High energy protons

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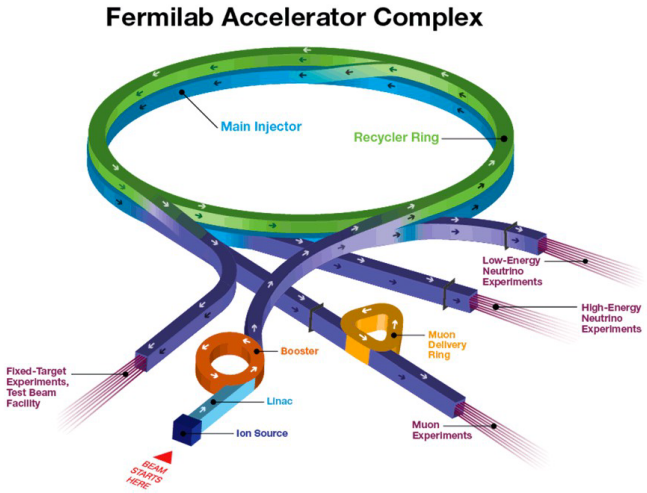
UC Santa Cruz

Booster replacement science opportunities meeting

Fermilab, May 19, 2020

The SeaQuest experiment



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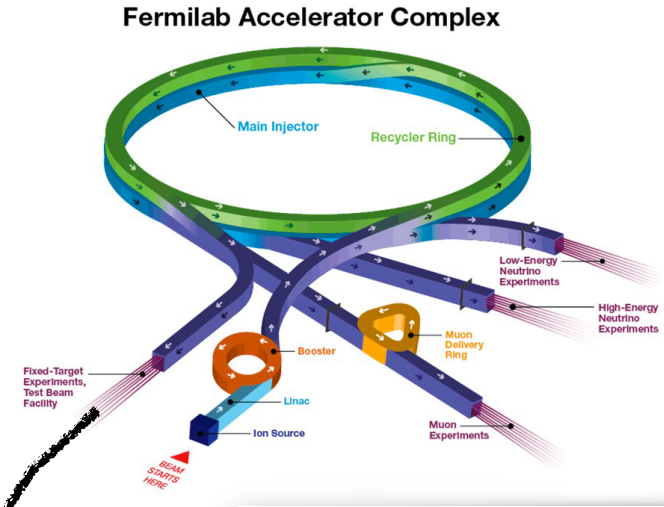
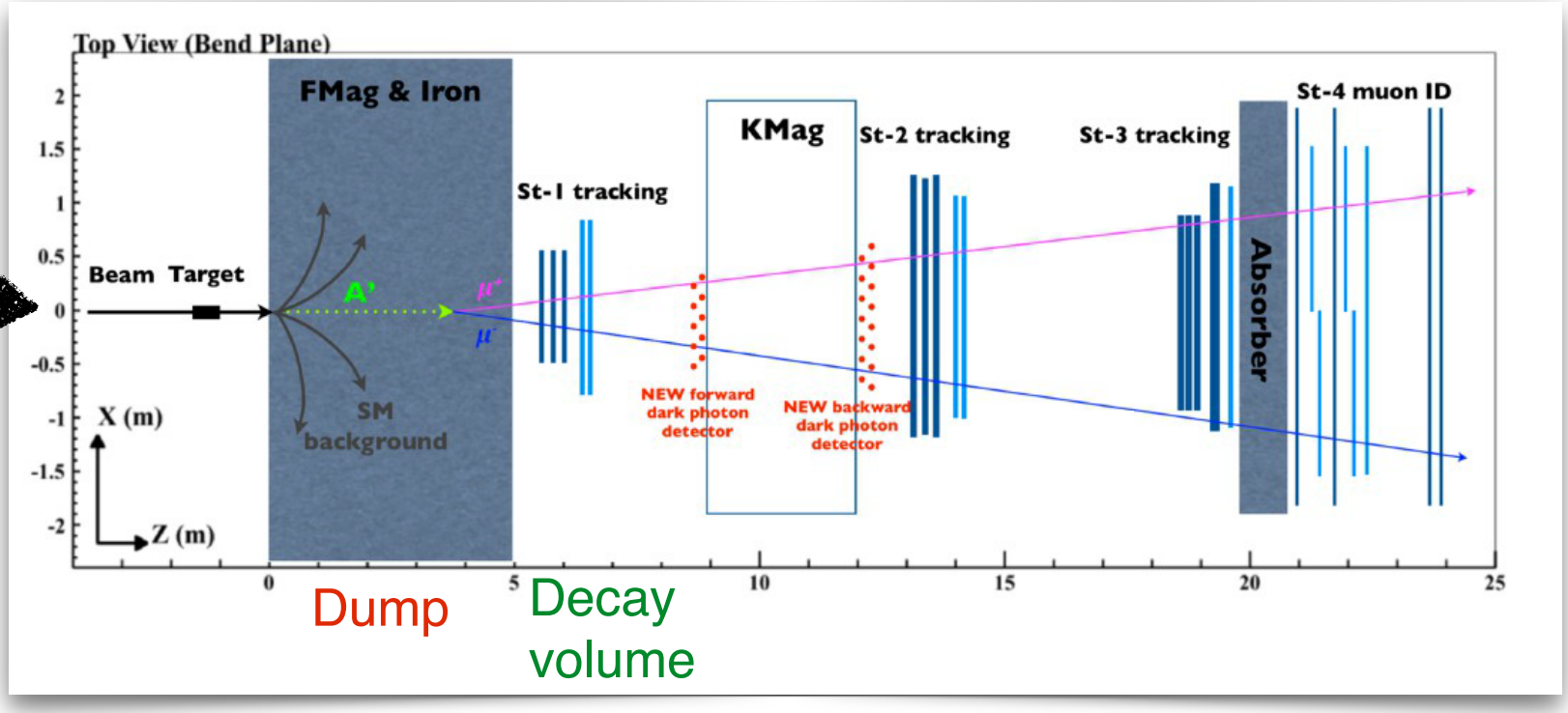


~ 5% main injector 120 GeV beam



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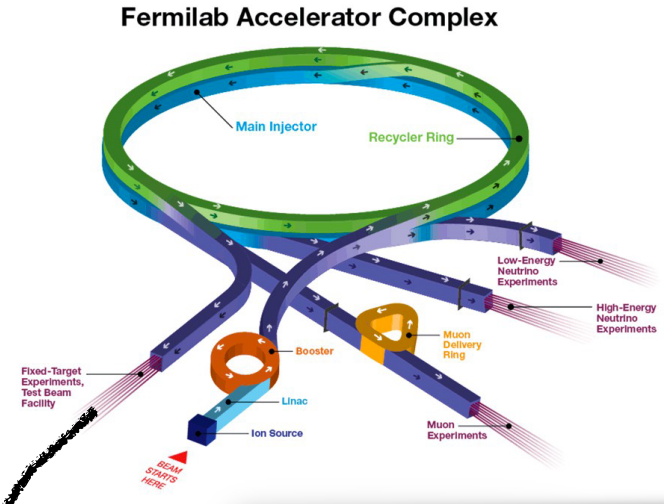

