Search for Light Dark Matter with the DarkMESA Experiment

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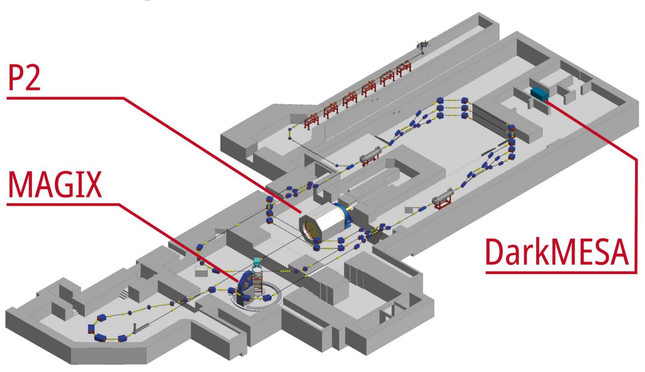
The MESA Accelerator

- Electron accelerator dedicated to **low-energy precision physics**

- 2 operating modes:
  - Energy-recovering mode:
    - Up to **1 mA @ 105 MeV**
    - Serves MAGIX
  - Extracted-beam mode:
    - Up to **0.15 mA @ 150 MeV**
    - Serves P2 and DarkMESA

MESA Experiments



3 Experiments: MAGIX, P2 and **DarkMESA:**

- **MAGIX**
  - Spectrometer-based detector system combined with a gas jet target
  - Research objectives: Dark Sector searches and Few-body physics

- **P2**
  - Utilises 150 MeV electron beam with a liquid hydrogen target
  - Research objective: Measurement of the weak mixing angle

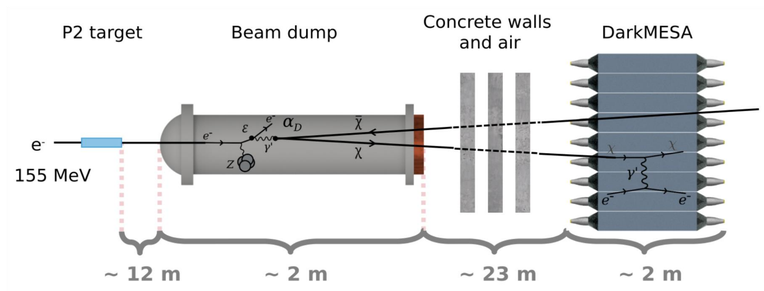
- **DarkMESA**
  - **Parasitic Dark Sector experiment** behind the beam dump of P2
  - Research objective: Direct detection of Dark Matter scattering processes

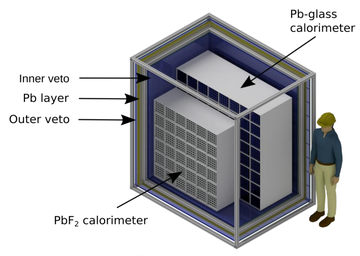
The DarkMESA Experiment

- **Lead glass** detector placed **23 m behind high-power beam dump of P2**

- **High beam intensities** for fast aquisition of large data sets

- **Staged** approach:
  - **Phase A:** PbF_2 crystals, 7.45×10^{21} EOT @ 55 MeV
  - **Phase B:** PbF_2 crystals + SF5 crystals, 2.22×10^{22} EOT @ 150 MeV
  - **Phase C:** Phase B setup + DRIFT detector (proposed), 4.45×10^{22} EOT @ 150 MeV





DarkMESA Phase B setup

- **Experimental concept** [1]**:**
  - **Light Dark Matter** could interact with SM matter through a **Dark Photon**
  - Production of Dark Photons in the beam dump through Dark Bremsstrahlung
  - Decay of a Dark Photon to **a Dark Matter pair**
  - Dark Matter **scatters off electrons** inside DarkMESA detector

Simulation Studies for the DarkMESA Experiment

- **GEANT4**-based detector simulation to estimate experimental reach and optimise detector setup [2,3]

