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

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For the DarkQuest Working Group

BNL P5 Town Hall meeting

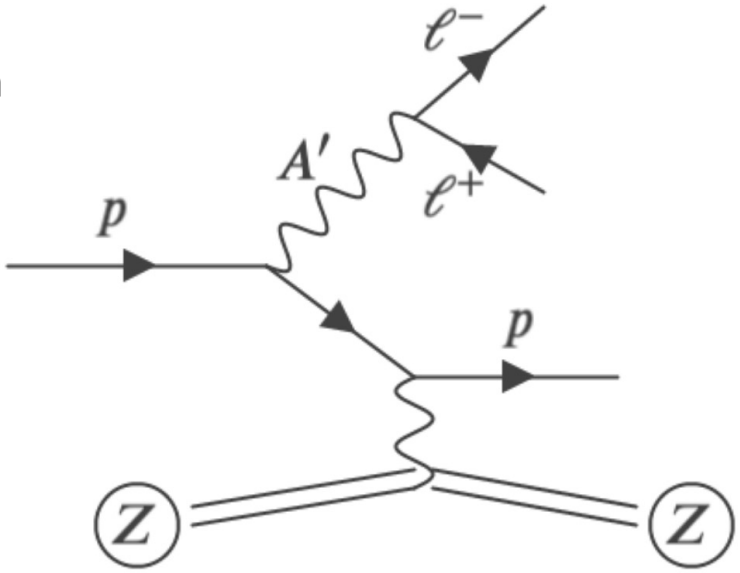
April 13, 2023

DarkQuest: Motivating a dark photon

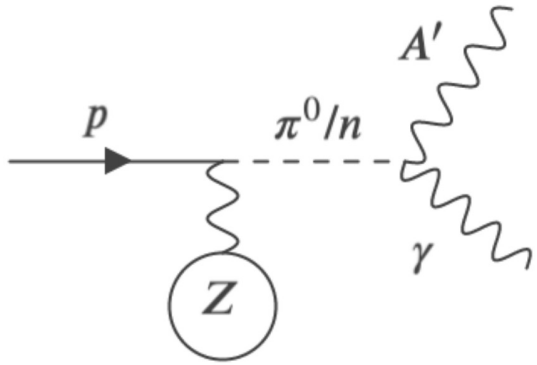
Theory papers inspiring this idea:
Dark forces at SQ: [1509.00050]
Dark Sectors at SQ: [1804.00661]

- As highlighted yesterday, a **dark sector** can give us thermal dark matter with mass below the Lee-Weinberg bound

A minimal **dark photon production** scenario:



Bremsstrahlung



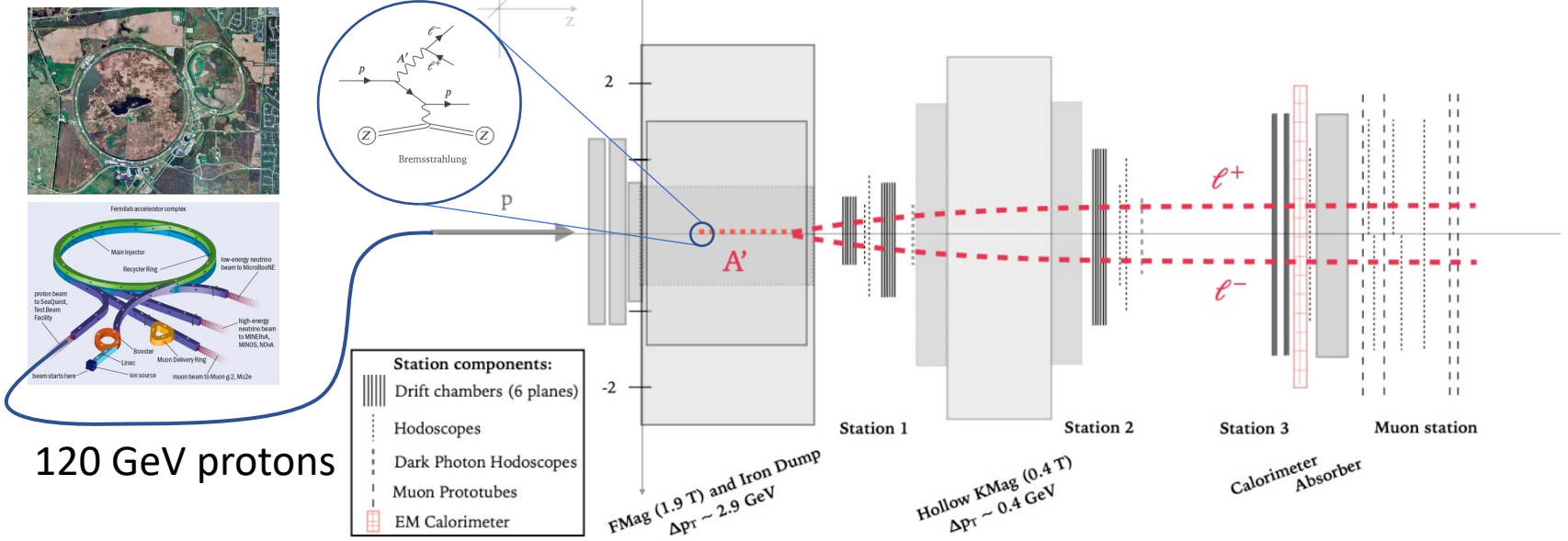
Meson production

Another production mechanism:
Meson decay

DarkQuest: An A’ production facility

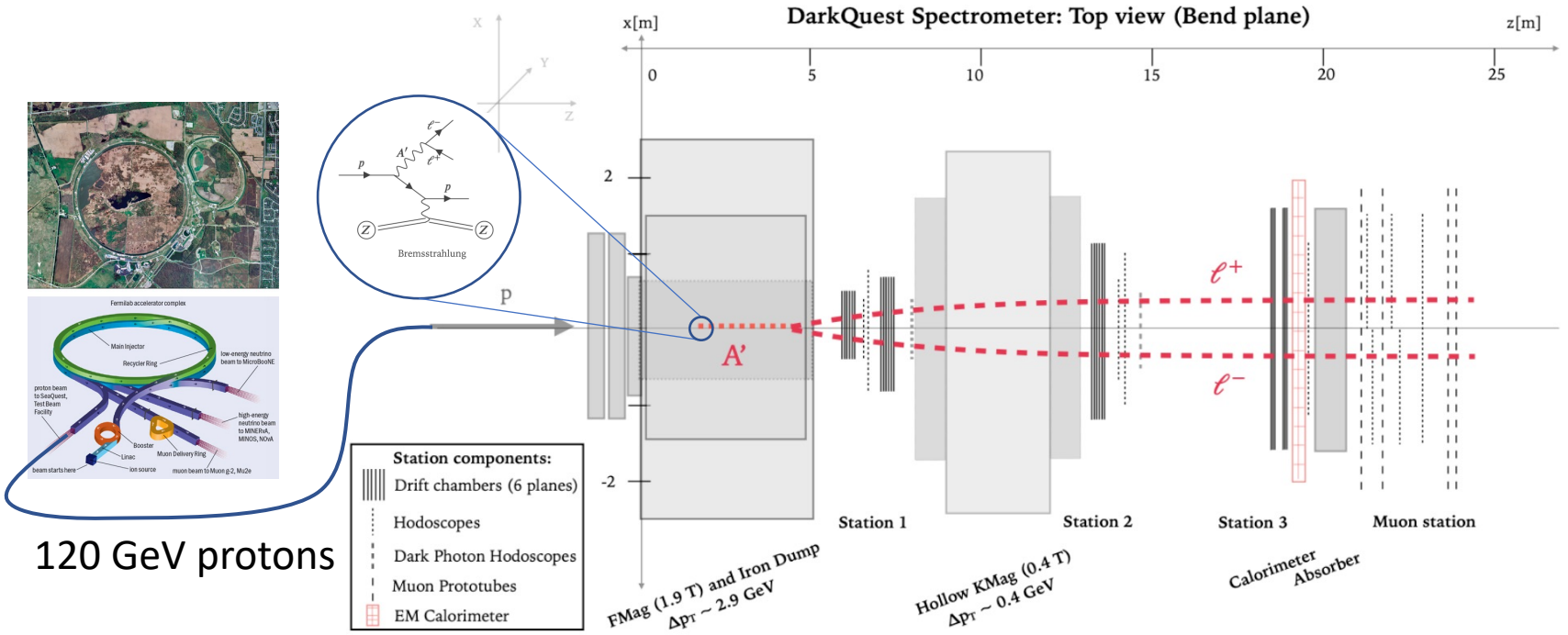
We can work *with* **SpinQuest**

- For this minimal scenario, **we need**:
  - High energy **proton beam**
  - Dense target/**shielding** that’s several meters thick
  - Lepton **spectrometer**