The experiment can look for:

1. **Prompt dark sector** particles
2. **Displaced dark sector** particles decaying into muons

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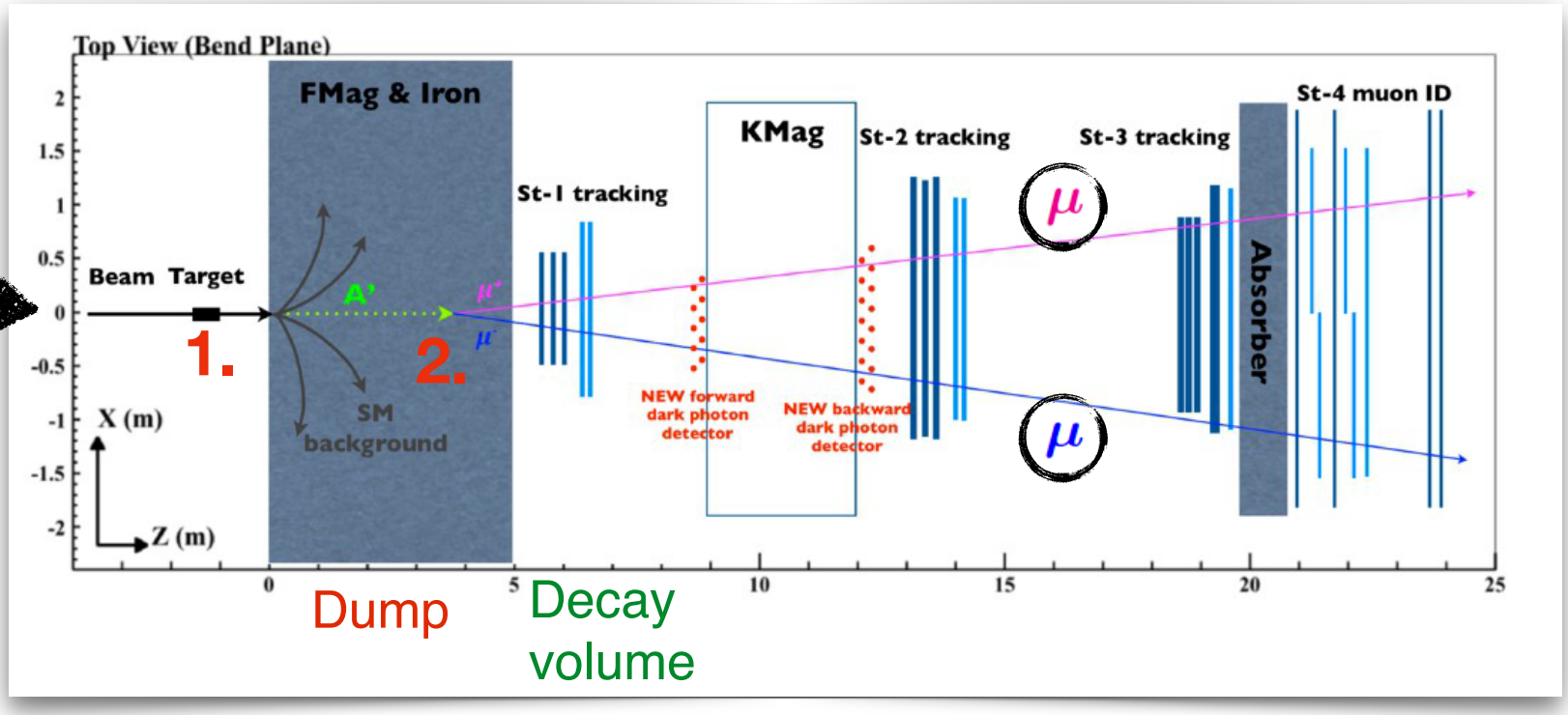
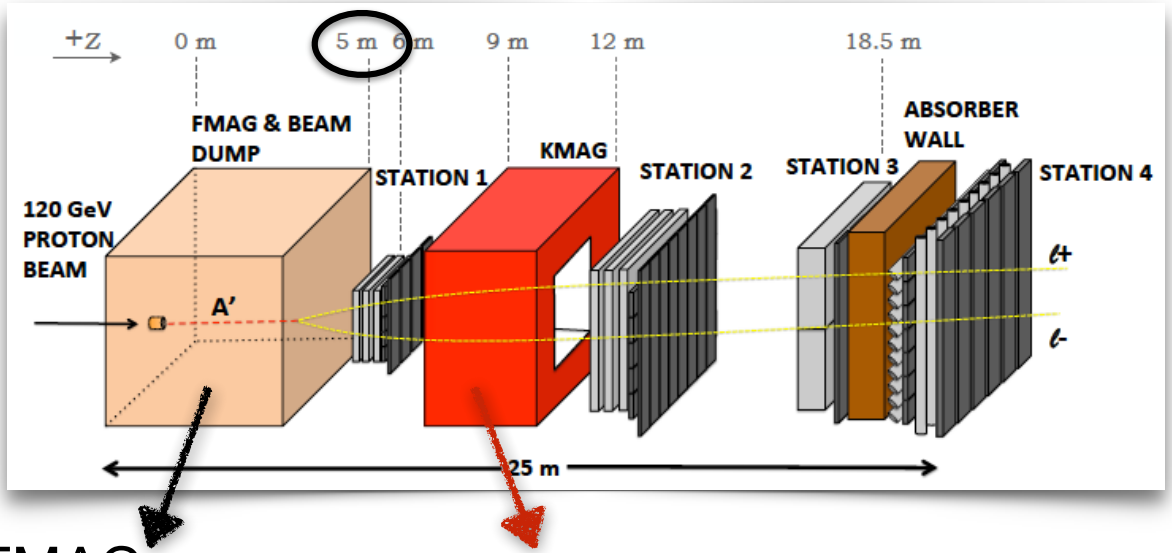


