Search for Light Dark Matter with the DarkMESA Experiment

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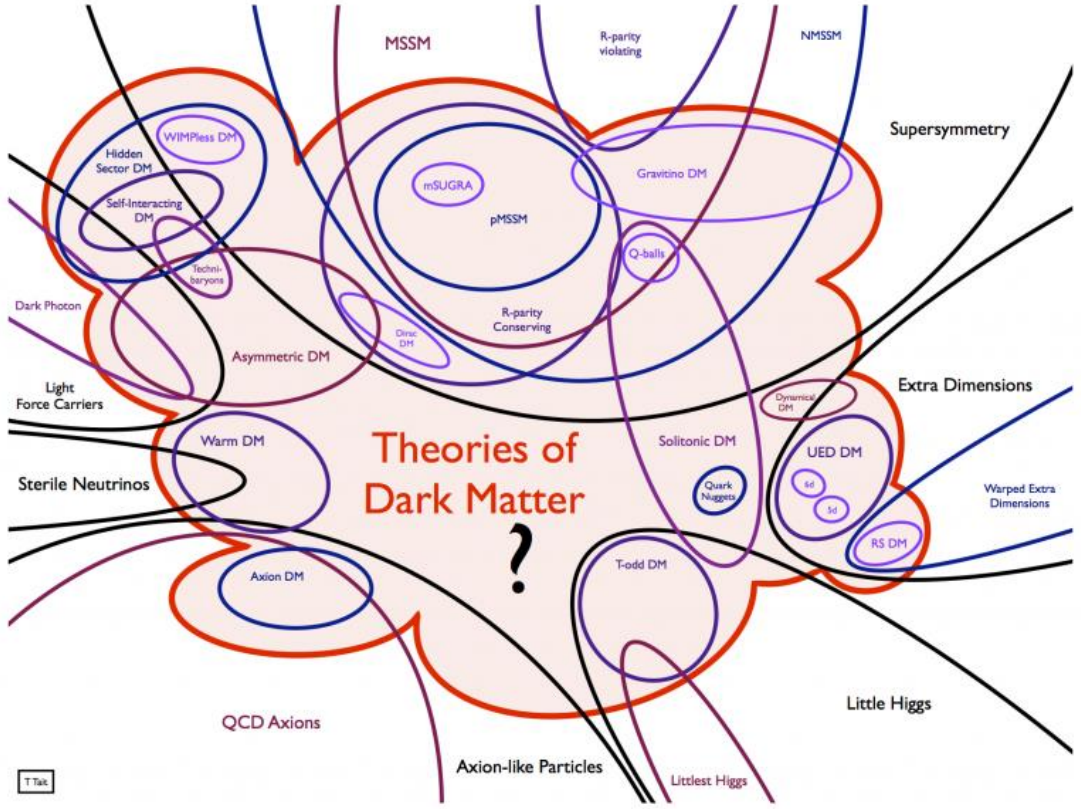
Dark Matter Searches

- Dark Matter searches needed to extend the Standard Model
  - Especially interesting: Models with possible SM interactions

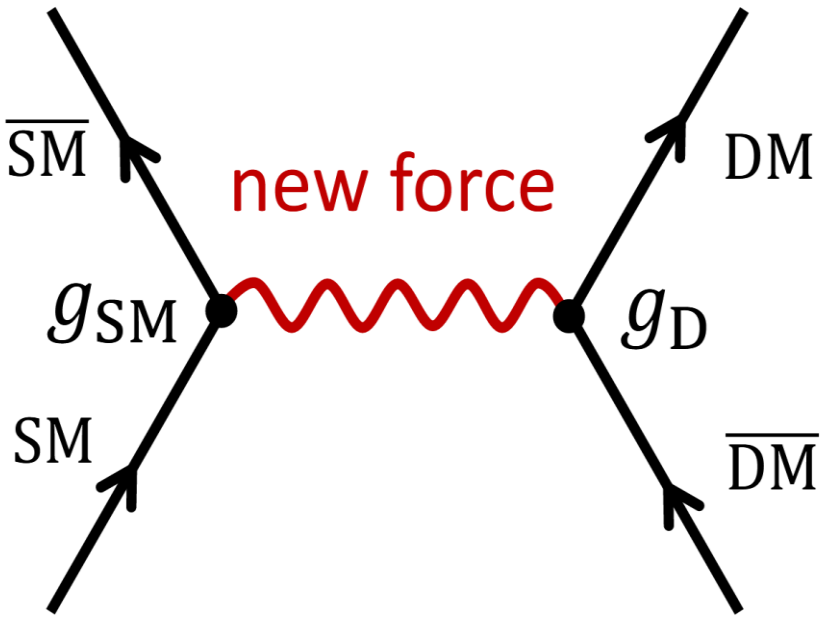
- Search for Dark Matter relies on large data sets due to rare processes
  - High intensity accelerator experiments needed!



