

# DarkQuest and LongQuest at the 120GeV Fermilab Main Injector

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For the (growing) DarkQuest/LongQuest Collaboration

Rare Processes and Precision Frontier Townhall Meeting

October 2, 2020

*Snowmass Letter of Interest: Topic area – RF6*

## DarkQuest and LongQuest at the 120 GeV Fermilab Main Injector

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### ABSTRACT

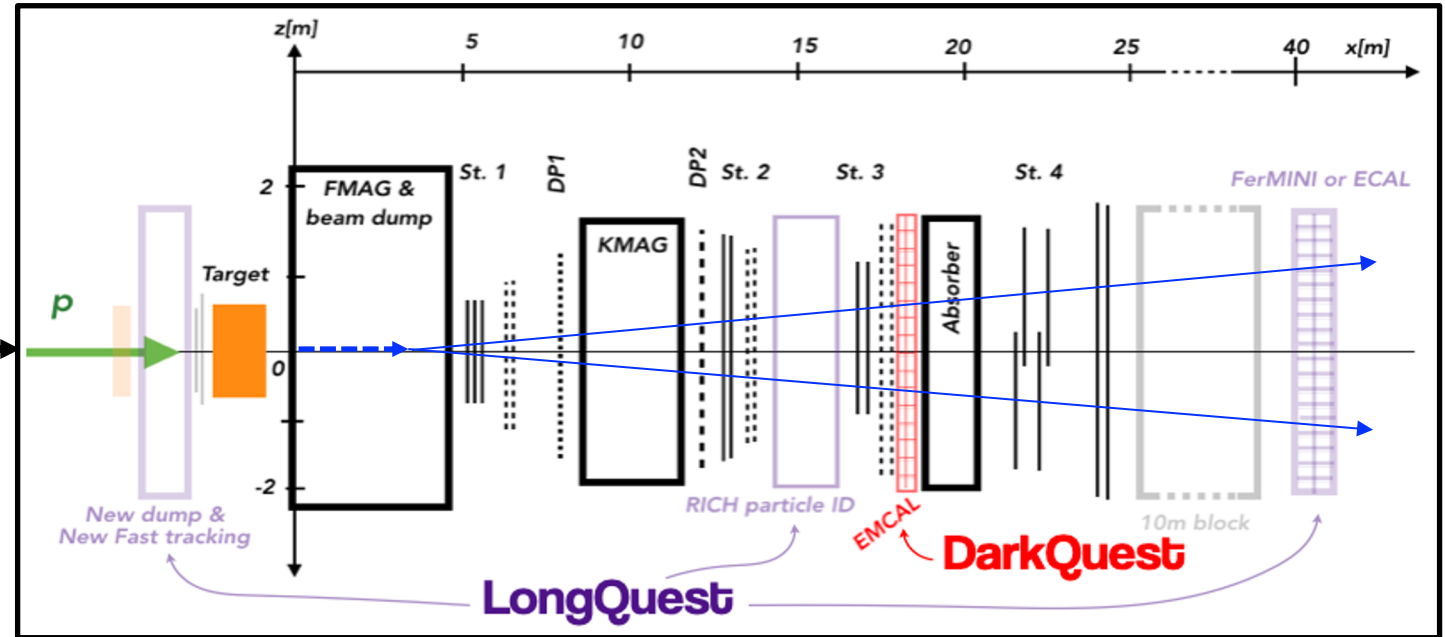
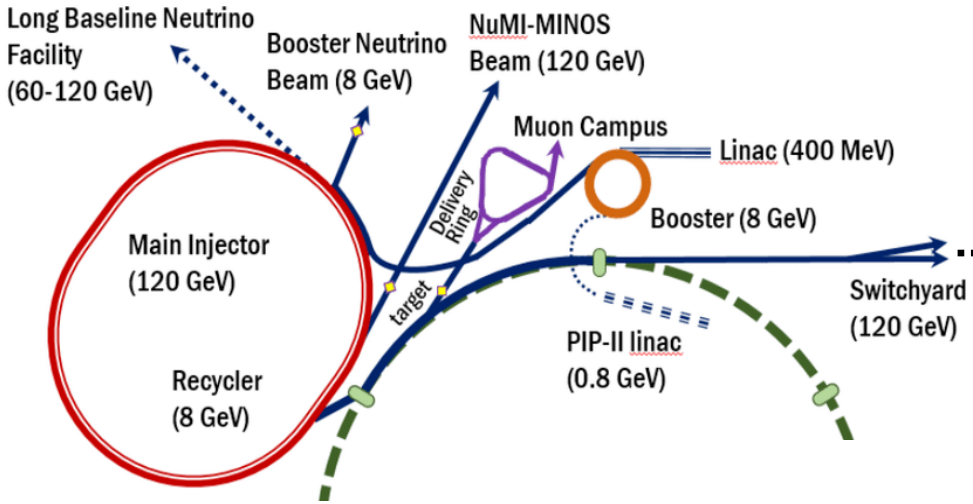
Expanding the mass range and techniques by which we search for dark matter is an important part of the worldwide particle physics program which has been specifically emphasized in the DOE Basic Research Needs for Dark Matter New Initiatives report. Accelerator-based searches for dark matter are a uniquely compelling part of this program as a way to both create and detect dark matter in the laboratory and explore the dark sector by searching for mediators and excited dark matter particles. This proposal focuses on developing the DarkQuest experimental concept and related enhancements collectively referred to as LongQuest. DarkQuest is a proton fixed-target experiment with particular sensitivity to an array of visible dark sector signatures in the MeV-GeV mass range. Because it builds off of existing accelerator and detector infrastructure, it offers a powerful but low-cost experimental initiative that can be realized on a short timescale.

