

DarkQuest - Probing Dark Sector with a Proton Fixed- Target Experiment at Fermilab

Outline

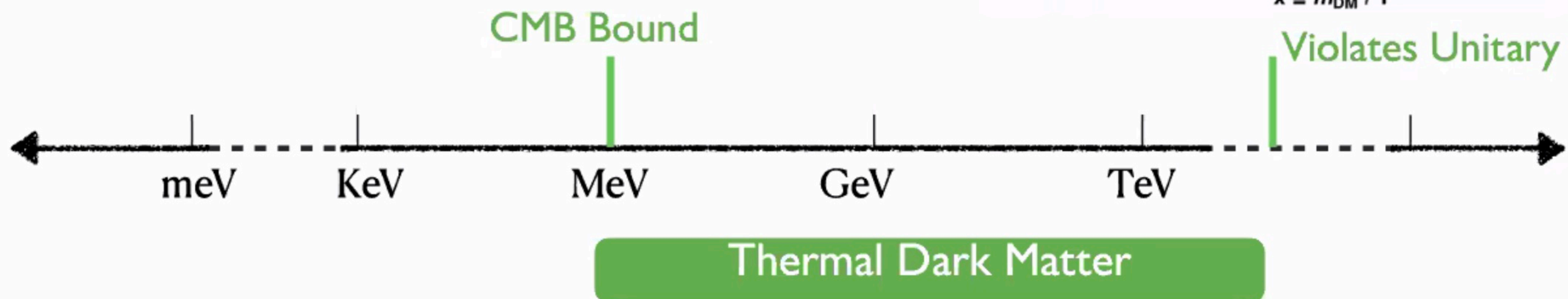
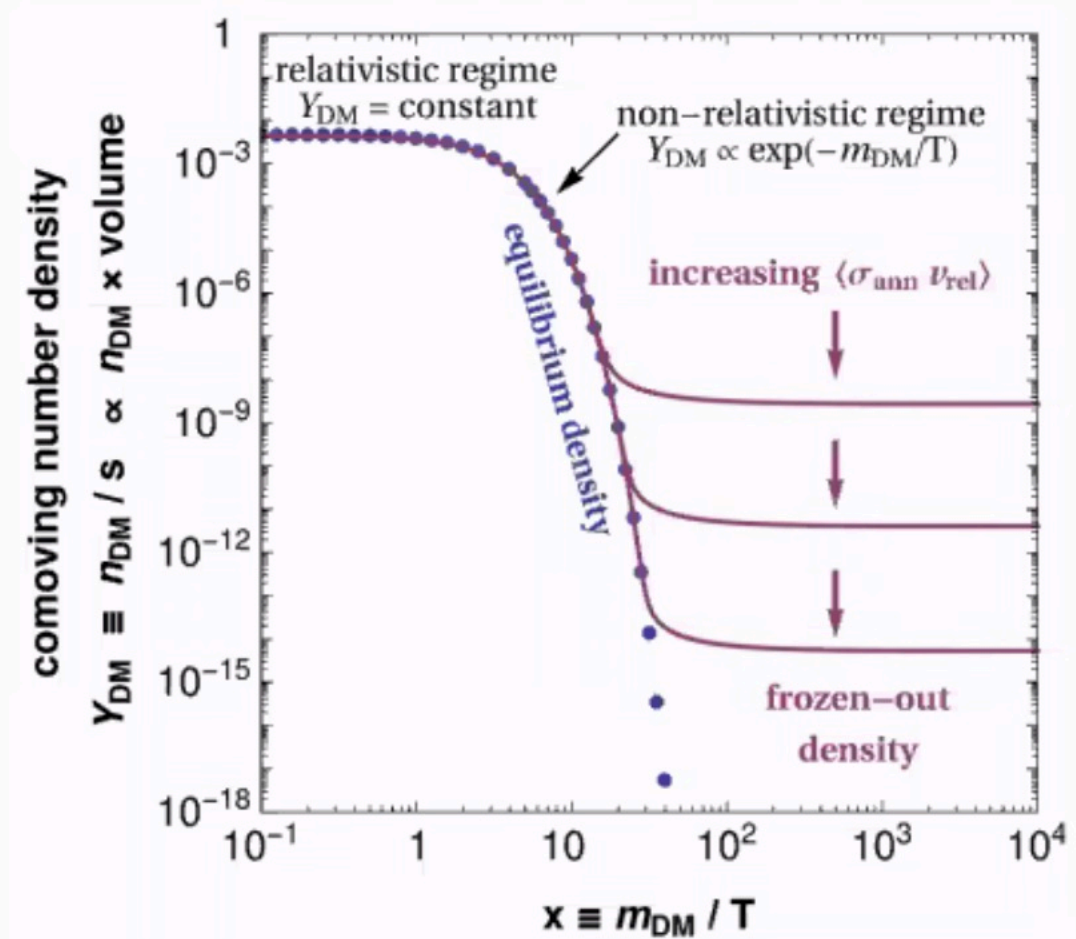
- Dark Sector:
 - ✦ What? Why? How?
- DarkQuest:
 - ✦ Proton fixed-target experiment based on SpinQuest
 - ✦ How to use DarkQuest to probe dark sectors:
 - ➔ Spectrometer upgrades
 - ➔ Simulation studies on calorimeter, tracking, triggering, ParticleID
 - ➔ Acceptance & Sensitivity

Dark Matter Mass Scale



Thermal Dark Matter

- Thermal freeze-out is a nice story for dark matter:
 - ✿ Easily realizable, predictive, UV insensitive
- Prefers the DM mass to be around MeV to TeV scale



WIMP

WIMP, from galactic halo, $10^{-3} * c$ speed



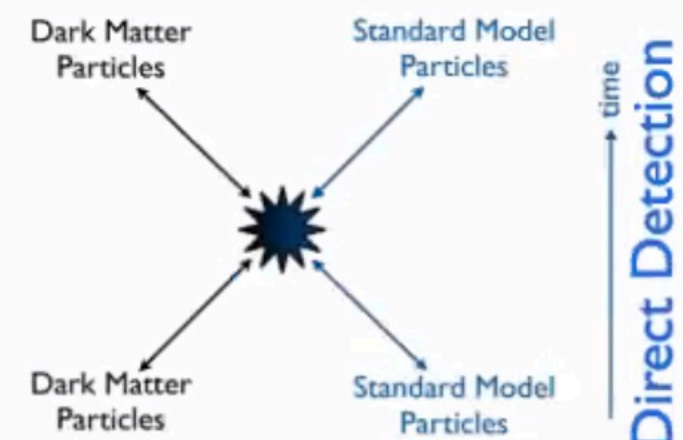
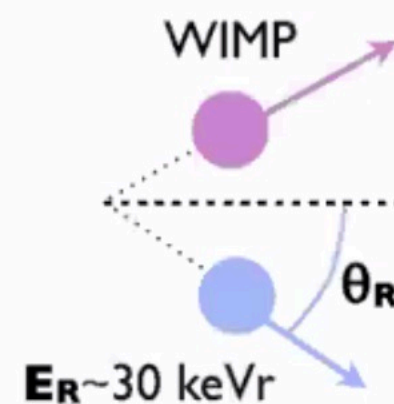
- Direct detection:
- typically underground, e.g., PANDA-X, LUX/LZ, SuperCDMS,

