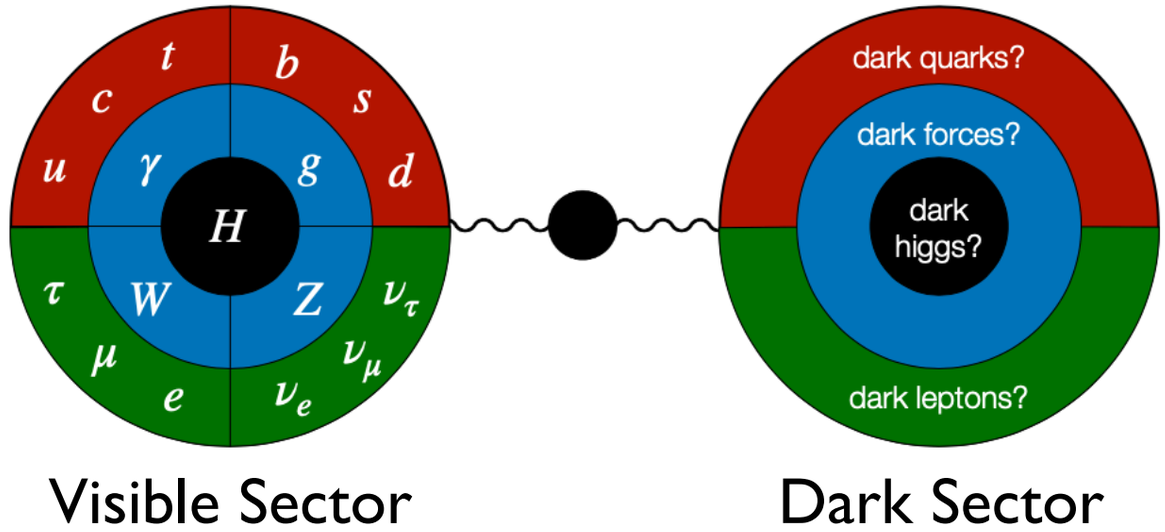
RF6 Big Idea 2: Exploring Dark Sector Portals at High Intensity Experiments

Brian Batell
University of Pittsburgh

with N. Blinov, C. Hearty and R. McGehee
arXiv: 2207.06905

Seattle Snowmass Summer Meeting 2022
July 17-26, 2022

RF6 - Dark Sector Studies at High Intensities



Visible Sector Dark Sector

<u>What is a Dark Sector?</u>

- Set of new particles which do not experience the known forces, but may be weakly coupled to visible sector through a mediator or "portal".

<u>Why Dark Sectors?</u>

- Dark matter may be a part of the dark sector, and dark sectors may play a role in addressing other outstanding puzzles (e.g., neutrino masses, matter-antimatter asymmetry, naturalness, …)

<u>Why High Intensities?</u>

- High intensities allow to probe weak portal couplings, and there is great potential to discover dark sectors and discern their structure with new searches and experiments in the coming years.

RF6 “Big ideas” solicited papers

- Organization around science goals/questions.
- Arrange the breadth of RF6 science so that all the main techniques have a chance to shine.
- Span ≳95% of white-paper interests

1. Detect dark matter particle production (production reaction or through subsequent DM scattering), with a focus on exploring sensitivity to thermal DM interaction strengths.
Editors: Gordan Krnjaic, Natalia Toro

2. Explore the structure of the dark sector by producing and detecting unstable dark particles: Minimal Portal Interactions.
Editors: Brian Batell, Nikita Blinov, Chris Hearty, Robert McGehee

3. New Flavors and Rich Structures in Dark Sectors.
Editors: Phil Harris, Philip Schuster, Jure Zupan

4. Experiments/facilities/tools
Editors: Phil Ilten, Nhan Tran

Slide from Stefania Gori

Big Idea 2 in broader context

- These studies build on previous community studies, including (i) Dark Sector 2016, (ii) US Cosmic Visions New Ideas in DM, (iii) CERN Physics Beyond Colliders.

- DOE OHEP DMNI calls out priority research direction "*Create and detect DM particles below the proton mass and associated forces, leveraging DOE accelerators that produce beams of energetic particles*" with Thrust 2 *"Explore the structure of the dark sector by producing and detecting unstable particles"*

Process

- Organizational / planning meeting for Big Idea 2 whitepaper in January
- First draft circulated to RF6 Slack on May 4 for feedback
  - Several requests for additional curves and scheme to differentiate curves
  - Some deliberation on how to best define theory targets
- Additional summary plots created to emphasize high level RF6 objectives
- Final draft circulated to RF6 Slack on July 12, and submitted to arXiv few days later.

