Dark Sector Physics Opportunities at MESA

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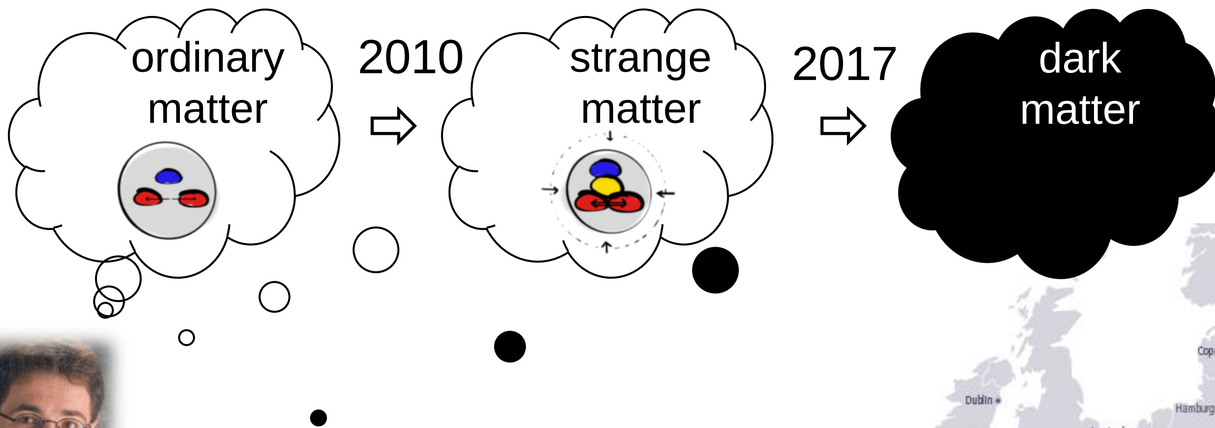
The 5 Ws (and an H)

Who, what, and where, by what helpe, and by whose:
Why, how and when, doe many things disclose.
Thomas Wilson: *The Arte of Rhetorique* (1560)



⇨ a real challenge

who:

me studying

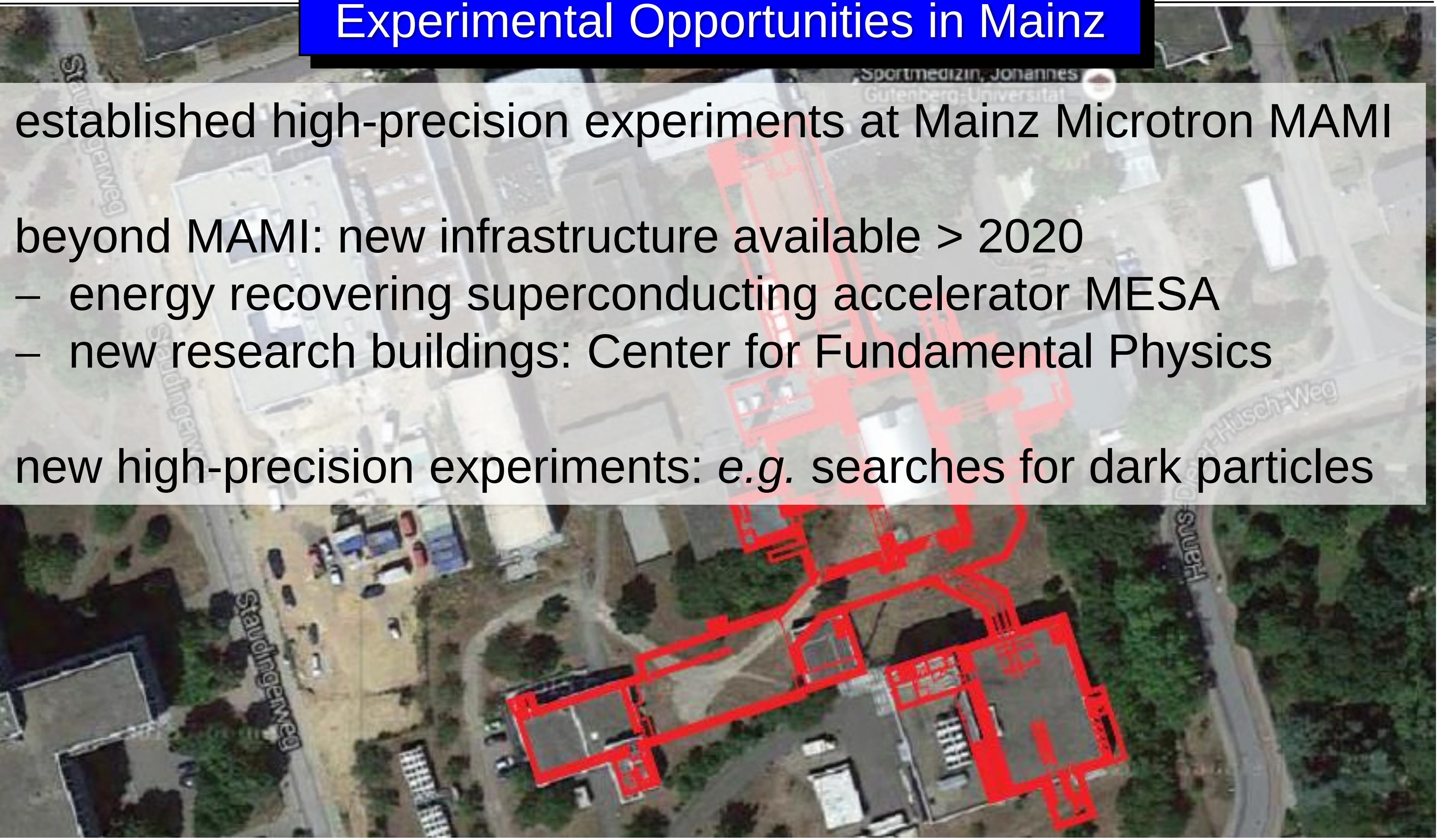
where:

Experimental Opportunities in Mainz

established high-precision experiments at Mainz Microtron MAMI

beyond MAMI: new infrastructure available > 2020
- energy recovering superconducting accelerator MESA
- new research buildings: Center for Fundamental Physics

new high-precision experiments: *e.g.* searches for dark particles



German excellence initiative: Cluster of Excellence
"Precision Physics, Fundamental Interactions and Structure of Matter" (PRISMA)

PRISMA SFB 1044

New Collaborative Research Center at Johannes Gutenberg-University Mainz:
The Low-Energy Frontier of the Standard Model
From Quarks and Gluons to Hadrons and Nuclei.

The Mainz Microtron

MAMI-B:

3 Race Track Microtrons

E_0 = 180 ... 883 MeV

energy spread ΔE = 13 keV

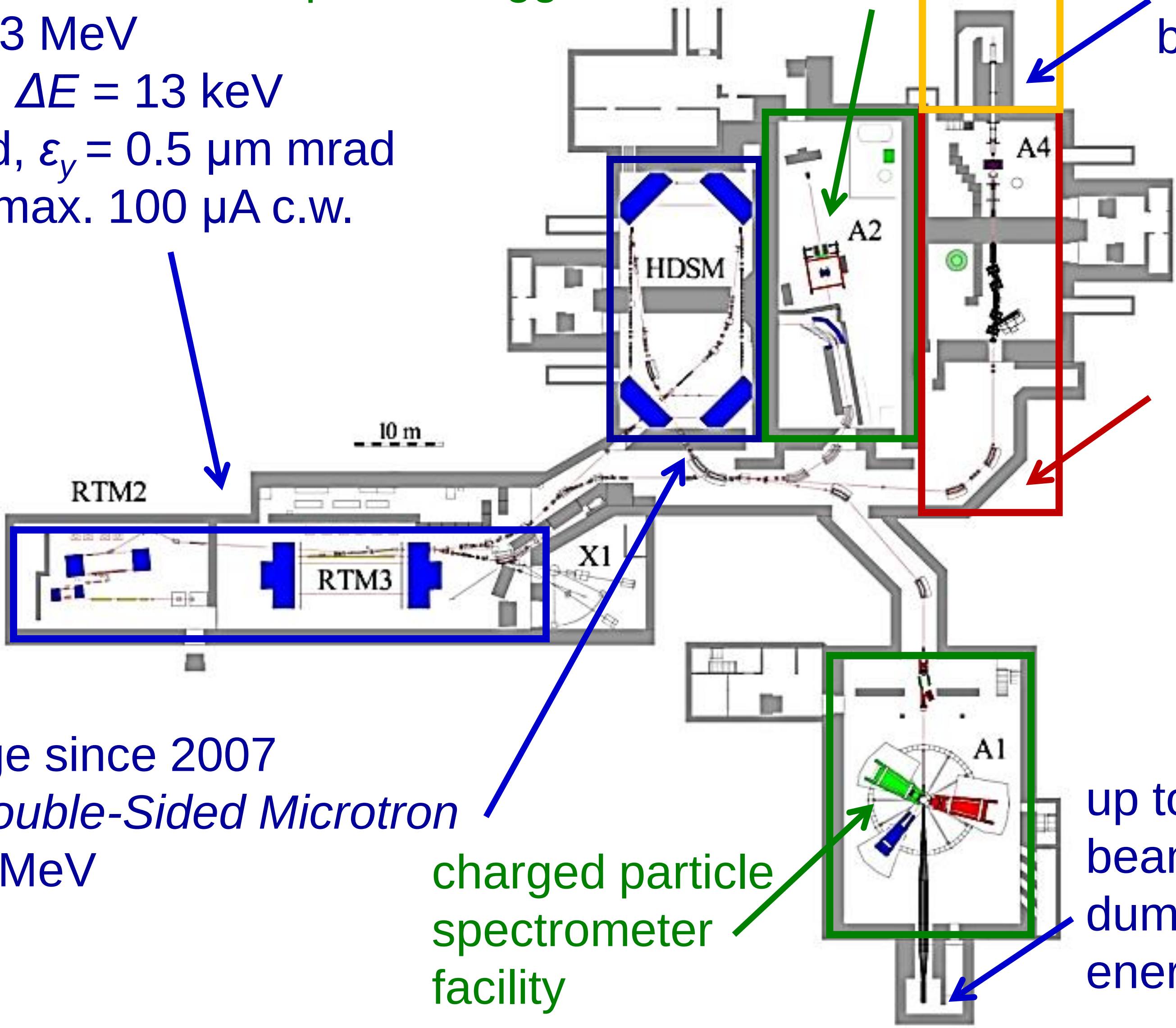
ε_x = 9 μm mrad, ε_y = 0.5 μm mrad

beam current max. 100 μA c.w.

photon tagger & 4π detector

CFP

high-power beam-dump



cleared for MESA

MAMI-C:

additional stage since 2007

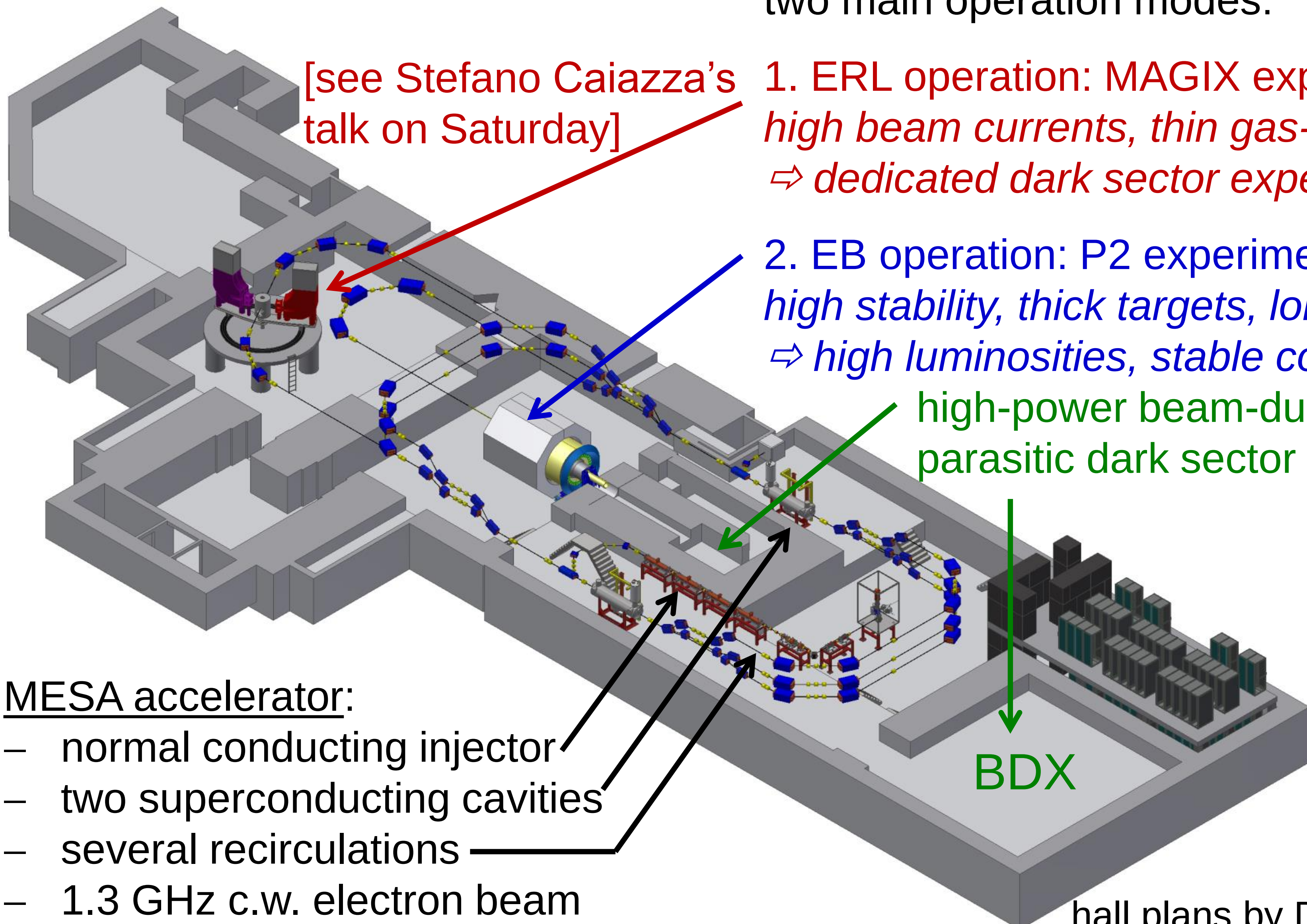
1 Harmonic Double-Sided Microtron

E_0 up to 1604 MeV

charged particle spectrometer facility

up to 160 kW beam power dumped at full energy

The MESA Facility



two main operation modes:

[see Stefano Caiazza's talk on Saturday]