Target Nucleus
in laboratory



$v \sim 0$ km/s

Scatterings



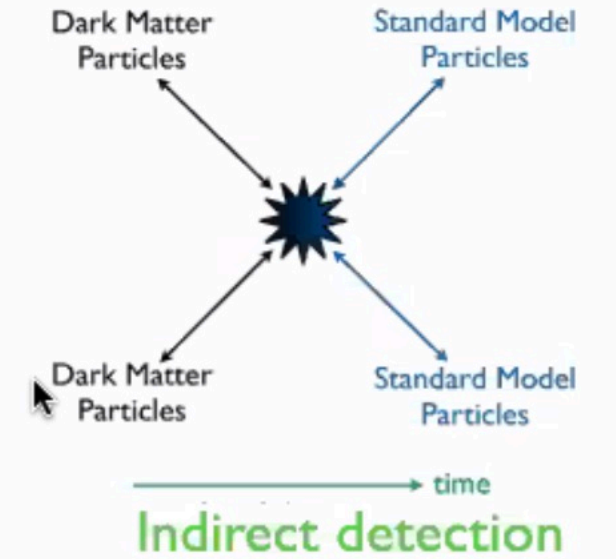
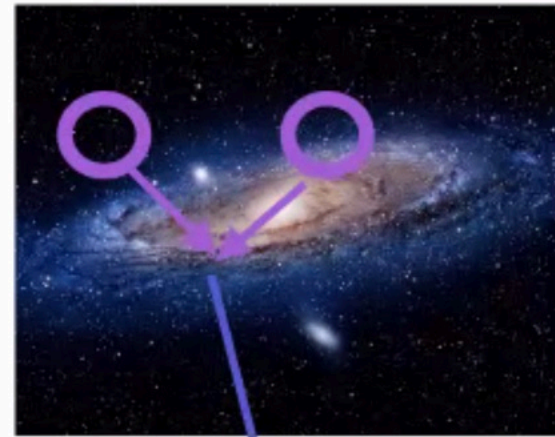
WIMP

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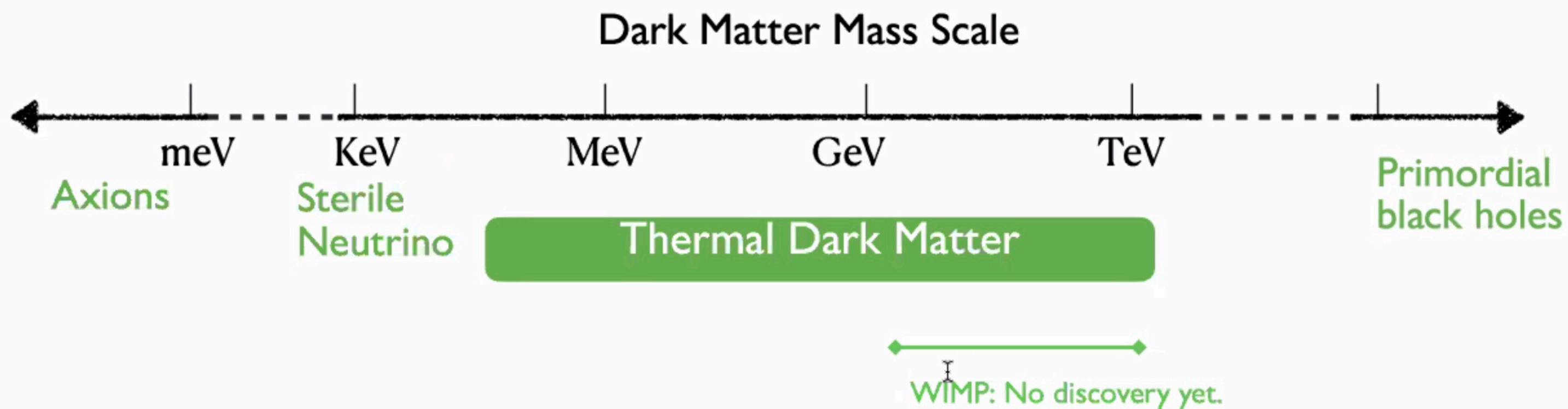
- Direct detection:
- typically underground, e.g., PANDA-X, LUX/LZ, SuperCDMS,



- Indirect detection:
- typically in the sky: DAMPE, AMS, FermiLAT

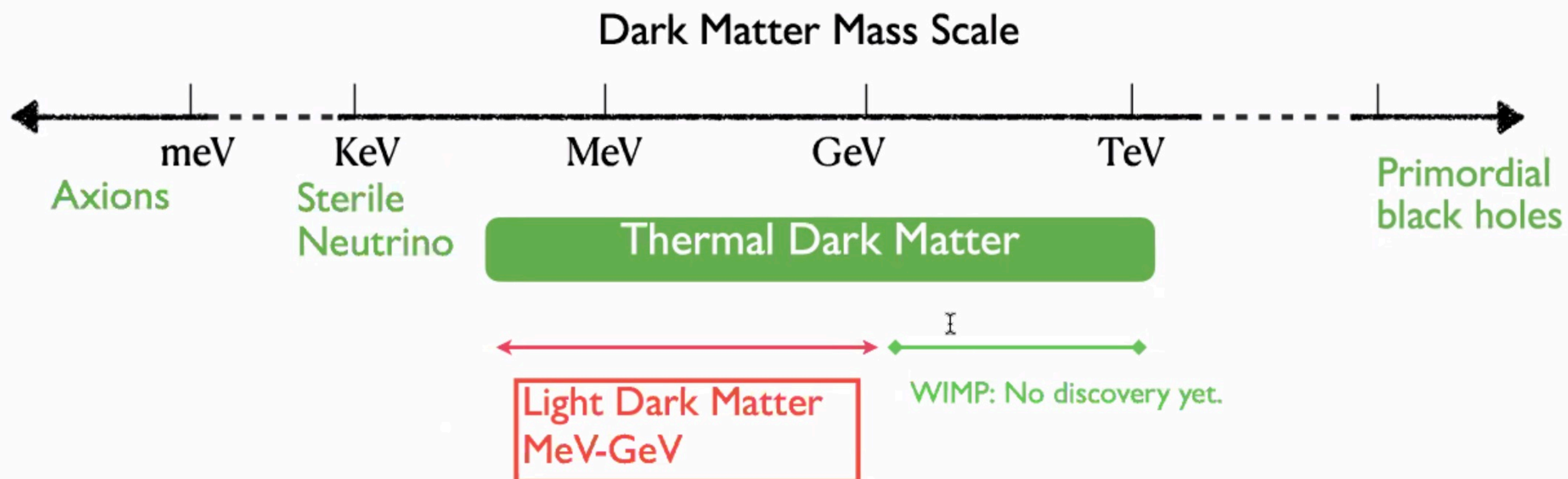


Light Dark Matter

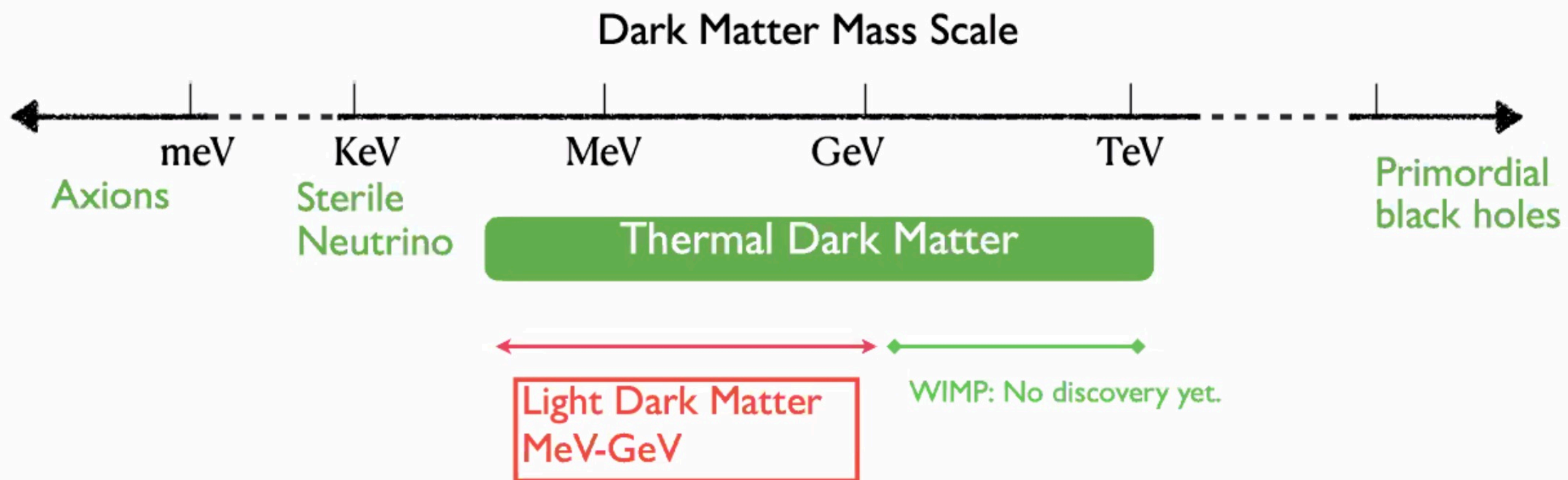


- What next?

