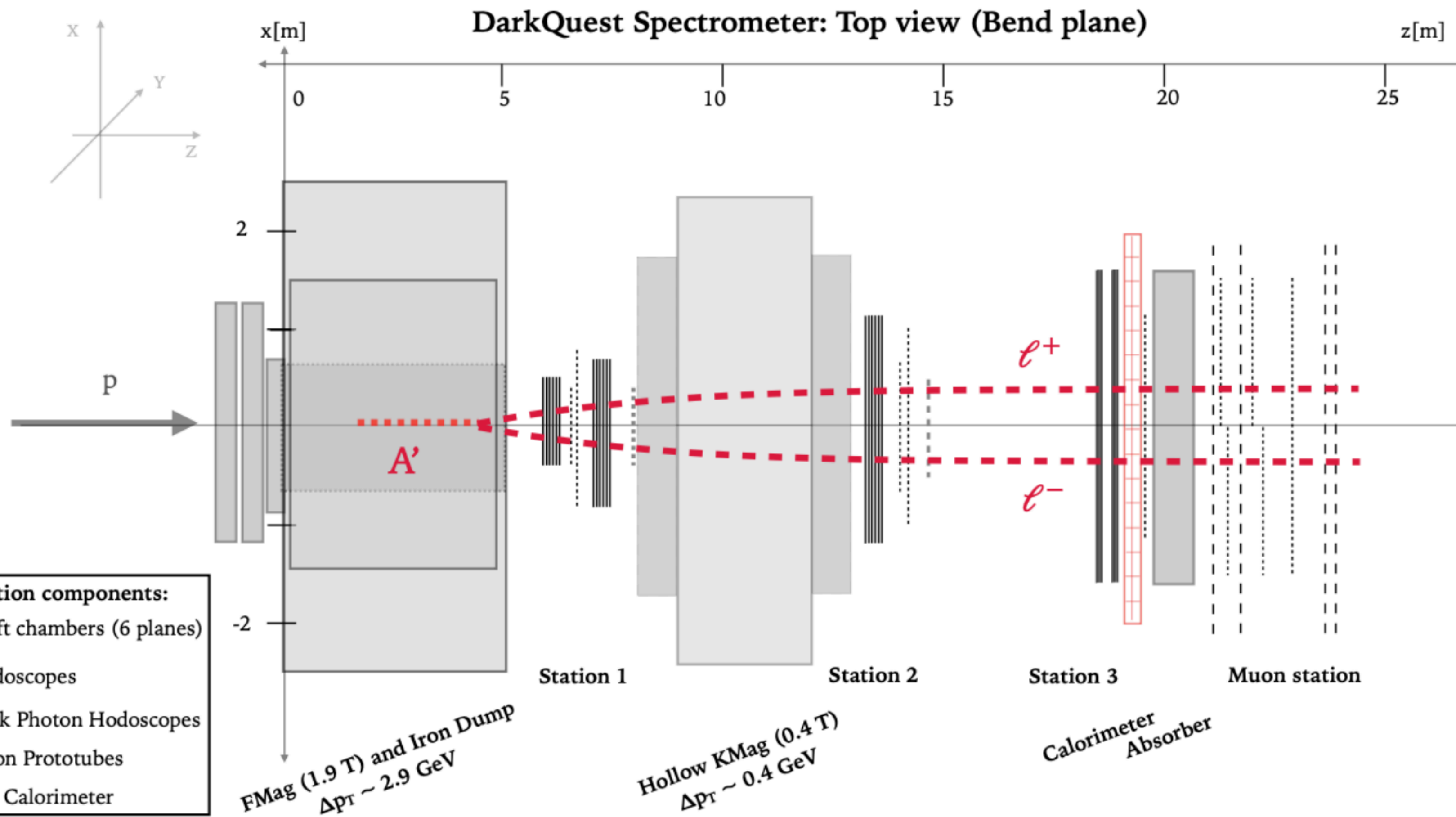
- 120 GeV high-intensity proton beam from the Fermilab Accelerator Complex
 - ❖ Expect 10^{18} Protons on target (POT) in a 2-year parasitic run, and 10^{20} POT after the PIP-II accelerator upgrade
- SpinQuest spectrometer 5m thick FMag as the beam dump and absorber; hollow KMag for tracking; and 4 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



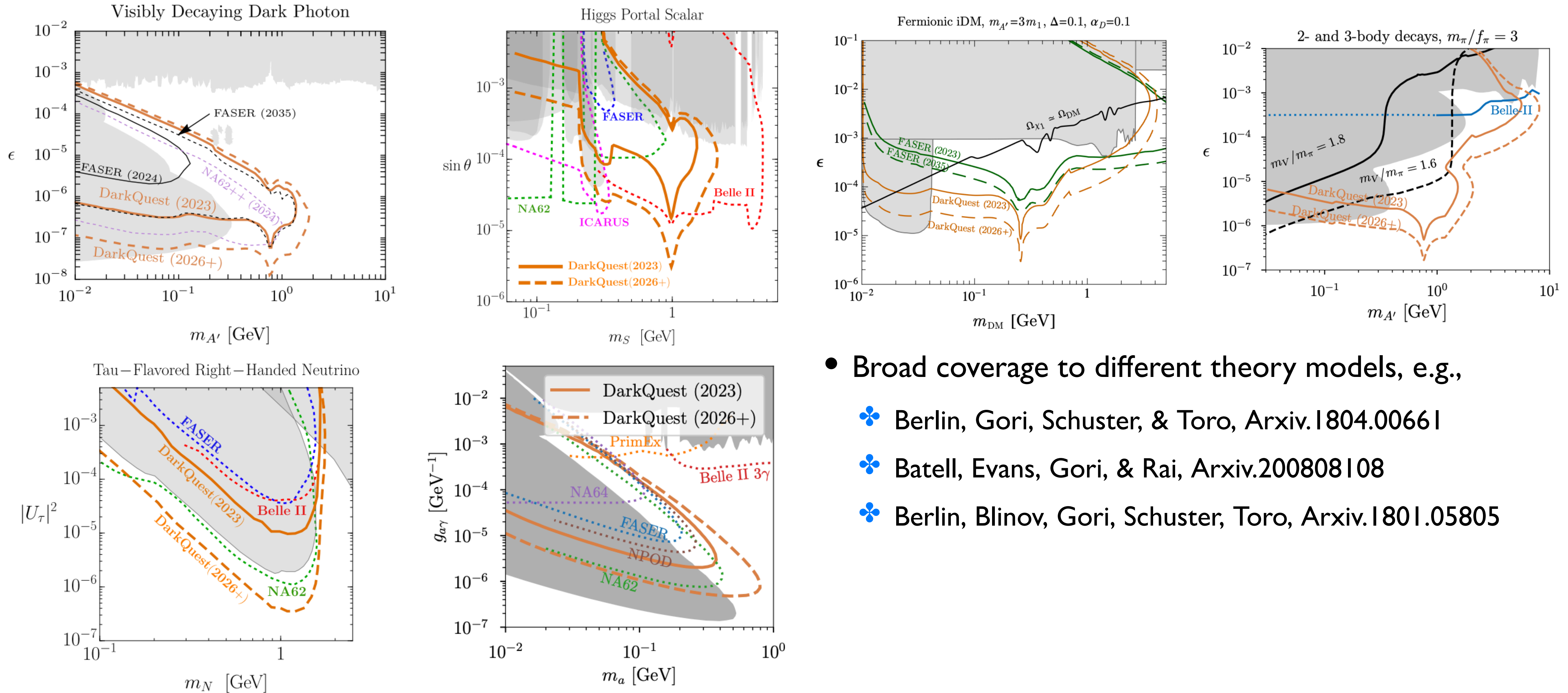
- Make full use of the existing SpinQuest spectrometer
- Upgrade with one Electromagnetic calorimeter (EMCal) sector (2mx4m, from PHENIX Experiment):
 - ✦ Provide access to electron and photon final states. Broaden the coverage to lower masses below $2m_\mu$
 - ✦ Provide more sensitivity by rejecting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