SeaQuest in a nutshell



1. Compact geometry

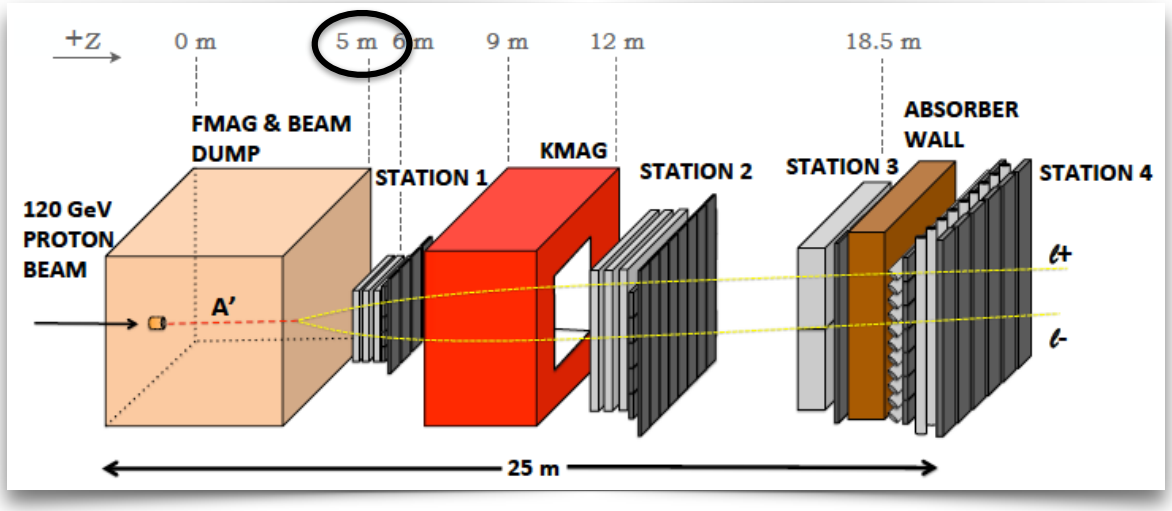
Sensitivity to (slightly) displaced dark particles with **d > 5m**

FMAG sweeps away soft SM radiation ($\Delta p_T \sim 2.9$ GeV)

2. KMAG separating even very forward muons ($\Delta p_T \sim 0.4$ GeV)

Identification of very light dark particles/squeezed spectra

SeaQuest in a nutshell



Unique setup

Experiment	Proton energy	POT	Dump	Decay volume	
SeaQuest	120GeV	10^{18}	5 m	10 m	
CHARM	400GeV	2.4×10^{18}	480 m	35 m	Past
LSND	800MeV	10^{22}	30 m	10 m	
NA62	400 GeV	10^{18}	100 m	250 m	Future
SHiP	400 GeV	10^{20}	65 m	125 m	

Key feature of high energy p-beams: huge production of dark particles

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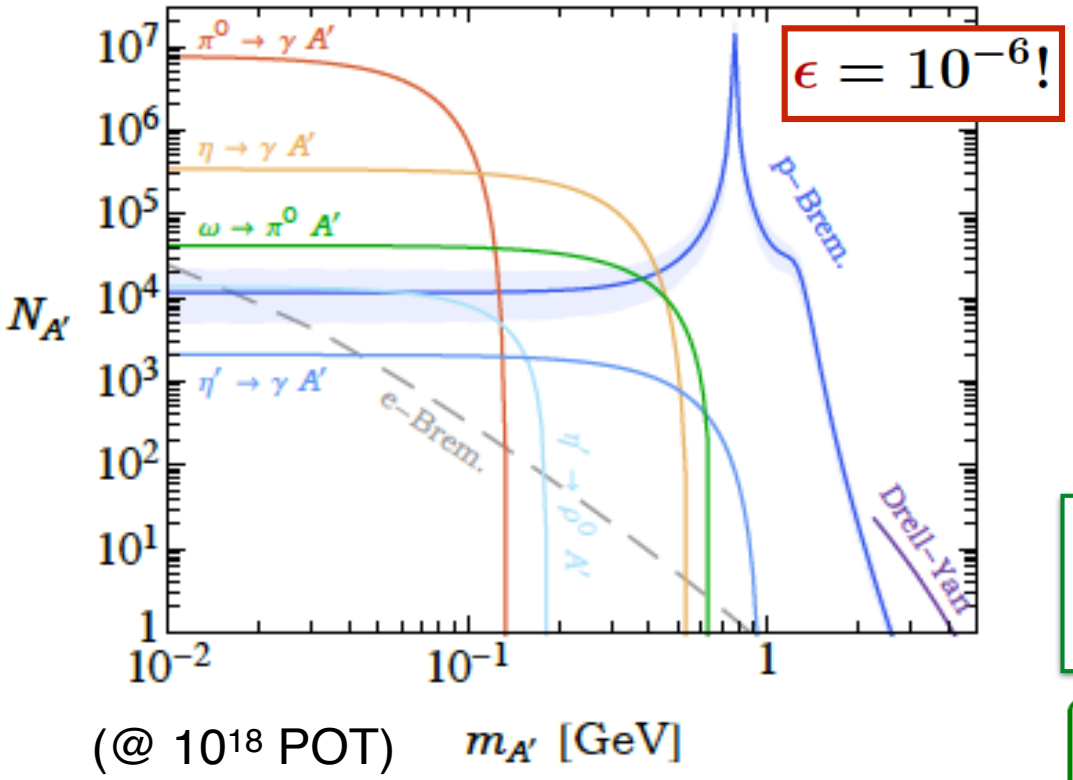
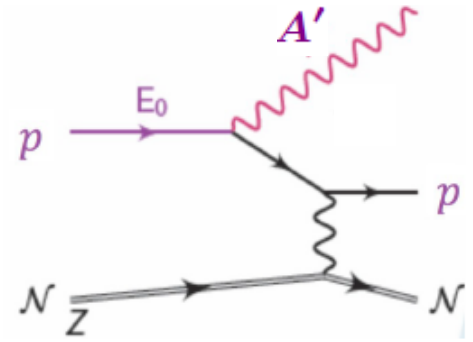
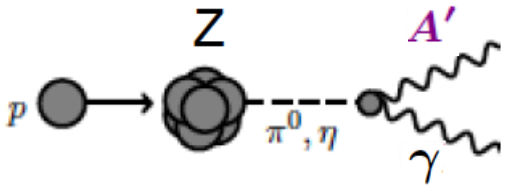
$\epsilon B^{\mu\nu} A'_{\mu\nu}$