## - Dark Sector Search at Fermilab Main Injector

A series of fixed target beam dump experiments based on the SeaQuest/SpinQuest dimuon spectrometer with 120GeV proton beam to search for low mass dark sector particles - **Dark Photon (vector portal), Dark scalar (Higgs portal) etc.**

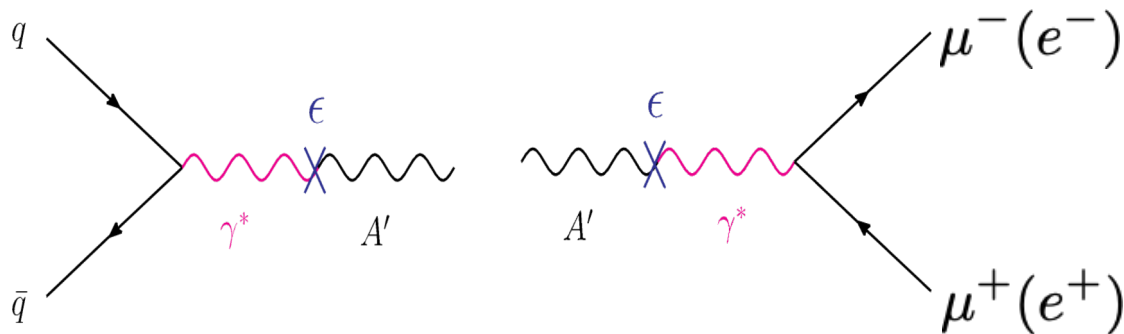
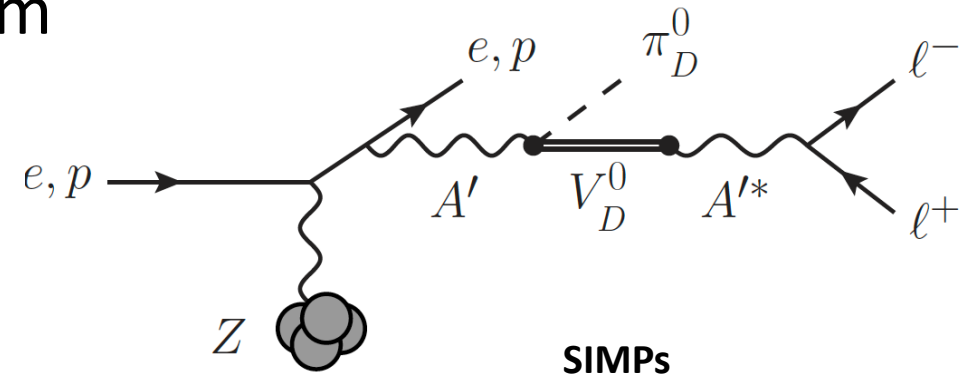
- **SeaQuest:** (2012 – 2017), nuclear targets (H, D, C, Fe, W); *Dark Photon displaced vertex trigger (DP) commissioned in 2017;*
- **SpinQuest:** 2020 - 2022, polarized proton target; DP trigger allows parasitic dark sector search in dimuon channel, POT:  $1.4 \times 10^{18}$
- **DarkQuest-I:** 2023 - 2024, **EMCal upgrade**; dimuon and dielectron channels, POT  $\sim 10^{18}$
- **DarkQuest-II/LongQuest:** 2026+, additional detectors for long-lived BSM particles, POT  $\sim 10^{20}$