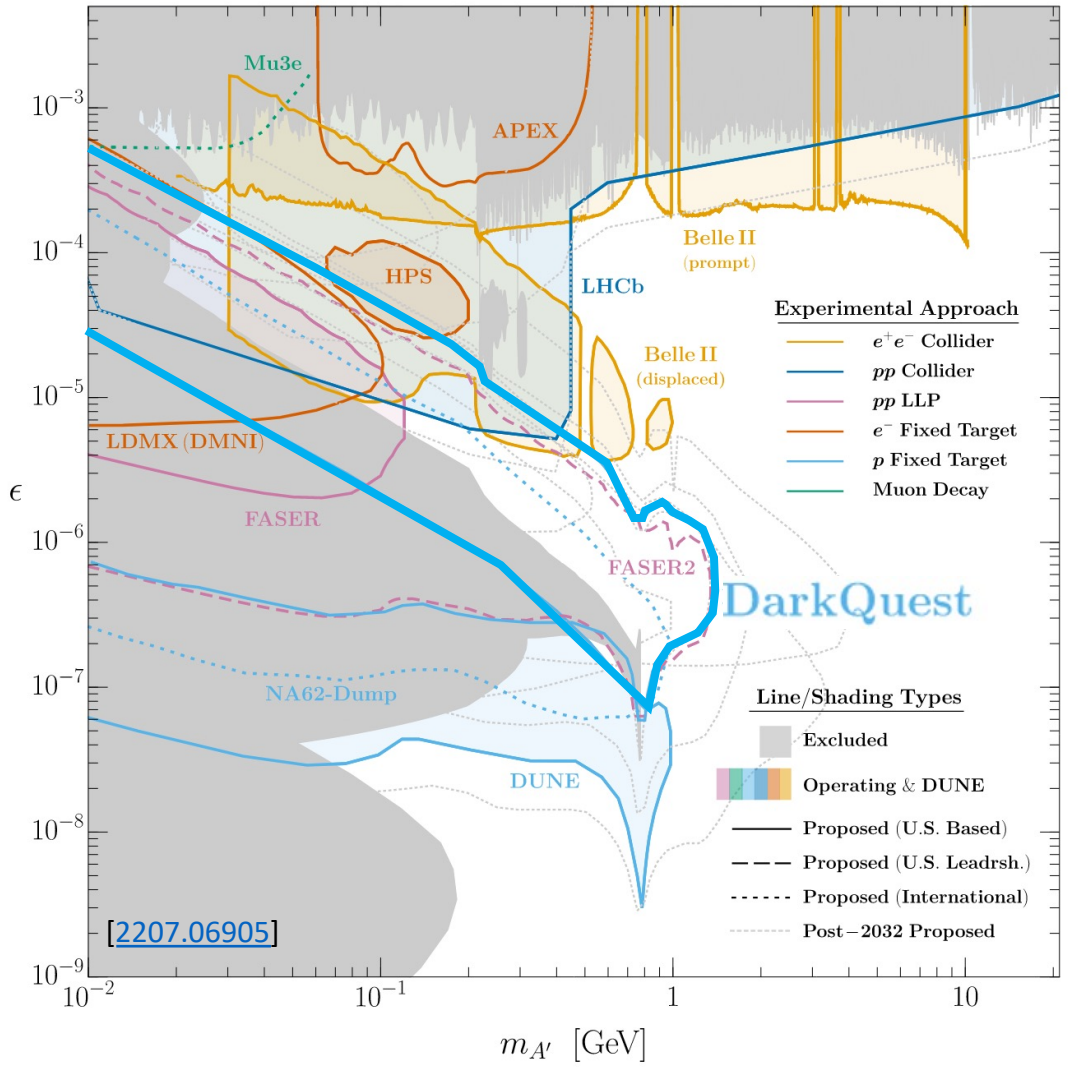
DarkQuest: A unique opportunity

- DarkQuest (DQ) Unique Features:
  - **Highest intensity** proton beam **in US** (with energy > 10 GeV)– we can reach $m_A, \sim \mathcal{O}(10)$ GeV
  - Uniquely **short baseline** with good shielding – can probe lifetimes $\mathcal{O}(.1-1)$m
  - Could reach $\mathbf{10^{18}}$ **POT by 2026**
  - Maintains SpinQuest's complimentary nuclear physics program