Why DarkQuest



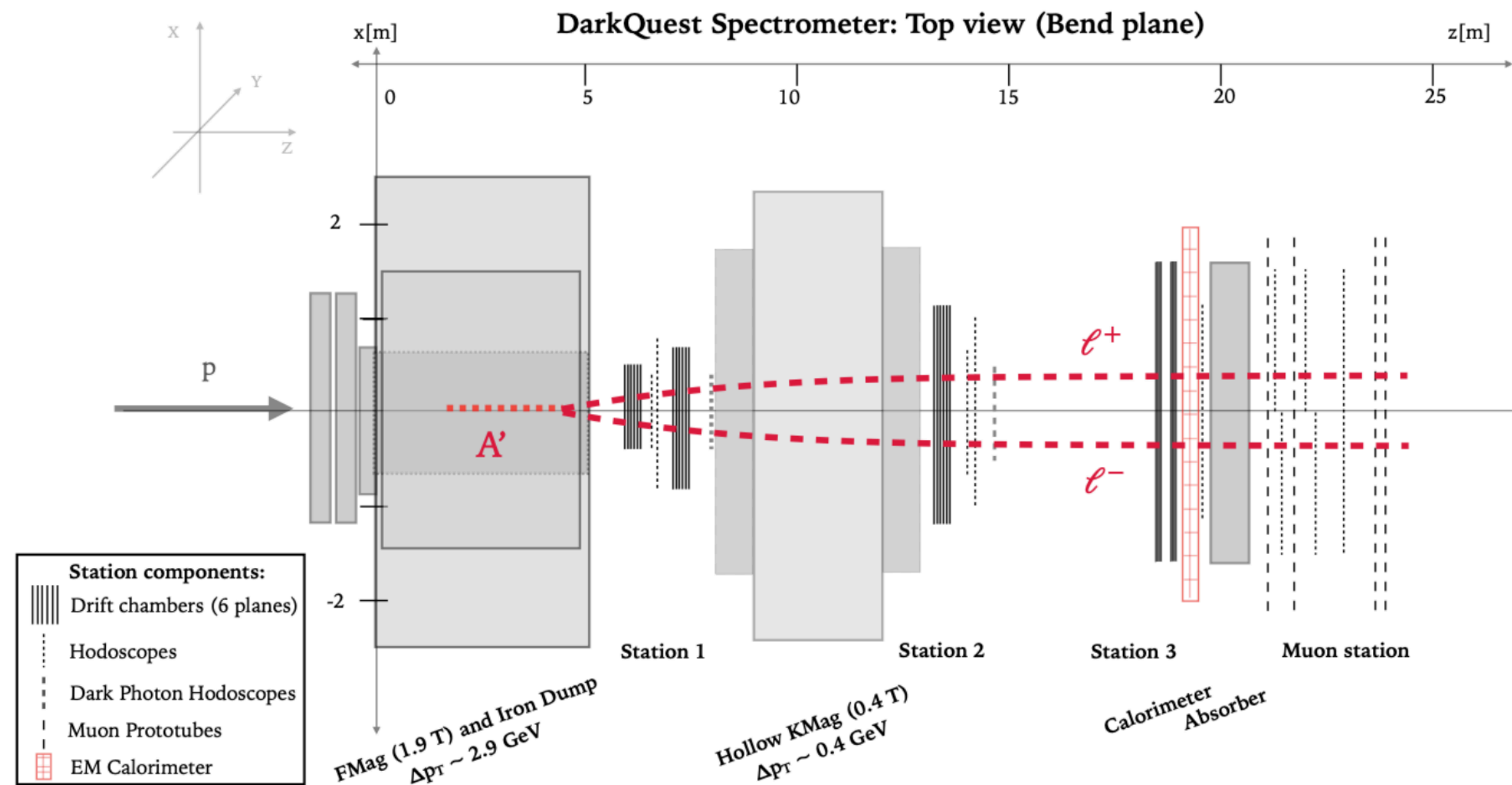
- Large dark sector production cross section with 120GeV high-intensity proton beam
- Compact geometry and relatively short displacement baseline ($\mathcal{O}(m)$) to cover unique and broad phase space:
 - ❖ KMag and 3-4 tracking layers provide good momentum measurement
 - ❖ Scintillator hodoscopes + 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

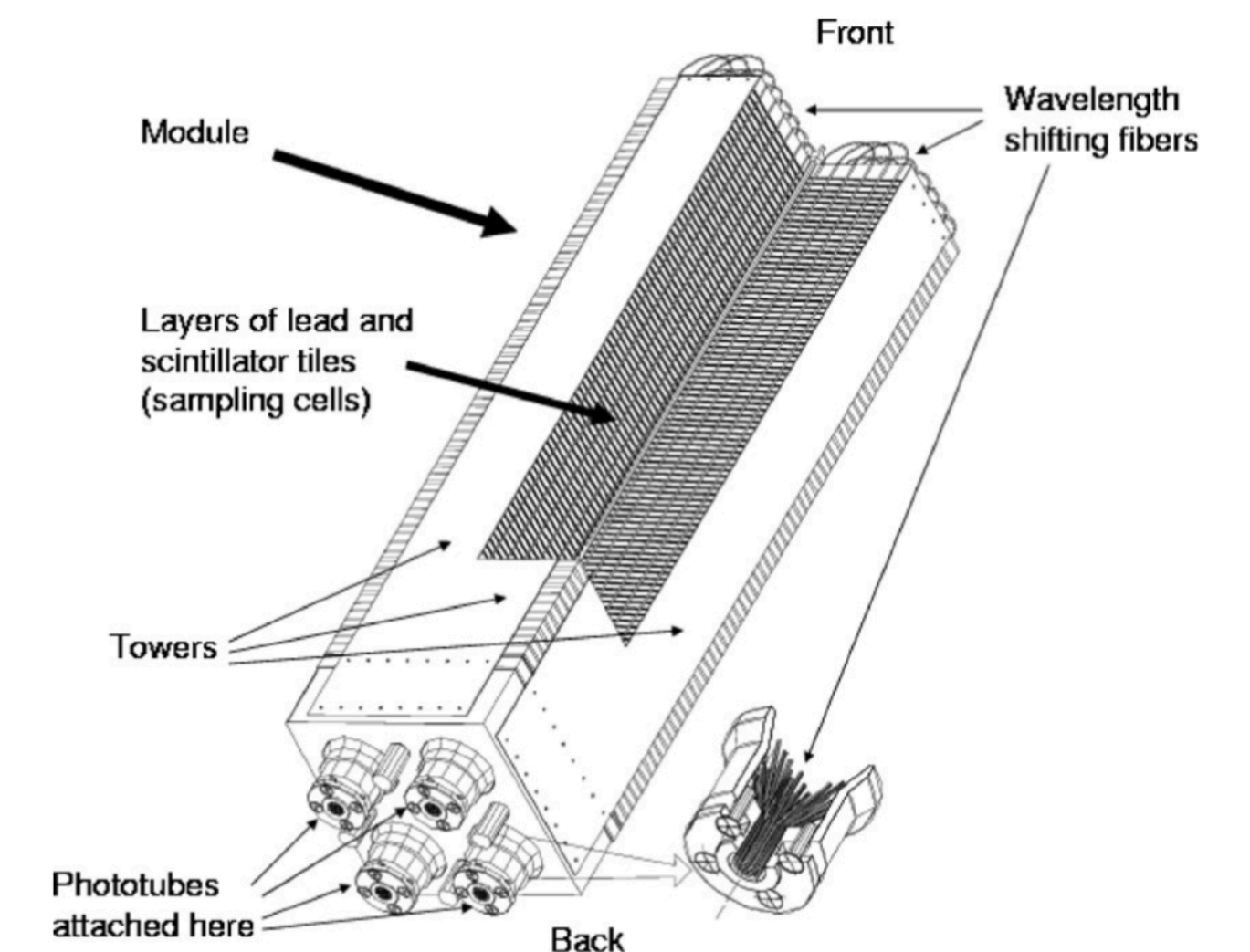


- Broad coverage to different theory models, e.g.,
 - Berlin, Gori, Schuster, & Toro, Arxiv.1804.00661
 - Batell, Evans, Gori, & Rai, Arxiv.200808108
 - Berlin, Blinov, Gori, Schuster, Toro, Arxiv.1801.05805