**SpinQuest setup, with future DarkQuest and LongQuest**

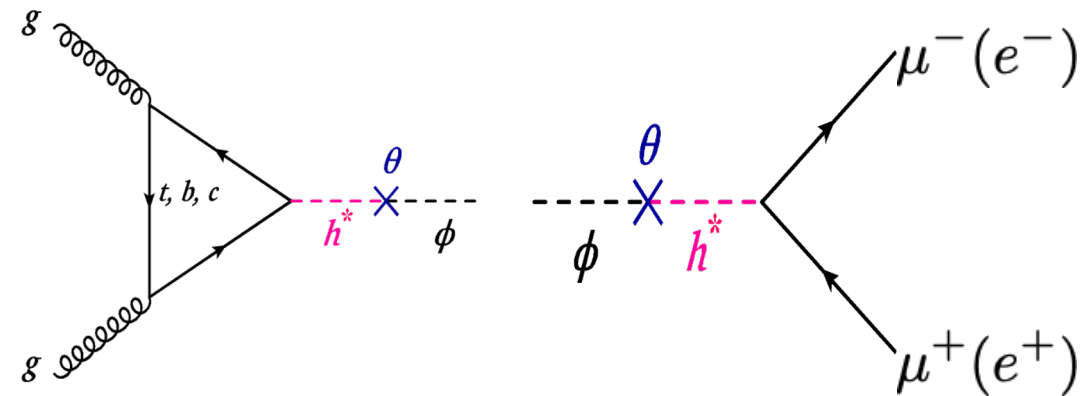


# Physics of the DarkQuest Experiment

- A broad dark sector physics search program
  - Dimuons (current)
  - Di-electrons
  - Di-photons, ALP
  - Hadrons, pi, K etc.
  - and more ...



**Vector portal: dark photon**



**Higgs portal: dark scalar**

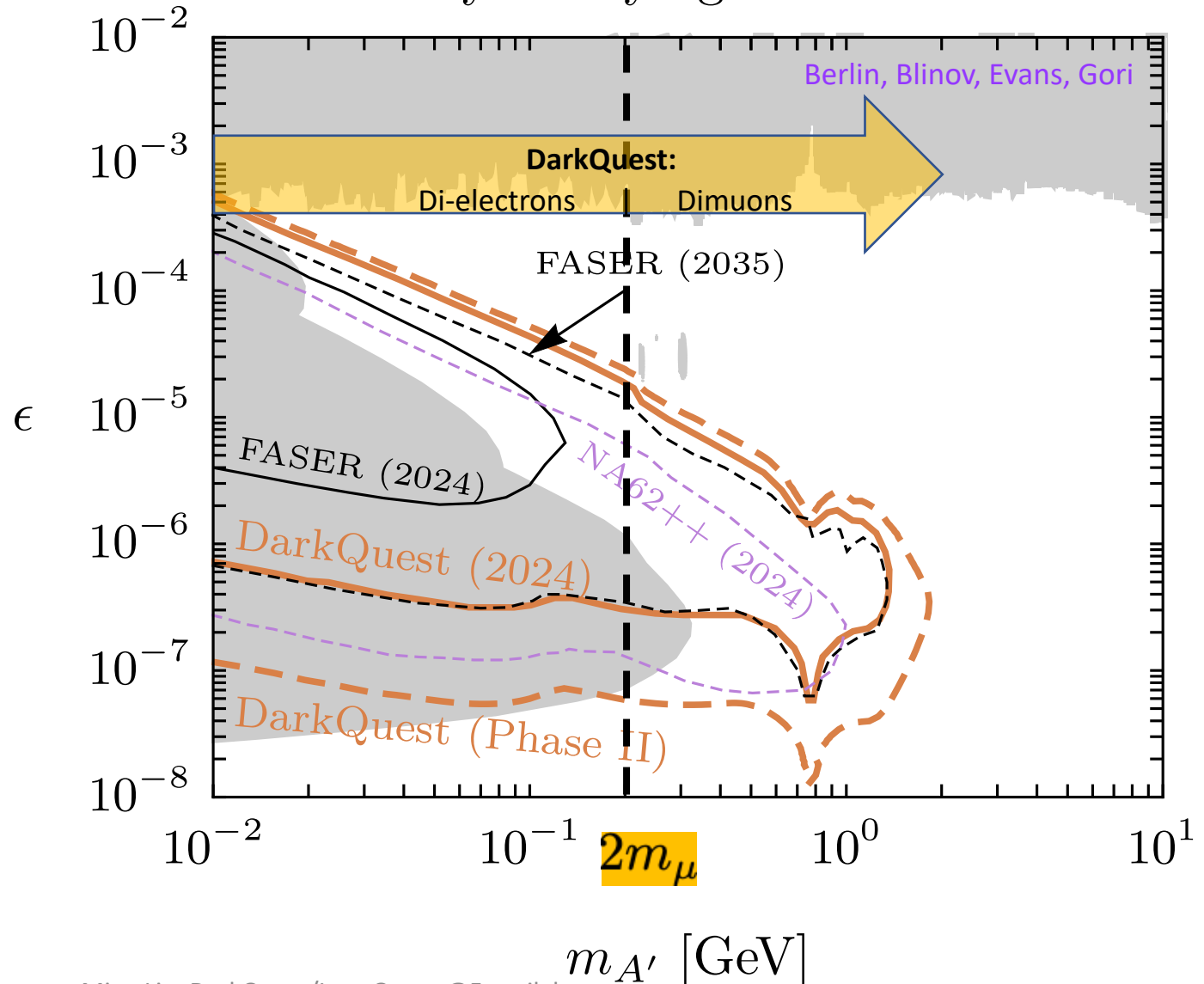
# Projected Sensitivity: Dark Photons as an Example