1. ERL operation: MAGIX experiment
high beam currents, thin gas-jet targets,
⇨ *dedicated dark sector experiments*

2. EB operation: P2 experiment
high stability, thick targets, long runs
⇨ *high luminosities, stable conditions*

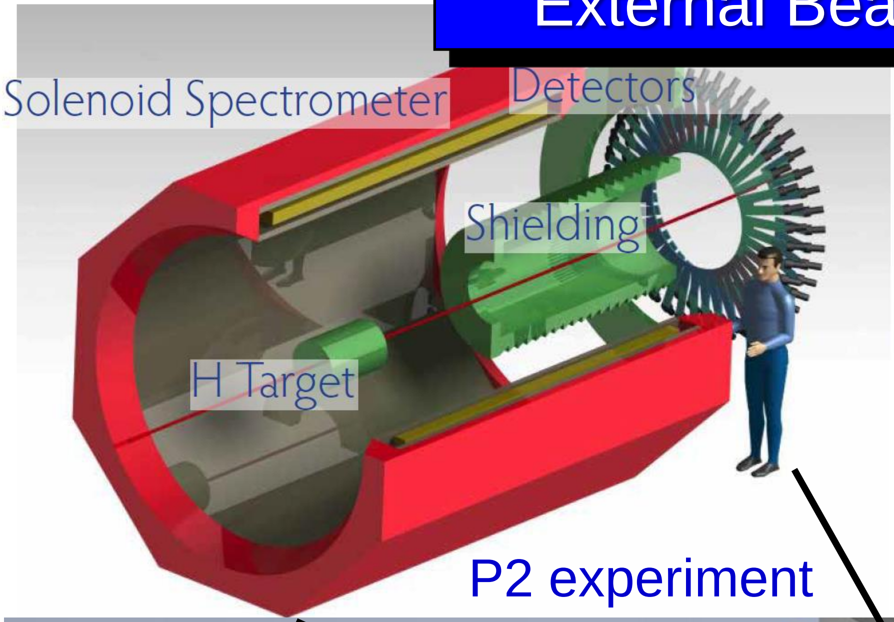
high-power beam-dump
parasitic dark sector experiment