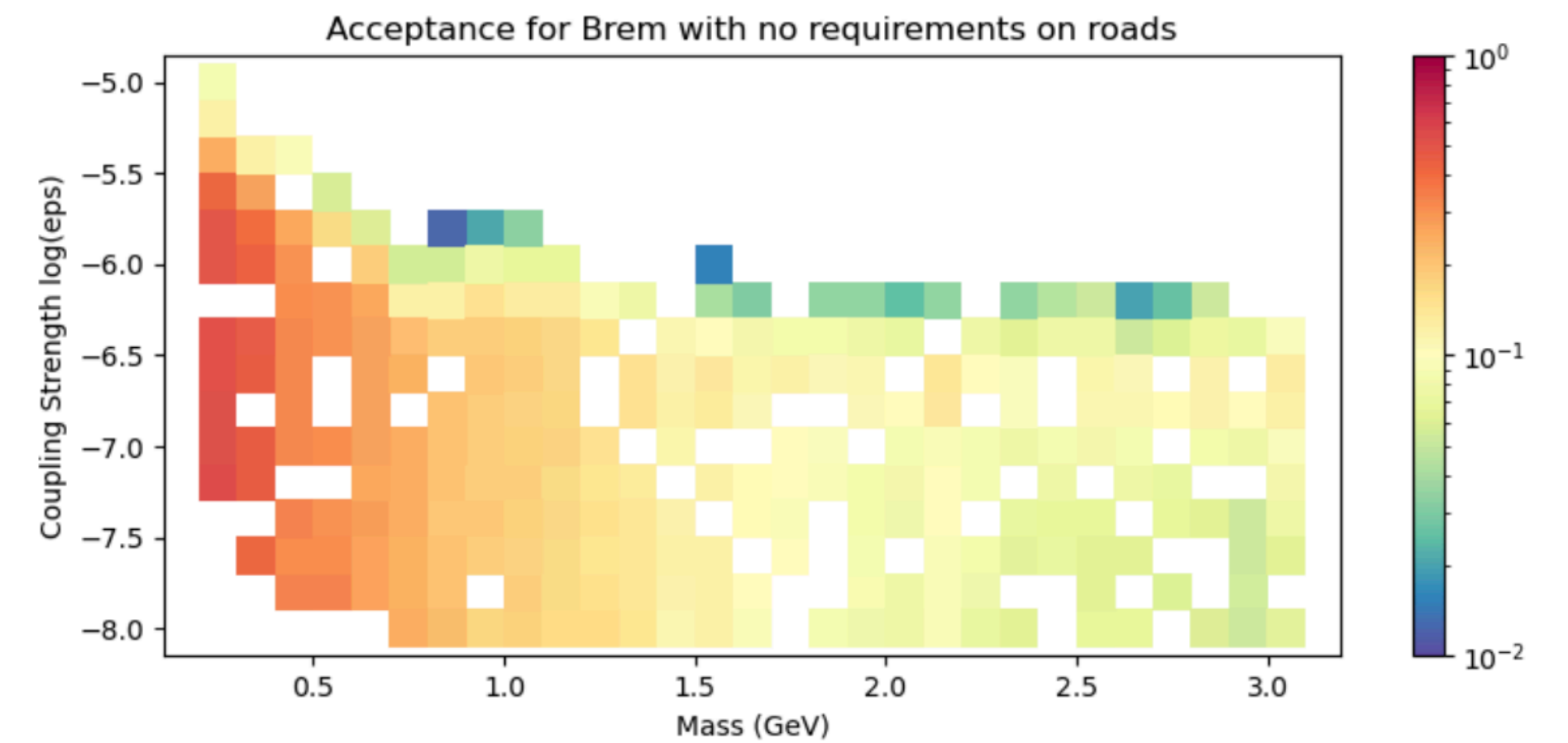
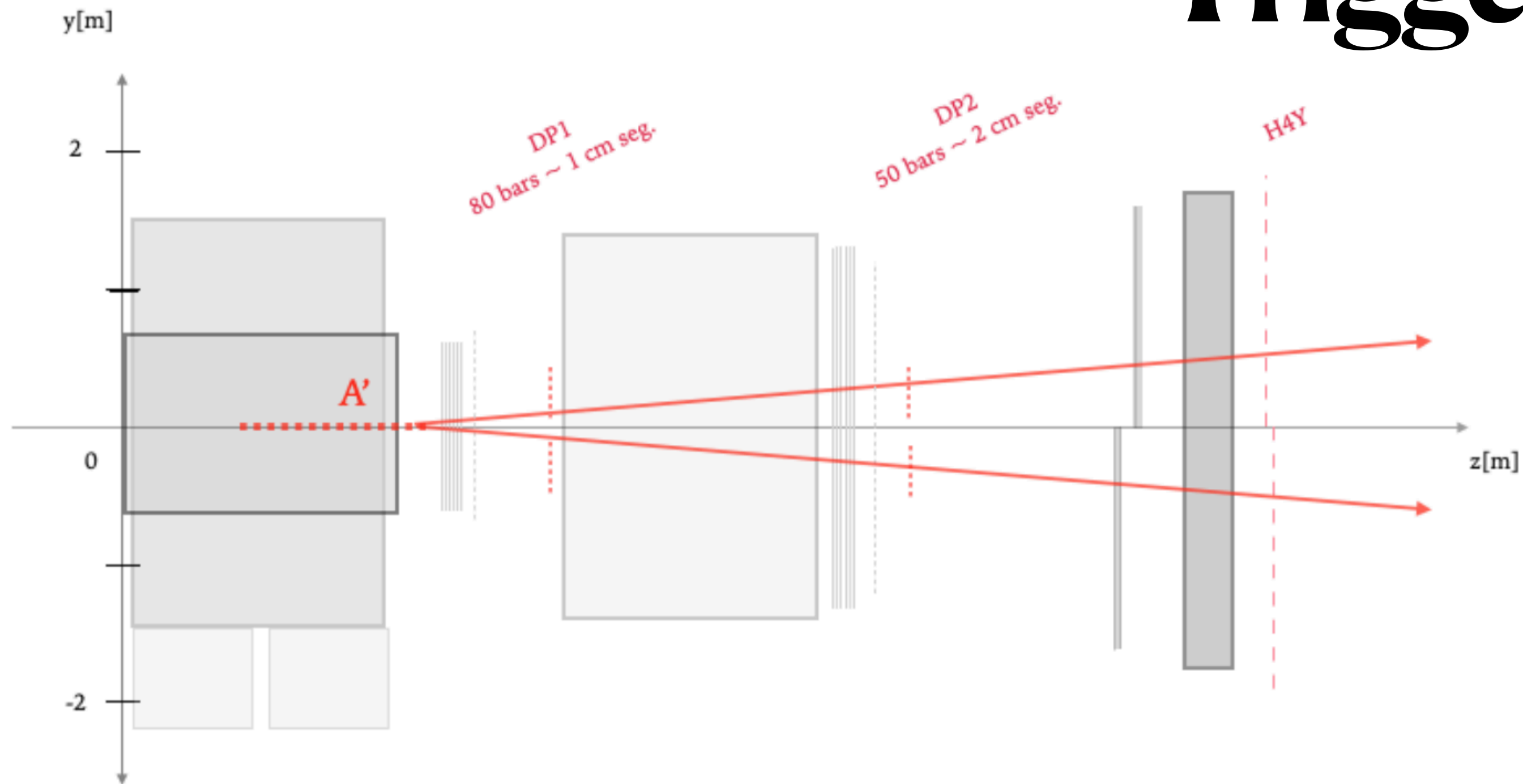
Spectrometer Upgrade



- 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



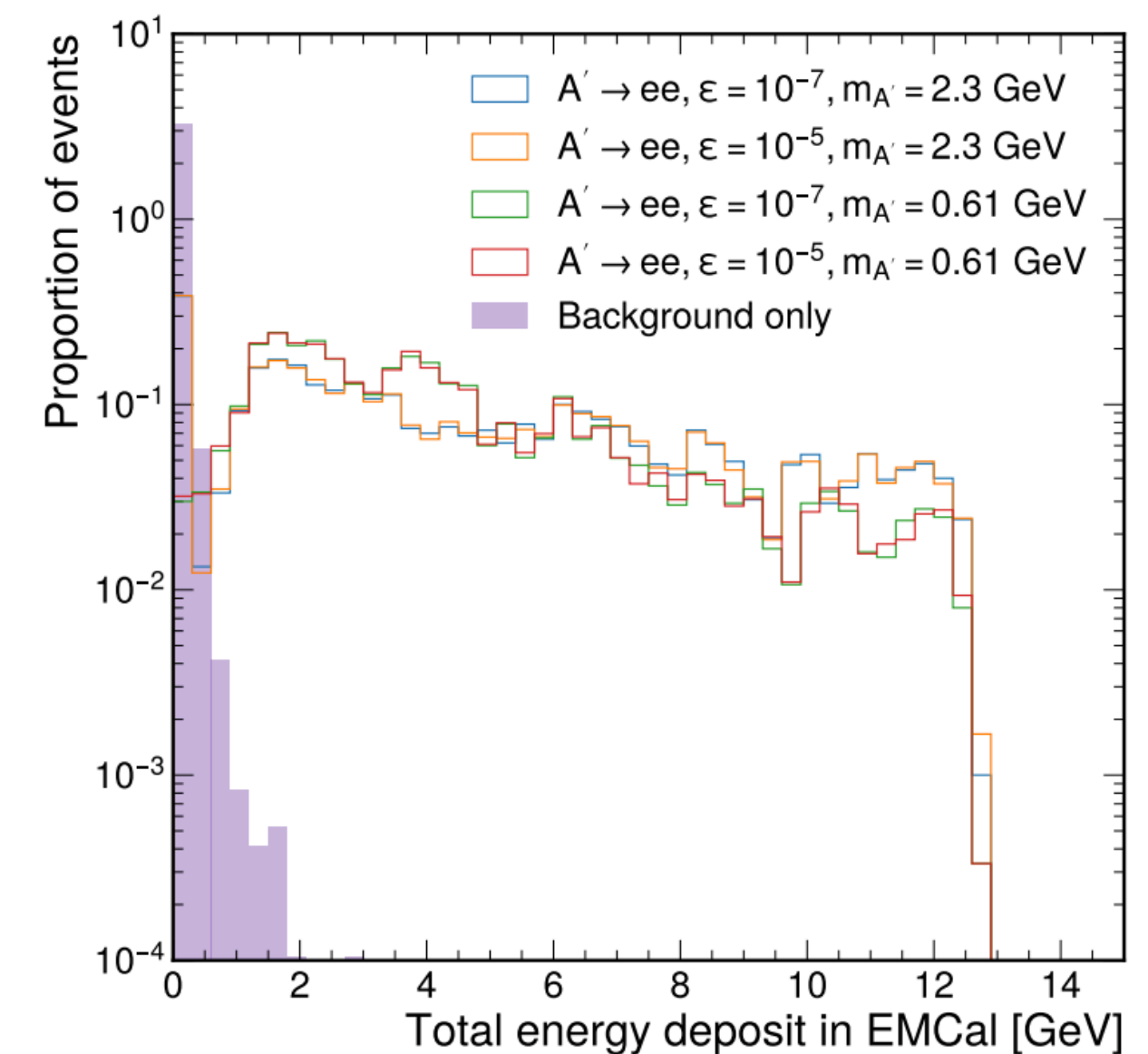
- Exploring newly installed Dark Photon trigger:

- ❁ Large improvements on the displaced signals compared with the existing standard hodoscope triggers