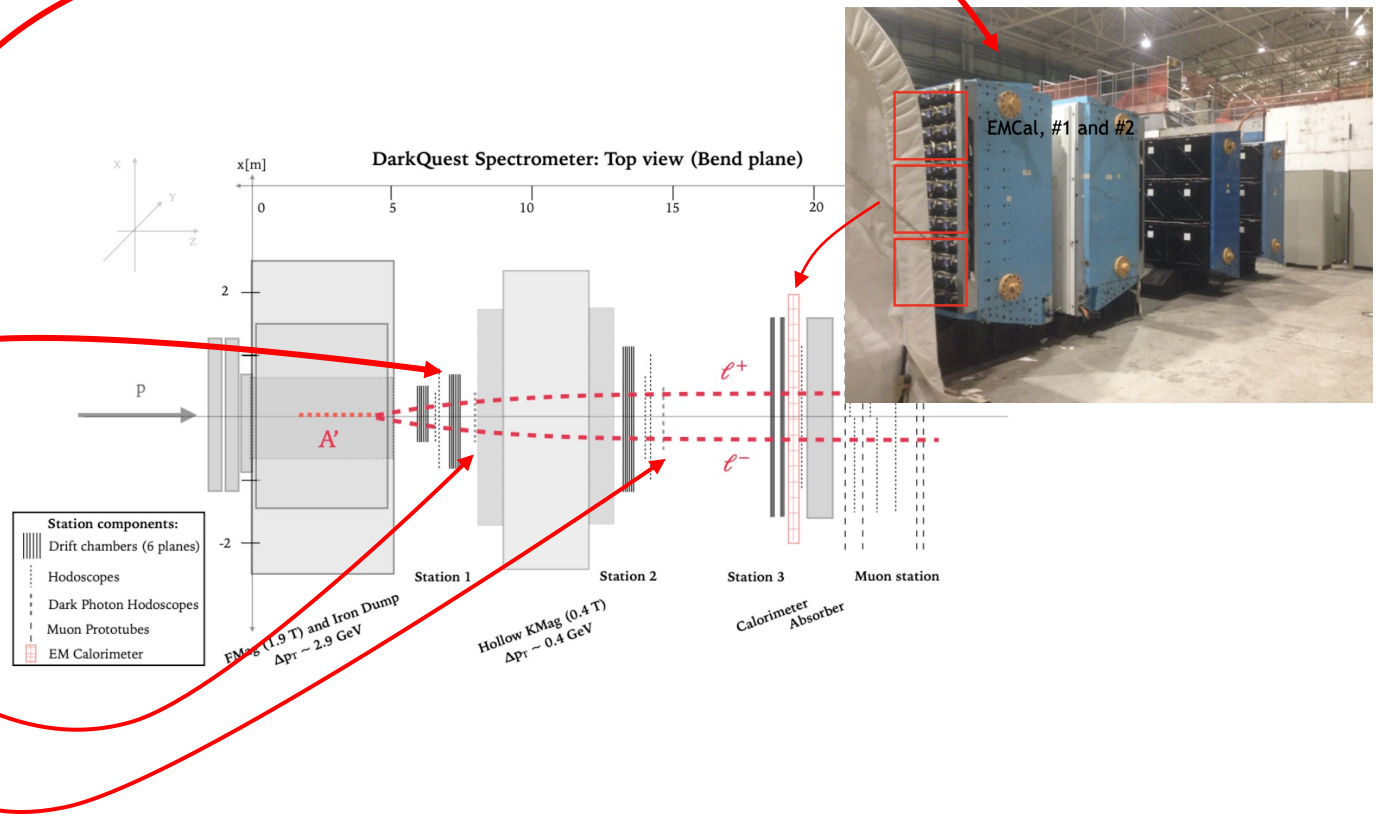
DarkQuest: Breadth for less

- See Stefania's talk from yesterday for more detail on physics goals of DQ and expected limits. We expect sensitivity to
  - **Dark photon visible portal** benchmarks
  - **SIMP** benchmarks
  - Muon-philic **scalars that modify g-2**
  - Different portals: scalar, vector, axion-like (by using different flavor pairs)