Scope of Big Idea 2 - Minimal Portals

- Minimal renormalizable and axion-like particle (ALP) portals:

$\frac{\epsilon}{2\cos\theta_W} F'_{\mu\nu} B^{\mu\nu}$	Vector Portal
$(A\,S + \lambda\,S^2)\,H^\dagger H$	Higgs Portal
$yNLH$	Neutrino portal
$c_{\gamma\gamma}\frac{\alpha}{4\pi}\frac{a}{f}F_{\mu\nu}\widetilde{F}^{\mu\nu}\,,\quad c_{GG}\frac{\alpha_s}{4\pi}\frac{a}{f}G^a_{\mu\nu}\widetilde{G}^{a,\,\mu\nu}$	ALP Portal

- Assume other dark sector states are heavier than the mediator, which implies a simple mass — coupling parameter space

- The mediator is produced and decays back to visible SM final states through the same portal coupling (mediator can be prompt or displaced / long lived)

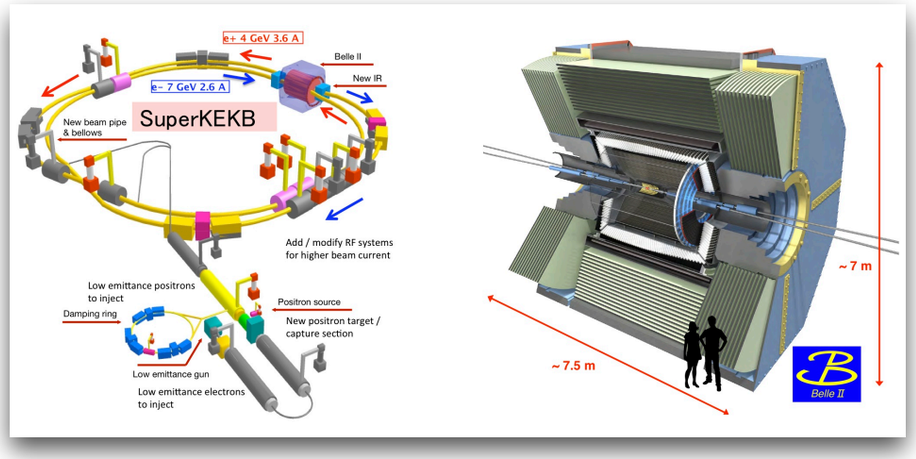
- There are other possibilities for the mediator and portal. Some of these are considered in Big Ideas 1 and 3.

Key Takeaways from the Big Idea 2 Whitepaper

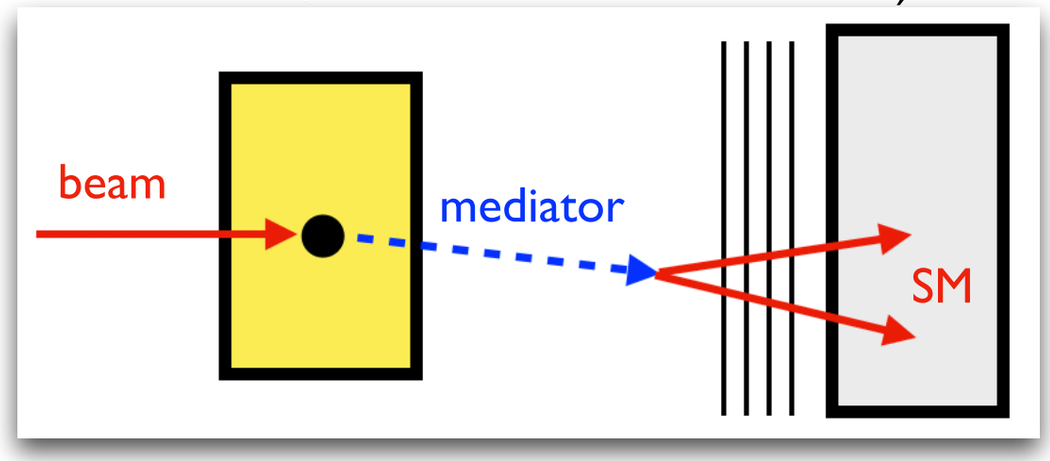
- The minimal portals are well motivated from various perspectives and provide key targets for experiments:
  - Portal scheme is motivated by bottom-up EFT logic
  - Thermal relic dark matter can be realized over a wide range of mediator masses and couplings
  - Minimal portals commonly appear in top-down solutions to the big questions (seesaw mechanism, baryogenesis, twin Higgs, relaxion, light inflaton, QCD axion,…)
- A variety of search techniques, experiments and facilities are required for to probe the broadest range of models and parameter space
- There are exciting opportunities in the near term and in the future to discover or explore uncharted territory in these models
- US scientists and institutions can provide key leadership in this enterprise. This requires continuing support for existing experiments and facilities, investments in new experiments, and promoting dark sector theory