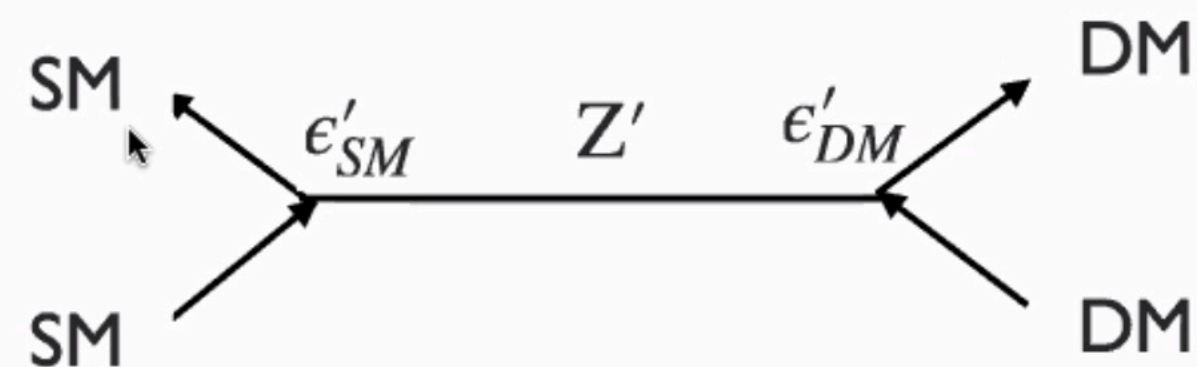
Light Dark Matter



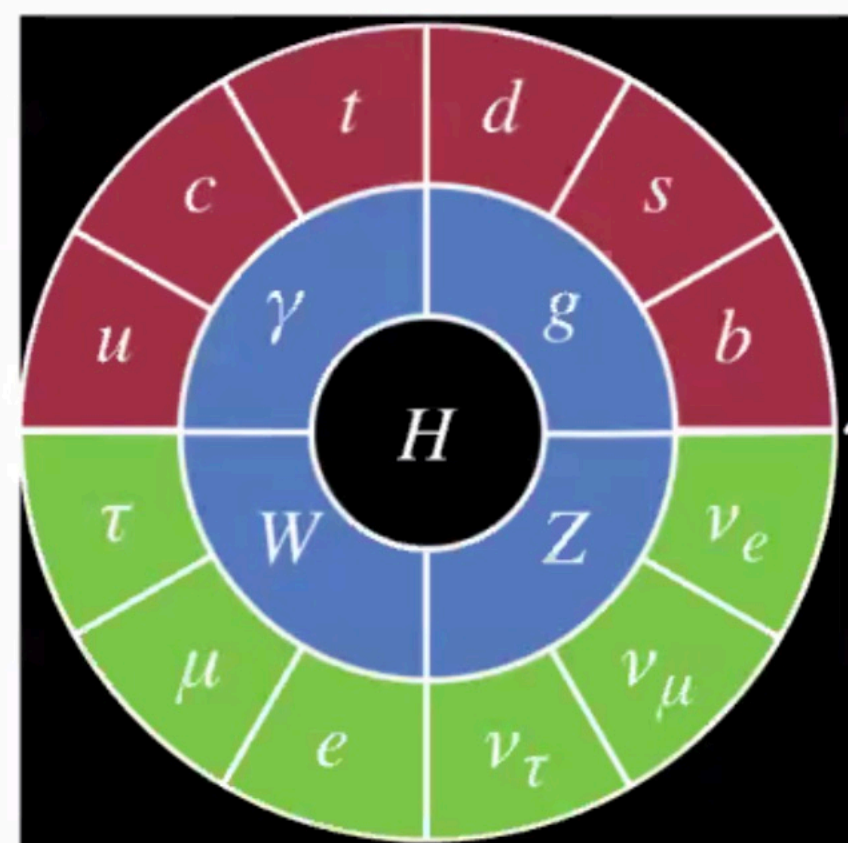
Light Dark Matter



- Light dark matter requires light mediators -> **Dark Sector**

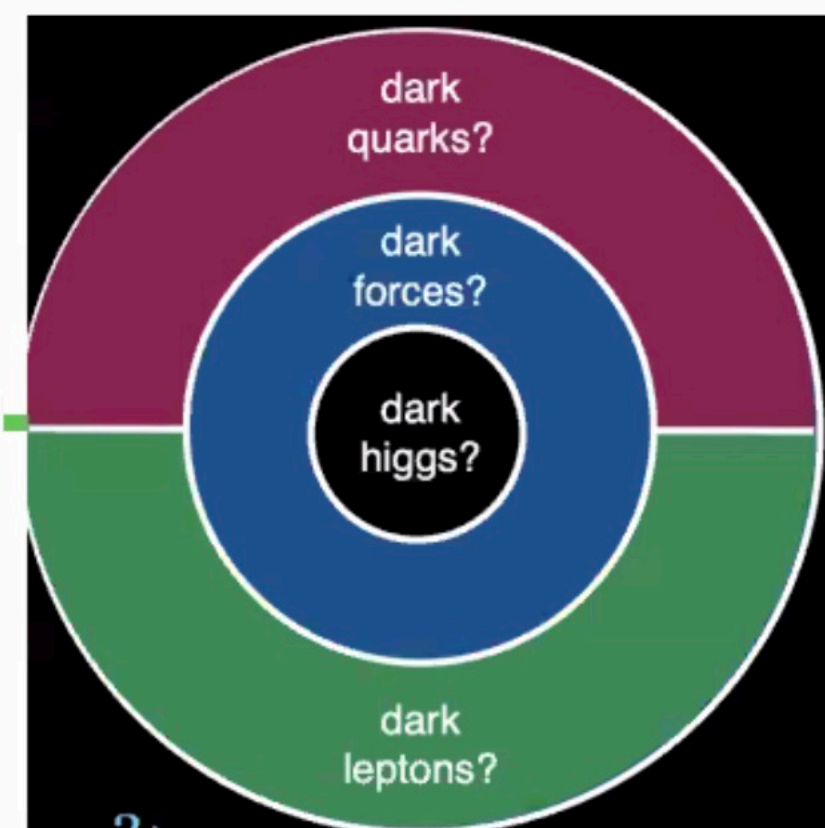


Dark (Hidden) Sector



SM

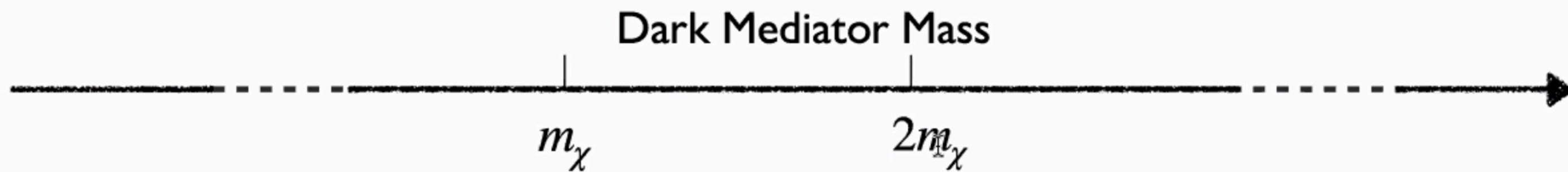
- Vector Portal: dark photons
- Higgs Portal: dark scalar
- Neutrino Portal: heavy neutral leptons
- Axion Portal: Axion-like particles



DM

- Dark Sectors can connect to SM sectors via some new couplings.
- Can probe the dark sector by looking at the dark mediators and their decay products: missing E/p/m, displaced lepton/hadrons, etc