Tim Tait, https://physics.aps.org/articles/v11/48

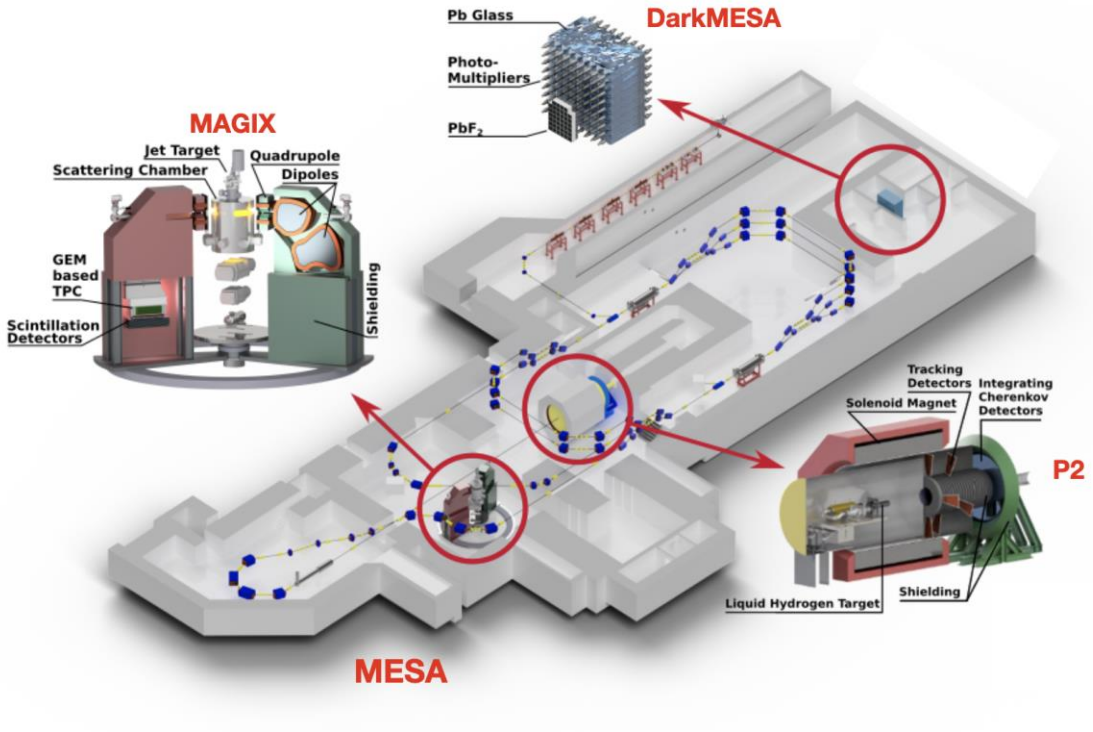
Light Dark Matter Searches

- Especially interesting for low-energy accelerators
- Thermal relic targets exist for the MeV-GeV scale
- Beyond the Standard Model forces required
- Different portals possible:
  - Vector (Dark Photon)
  - Axion
  - …