Experimental approaches

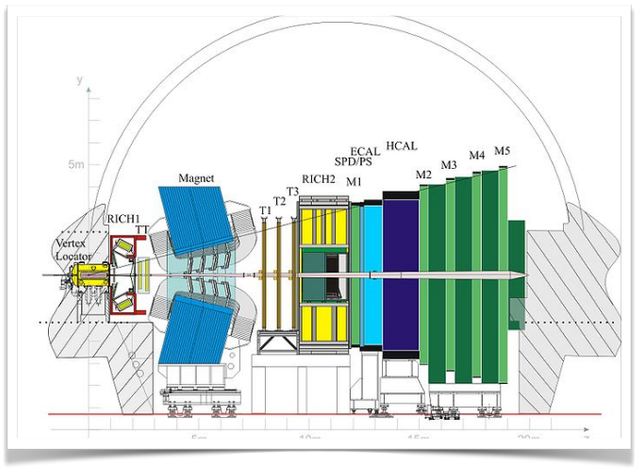
e^+e^-colliders (e.g., Belle II, …)



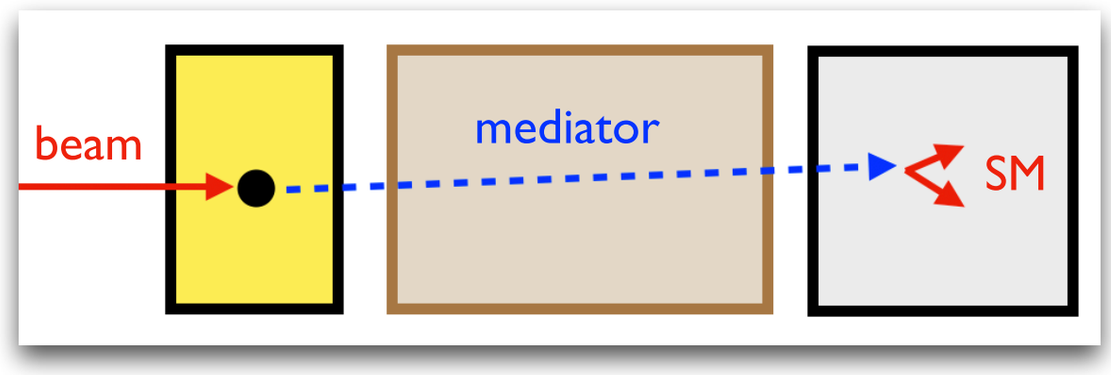
Fixed target spectrometer (HPS, DarkQuest, NA64, LDMX,M³…)



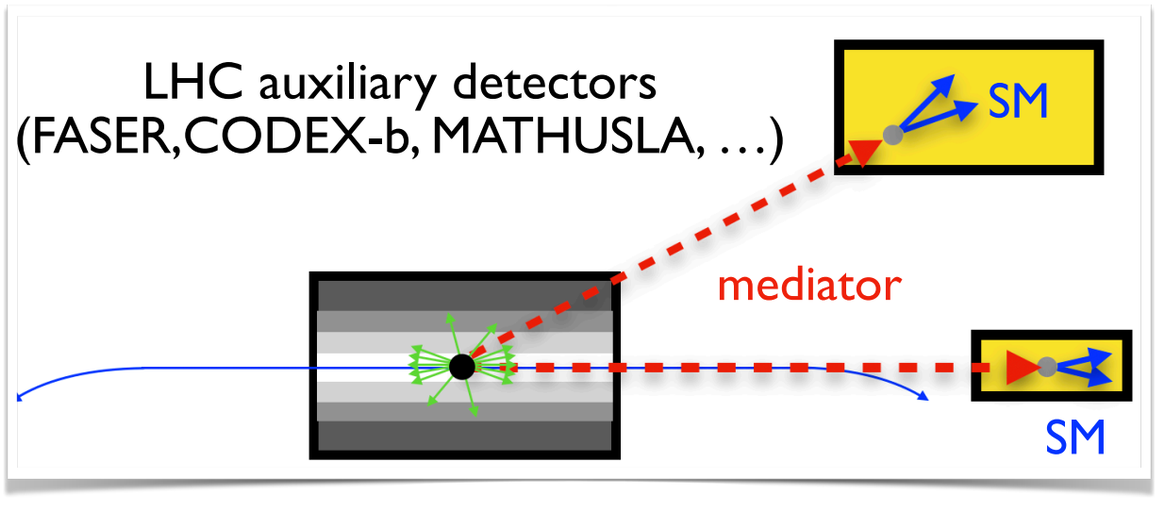
LHC main detectors (LHCb, CMS, ATLAS,…)