## Visibly Decaying Dark Photon

Updated based on  
arXiv: 1804.00661

**SpinQuest:**  
dimuon channel only,  
 $m_{A'} > 200\text{MeV}$

**DarkQuest:**  
extension with EMCal upgrade,  
will probe lower mass region,  
 $m_{A'} < 200\text{MeV}$  with di-electrons;  
also other signals like ALP, SIMPs



# More Dark Sector Signatures

Signature	Model
$e^+e^-$	dark photon dark Higgs leptophilic scalar*
$e^+e^-e^+e^-$	Higgsed dark photon
$e^\pm\pi^\mp, e^\pm K^\mp, \dots$	sterile neutrino
$e^+e^- + \text{MET}$	inelastic dark matter strongly interacting dark matter hidden valleys
$\pi^+\pi^-, K^+K^-, \dots$	dark Higgs*
$\gamma\gamma$	axion-like particle*

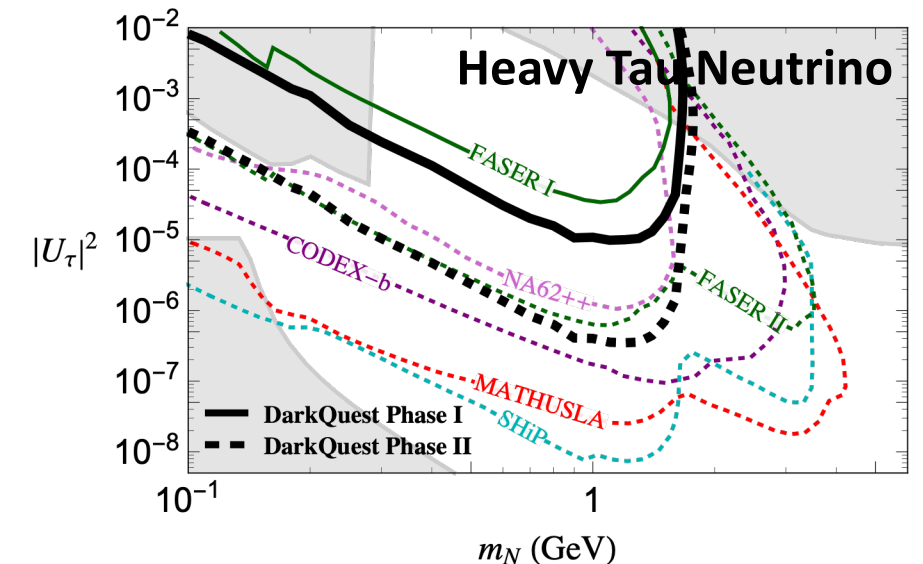
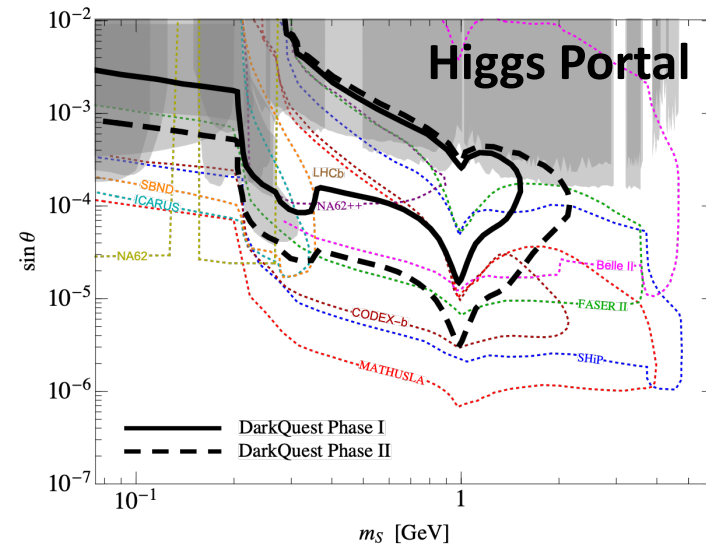
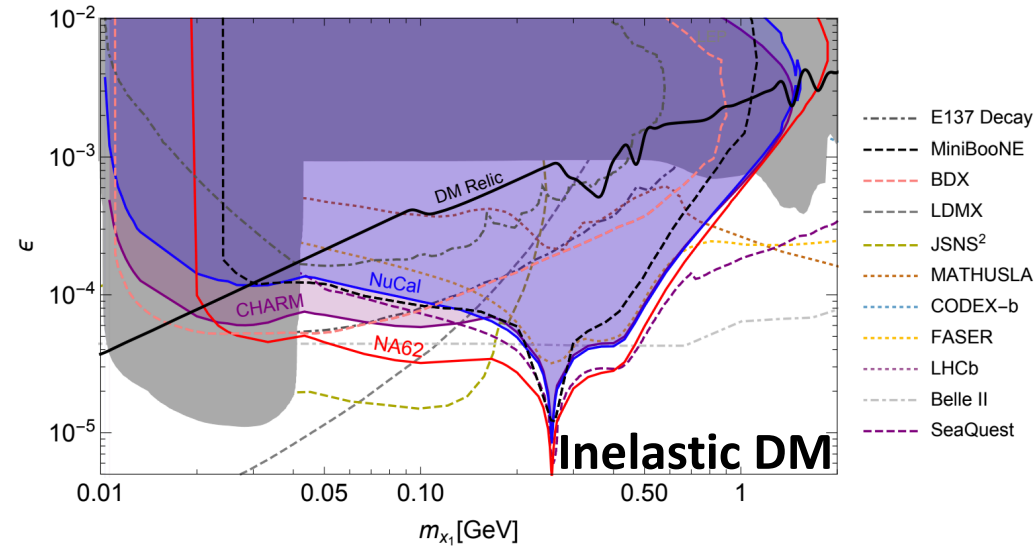
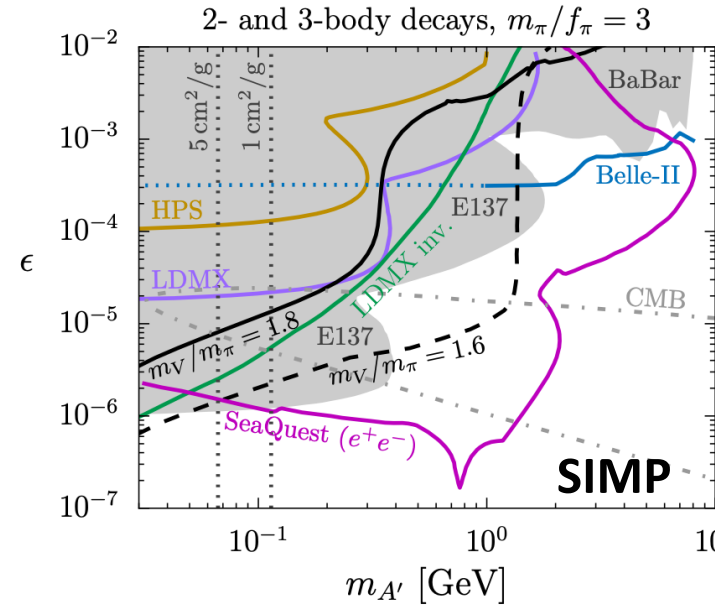
Plots from various sources:  
Batell, Berlin, deNiverville, Blinov, Evans, Gori,  
Toro, Tsai, Schuster et al.