How to Probe Dark Sector

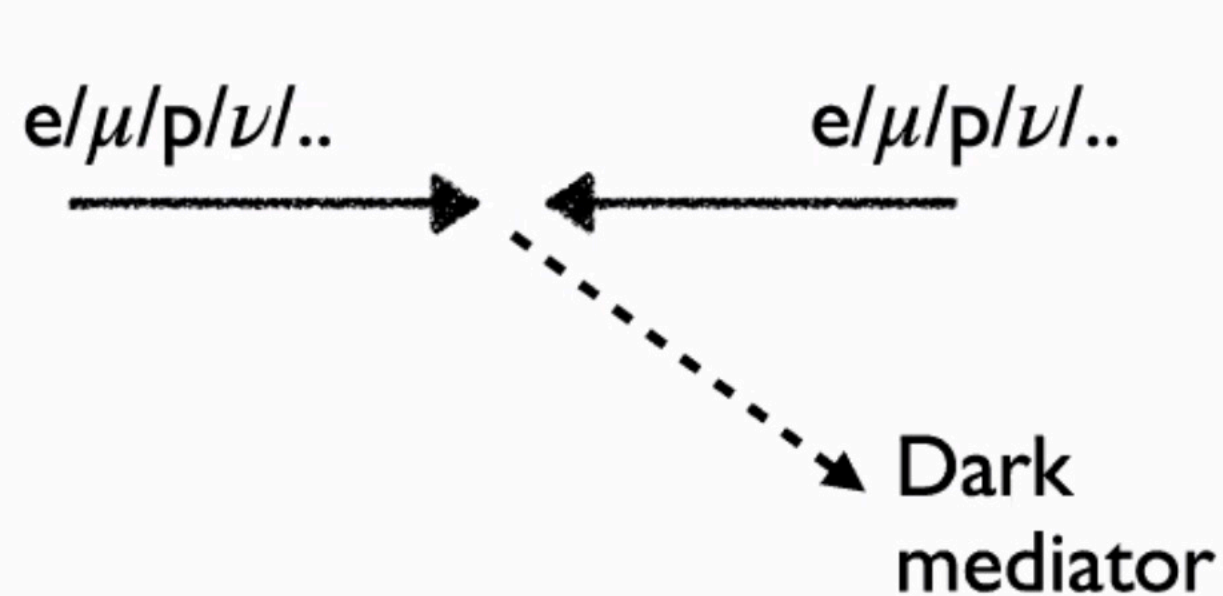


Probe Dark Sector with Accelerators



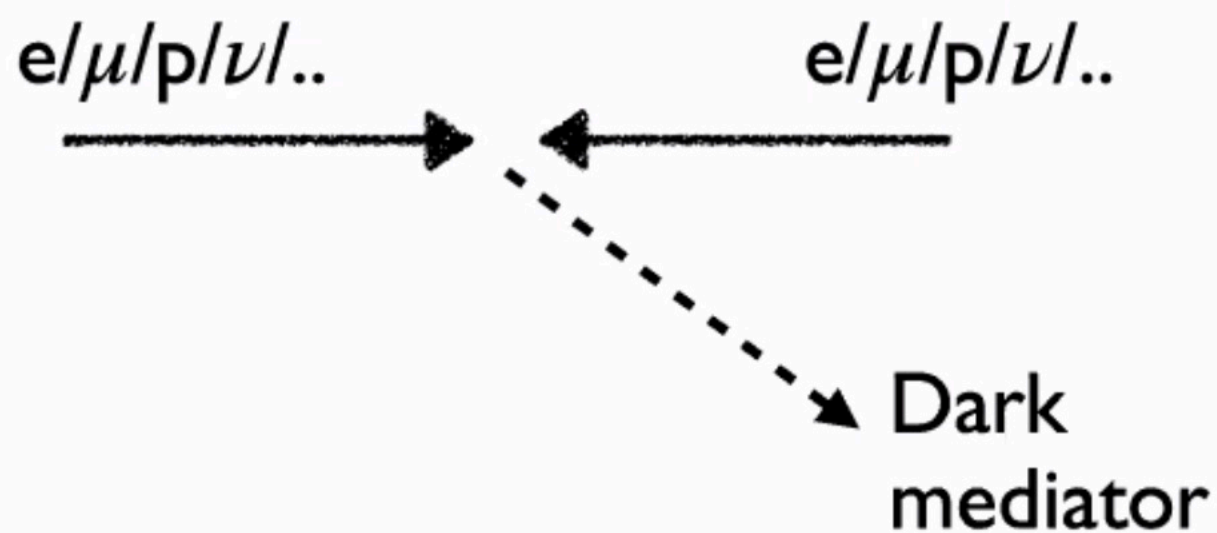
- Beam from accelerator: electron/muon/proton/
neutrino beam

Probe Dark Sector with Accelerators

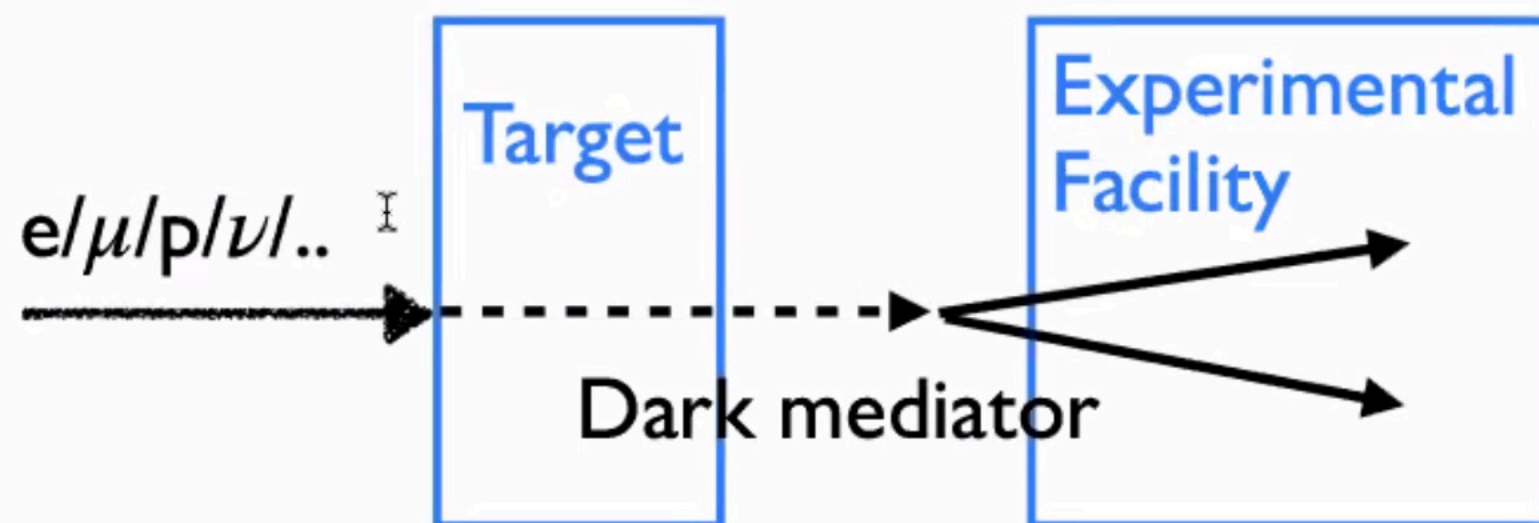


- Look for final states with bumps/
displaced signals/missing $E/p/m$
 - ✦ ATLAS/CMS/LHCb, Belle, BES?