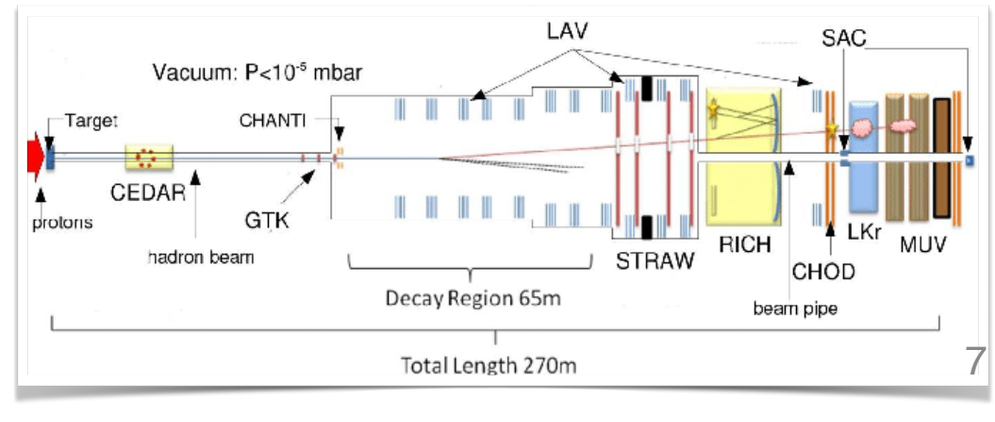
Beam dump (DUNE, ICARUS, SBND, SHADOWS,…)



LHC auxiliary detectors (FASER,CODEX-b, MATHUSLA, …)