Berlin, SG, Schuster, Toro, 1804.00661





brems-strahlung



meson decay

Generically larger rates than at electron fixed target experiments

$$N_{A'}(e\ \text{Brem.}) \sim \left(\frac{\epsilon}{10^{-6}}\right)^2 \left(\frac{m_{A'}}{\text{GeV}}\right)^{-2} \left(\frac{\text{EOT}}{10^{18}}\right)$$

$$N_{A'}(p\ \text{Brem.}) \sim 10^4 \times \left(\frac{\epsilon}{10^{-6}}\right)^2 \left(\frac{\text{POT}}{10^{18}}\right)$$

Visible decays of dark particles

Dark sector particles can generically decay to SM particles, producing visible signatures in our detectors

"portal interactions"

$$\epsilon B^{\mu\nu} A'_{\mu\nu}$$

$$\kappa |H|^2 |S|^2$$

$$y H L N$$

$$\frac{1}{f_s} F_{\mu\nu} \tilde{F}_{\mu\nu} a$$

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if the dark particle is the lightest particle of the dark sector:

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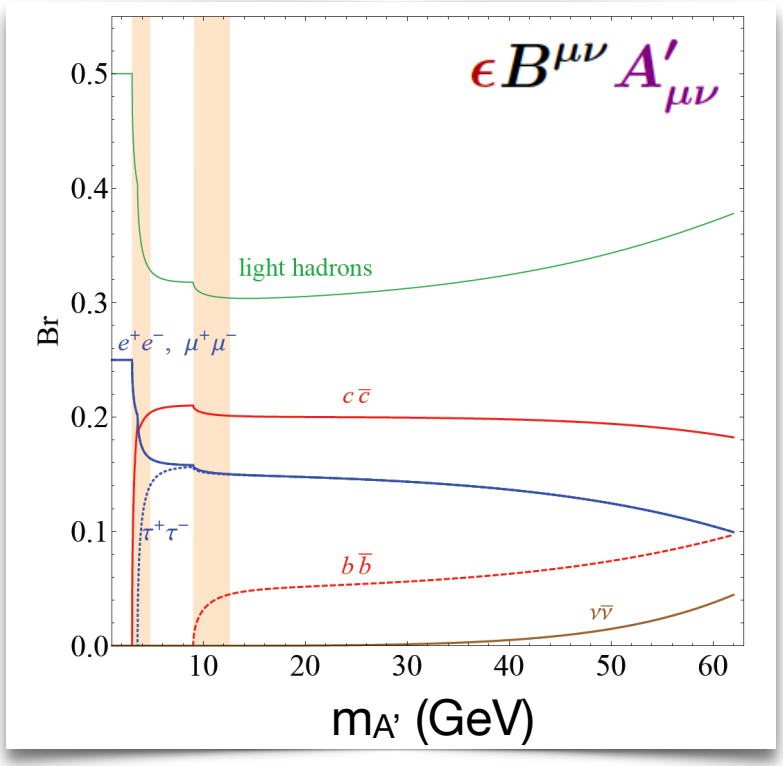
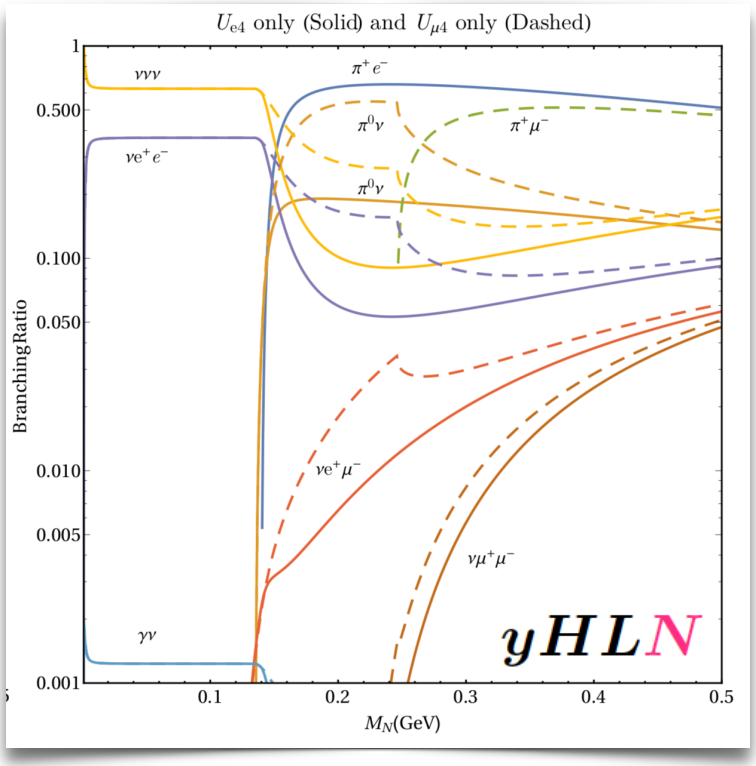
$\kappa |H|^2 |S|^2$

$yHLN$

$\frac{1}{f_s} F_{\mu\nu} \tilde{F}_{\mu\nu} a$





$\frac{1}{f_s} F_{\mu\nu} \tilde{F}_{\mu\nu} a$ ➡ a → γγ

DarkQuest upgrade

The SeaQuest experiment can be upgraded with the goal of capturing a large set of visible signatures (beyond 2 muons)