Probe Dark Sector with Accelerators

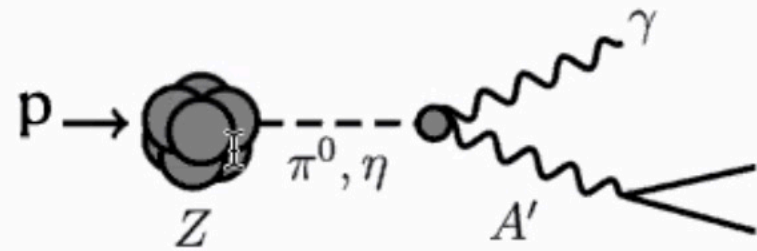


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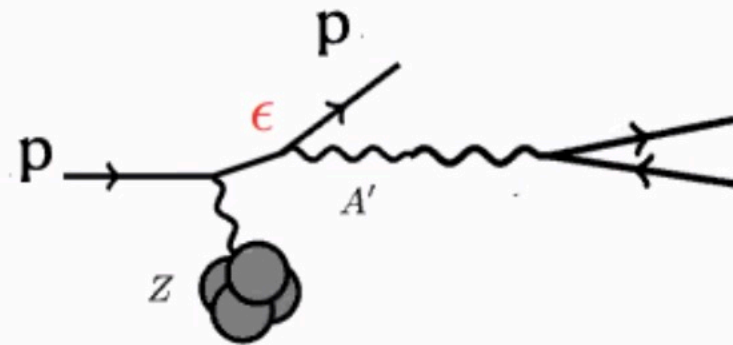


- Analyze the dark mediator decay products: bumps/displaced signals/missing E/p/m
- ✦ NA64 @ CERN, LDMX @ SLAC, **DarkQuest @ Fermilab**
- ✦ Usually low background, better sensitivity at low mass region

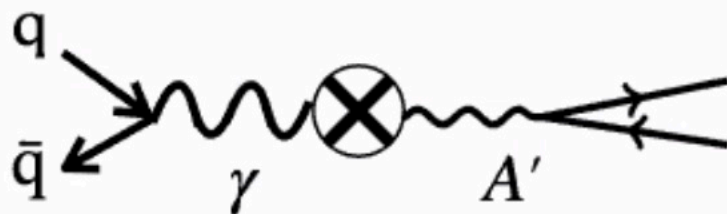
Example: Dark Photon Production with Proton fixed-target



Meson decays to A'

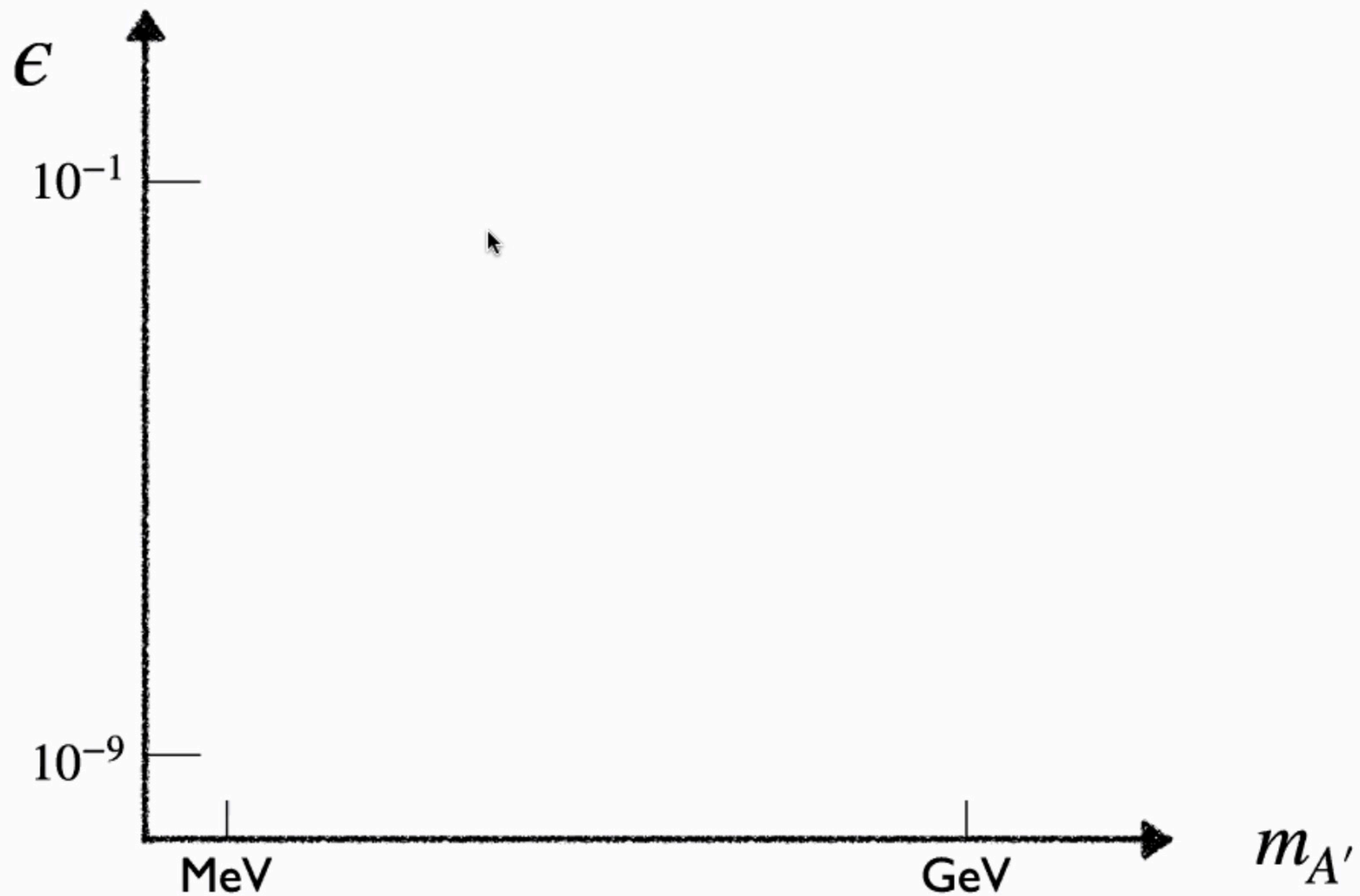


Proton bremsstrahlung to A'