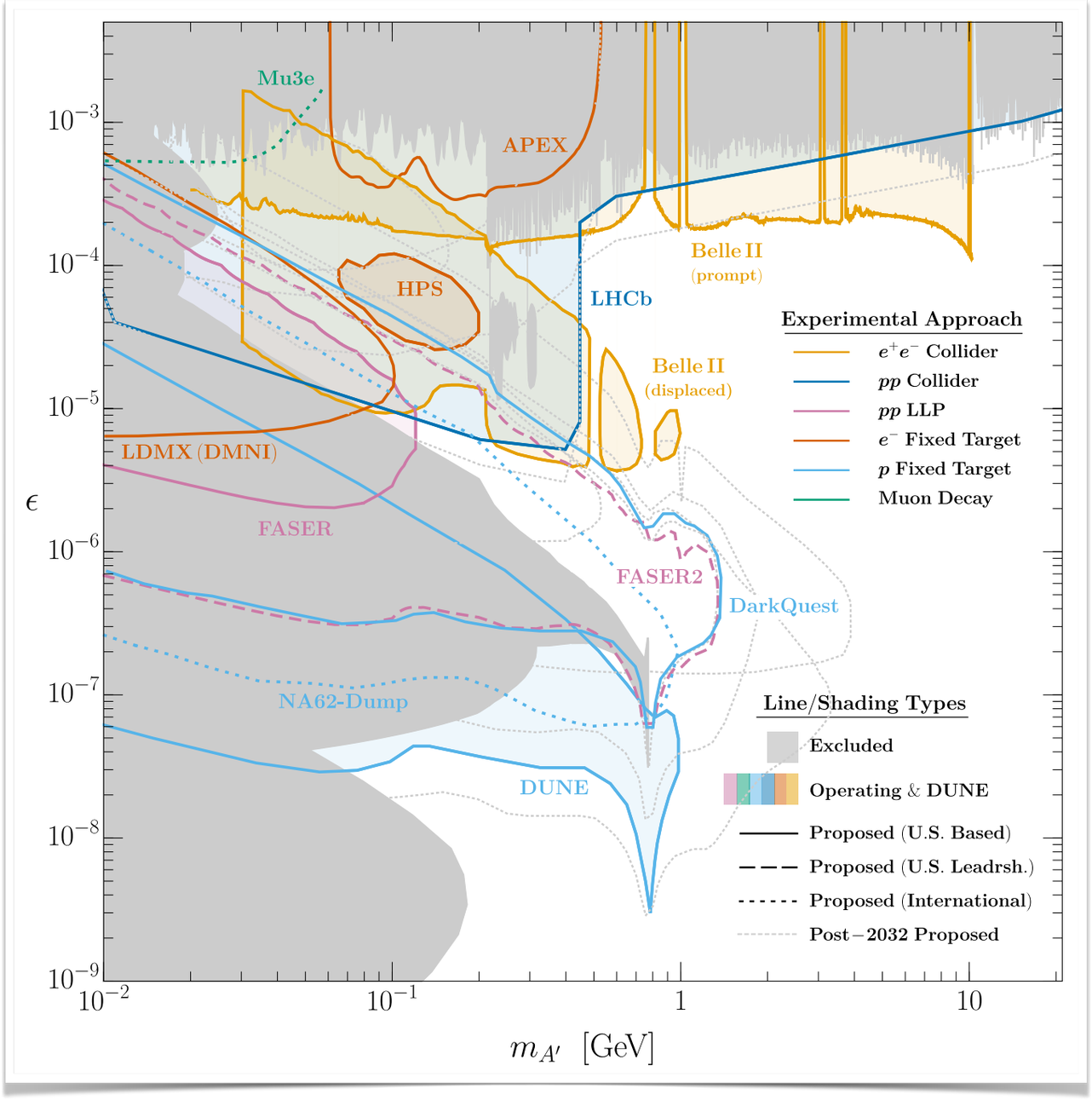


Meson/Lepton facilities (NA62, PIONEER, REDTOP, Mu3e,…)