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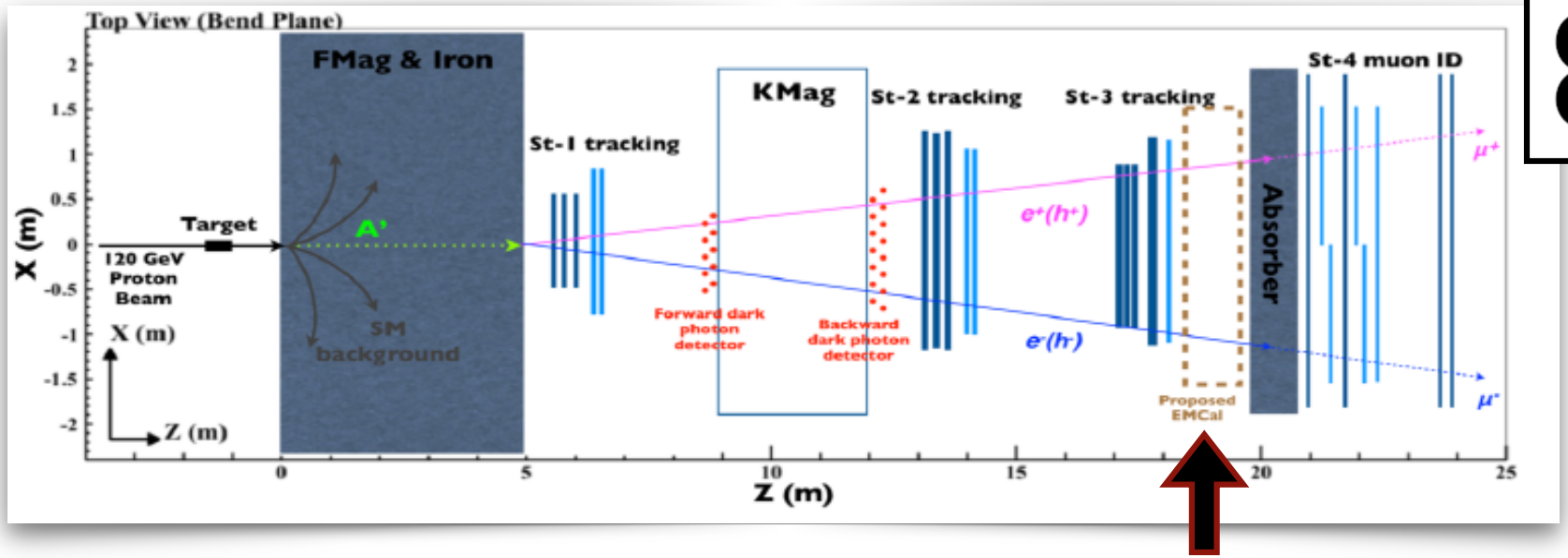
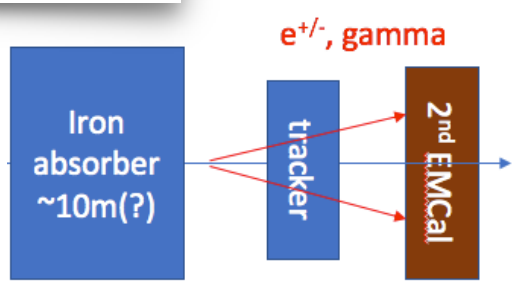


(*)

* Additional possible upgrades:

LongQuest (Tsai, deNiverville, Liu, 1908.07525)

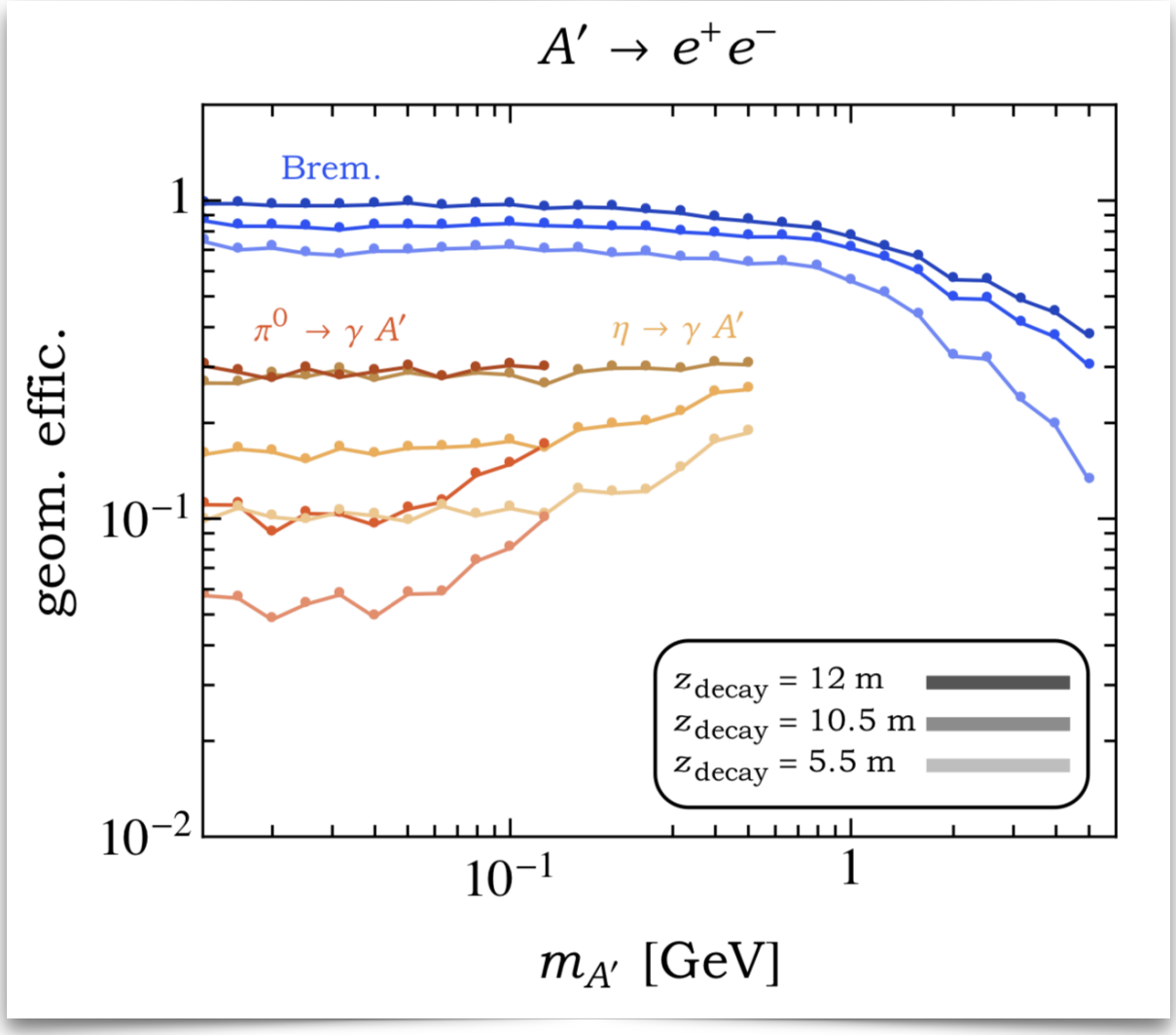
Introducing additional instrumentation after station 4 (*)



We are preparing a Snowmass'21 white paper (N.Tran et al.)