The MESA Accelerator

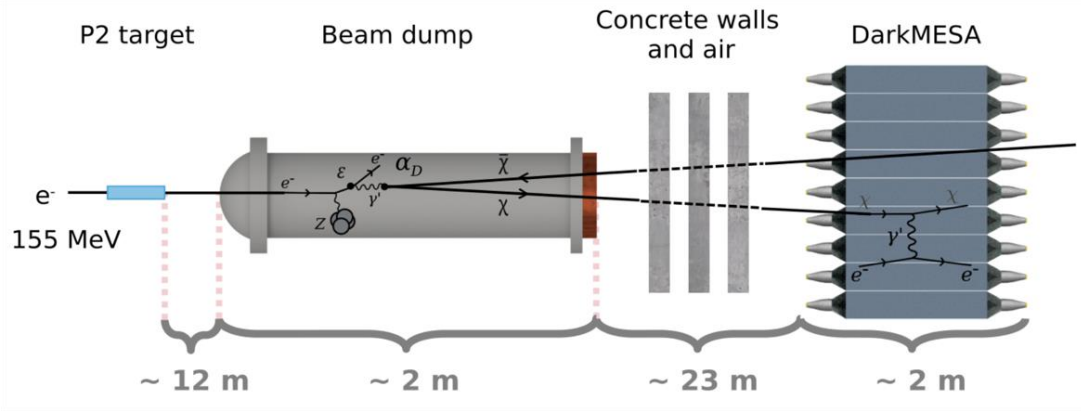
- Electron accelerator
- 2 modes of operation:
  - Energy recovery mode: 105 MeV @ 1 mA for MAGIX
  - Extracted beam mode: 150 MeV @ 0.15 mA for P2 and DarkMESA
- Currently under construction



https://magix.uni-mainz.de/mesa.php

The DarkMESA Experiment

- Parasitic beam dump experiment behind P2
- High-Z calorimeter
- Research objective: direct detection of Dark Matter

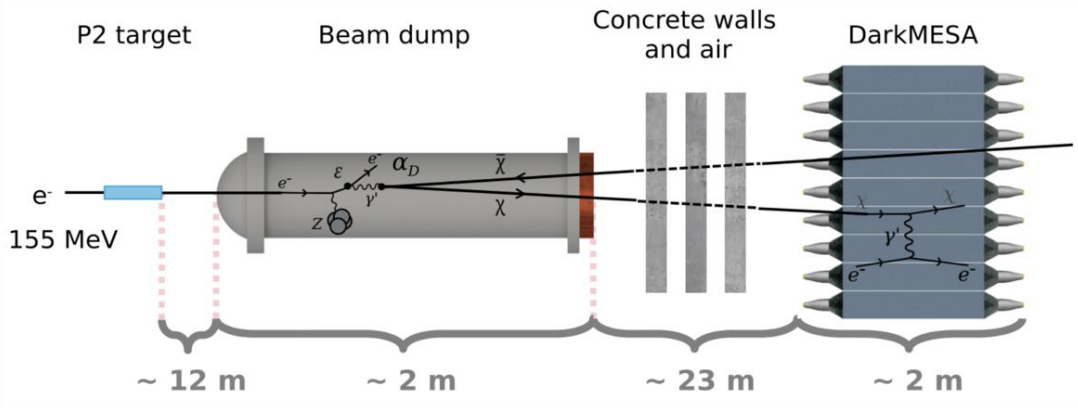


https://magix.uni-mainz.de/physics.php

The DarkMESA Experiment

Operating principle

- Produce Dark Matter in Bremsstrahlung processes in the beam dump
- Dark Matter particles travel through the beam dump and walls towards the detector
- Detect Dark Matter through scattering processes in the detector