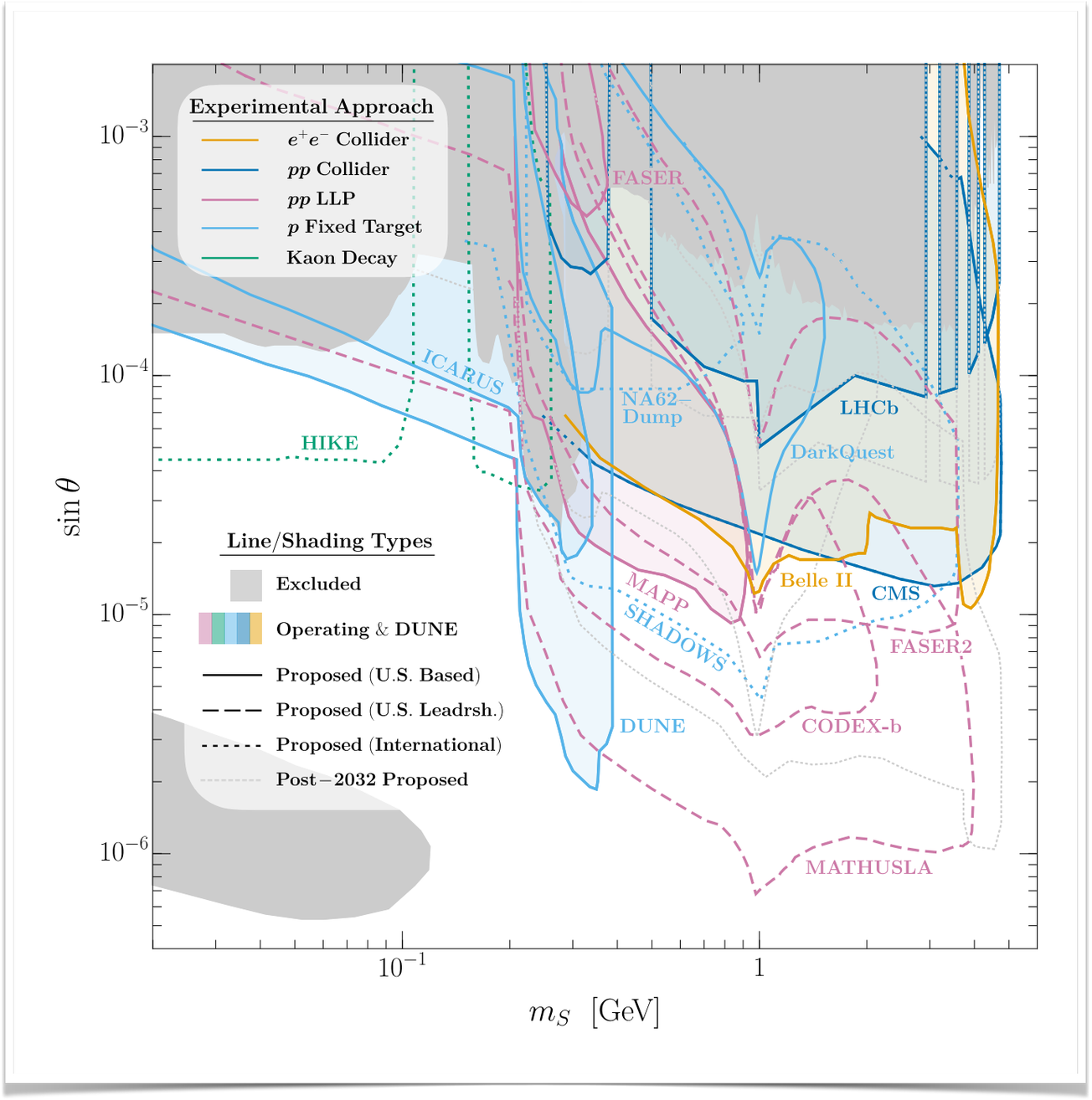
Kinetically mixed dark photon / vector portal