Exploring several benchmark scenarios in  
full simulation for Snowmass:

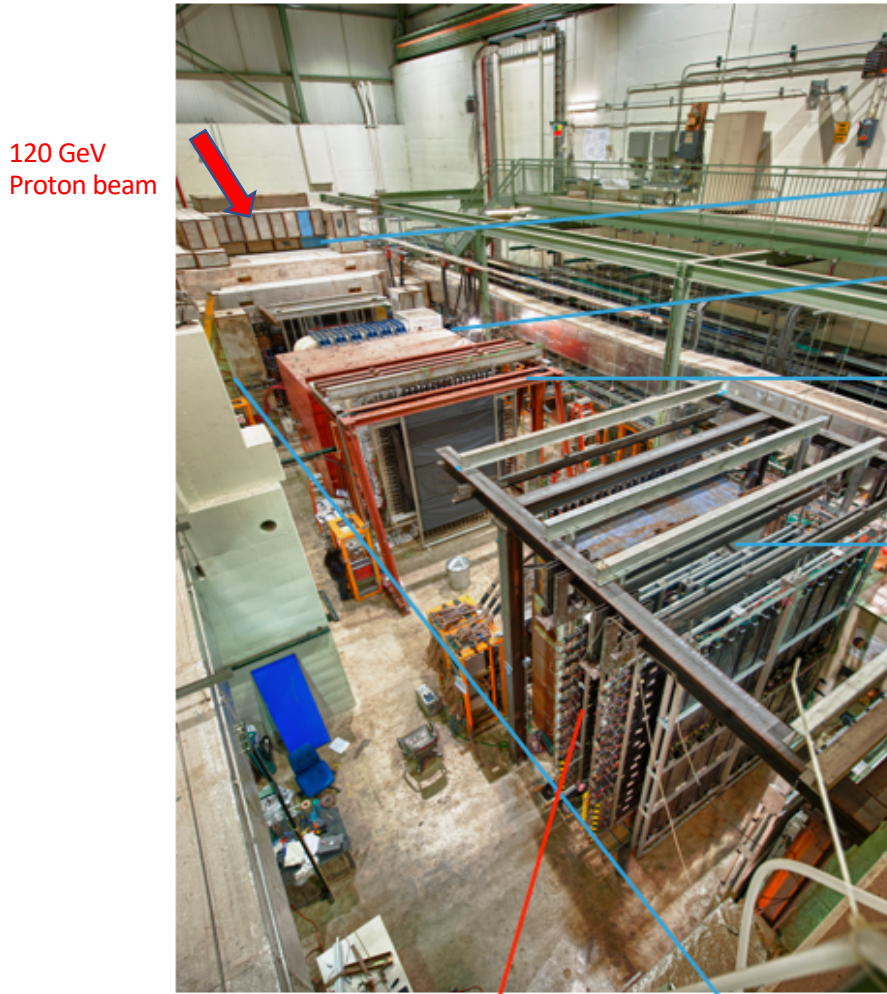
DarkQuest-I: 2023-2024, POT  $\sim 10^{18}$   
DarkQuest-II: 2026+, POT  $\sim 10^{20}$

Welcome to join us!