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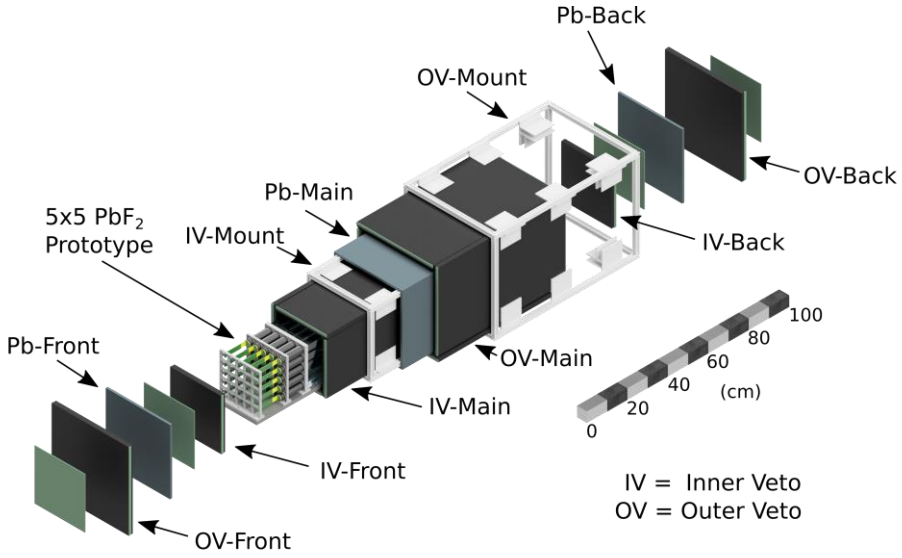
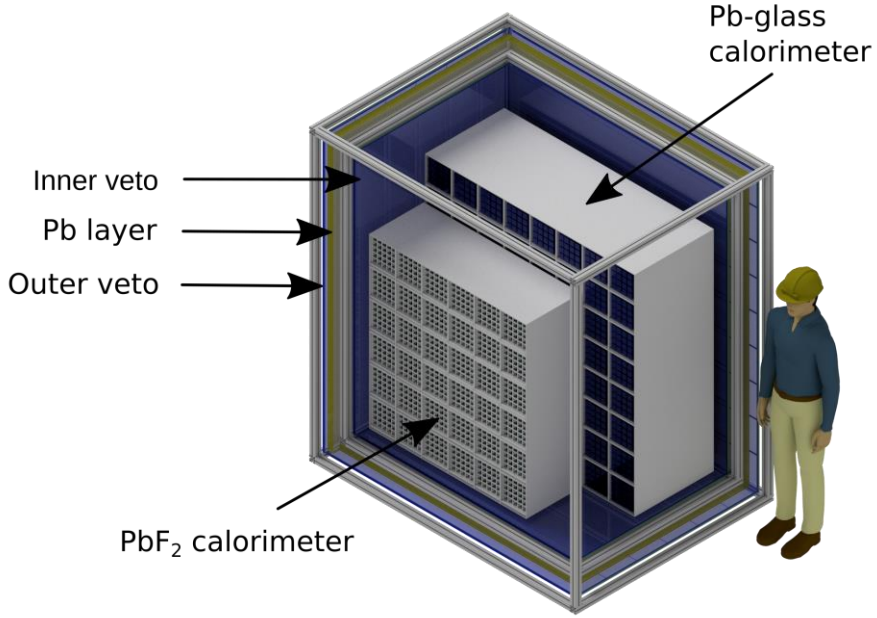
DarkMESA Setup

- Phase A: 1 PbF_2 module, 0.004 m^3 active volume



- Phase B: 30 PbF_2 + 64 SF5 modules, 0.7 m^3 active volume



https://magix.uni-mainz.de/DarkMESA.php

- Phase C (projected): Phase B setup + 1m^3 negative ion TPC

Simulations of the Experimental Reach

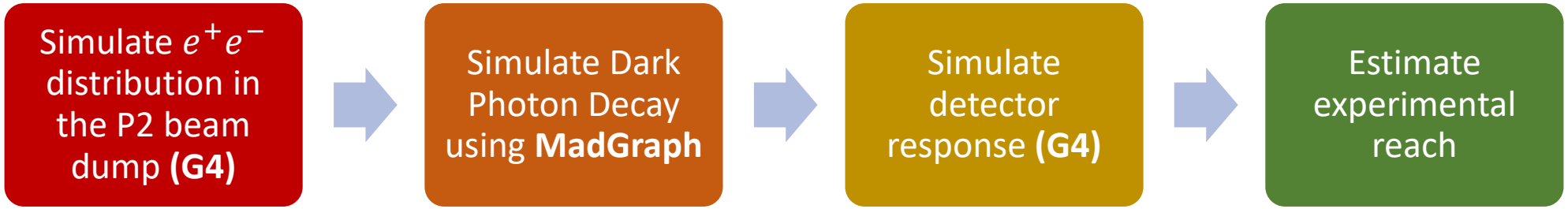
- Evaluation of experimental range necessary before start
  - Modeling of the accessible parameter space
  - Comparison for data analyses in the future
  - Creation of a research programme

- 3 Data taking Phases:
  - 55 MeV Phase A
  - 150 MeV Phase B
  - 150 MeV Phase C