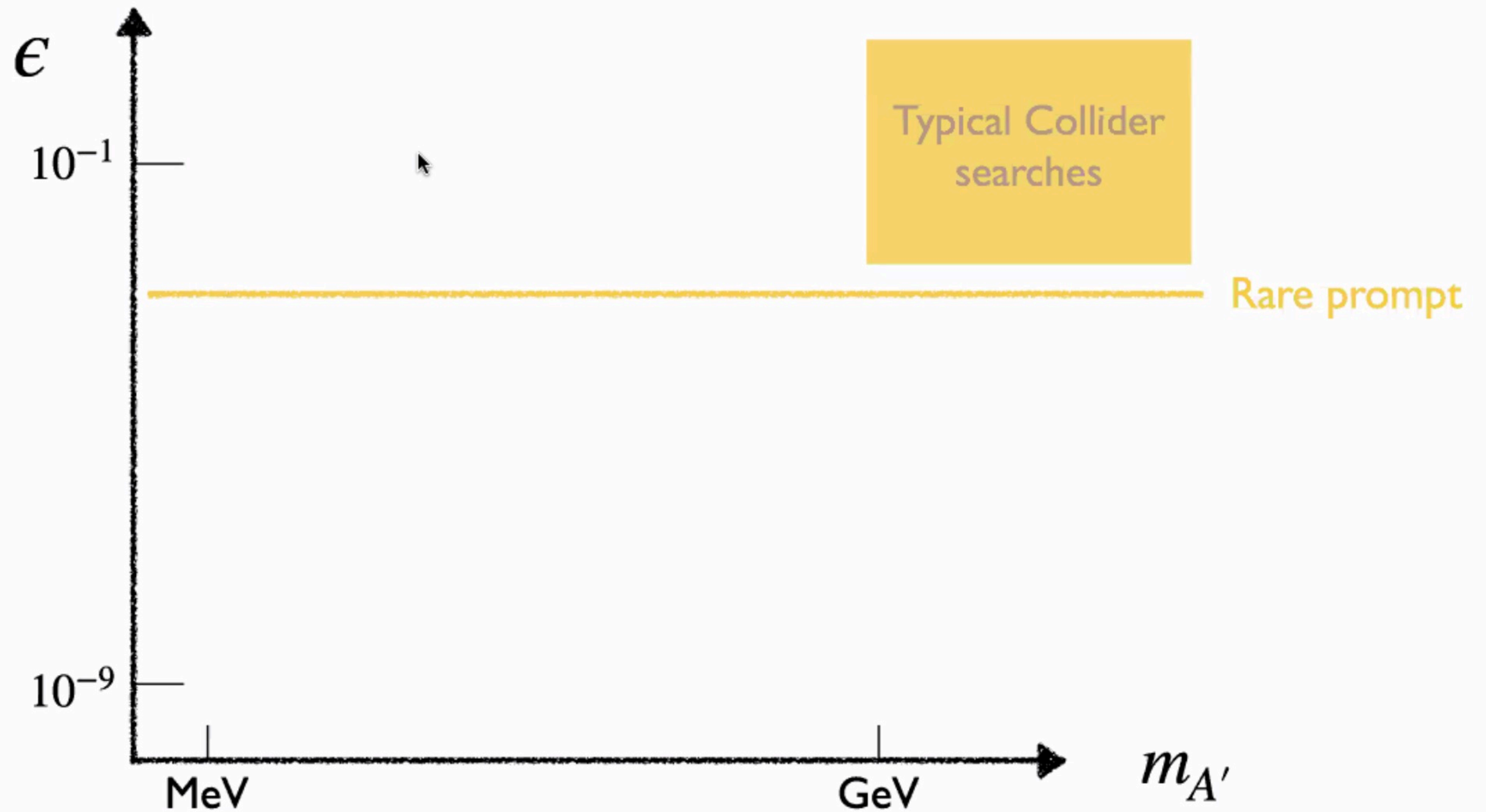


Drell-Yan process

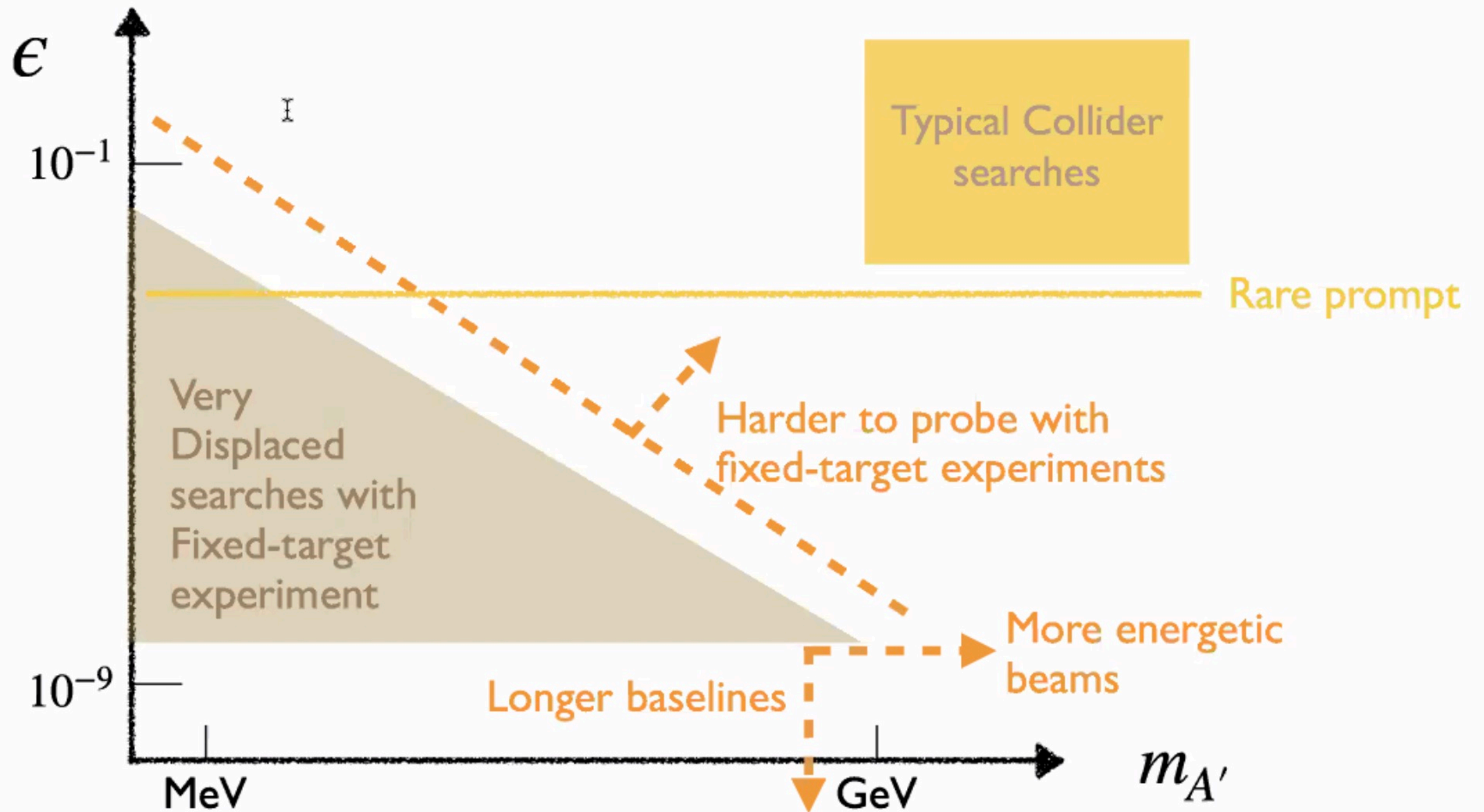
Dark Photon Phase Space



Dark Photon Phase Space

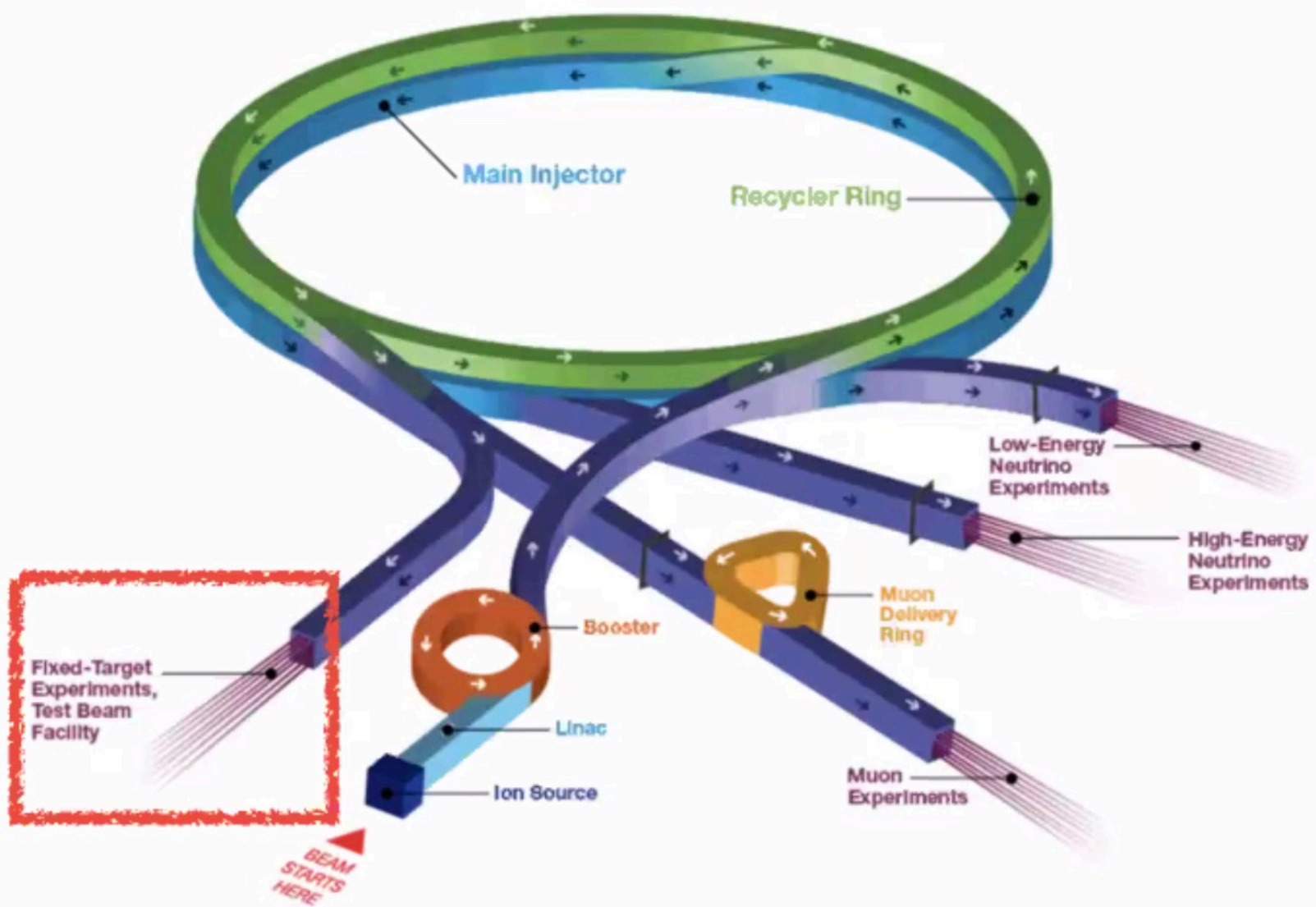


Dark Photon Phase Space



120GeV Proton Beam