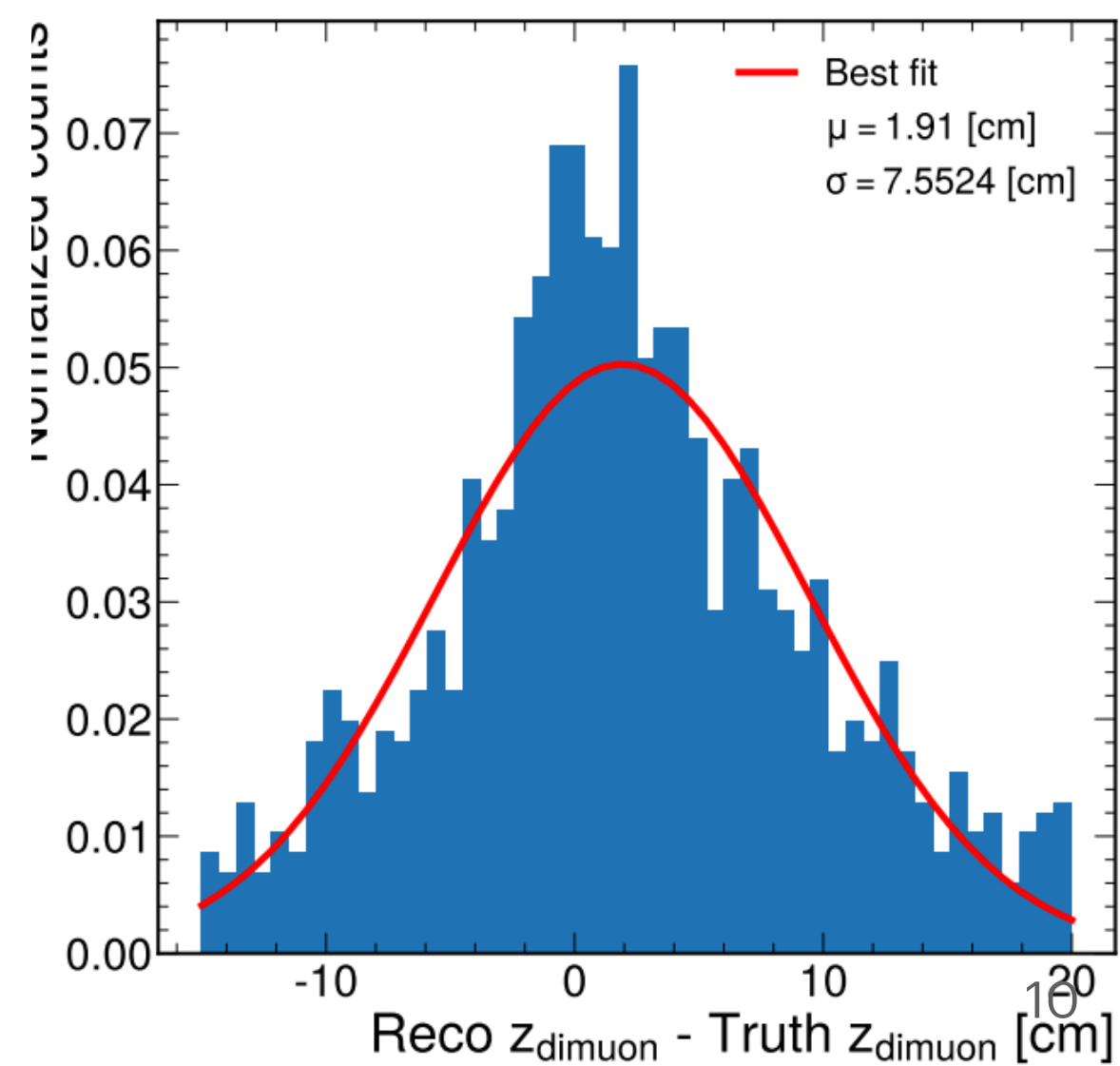
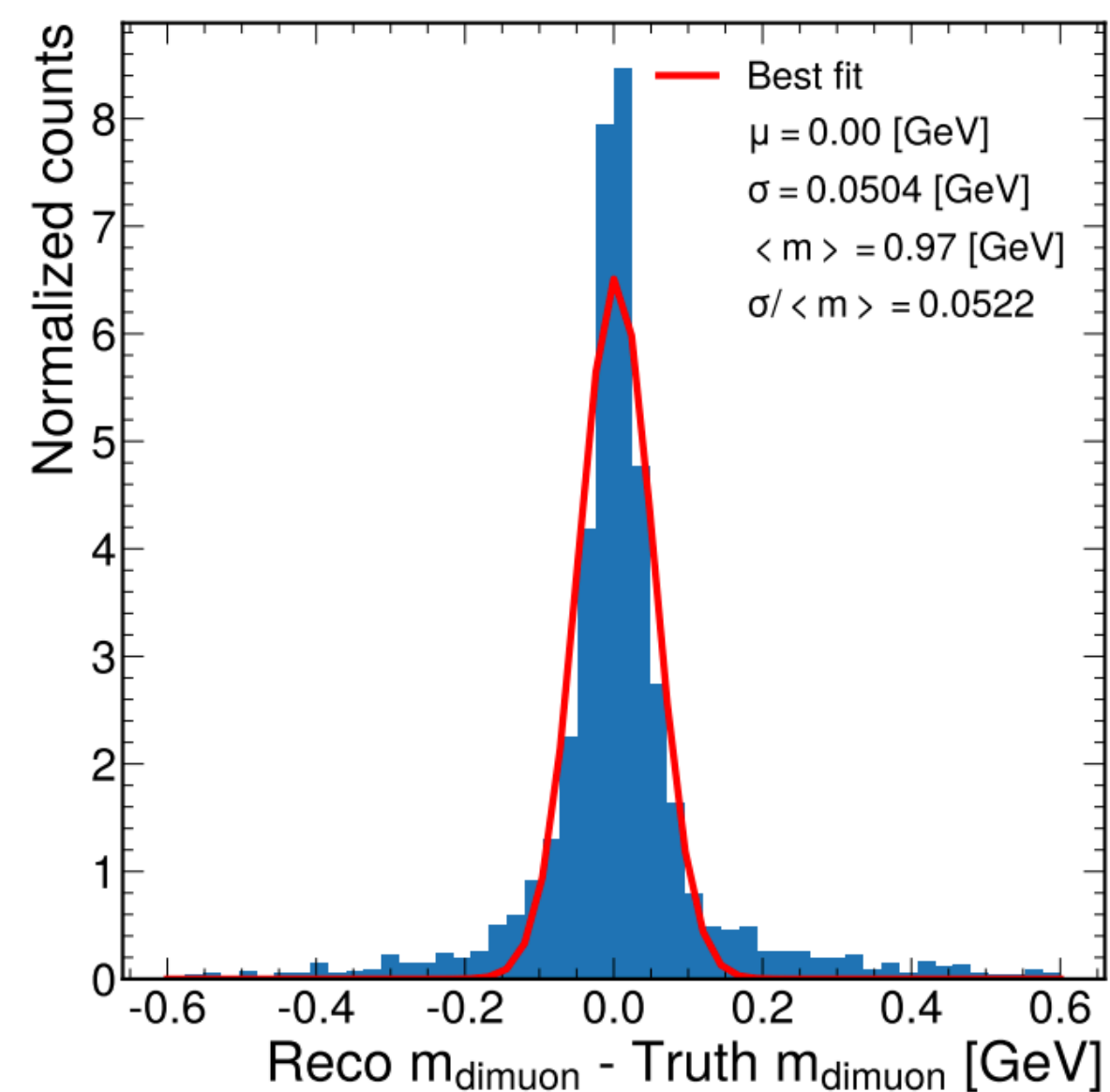
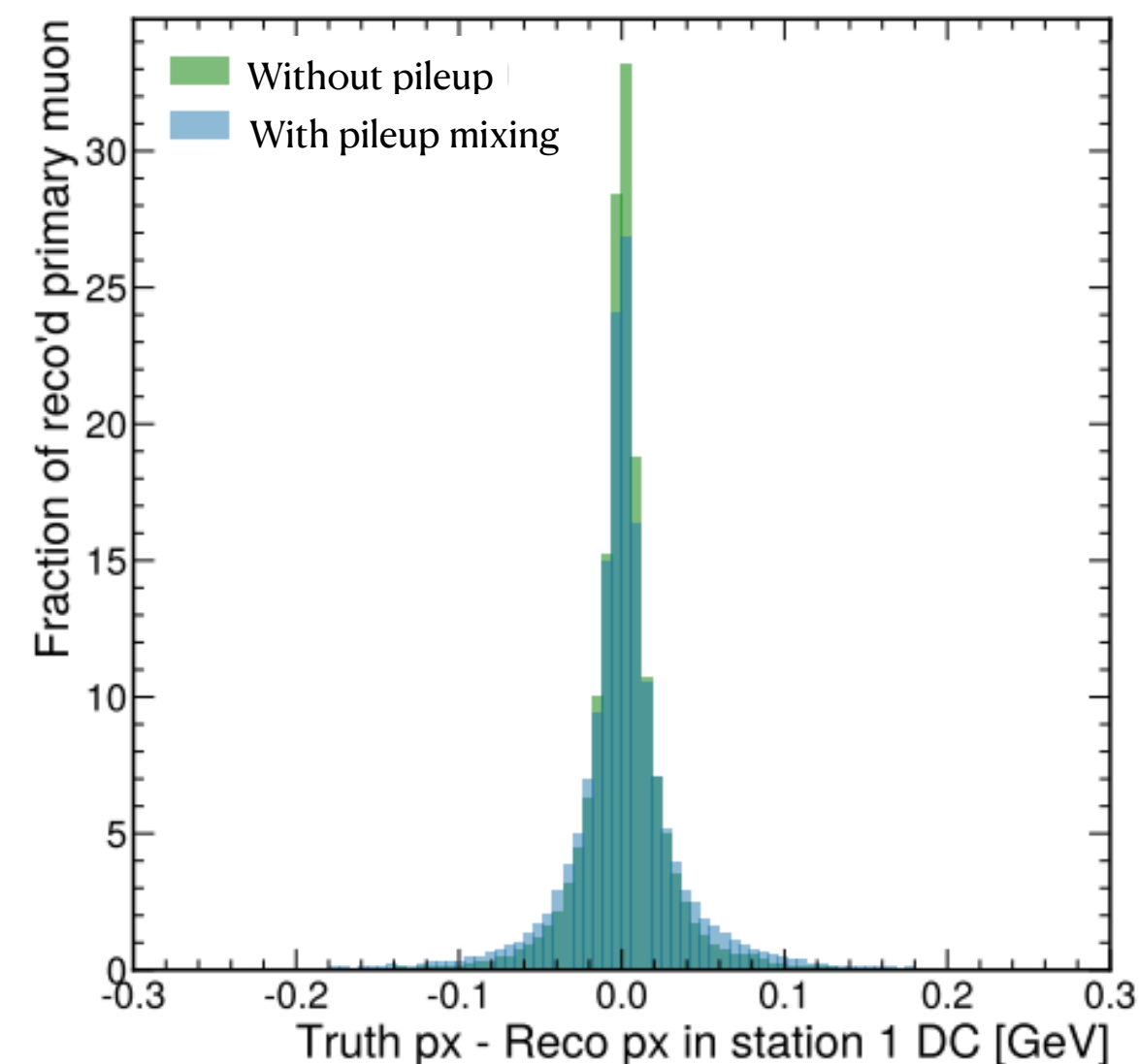
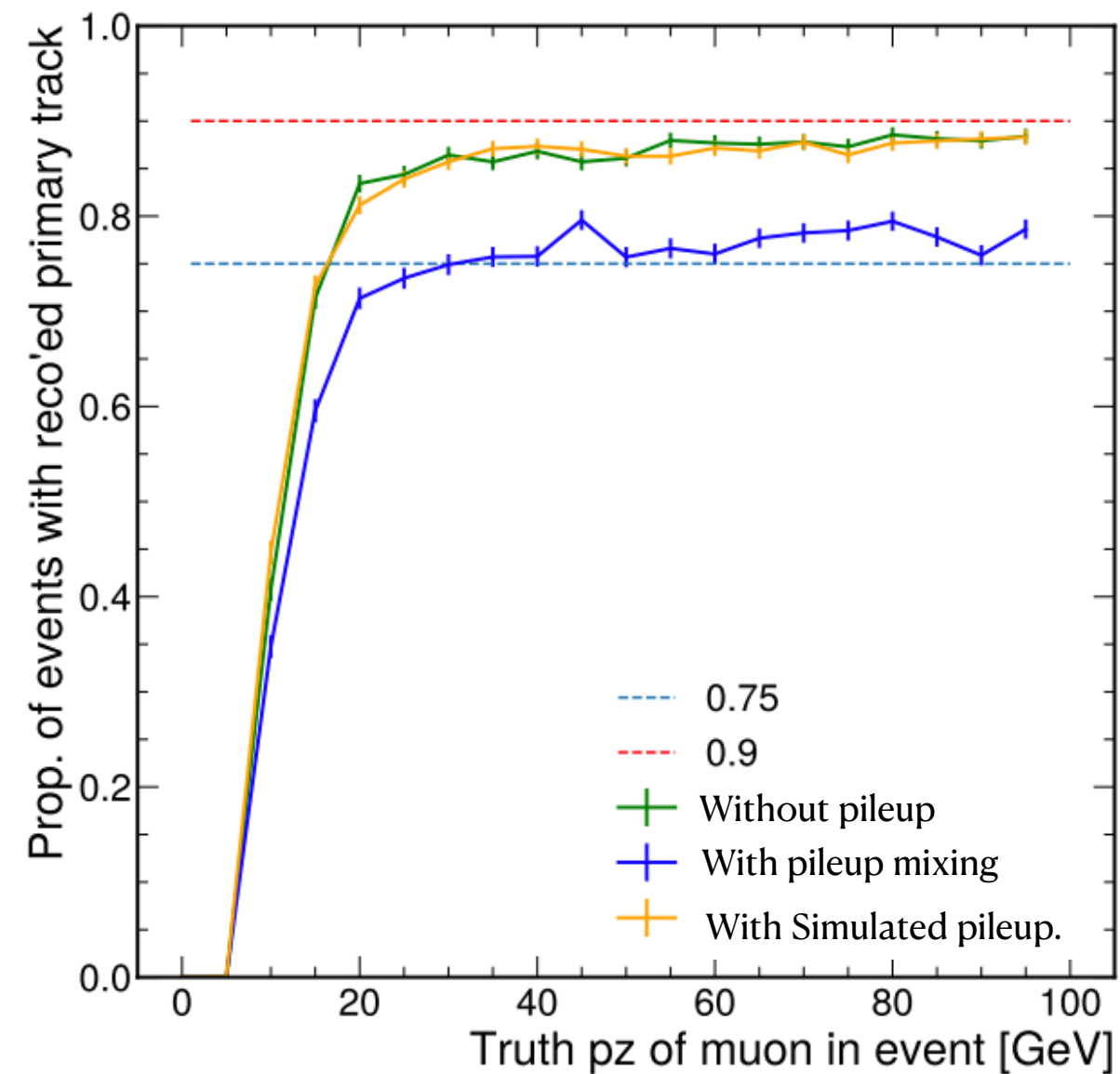
- ❁ Working on the trigger design and the implementations

