# Beam-Dump Experiment @ MESA

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At the *Institute for Nuclear Physics Mainz* the new electron accelerator MESA (*Mainz Energy-Recovering Superconducting Accelerator*) will go into operation within the next years. In the Extracted Beam Mode (155 MeV, 0.15 mA) the P2 experiment will measure the weak mixing angle in electron-proton scattering with a very high precision in 10,000 hours of operation time. The Beam-Dump of this experiment is ideally suited for a parasitic dark sector experiment that can significantly contribute to DM searches.

## MESA - A New Electron Accelerator in Mainz

- Low-energy Precision Physics
- Possible operation modes and their experiments
  - *Energy Recovery Linac* (ERL) mode allows very high electron-beam luminosities on internal targets (beam current up to 1 mA) at low energies → MAGIX
  - *Extracted Beam* (EB) for spin-polarized electrons (beam current up to 0.15 mA) → P2
- The P2 Experiment
  - The electrons have an energy of 155 MeV (3 circulations)
  - Measurement of the weak mixing angle in electron-proton scattering at low momentum transfer
  - 60 cm liquid hydrogen target → energy loss ~ 17 MeV
  - Beam-Dump 12 meters after target
  - 10,000 h → ~ $3.37 \cdot 10^{22}$ electrons → ~ 5400 C dumped
- Threshold energy for pion production is 150.54 MeV

  → reduce energy? → no neutrinos
- Possibility of a **parasitic dark sector experiment**

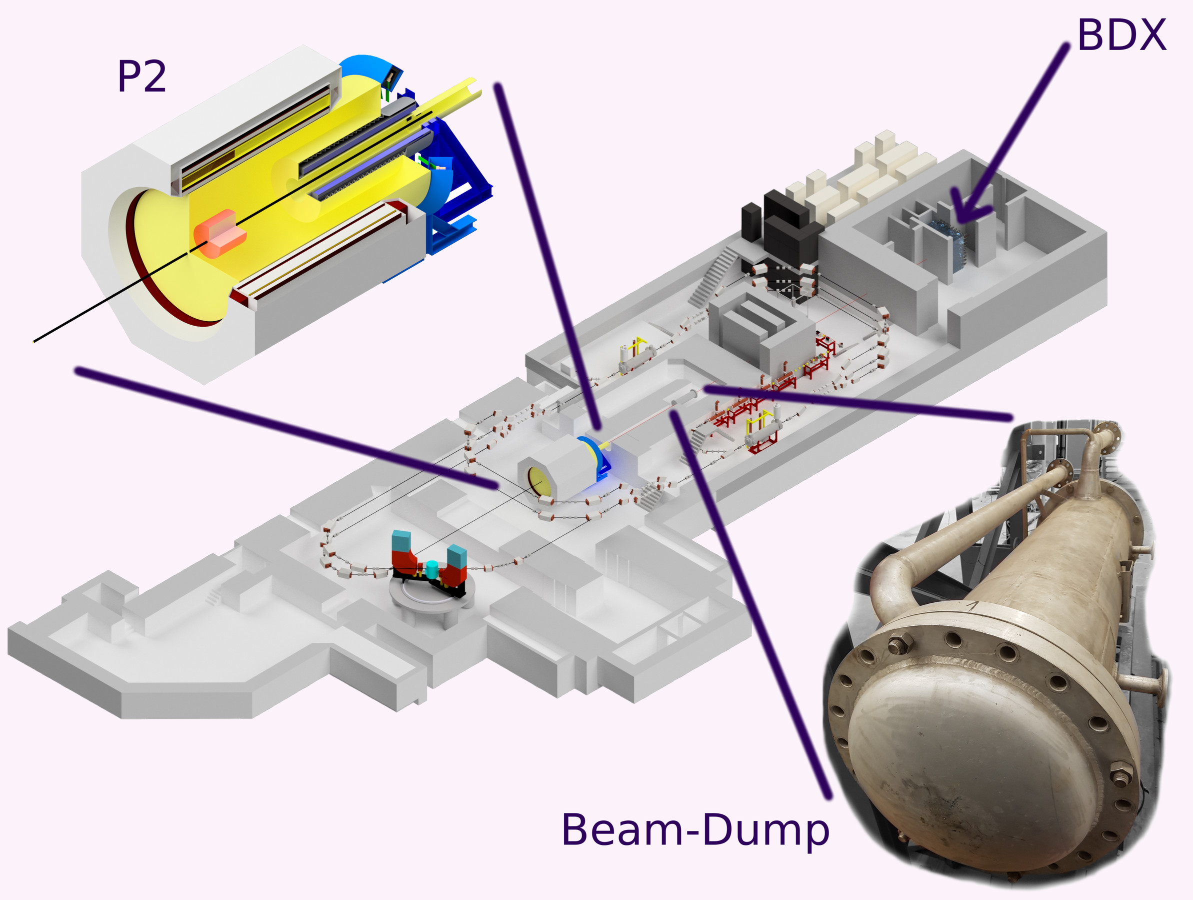
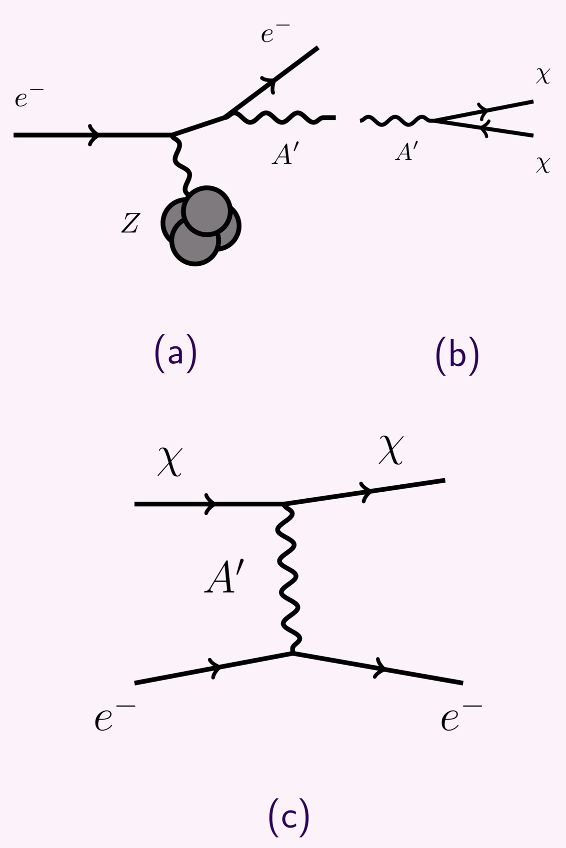