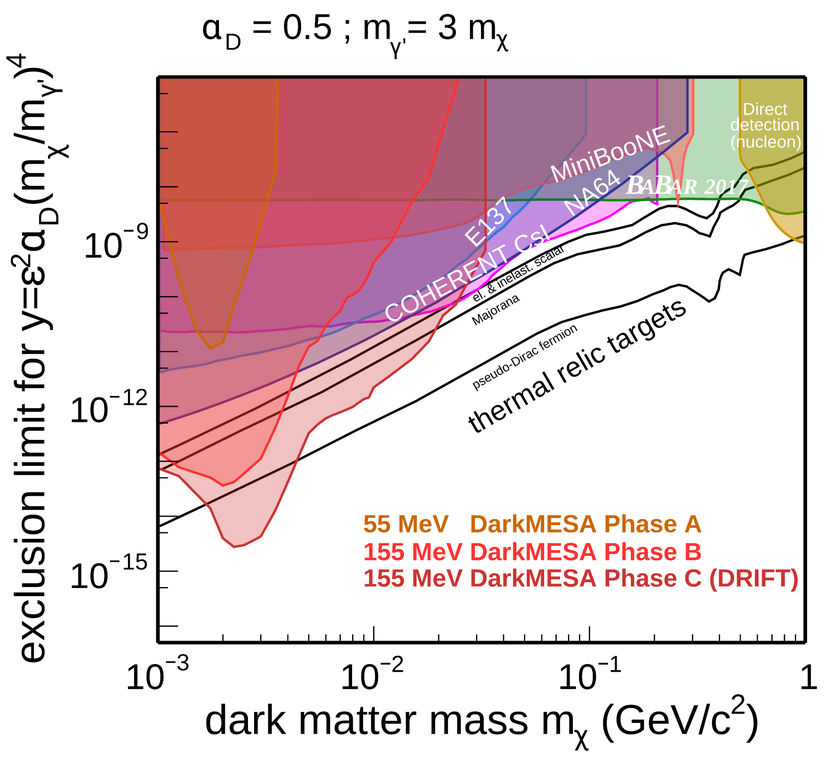
- **Simulation workflow:**

Simulate e^+e^- energy distribution in the P2 beam dump (**G4**) → Simulate Dark Photon decay using **MadGraph** → Simulate detector response (**G4**) → Estimate experimental reach

- Dark Photon decays can be simulated in two ways:
  - **Dark Bremsstrahlung** processes only
  - **Dark Bremsstrahlung and positron annihilation** processes

- Cross section calculations are performed after Bjorken [4]

➡ **DarkMESA is especially sensitive to Dark Matter masses of $m_\chi \approx 5$ MeV!**

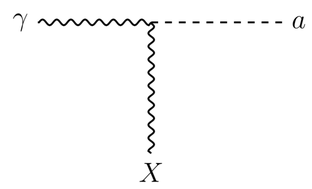


Outlook: Expanding the research programme of DarkMESA

- GEANT4 simulation limited to invisible Dark Photon decays

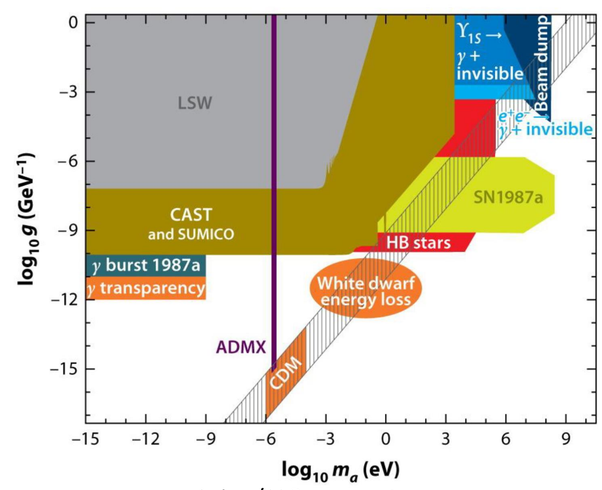
- **Utilise DMG4 package** [5]**:**
  - Direct integration into GEANT4 simulation possible → reduces computation time
  - **Includes several Dark Matter models**

- **Introduce Axion Dark Sector models**
  - Axions/ALPs could solve the strong CP problem [6]
  - Simulate decay via **Primakoff processes**



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

Dark Matter Models implemented in DMG4



Axion/ALP parameter space

References:
[1] L. Doria et al.: „Dark Matter at the Intensity Frontier: the new MESA electron accelerator facility“, DOI: 10.22323/1.360.0022
[2] M. Christmann et al.: „Instrumentation and optimization studies for a beam dump experiment (BDX) at MESA — DarkMESA, DOI: 10.1016/j.nima.2019.162398
[3] M. Christmann: „Design studies for the beam-dump experiment DarkMESA“, DOI: 10.25358/openscience-9076
[4] J. Bjorken, R. Essig, P. Schuster and N. Toro: „New Fixed-Target Experiments to Search for Dark Gauge Forces“, DOI: 10.1103/PhysRevD.80.075018
[5] M. Bondi et al: „Fully Geant4 compatible package for the simulation of Dark Matter in fixed target experiments“, DOI: 10.1016/j.cpc.2021.108129
[6] R.D. Peccei and H.R. Quinn. „CP Conservation in the Presence of Pseudoparticles“, DOI: 10.1103 / PhysRevLett.38.1440

Images:
MESA, https://www.mesa.uni-mainz.de/eng/
Beam Dump Experiment principle, https://magix.uni-mainz.de/physics.php
DarkMESA Phase B, https://magix.uni-mainz.de/DarkMESA.php
DMG4, https://indico.cern.ch/event/1106990/contributions/4997221/attachments/2535513/4363626/hsieber-bari-DMG4-v1.pdf
Axion/ALP parameter space: https://journals.aps.org/prd/abstract/10.1103/PhysRevD.80.075018