- Include EMCal information in the trigger system

- ❁ Good separation of electron/photon signals out of hadron and muon backgrounds

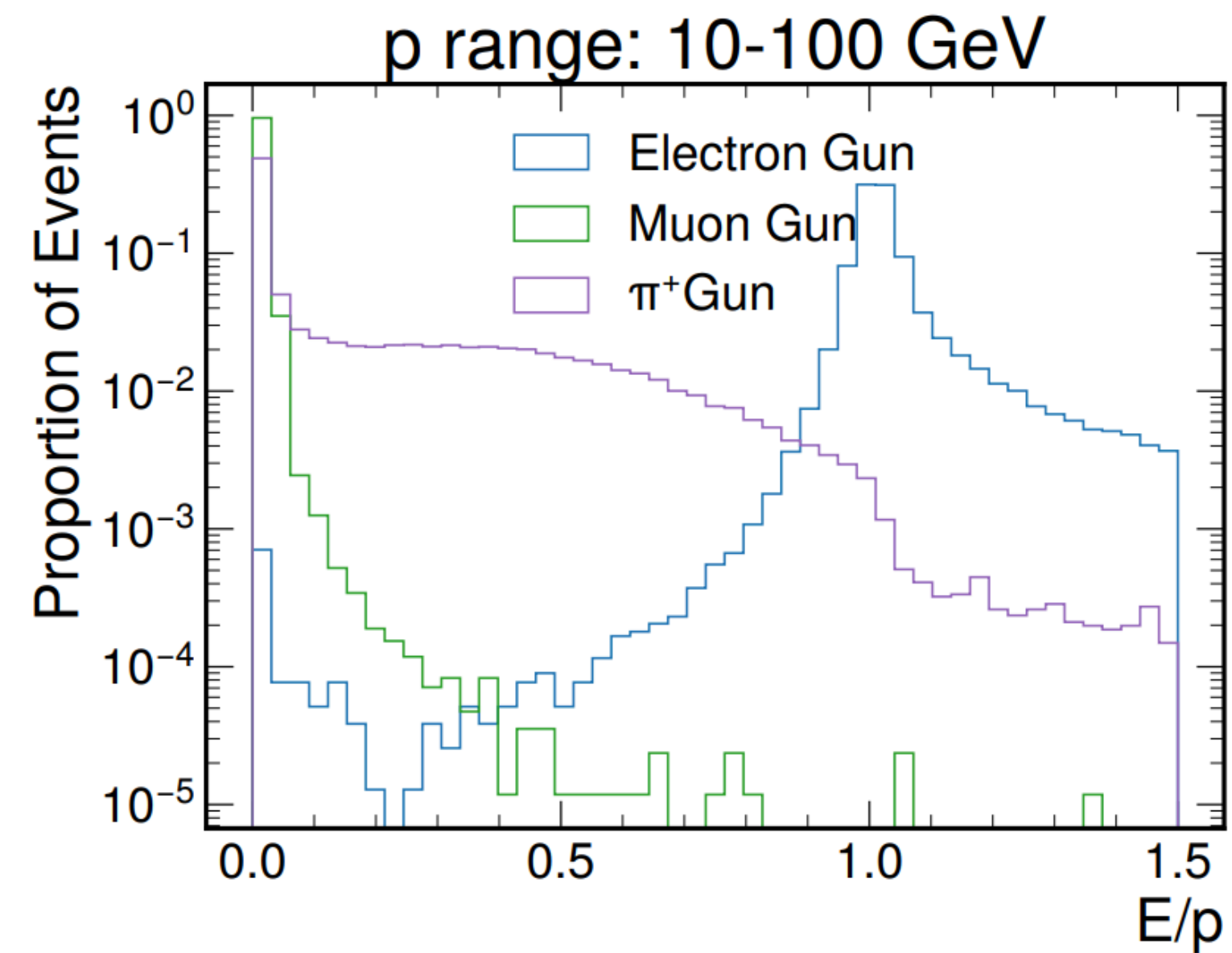
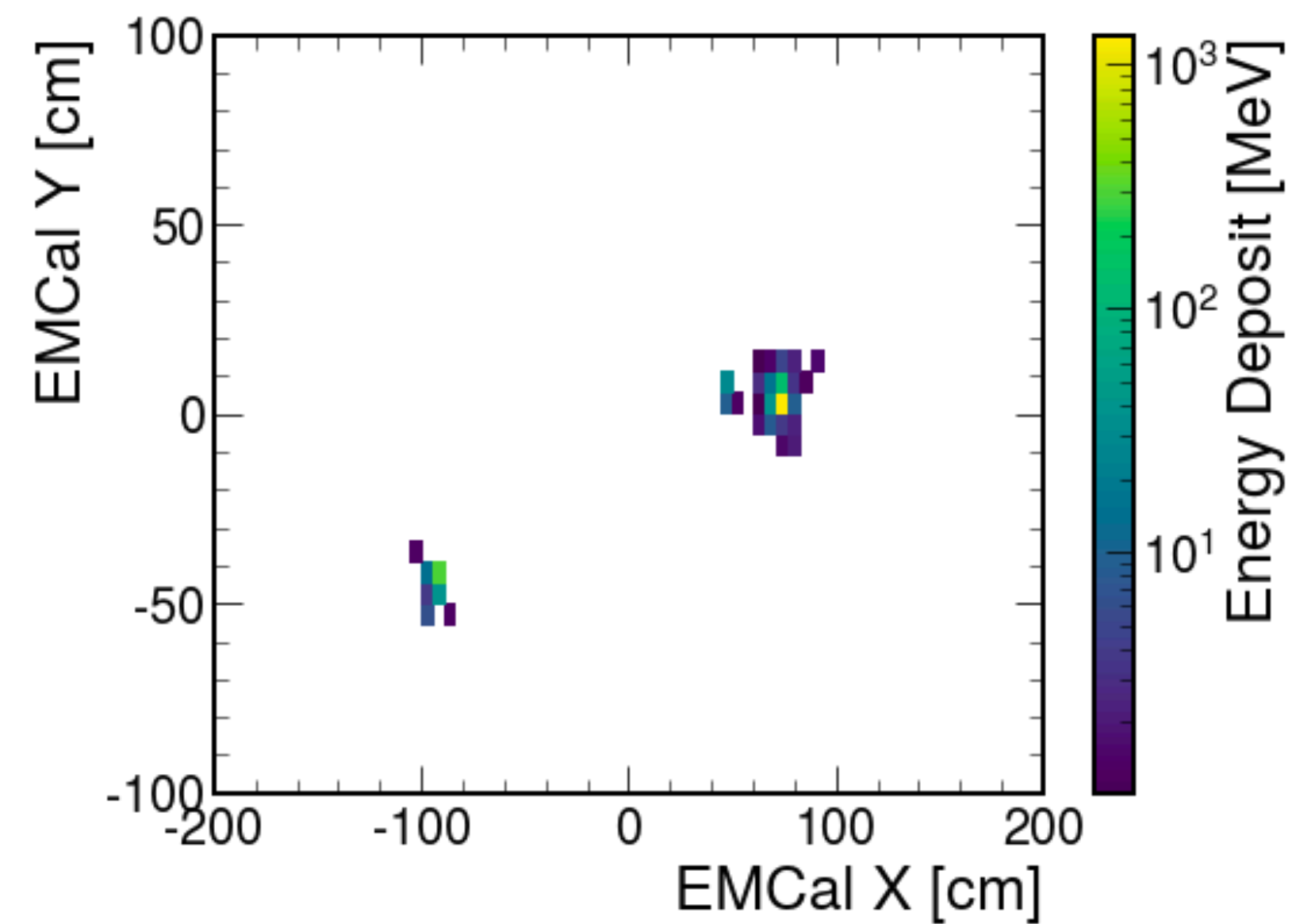