Fig. 1: Model of MESA (further developed from [1]) with enlarged P2 Experiment and Beam-Dump

## Physical Motivation

- Assumption: Light Dark Matter (LDM) interacts with the Standard Model through a (massive) dark photon A' coupling with $\epsilon$
- Dark photons are generated by a process respective to common photon bremsstrahlung (a)
- Invisible decay of A' to dark matter pair coupling with $\alpha_D$ in the Beam-Dump (b)
- Fraction of the dark matter particles scatter off electrons in the BDX detector (c)
- The MESA situation is shown beneath. DM particles produced in the Beam-Dump cross 8 m concrete and 15 m air undisturbed while all SM particles are eliminated



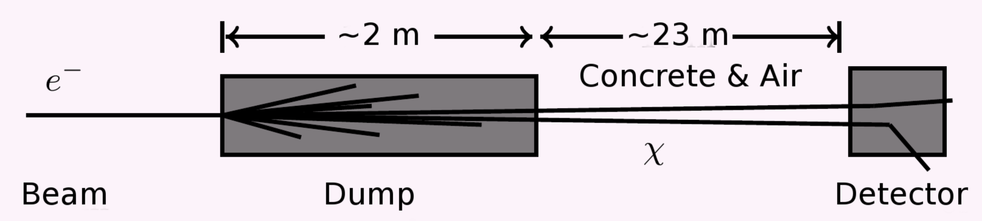




Fig. 5: Sketch of the BDX setup @ MESA (modified from [2])

## Dark Matter Production in Beam-Dump

- Lateral width of electron beam at dump ~ 0.4 m
- First 155 mm of Beam-Dump is $H_2O$ → energy loss ~ 30 MeV

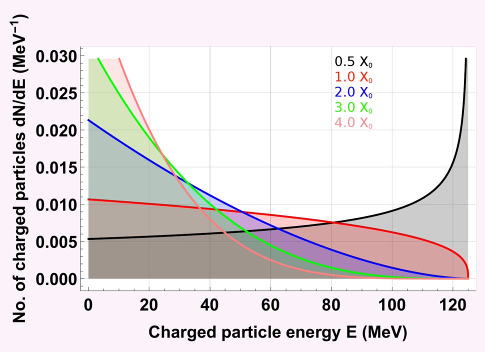



Fig. 6: Energy distribution at different depths [4]