10/02/2020



# Readiness: Fully Working SpinQuest @NM4

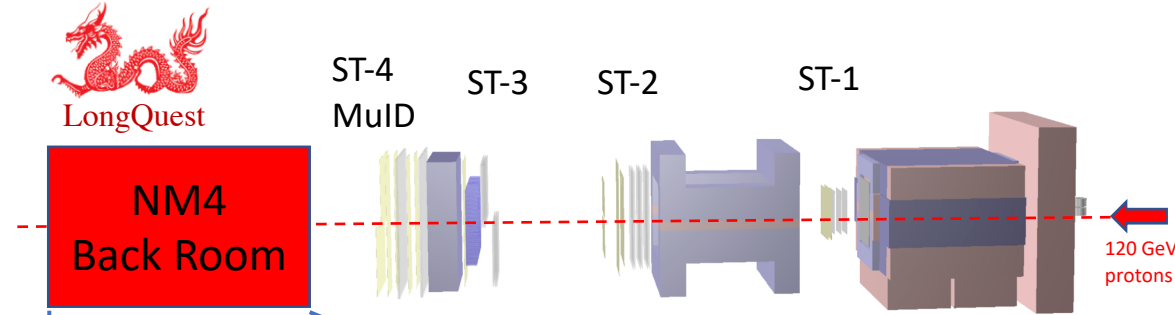


- Beam dump
- Magnet
- Drift chambers + Hodoscopes
- Muon ID

Beam Axis

**Possible EMCAL (~20m)**

**25m**



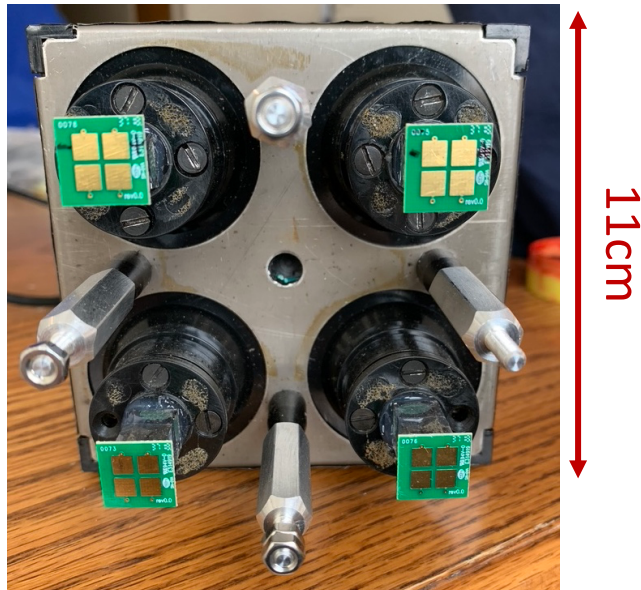
# EMCal R&D Status and Plan

- Test beam results from STAR (2019) confirmed performance
- Recycled PHENIX EMCAL modules in hand
- Build a prototype EMCAL (2 x 2 modules or larger ) to measure background in SPinQuest in 2021

## Recycle PHENIX EMCAL detectors:

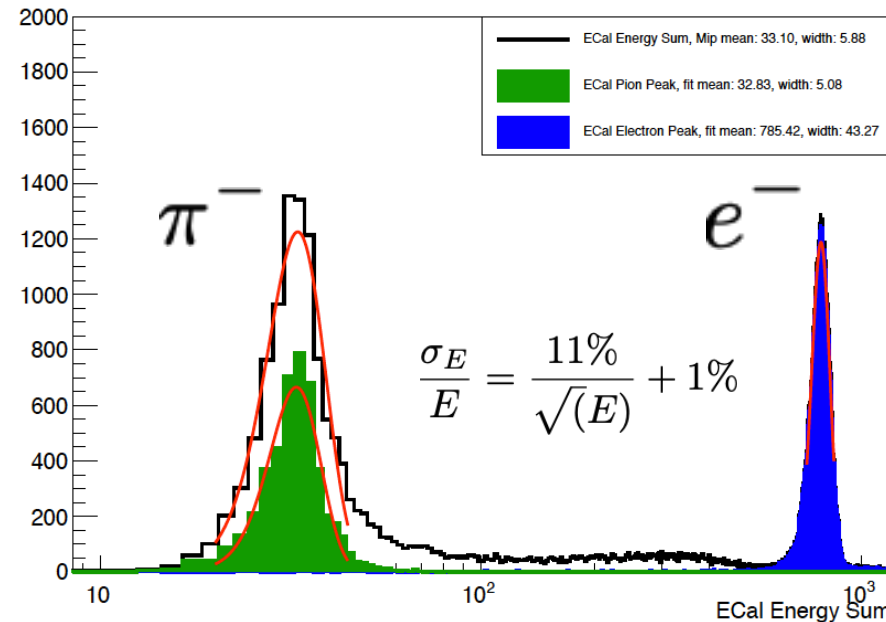
- 2 sectors available, 2m x 4m each
- One for DarQuest
- One for LongQuest in the backroom