Tracking and Vertexing



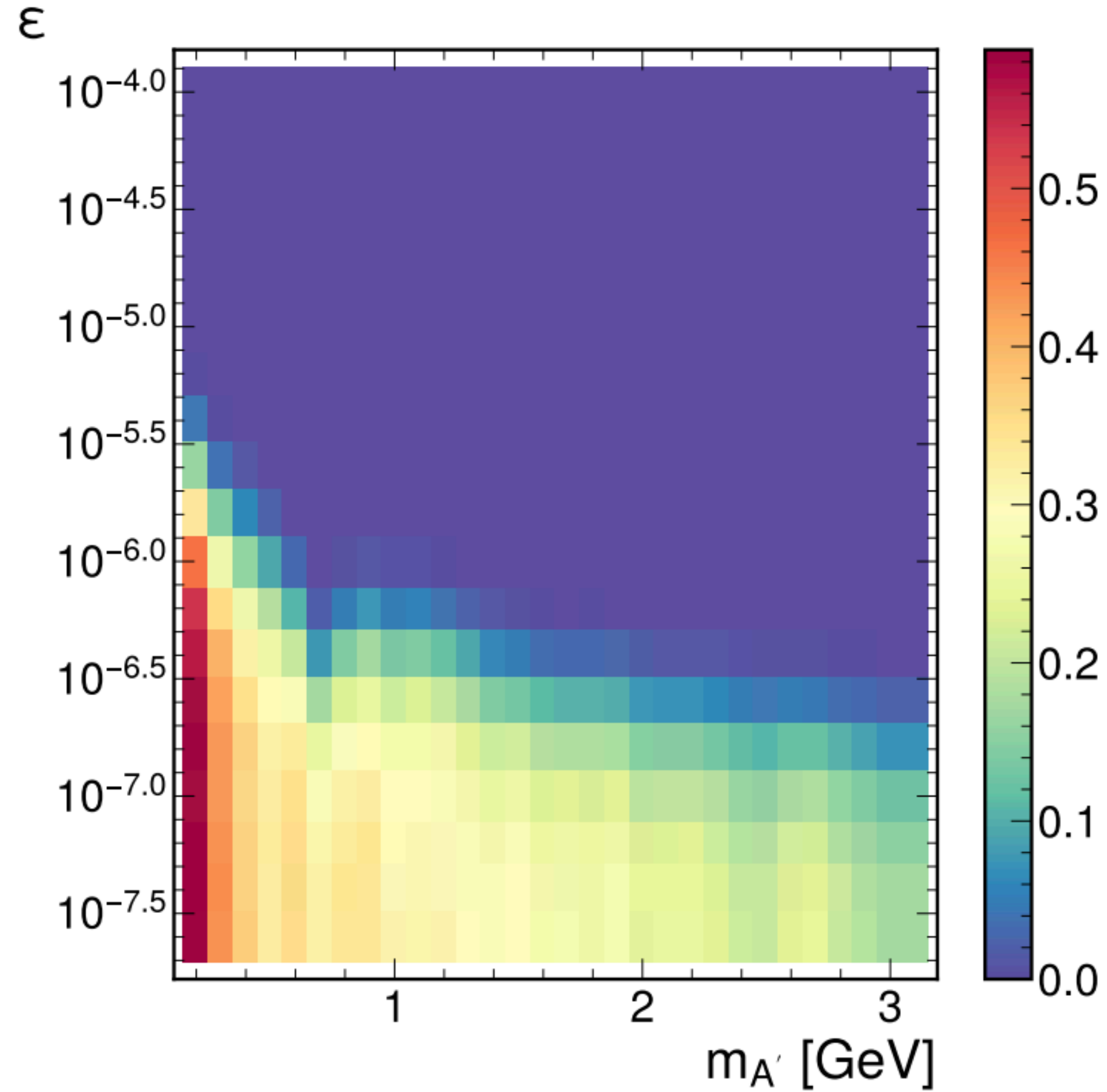
- Improved tracking and vertexing for displaced tracks and vertices based on the existing SpinQuest code:
 - ✿ Better resolution for tracks and vertices compared with prompt DY signals because of the less impact from the FMag in the front.
 - ✿ 75% track reconstruction efficiency for high momentum particles; 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

Aram Apyan¹, Brian Batell², Asher Berlin³, Nikita Blinov⁴, Caspian Chaharom⁵, Sergio Cuadra⁶, Zeynep Demiragli⁵, Adam Duran⁷, Yongbin Feng³, I.P. Fernando⁸, Stefania Gori⁹, Philip Harris⁶, Duc Hoang⁶, Dustin Keller⁸, Elizabeth Kowalczyk¹⁰, Monica Leys², Kun Liu¹¹, Ming Liu¹¹, Wolfgang Lorenzon¹², Petar Maksimovic¹³, Cristina Mantilla Suarez³, Hrachya Marukyan¹⁴, Amitav Mitra¹³, Yoshiyuki Miyachi¹⁵, Patrick McCormack⁶, Eric A. Moreno⁶, Yasser Corrales Morales¹¹, Noah Paladino⁶, Mudit Rai², Sebastian Rotella⁶, Luke Saunders⁵, Shinaya Sawada²¹, Carli Smith¹⁷, David Sperka⁵, Rick Tesarek³, Nhan Tran³, Yu-Dai Tsai¹⁸, Zijie Wan⁵, and Margaret Wynne¹²