- Main absorber material is Aluminium

  → shower maximum within first $X_0$
- DM production for m « 120 MeV can be tested
- Fig.6 shows the energy distribution at shower depths from 0.5 $X_0$ (black) to 4 $X_0$ (pink)
- Example
  - Calculation according to Bjorken [3]
  - Produced A' of mass $m_{A'}$=50 MeV/$c^2$ with $\epsilon$=$10^{-4}$ → distribution in Fig.7

    → Integration → 2.5 · $10^6$ A' in total
- Beam-Dump as possible "dark matter source"

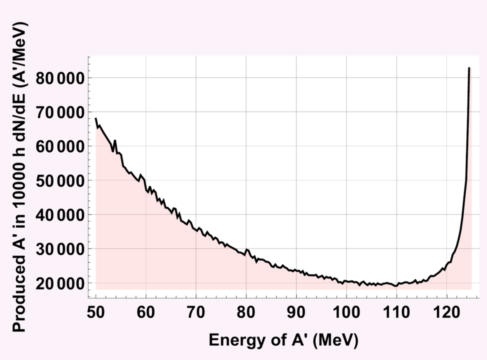
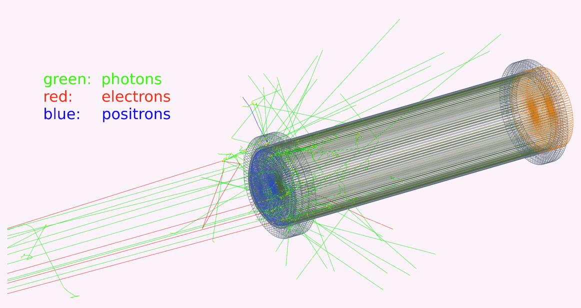
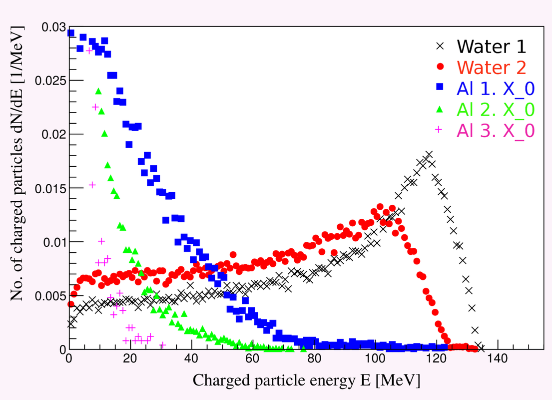



Fig. 7: Produced A' for $m_{A'}$ = 50 MeV/$c^2$ and $\epsilon$ = $10^{-4}$ (example) [4]



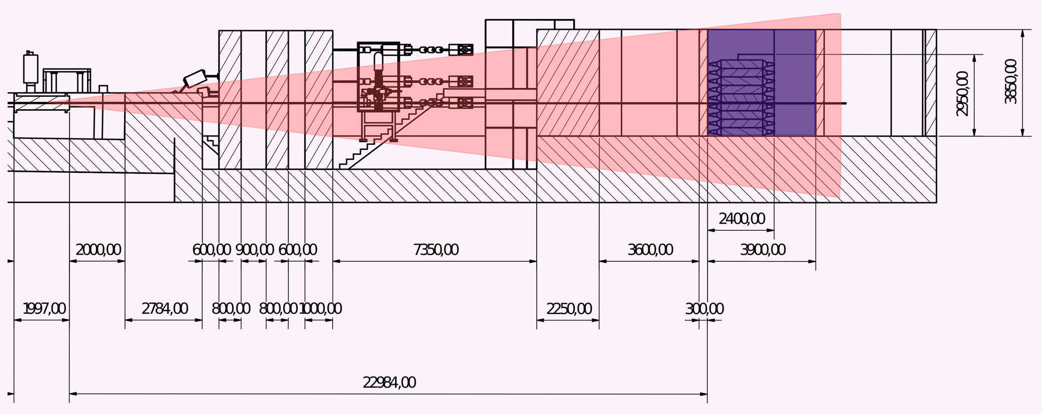

- **Implementation in GEANT4**
  - Simulation recently begun
  - Geometry of P2-Target and Beam-Dump implemented
  - 155 MeV electron source
- Comparison with simplified Mathematica calculations (i.e. Normalised energy distribution of charged particles depending on the shower depth)
- Dark photon generators need to be implemented