- Operating experiments (LHCb, Belle II, FASER, HPS) will cover low mass, large mixing region
- DUNE (w/near detector) will probe small mixings ($\epsilon \sim 10^{-8} - 10^{-6}$) for masses below ~ 1 GeV
- Exciting opportunities for DarkQuest and FASER2 to probe intermediate mixings ($\epsilon \sim 10^{-7} - 10^{-5}$) for masses below ~ 1 GeV
- Viable thermal dark matter can be realized over the entire parameter space



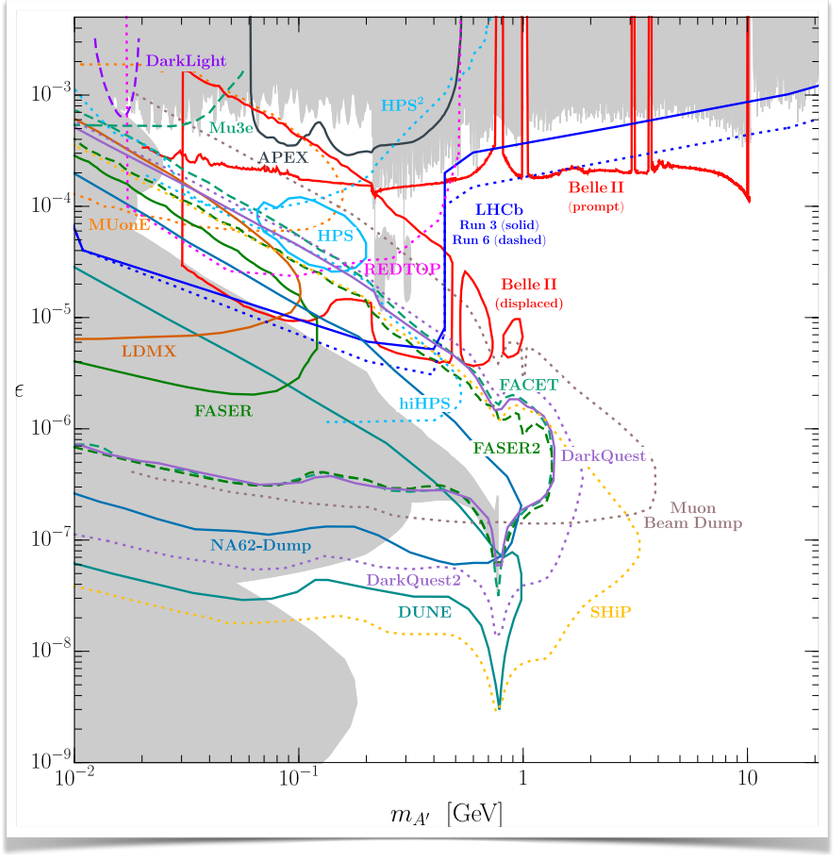
Dark Scalar / Higgs Portal Summary Plot

- Operating experiments (ICARUS, LHCb, CMS, Belle II, FASER, MoDEL-MAPP) will cover substantial regions of parameter space below ~5 GeV
- DUNE (w/near detector) will have powerful sensitivity to light scalars produced in Kaon decays
- Exciting opportunities for DarkQuest, FASER2, CODEX-b, MATHUSLA, SHADOWS, HIKE to extend the reach to smaller mixing angles
- Viable thermal dark matter can be realized over the entire parameter space