  - Electrons, muons, charged pions, photons, etc.



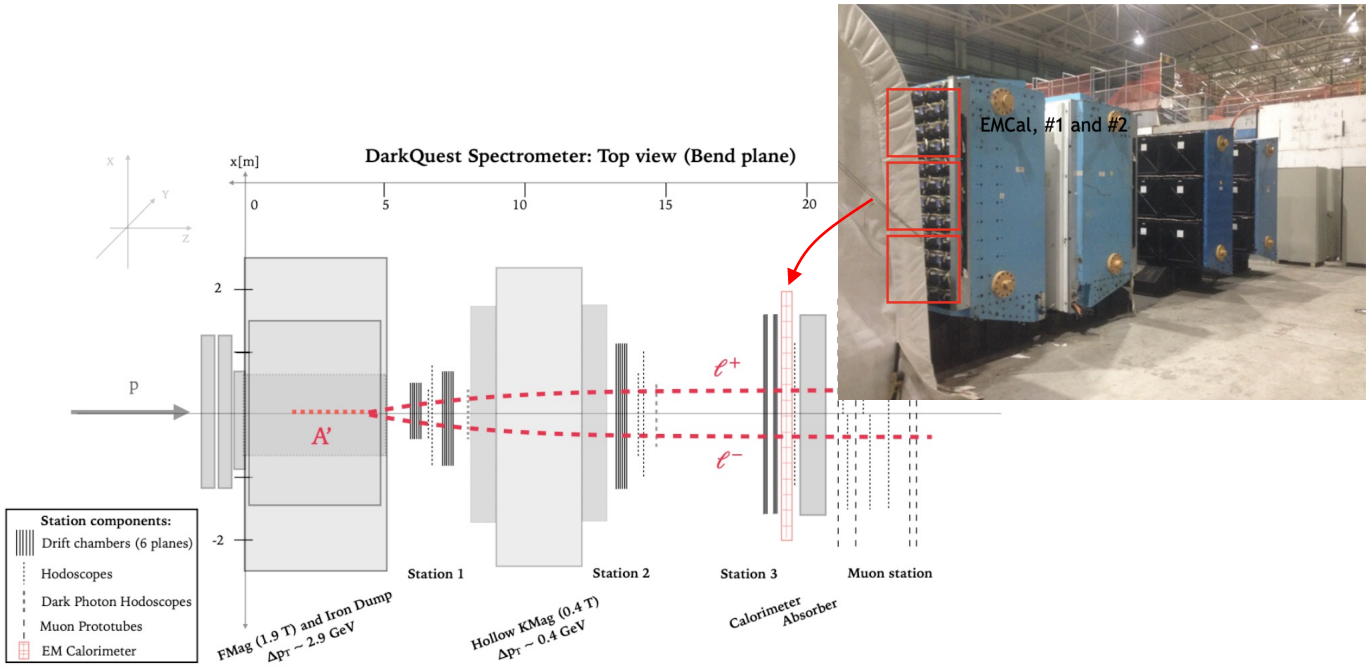
DarkQuest: The hardware

- Goals for DQ:
  - Add **decommissioned PHENIX EMCal** to **enable sensitivity to electrons** (+other visible signatures)
  - Add prop. chambers from finished experiment (HyperCP) to **increase detection baseline**
  - Use hodoscopes for **dark-sector-specific triggers**