¹Brandeis University, Waltham, MA 02453, USA

²University of Pittsburgh, Pittsburgh, PA 15260, USA

³Fermi National Accelerator Laboratory, Batavia, IL 60510, USA

⁴University of Victoria, Victoria, BC V8P 5C2, Canada

⁵Boston University, Boston, MA 02215, USA

⁶Massachusetts Institute of Technology, Cambridge, MA 02139, USA

⁷San Francisco State University, San Francisco, CA 94132, USA

⁸University of Virginia, Charlottesville, VA 22904, USA

⁹University of California Santa Cruz, Santa Cruz, CA 95064, USA

¹⁰Michigan State University, East Lansing, Michigan 48824, USA

¹¹Los Alamos National Laboratory, Los Alamos, NM 87545, USA

¹²University of Michigan, Ann Arbor, MI 48109, USA

¹³Johns Hopkins University, Baltimore, MD 21218, USA

¹⁴Yamagata University, Yamagata, 990-8560, Japan

¹⁵KEK Tsukuba, Tsukuba, Ibaraki 305-0801 Japan

¹⁶Yerevan Physics Institute, Yerevan, 0036, Republic of Armenia

¹⁷Penn State University, State College, PA 16801, USA

¹⁸University of California Irvine, Irvine, CA 92697, USA

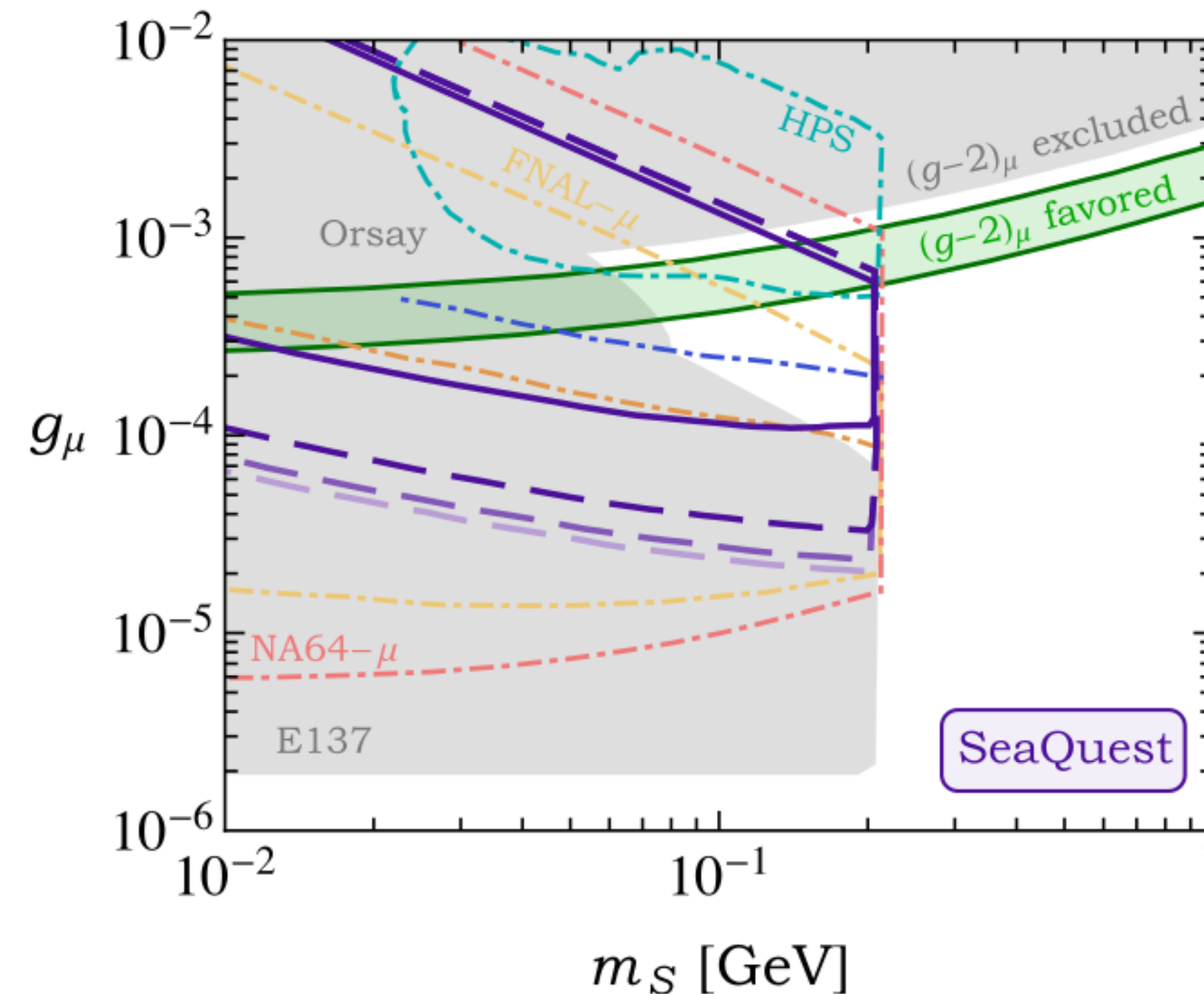
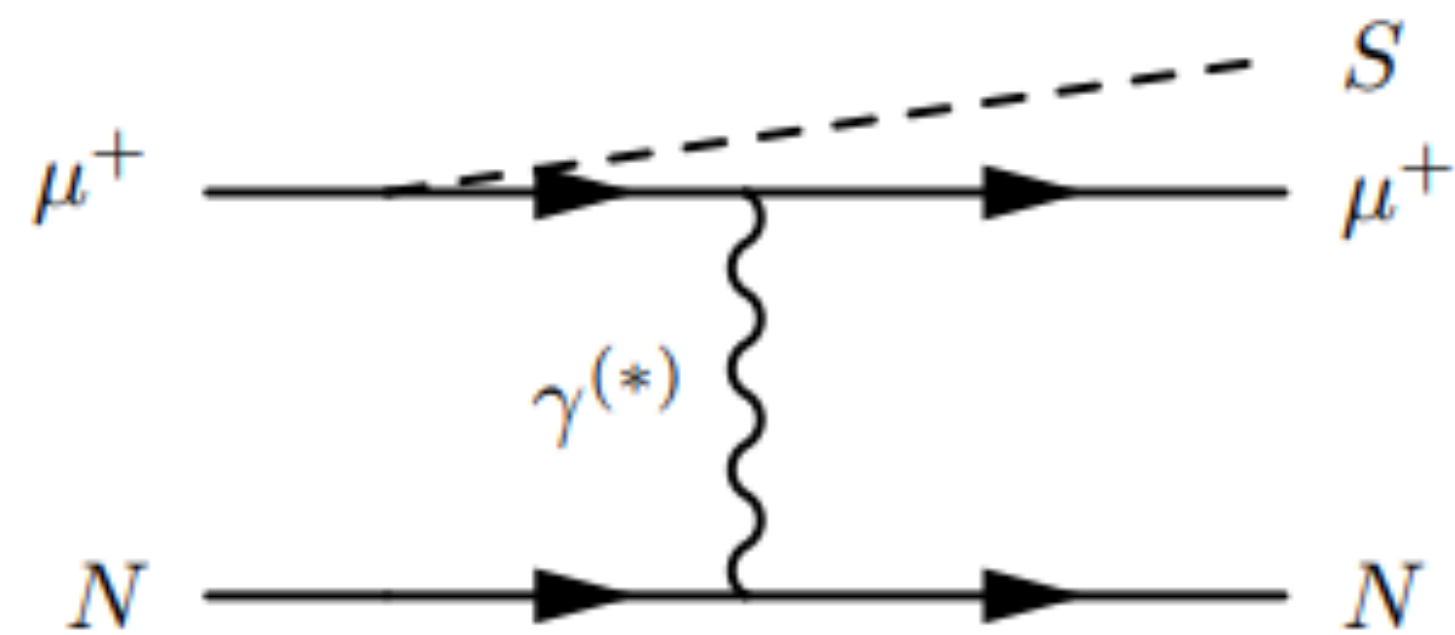
Summary

- 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

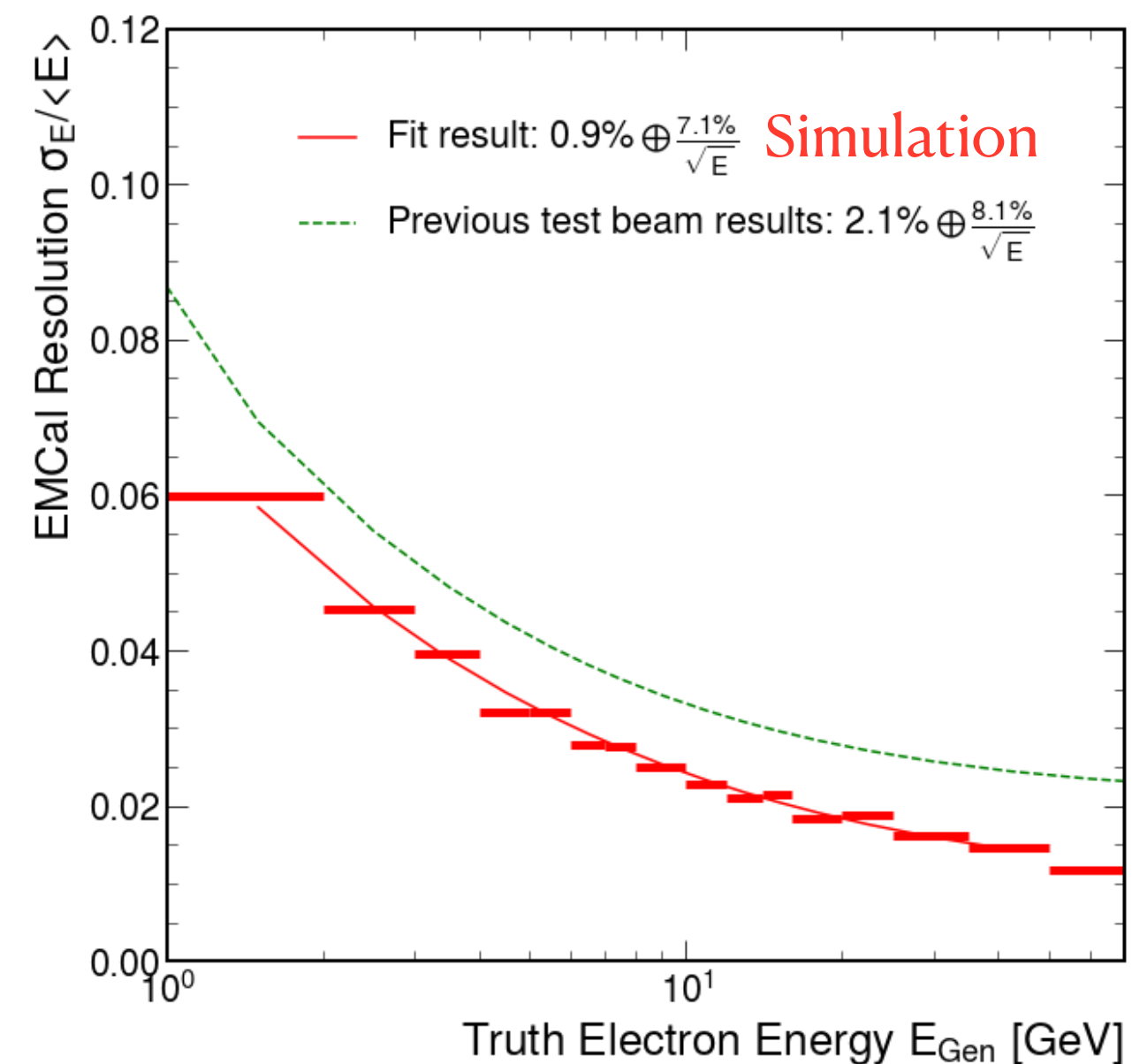
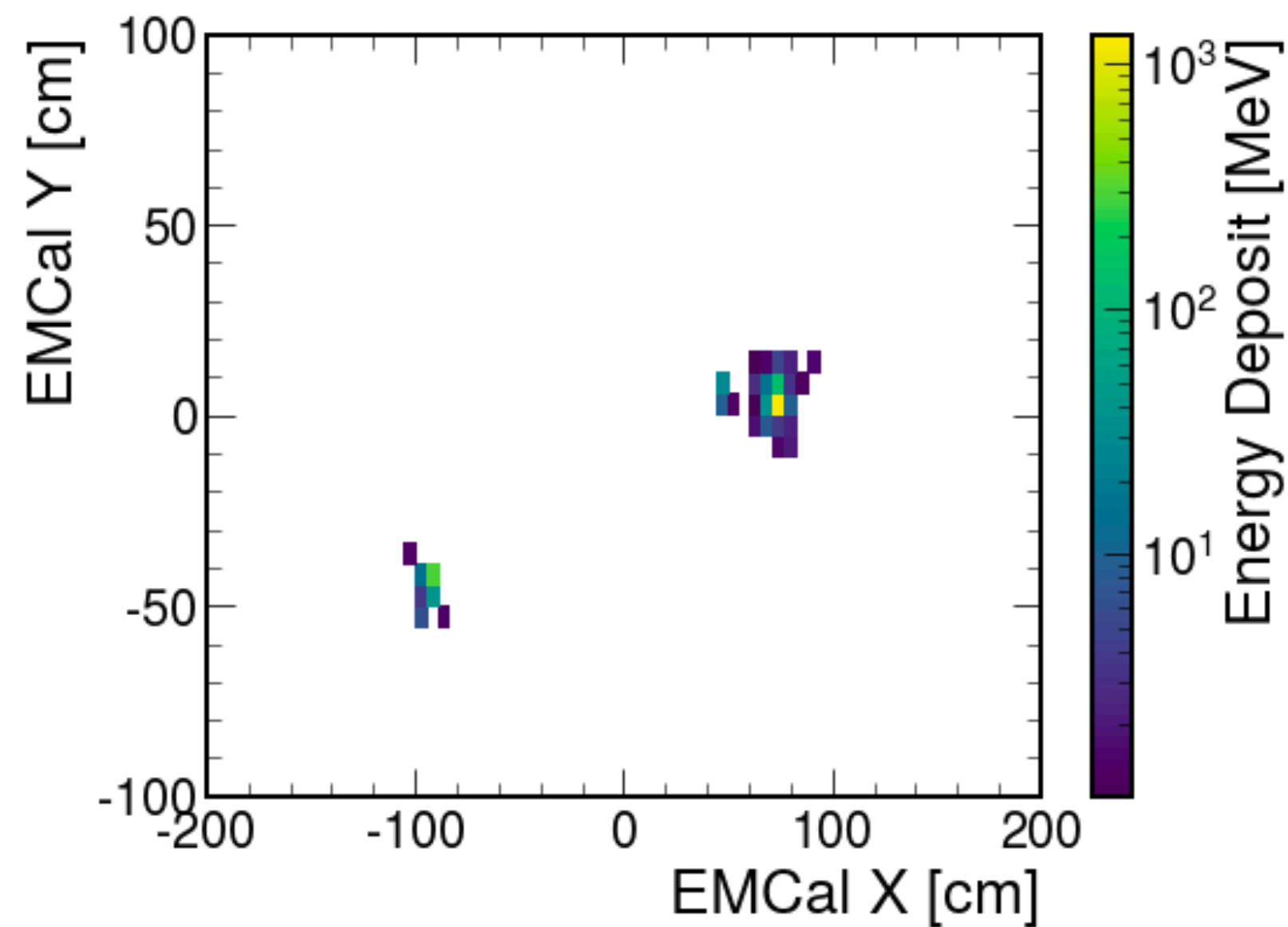
Why DarkQuest: Connection with (g-2) Anomaly