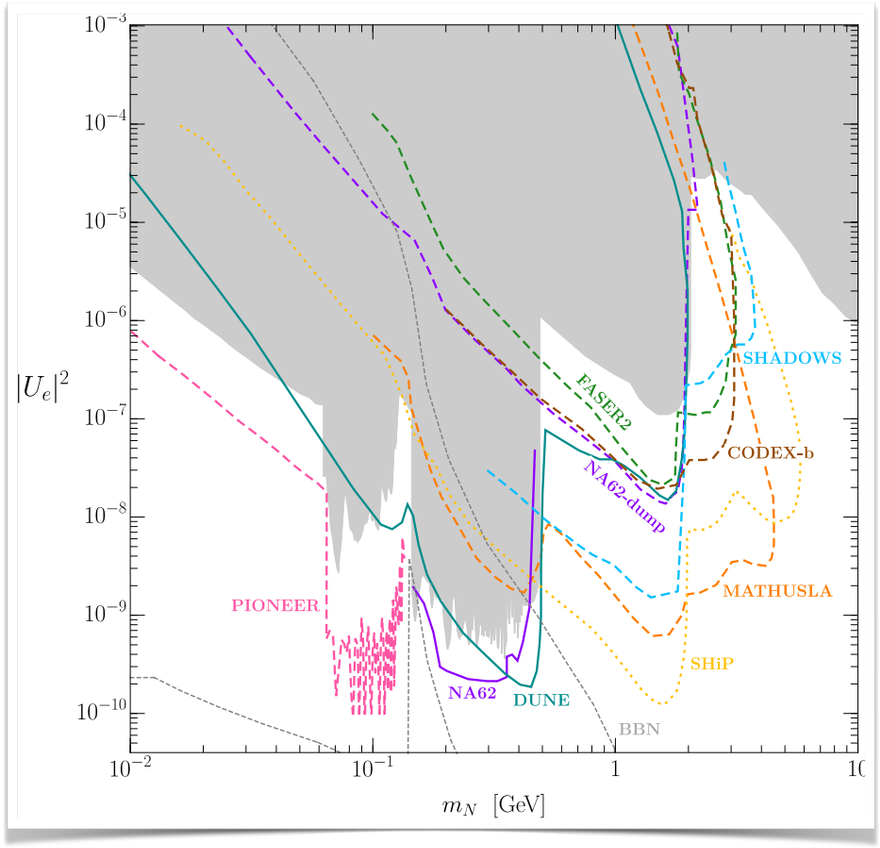


Some Minimal Portal Case Studies

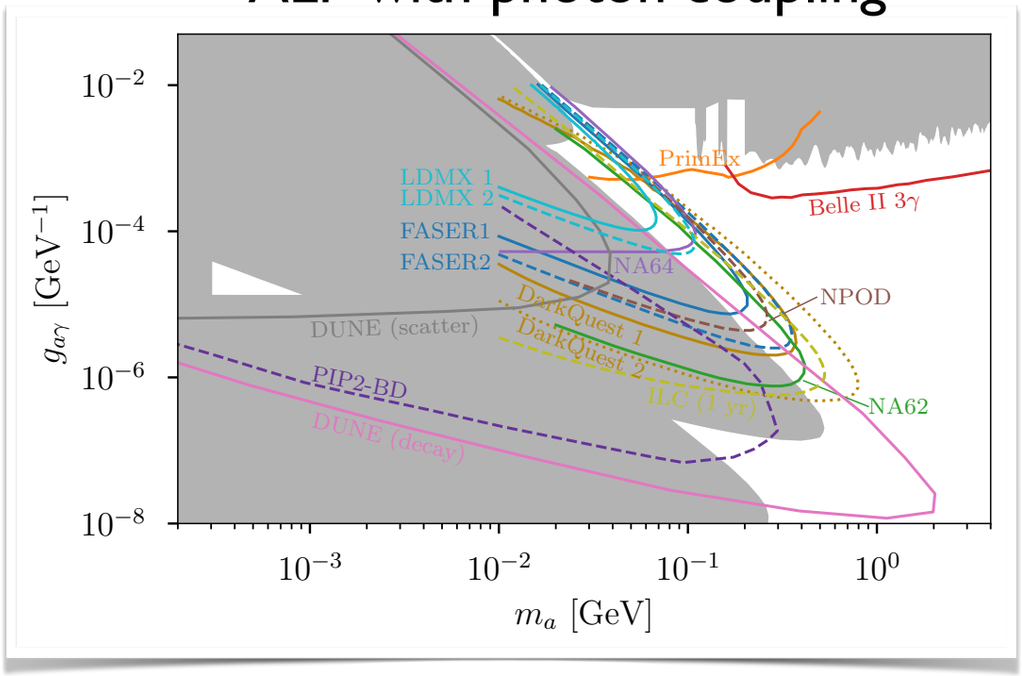
Dark photon



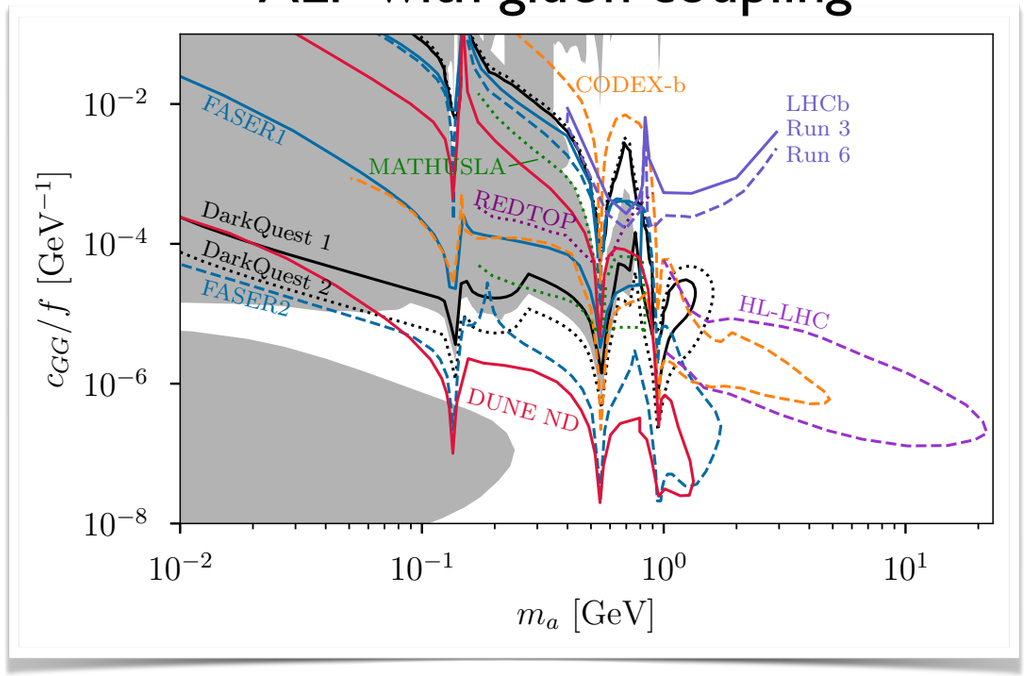
HNL (electron-dominance)



ALP with photon coupling



ALP with gluon coupling



Summary and Outlook

- The minimal portals highlighted in Big Idea 2 form the foundation of the dark sector paradigm. They are motivated from both bottom-up and top-down considerations (EFT logic, dark matter, solutions to big puzzles, …)

- Significant progress in probing minimal portals has been made over the last decade, but many exciting opportunities remain!

- Continued support of existing/operating experiments, along with modest upgrades to existing experiments and investment in new experiments, will significantly expand the reach to minimal dark sector portals. Support for theory research is critical in this effort.

- These searches form a core part of a broader dark sector search program, including the ideas highlighted in Big Idea 1 (dark matter production) and Big Idea 3 (Rich Dark Sectors, New Flavors).