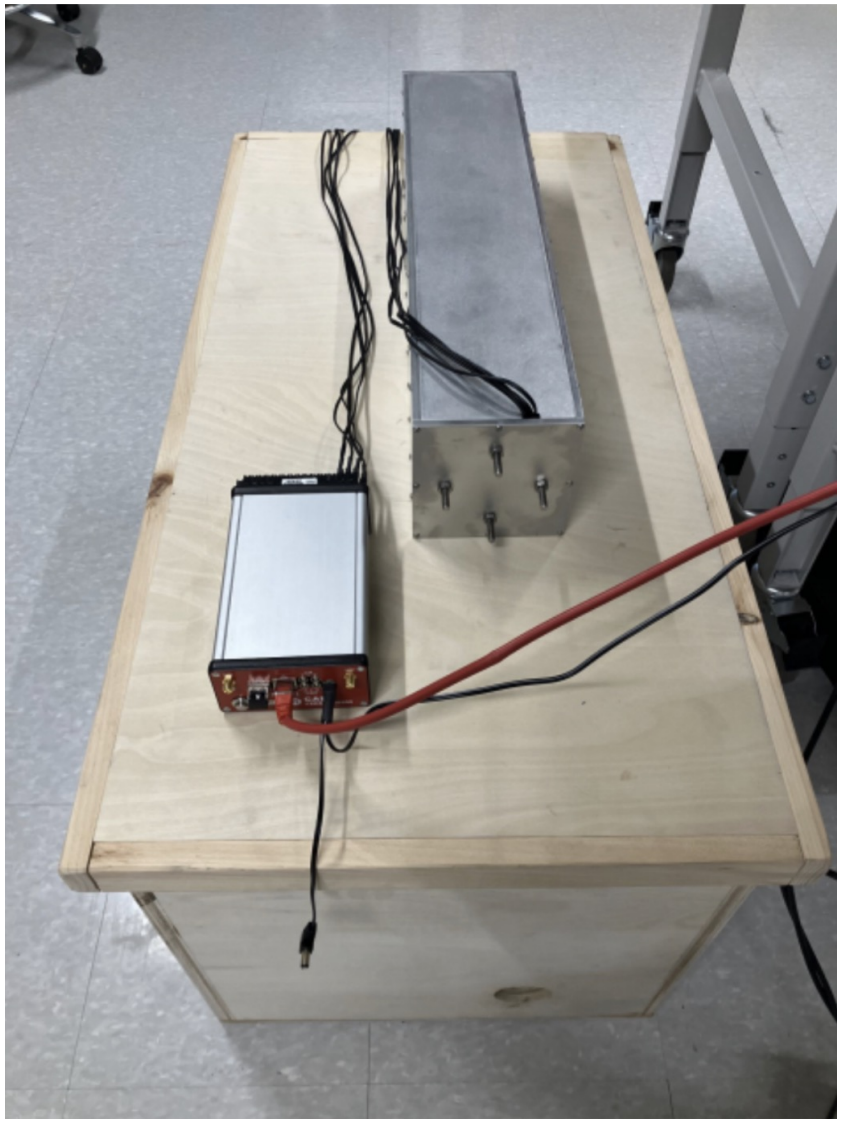
DarkQuest: Experimental Status

- **Core idea** of DQ: work with **existing experiment and detector components** to achieve **affordable experiment**. Have access to **new** dark sector parameter space **quickly** (~few year timescale)
  - E.g. should have a batch of new di-muon data later this year
  - Aiming to add EMCal soon
- This is a **US-based experiment!**
- Experimental to-do list:
  - Develop **EMCal readout and triggering** scheme
  - Create **reconstruction algorithms** for highly displaced vertices and for particle flavor tagging