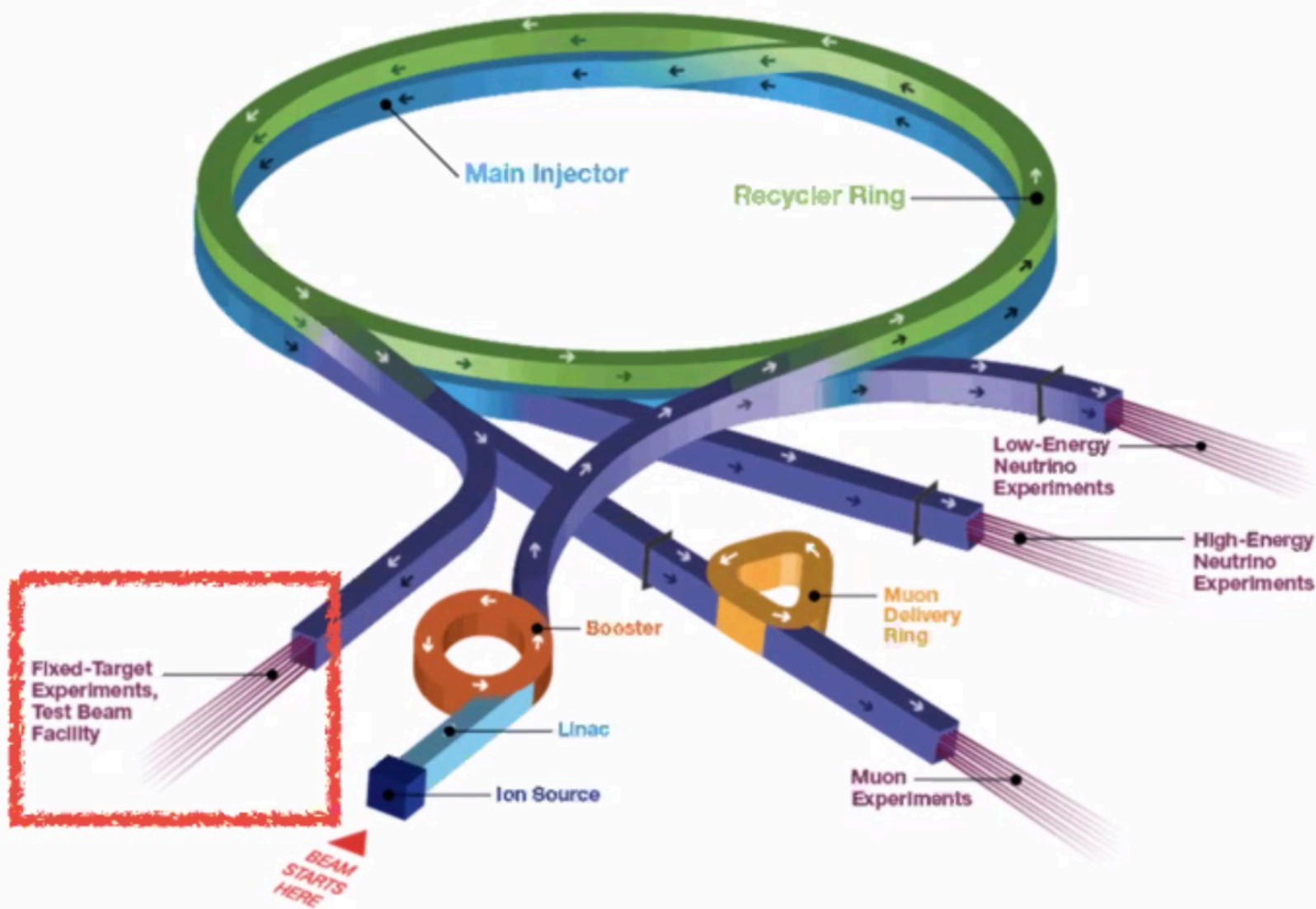
Fermilab Accelerator Complex



- 120 GeV high-intensity proton beam from the Fermilab Accelerator Complex
 - ✿ Expect 10^{18} Protons on target (POT) in a 2-year parasitic run
 - ✿ 10^{20} POT for longer term runs