Phase	Time	EOT
A	2.200 h	$7.42 \cdot 10^{21}$
B	6.600 h	$2.22 \cdot 10^{22}$
C	13.200 h	$4.45 \cdot 10^{22}$

Simulation of the Experimental Reach

- GEANT4-based detector simulation
- Utilise MadGraph to calculate BSM process
- Select LDM model: Dark Photon decays



Simulations of the Experimental Reach

- Limits are calculated for $m_{\gamma'} = 3\, m_{\chi}$ and $\alpha_D = 0.5$
- Considered decay processes:
  - Dark Bremsstrahlung
  - Positron Annihilation

Phase	Time	EOT
A	2.200 h	$7.42 \cdot 10^{21}$
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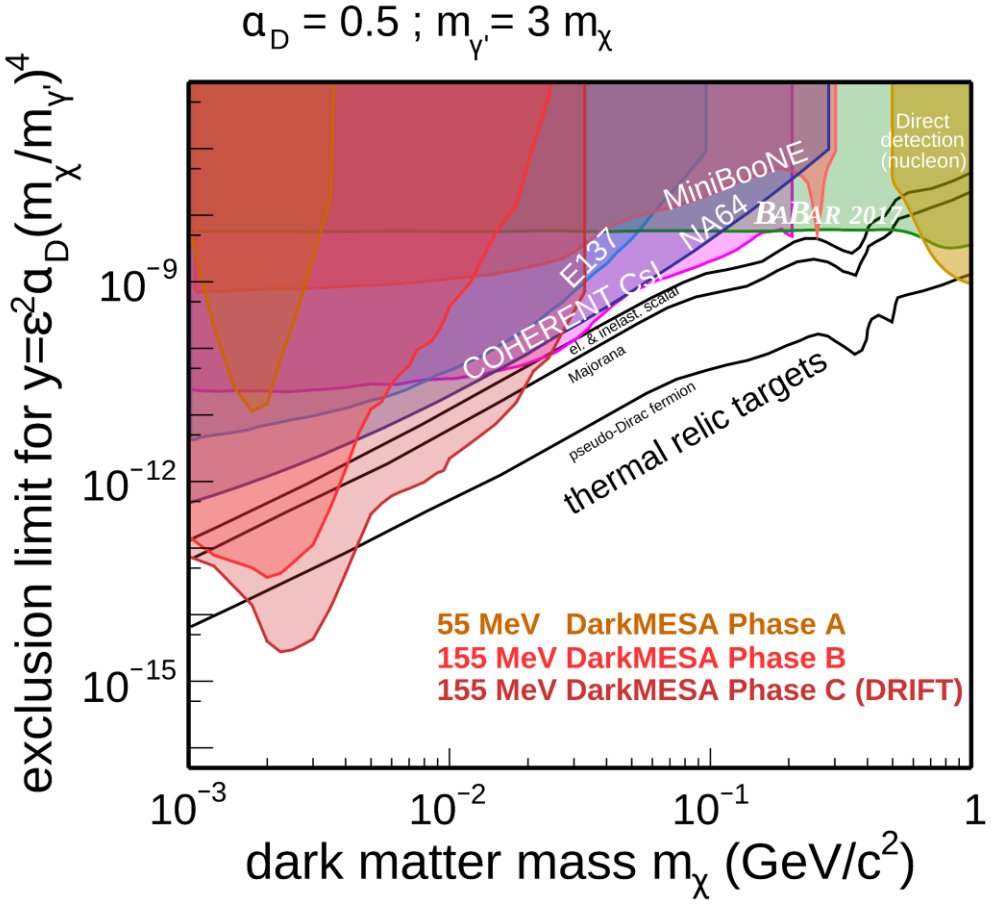
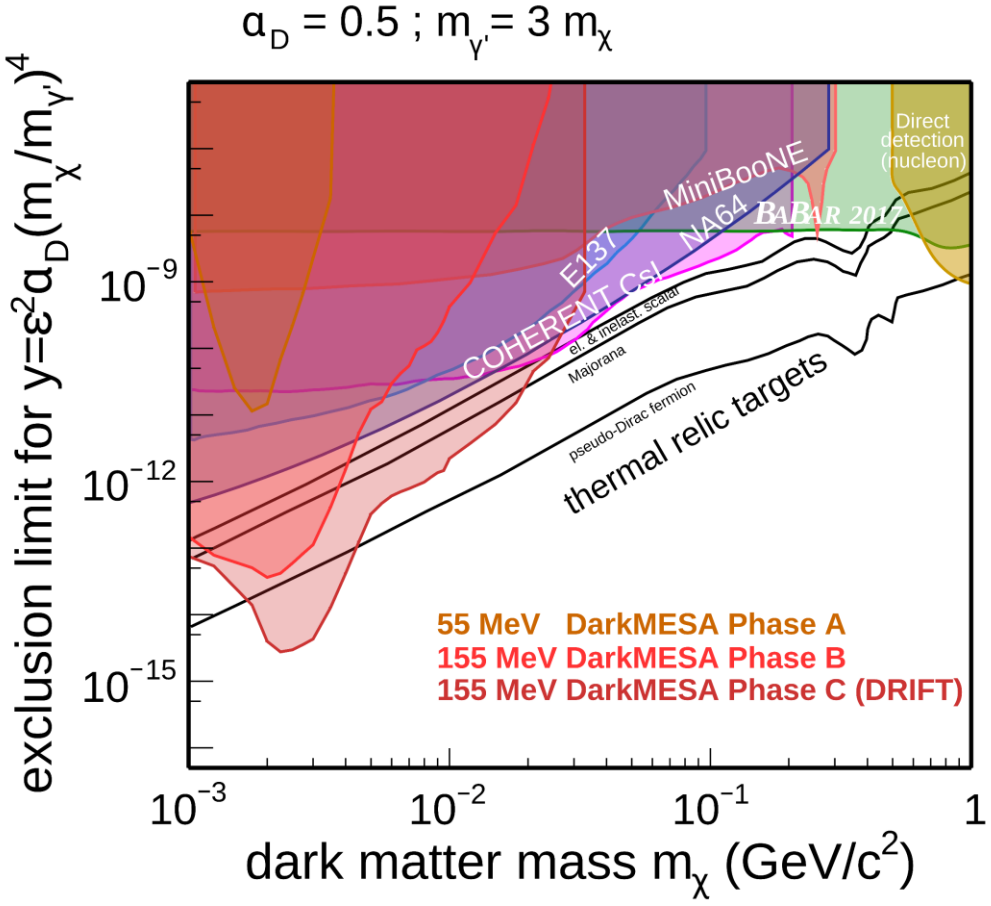