Please contact us if you are interested in joining! (sgori@ucsc.edu, ntran@fnal.gov)

High geometric acceptance…

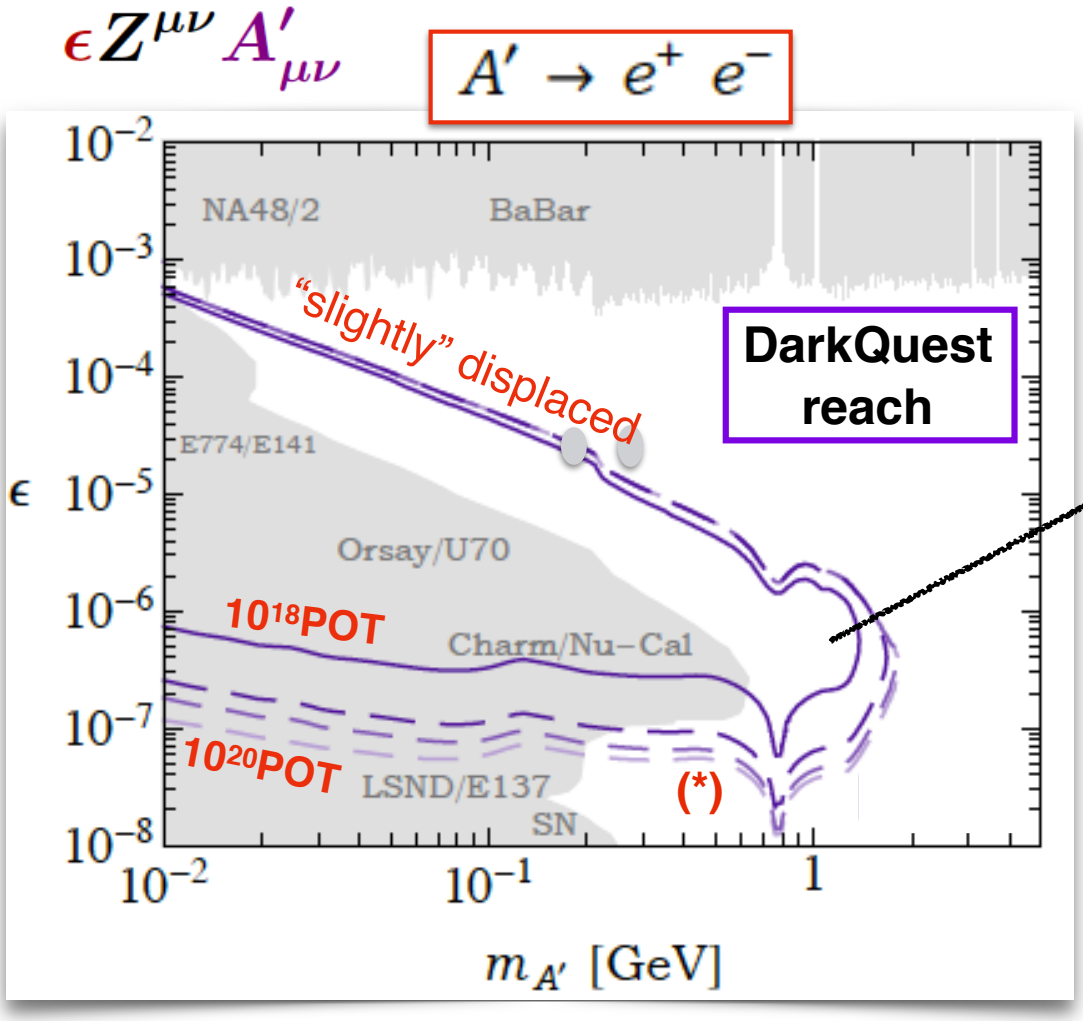


Berlin, SG, Schuster, Toro, 1804.00661

…thanks to
the relatively
compact geometry

Reach on dark photon models

Minimal model: pp → A' → e^+e^-



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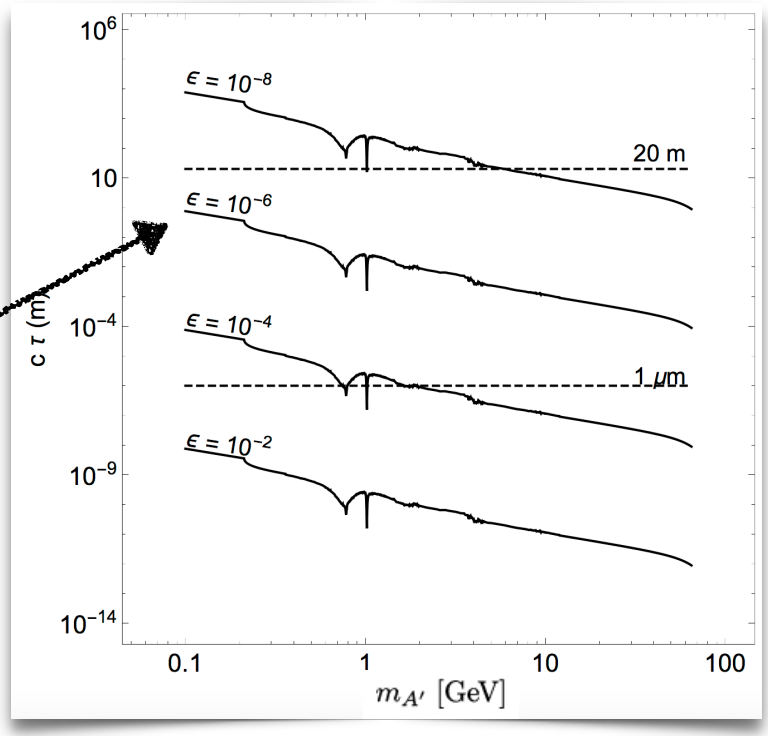

Curtin, Essig, SG, Shelton, 1412.0018

Reach on dark photon models

Example of a non-minimal model:

$pp \rightarrow A' \rightarrow X_1 X_2 \rightarrow e^+e^- X_1 X_1$

As realized e.g. in models of:

- Inelastic Dark Matter
- Strongly interacting Dark Matter

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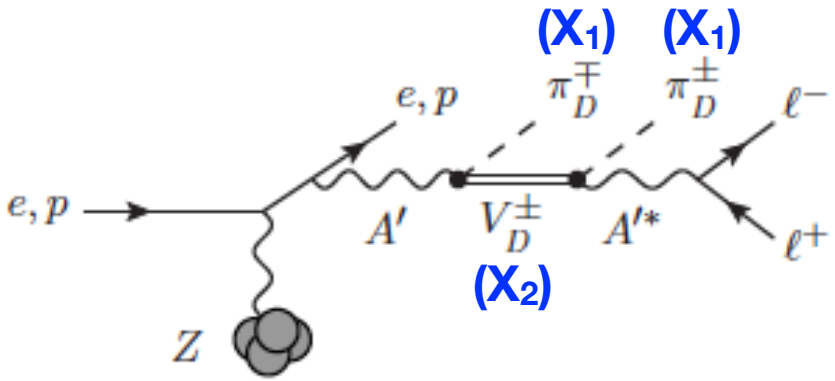