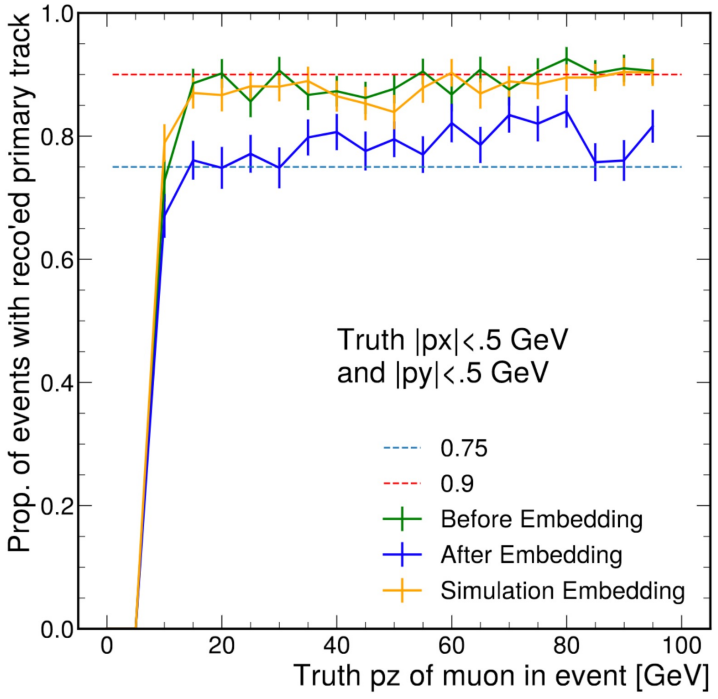
DarkQuest: Adding an EMCal

- We currently have a few calorimeter cells (lead tungstate+iron sampling calorimeter)
  - EMCal **test stand has been assembled** to test readout electronics
- Target: **install test stand** in experiment hall this year for testing and to measure background rates