A.Berlin, S.Gori,
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Arxiv:1804.00661

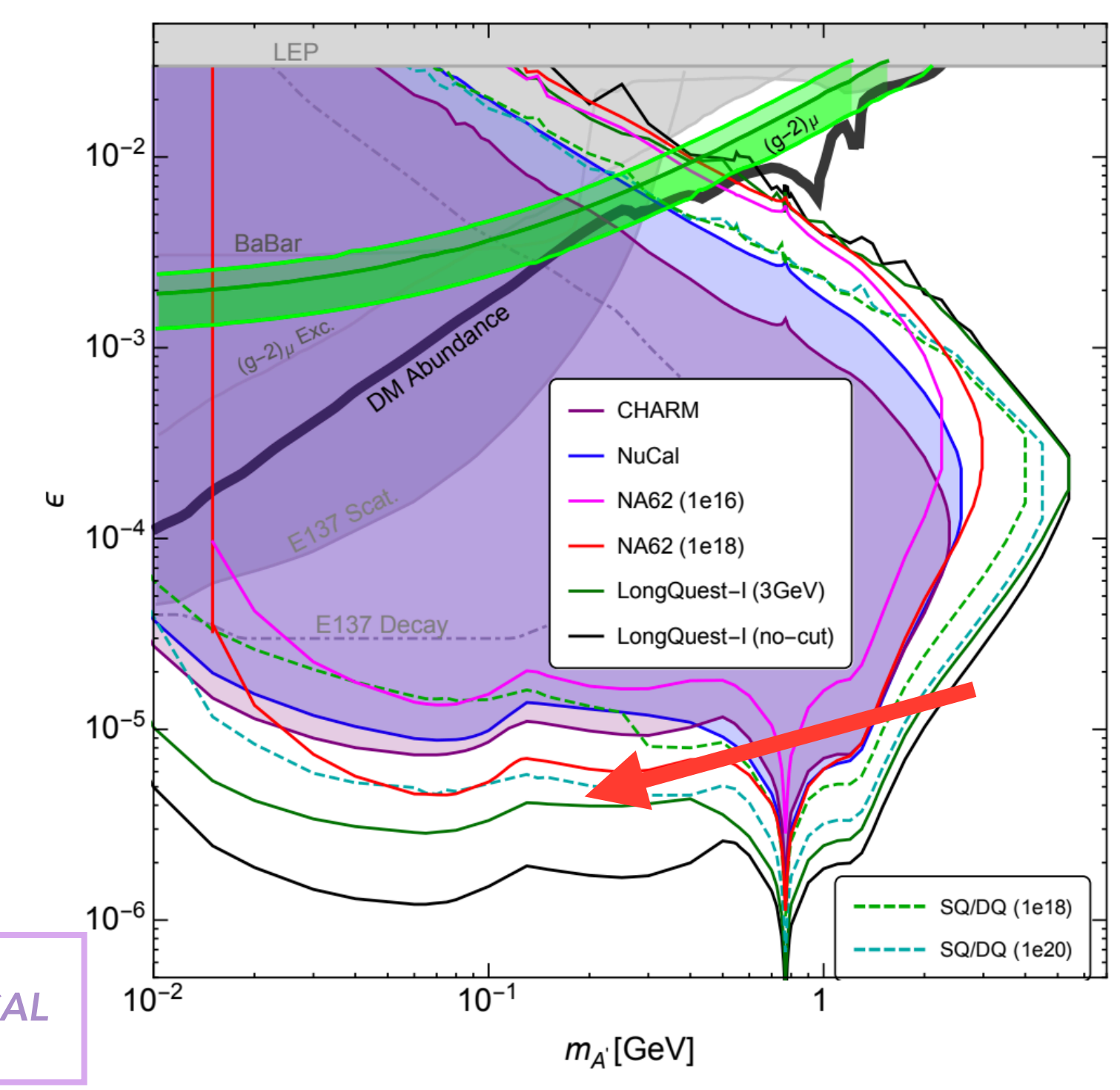
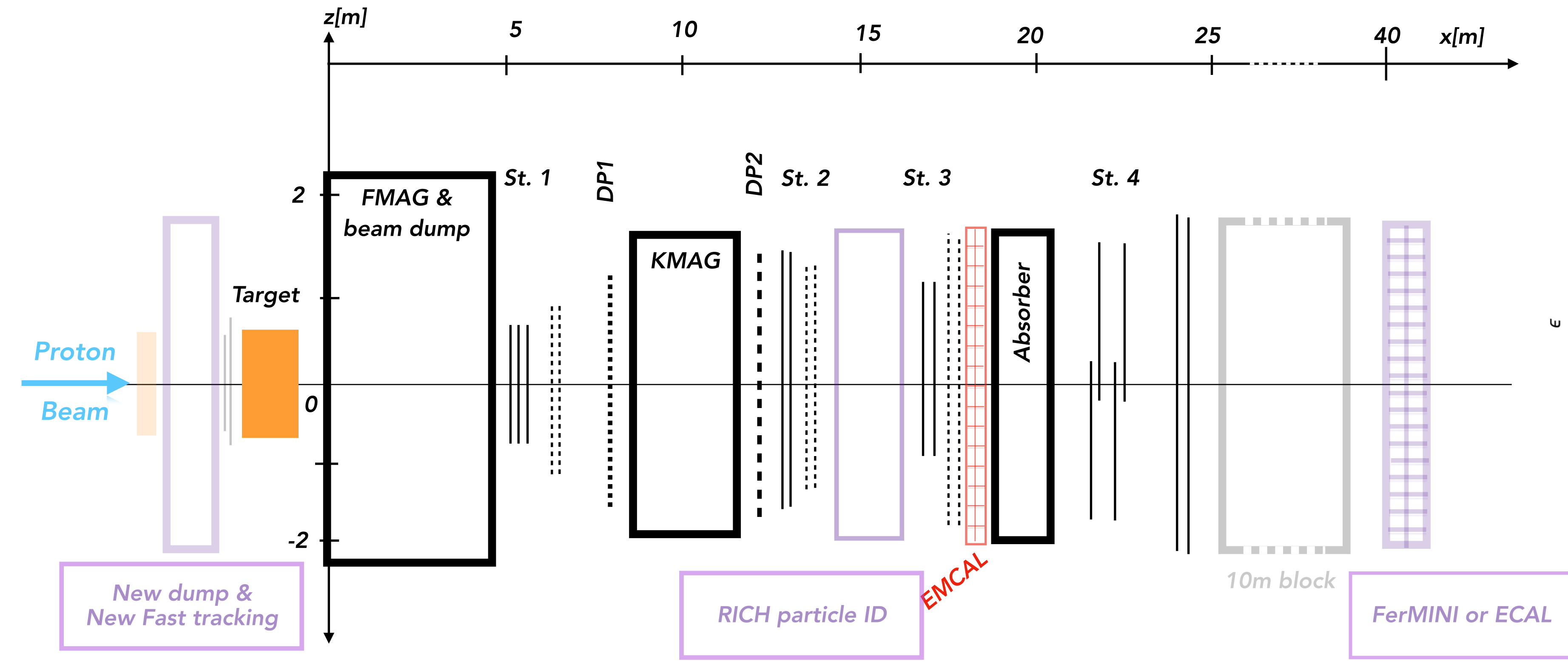
- Large flux of secondary muons from pion decays traversing a thick target, which makes DarkQuest a muon beam dump experiment
- Search for displaced decays of light muon-coupled mediators

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