BDX

MESA accelerator:
- normal conducting injector
- two superconducting cavities
- several recirculations
- 1.3 GHz c.w. electron beam

hall plans by Daniel Simon

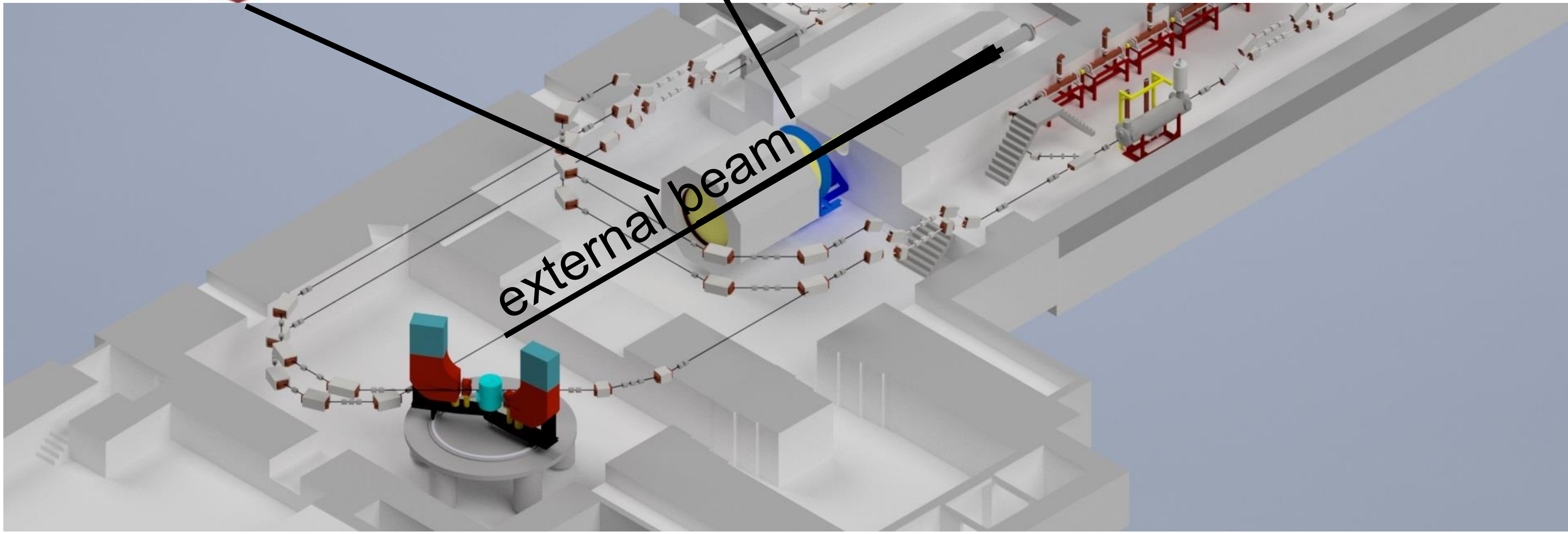
External Beam Degrading



beam energy ~ 147-155 MeV
beam current ~ 150 µA