PHENIX EMCAL module  
11cm

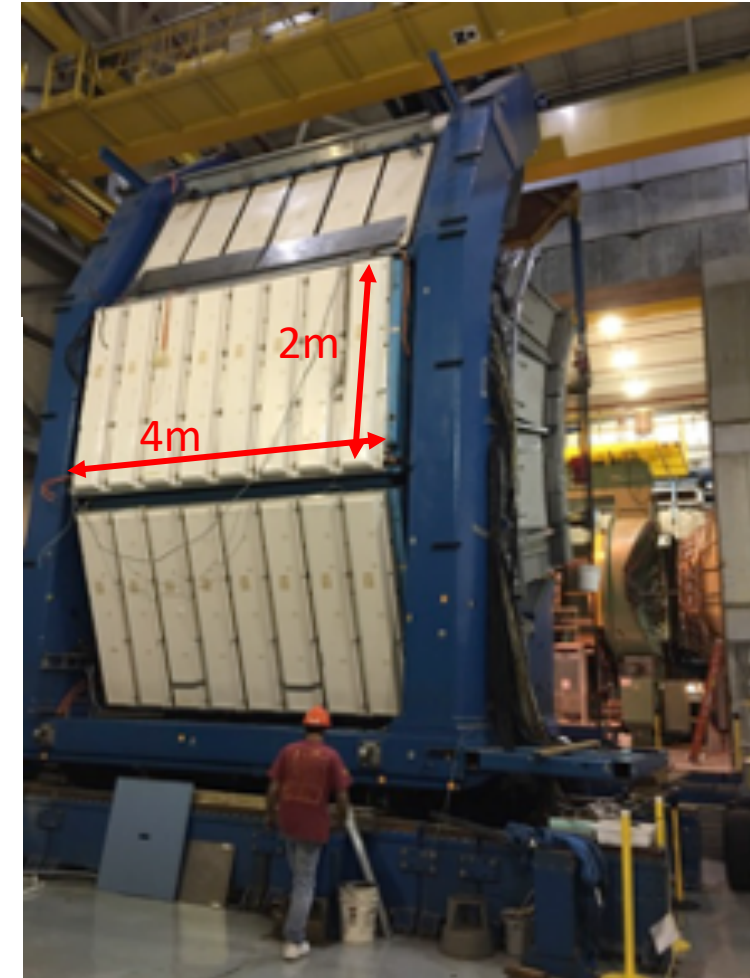


2019 Test Beam @Fermilab (STAR)

6 GeV,  $\pi^-$



Ming Liu, DarkQuest/LongQuest @Fermilab



- **Simulation of signal acceptance and reconstruction**
  - Dark photons, dark Higgs, ALP, RH-neutrino etc.
  - Exploration of signatures of new dark sector models and their connections to cosmology
  - Produce experimental sensitivity plots
- **Simulation of rare SM backgrounds**
  - e.g.,  $K_L^0$  for electron dark sector backgrounds
- **Study detector background with real data**
  - 2017 SeaQuest data for DP trigger and detector hit rates
- **Evaluate EMCal background for DarkQuest**
  - Build an EMCal telescope to study background rate in situ during SpinQuest run in 2021
- **Complete first LongQuest conceptual design**
  - e.g., milli-charged particles
- **Produce a technical report for the Snowmass Whitepaper**



# How Can Snowmass Help Us?

- **Build community support around (semi)visible dark sectors program**
  - Define benchmark models to provide good program coverage with potential milestones in parameter space
- **Further explore physics opportunities**
  - New ideas, new search channels and technologies
- **Join our effort on simulation and detector R&D**
  - Full GEANT detector simulations
  - Rare SM background study
  - EMCal integration – mechanical, readout and trigger
  - Additional detectors for new opportunities, PID etc.



# Backup slides

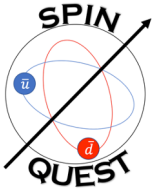
# Terminology

*Mod.Phys.Lett.A* 32 (2017) 10, 1730008; *Phys. Rev. D* 98, 035011 (2018); <https://arxiv.org/abs/1908.07525>



- **SeaQuest: (2012-2017)**

Official name for the unpolarized fixed target Drell-Yan experiment E906 at NM4 building. The primary physics goal is to study sea quark flavor asymmetry inside the nucleon,  $\bar{d}/\bar{u}$ .



- **SpinQuest: (2020-2022)**

A new official name for the polarized fixed target Drell-Yan experiment E1039 at NM4 building (using the previous SeaQuest/E906 dimuon spectrometer setup). The primary physics goal is to study the sea-quarks' Sivers' transverse single spin asymmetry



- **DarkQuest-I: (2023-2024+)**

Add an Electromagnetic Calorimeter (EMCal) in the main SpinQuest detector to search for Dark Sector Particles in both dimuon and di-electron channels, as well as di-photons

(shorter target-detector distance comparing to LongQuest)



- **DarkQuest-II/LongQuest: (2025+)**

Add a 2nd EMCal behind a 10 m iron block behind the SpinQuest main detector + other supporting detector/upgrades, including PID and tracking near the target

(longer target-detector distance, but low background + not interfering SpinQuest operation, possibly lower cost)

**Strong collaborative effort between experimental and theoretical groups to further develop the physics program**