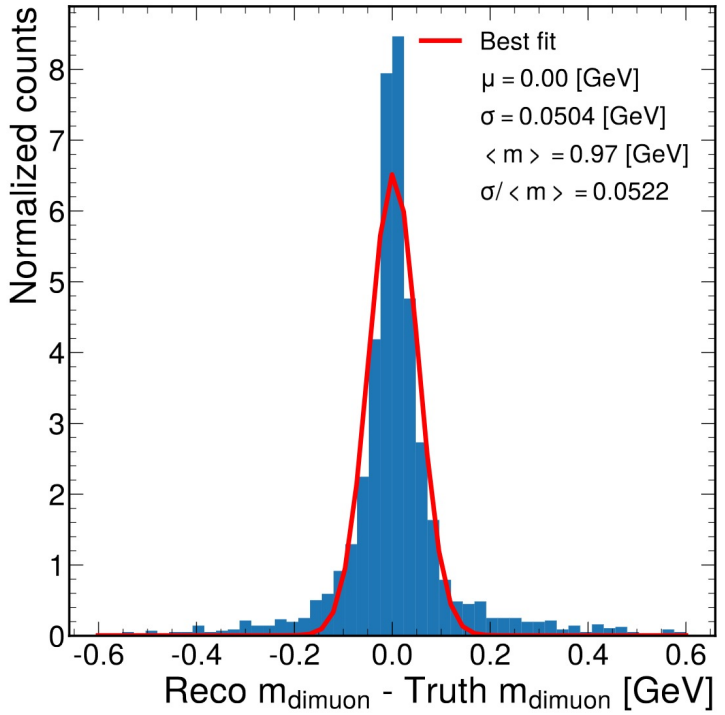


DarkQuest: New algorithms

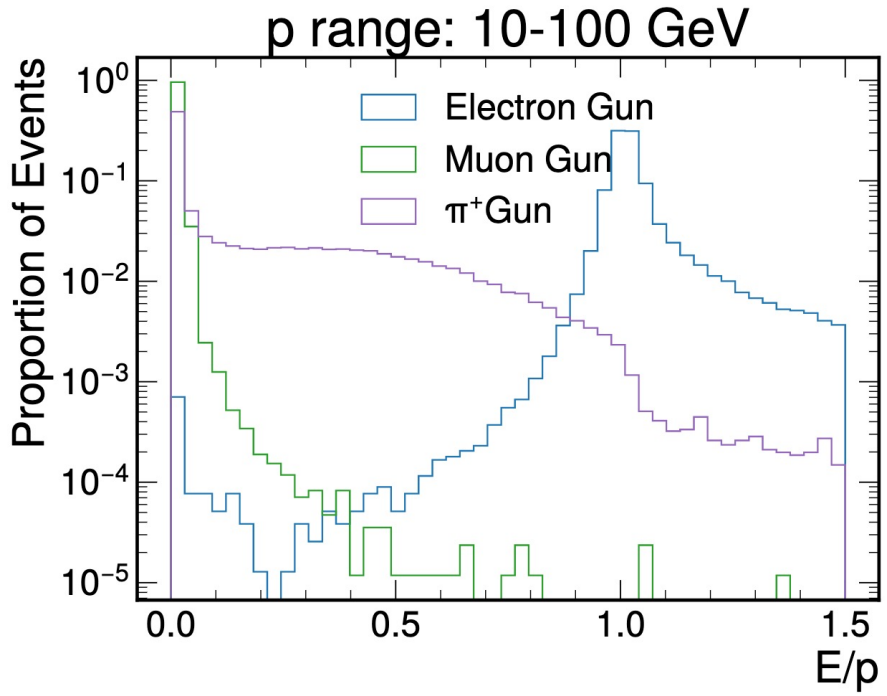
- Original SQ reconstruction software only designed to find di-muon events produced before iron block (DQ's target)
  - Significant rewrites of code!



Rewritten code can **find charged particles** created after iron block **with high efficiency**



We achieve **good di-muon mass resolution** (~0.05 GeV resolution)



Flavor tagging algorithm uses **EMCal cluster** energy & width information and **tracking information**

DarkQuest: Snowmass paper

- Please check out our Snowmass paper for more details!
  - https://arxiv.org/pdf/2203.08322.pdf
- We are a strong team of experimentalists and theorists
  - Has been a unique chance for early career scientists to gain experience on a small scale experiment
  - Please let us know if you have questions or are interested in contributing

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

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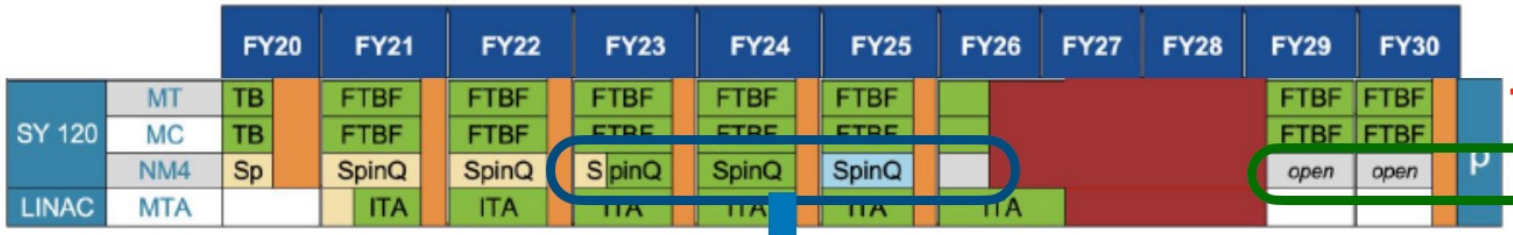
Backup

Proposed timeline*

*Taken from Stefania Gori's slides



SpinQuest — **SpinQuest & DarkQuest**

FY23 | **FY24** | **FY25** | **FY26**

- Simulation studies
- Trigger tests
- Electronic designs

Approved

Data taking for Spin physics & dark sector physics (muon channel)

- Adding tracking layers
- EMCal installation

Explore dark sector physics (all visible channels)

Proposed

~10^{18} POT

Budget: ~1.5M

Possible long term project ahead for Fermilab.

"A Booster replacement will enable the capability of the complex to serve precision experiments and searches for new physics with beams from 1-120 GeV"