## Dark Matter Scattering in a Detector

- Limited but dedicated space for BDX
  - Floor space ~ 12 $m^2$
  - Maximum length 2.4 m in beam direction
  - Pumping system has to be accessible by workshop
- Multiple scattering in first $X_0$ of Beam-Dump ~ 10°

  → lateral width of dark matter beam at detector ~ 4 m



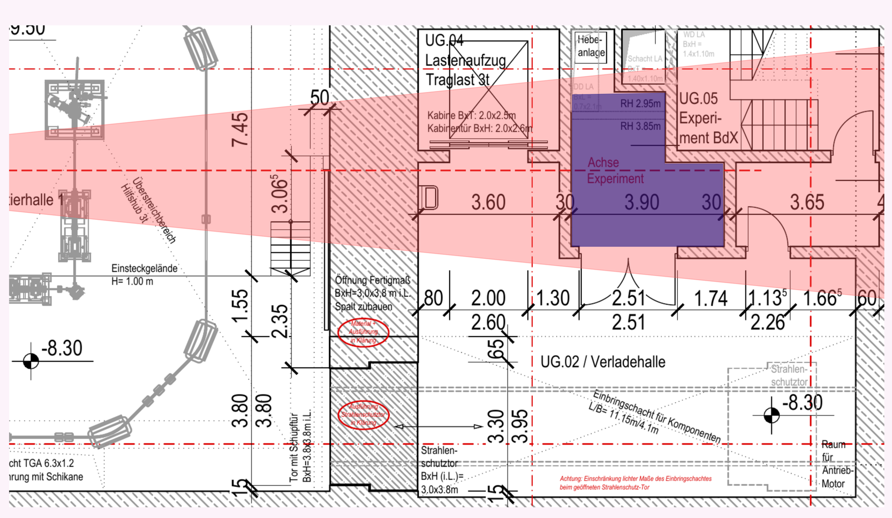
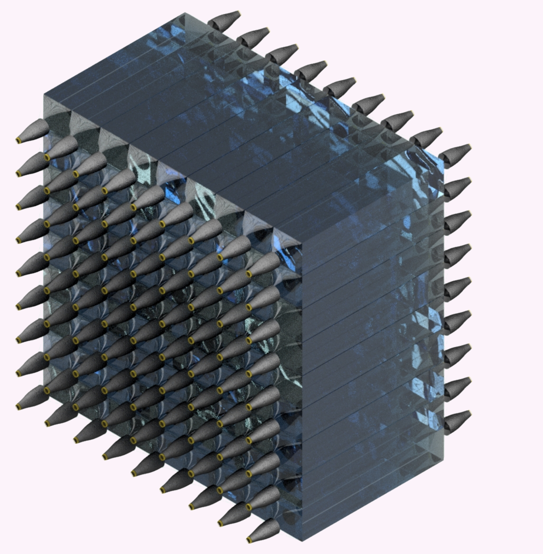


Fig. 11: Plan of the BDX room (modified from [5])

- Simulation of neutron background looks promising
- Background suppression
  - Beam on/off information
  - Read-out on front and back side
  - Additional veto detector?
  - Segmentation of the read-out
  - Symmetric layout → detector can be rotated



- Dark beam is large in size → maximize active volume
  - 81 blocks (30 × 30 × 150 $cm^3$) → ~ 11 $m^3$ active volume
  - ~ 7 $m^2$ cross section
  - Material: lead glass?
- 5 inch PMTs (Hamamatsu R1250)
- Test of prototypes at MAMI with 3.5 or 14 MeV electron beams

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## References

[1] D. Simon. *Autodesk Inventor Datafiles*. Institute for Nuclear Physics, Johannes Gutenberg-University Mainz. 2016.
[2] M. Battaglieri et al. *Dark matter search in a Beam-Dump eXperiment (BDX) at Jefferson Lab*. arXiv:1607.01390v1 [hep-ex]. 2016.
[3] J. D. Bjorken et al. *New fixed-target experiments to search for dark gauge forces*. Physical Review D 80, 075018 (2009).
[4] P. Achenbach. *Mathematica calculations*. Institute for Nuclear Physics, Johannes Gutenberg-University Mainz. 2017.
[5] Landesbetrieb LBB. *Preliminary draft of new MESA hall*. Mainz. 2016.