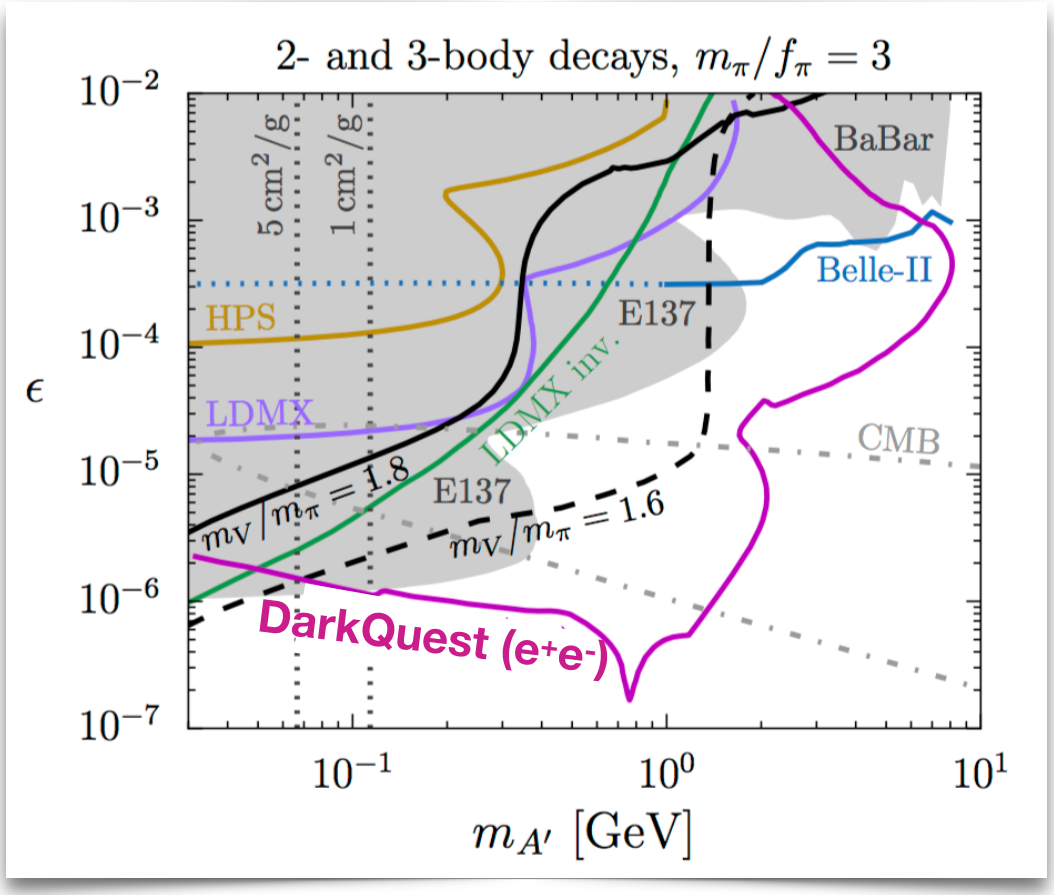

Berlin, Blinov, SG, Schuster, Toro, 1801.05805

Beyond dark photon…

Many additional dark particles can be tested up to O(GeV) masses.

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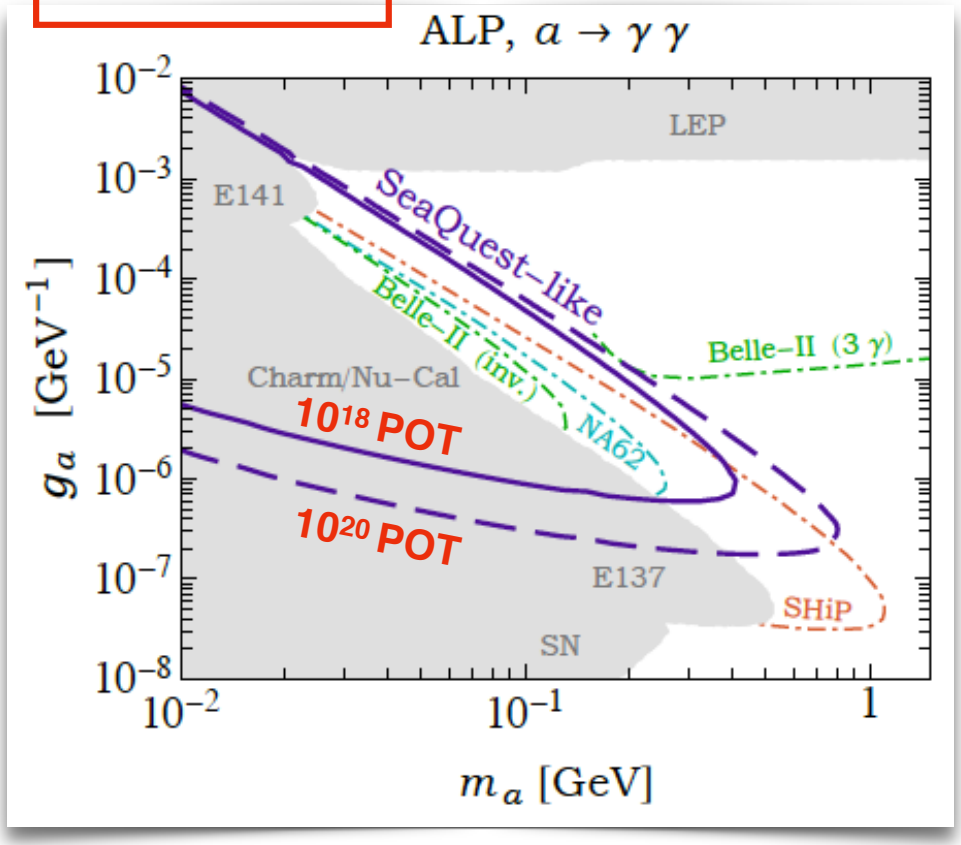
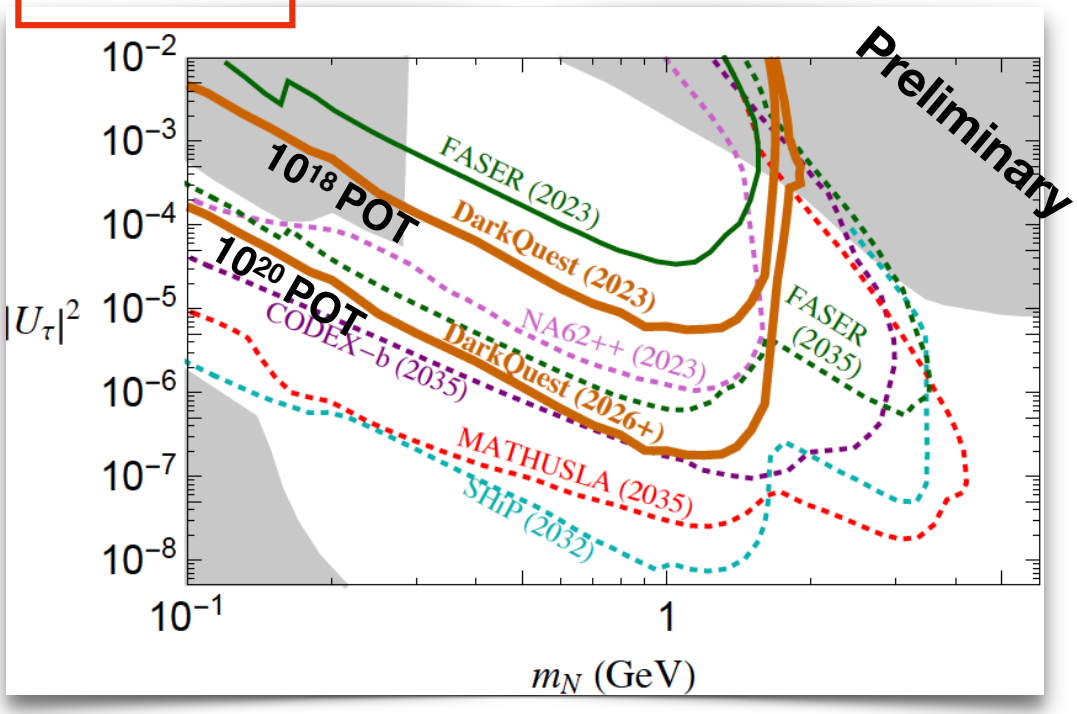
$g_a\, a\, F_{\mu\nu}\, \tilde{F}^{\mu\nu}$ **Axion-like-particles**