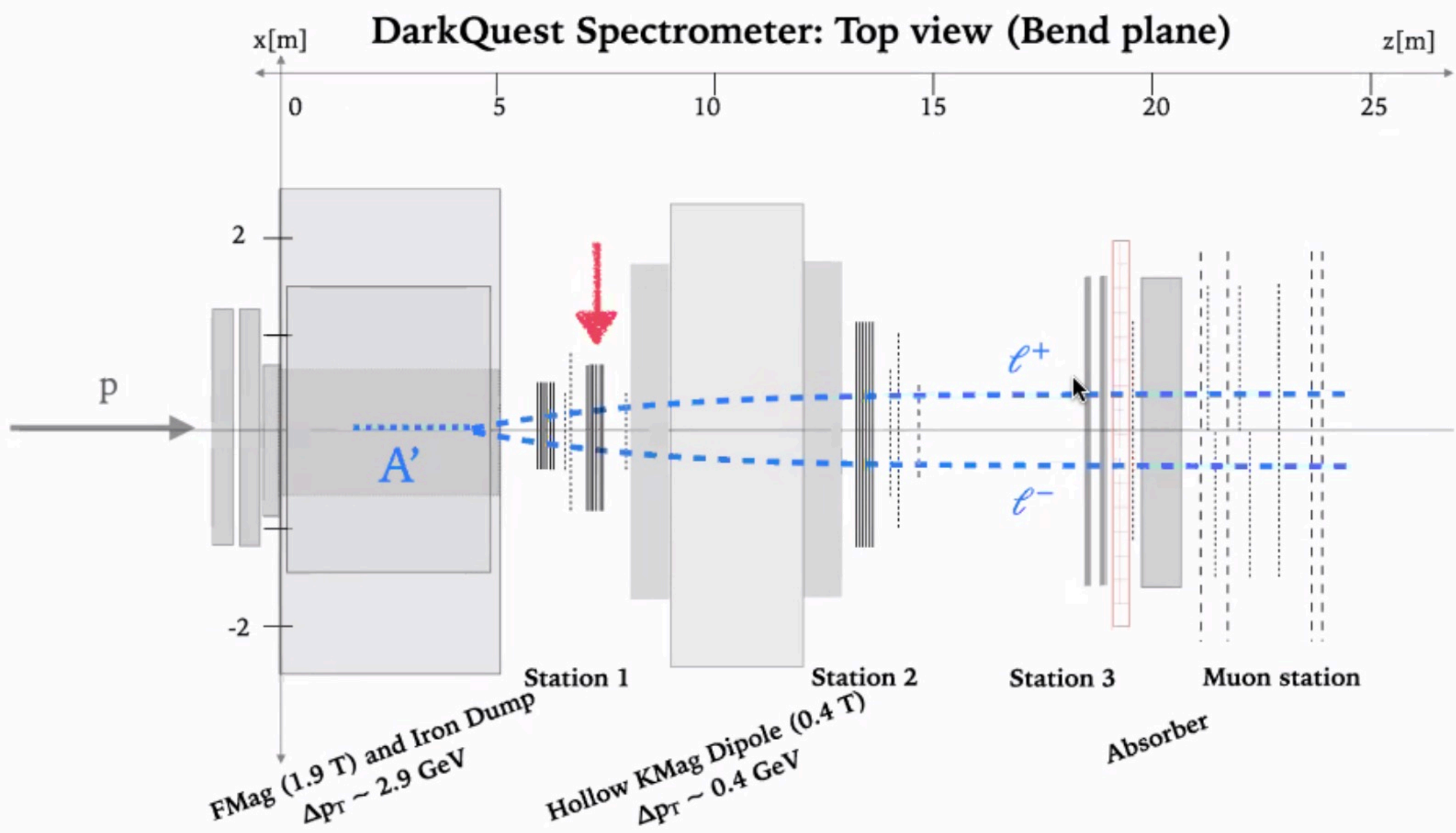
120GeV Proton Beam

Fermilab Accelerator Complex



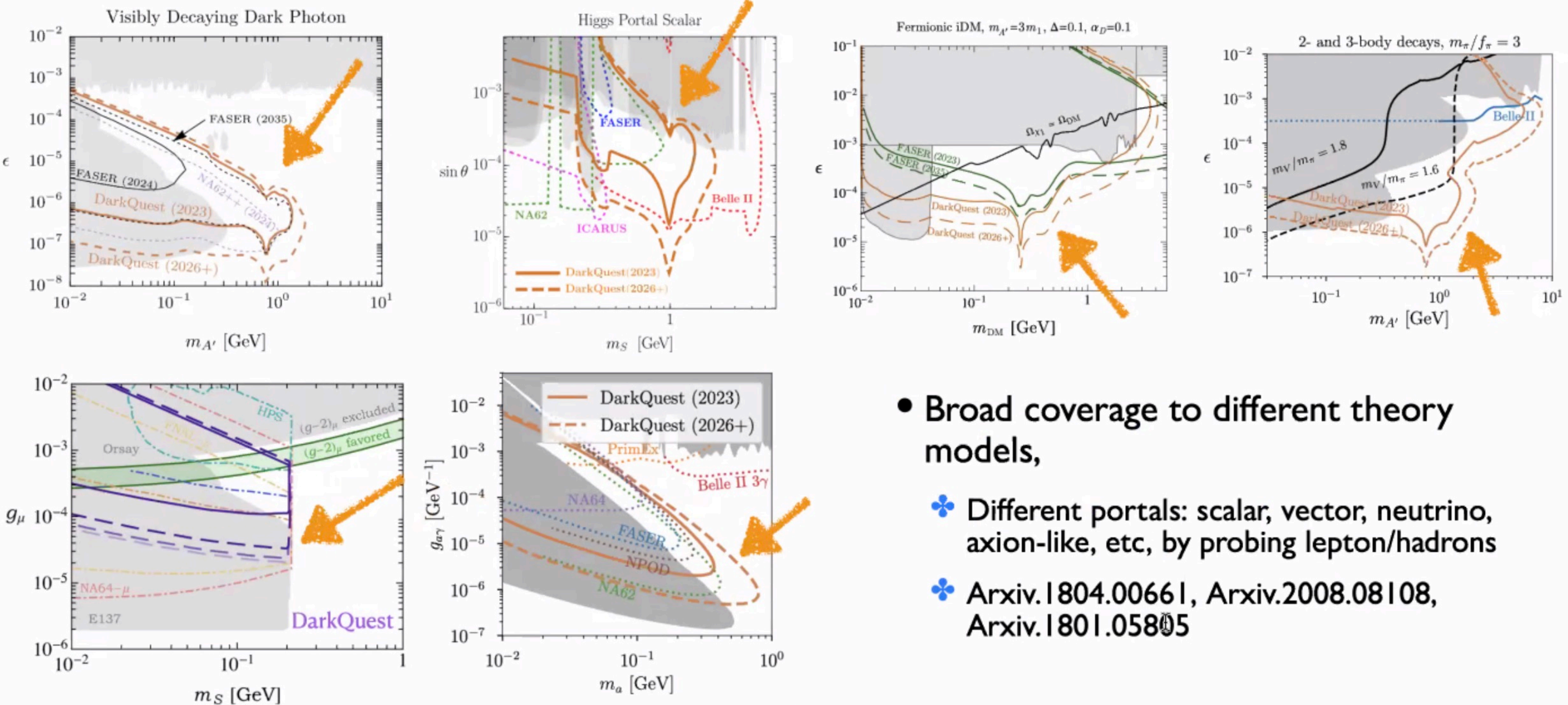
- LHC 13TeV run: $\sim 150 \text{ fb}^{-1}$ of data, inelastic scattering $\sigma \sim 80 \text{ mb}$. This brings to about 10^{16} “protons on target”
- 120 GeV high-intensity proton beam from the Fermilab Accelerator Complex
 - ✿ Expect 10^{18} Protons on target (POT) in a 2-year parasitic run
 - ✿ 10^{20} POT for longer term runs

DarkQuest Spectrometer



- DarkQuest spectrometer:
 - ✿ Probing dark sector by looking at displaced signals
- Upgrades on SpinQuest:
 - ✿ Additional tracking layers from HyperCP experiment

Broad Sensitivity Coverage



- Broad coverage to different theory models,

- Different portals: scalar, vector, neutrino, axion-like, etc, by probing lepton/hadrons
- Arxiv.1804.00661, Arxiv.2008.08108, Arxiv.1801.05805

Collaboration

- A strong team assembled of both experimentalists and theorists:



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

- One Snowmass paper: <https://arxiv.org/pdf/2203.08322.pdf>

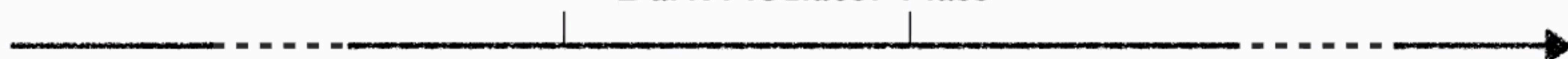
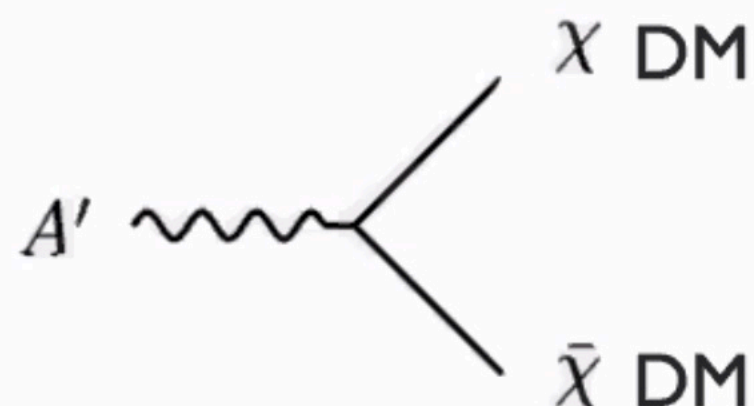
Summary

- Dark sector and light dark matter is an interesting yet not constrained region to explore
- 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



Dark (Hidden) Sector

Dark Mediator Mass


 m_χ
 $2m_\chi$


- For mediator mass $> 2m_\chi$, can probe dark mediator decaying to dark matter
- Look for missing momentum/energy/mass



- Can probe the channel of dark mediator decaying to SM particles for the whole phase space

• Vector Portal: $F^{\mu\nu} A'_{\mu\nu}$:

$A' \rightarrow$ lepton pairs...

• Scalar Portal: $\phi h h^\dagger + \phi^2 h h^\dagger$:

$\phi \rightarrow$ lepton/hadron pairs..

• Neutrino Portal: $h L N$:

$N \rightarrow$ lepton + hadrons..

• Axion Portal: $a(\vec{G}_{\mu\nu} \vec{G}^{\mu\nu} + F_{\mu\nu} F^{\mu\nu})$: $a \rightarrow$ photon/hadron pairs