Expanding the Simulation

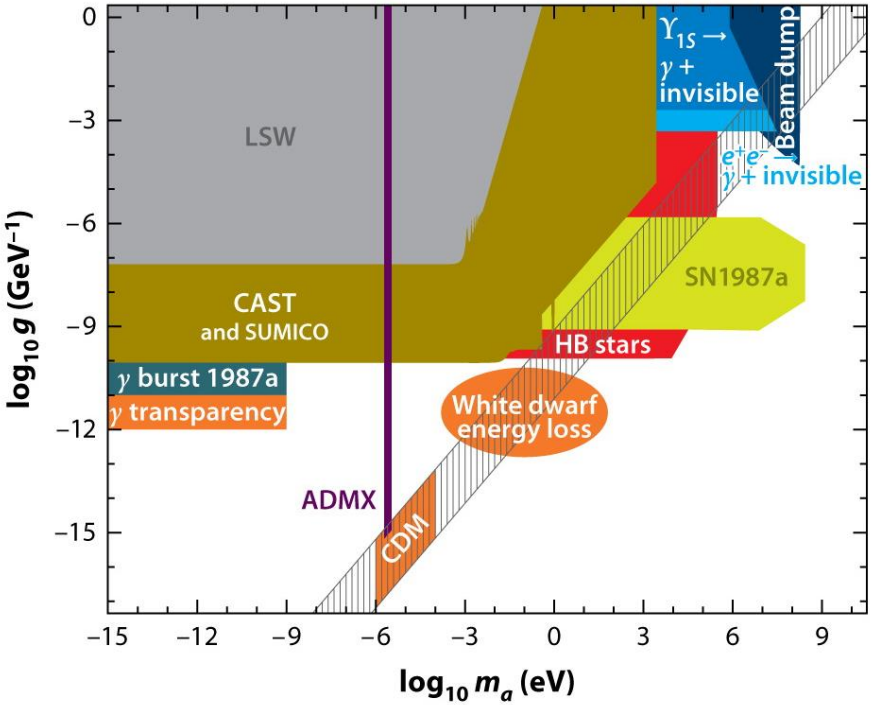
- Dark Photon models are interesting, but not the only viable candidate
- Other portal models explorable by DarkMESA
- Potentially interesting cases:
  - Dark Photon decay to visible
  - Axions/ALPs