Berlin, SG, Schuster, Toro, 1804.00661

Y_τ H N L **Sterile neutrinos**



Batell, Evans, SG, Rai, to appear

Conclusions & Outlook

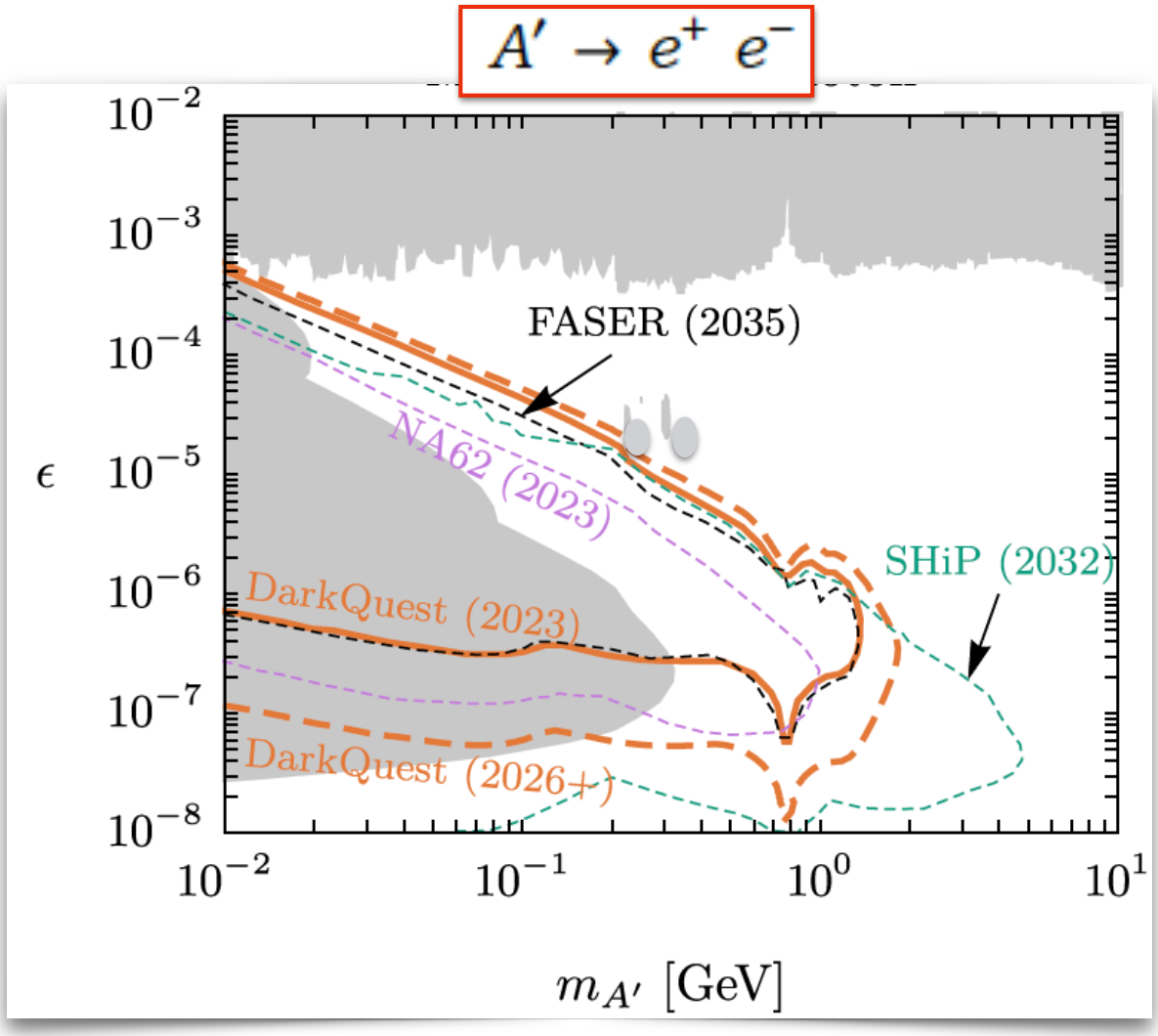
Interesting classes of Dark Matter models
at the **GeV scale** are still hidden to our experiments

Fermilab can cover a crucial role in the search
for GeV-scale dark sectors utilizing the high energy,
120 GeV, proton beam.

A “SeaQuest-like” spectrometer experiment can
test a large set of visible signatures.

DarkQuest: a very interesting opportunity to probe
long-lived visible dark particles.
High acceptance due to the compact geometry

Comparison with other proposed exp.



FASER:
Feng et al.,
1708.09389

NA62:
Lanfranchi
@ CERN-EPFL-Korean
theory institute

SHiP:
Alekhin et al.,
1504.04855