The QCD Axion

- QCD allows for CP violation through
$$\mathcal{L}_\theta = -\frac{\alpha_s}{8\pi}\theta \tilde{G}^a_{\mu\nu} G^a_{\mu\nu}$$
- however: θ is extremely small, making QCD CP conserving

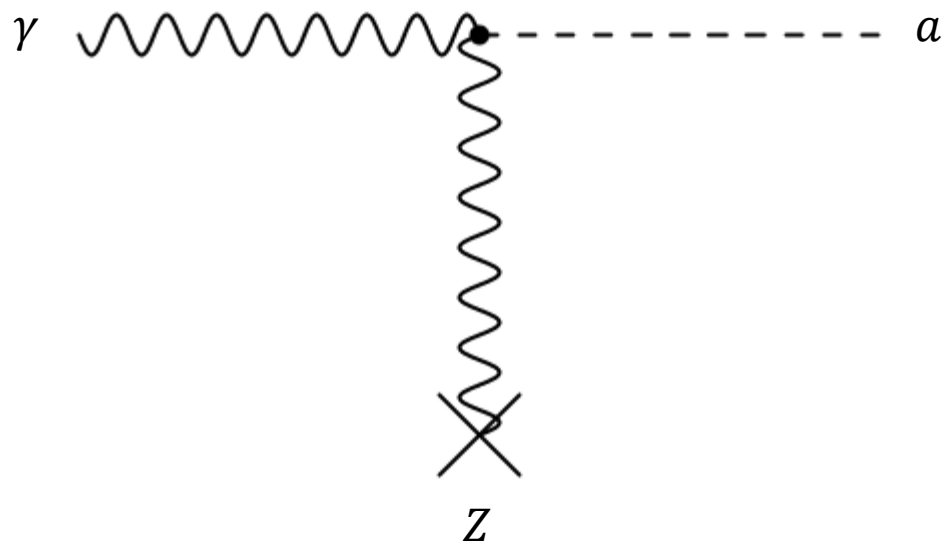
- introducing new global $U(1)_{PQ}$ symmetry could explain smallness of θ
- Symmetry breaking gives rise to pseudo-Goldstone boson a, the Axion



https://journals.aps.org/prd/abstract/10.1103/PhysRevD.80.075

Production of Axions at DarkMESA

- Axions are produced via Primakoff processes
- Decay into two photons
  - Need to be stable enough to decay only in the detector
- **Simulation question: How efficient is DarkMESA in detecting axions?**



Upgrading the Simulation

- Current simulation framework only able to simulate $\gamma' \rightarrow \bar{\chi}\chi$
- Need more versatile approach: DMG4

DMG4

- Fully compatible with GEANT4, no separate simulations needed
- Includes several LDM models
- Fully customizable parameters

Model	Parent PDG
Dark Photon (Annihilation)	**e^- (e^+)**
Dark Scalar (Annihilation)	e^- (e^+)
Dark Pseudoscalar (Annihilation)	e^- (e^+)
Dark Axial (Annihilation)	e^- (e^+)
Spin-2 Dark Matter (Annihilation)	e^- (e^+)
ALP	**γ**
Dark Vector	e^-
Dark Z	μ
Dark Muphilic Scalar	μ
Dark Muphilic Pseudoscalar	μ

https://arxiv.org/pdf/2101.12192.pdf

Upgrading the Simulation

DMG4

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Simulation is currently being reworked to include DMG4!

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Conclusion

- High intensity experiments provide a great environment for LDM searches
- DarkMESA will search for LDM at MESA
- Current simulation only includes $\gamma' \rightarrow \bar{\chi}\chi$
- Utilise DMG4 package to expand the simulation and streamline the generation
- **First tests with Axions/ALPs will be completed soon – stay tuned!**