P2 target: 60 cm liquid hydrogen

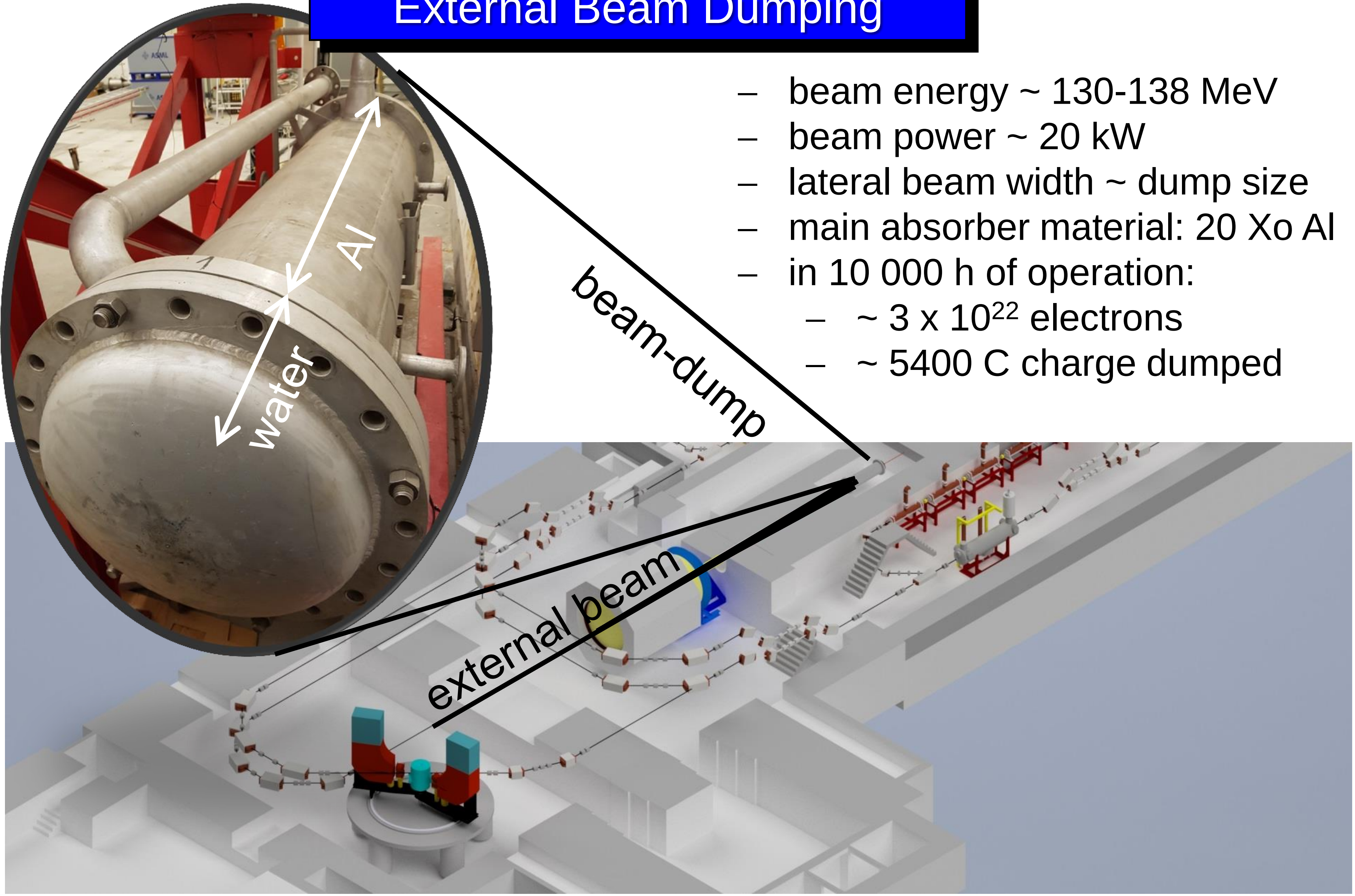
- 3 kW beam power loss
- 17 MeV beam energy loss
- 2° multiple scattering angle

no pion/muon/neutrino production
beam dumped at full energy after 12 m



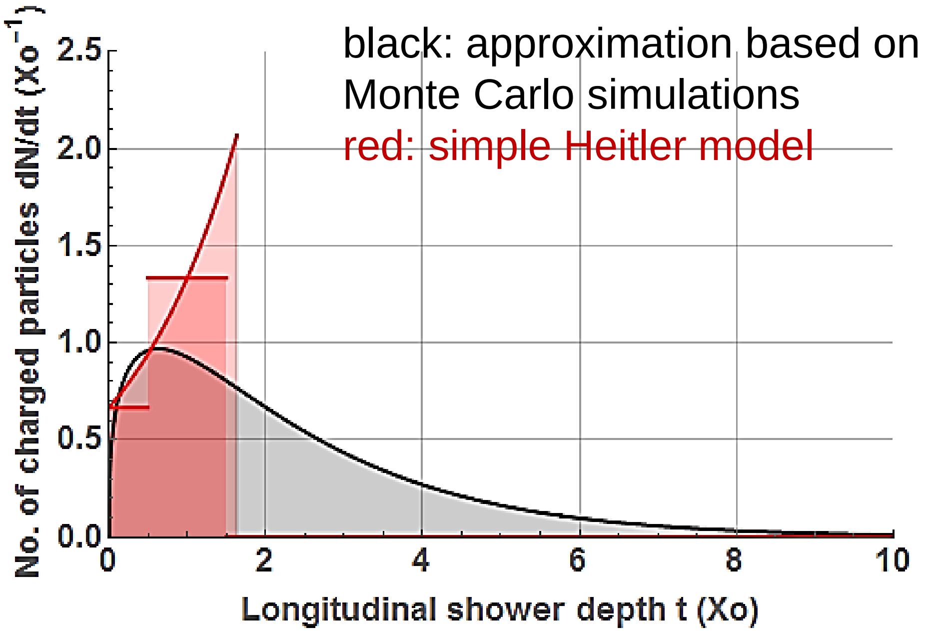
External Beam Dumping

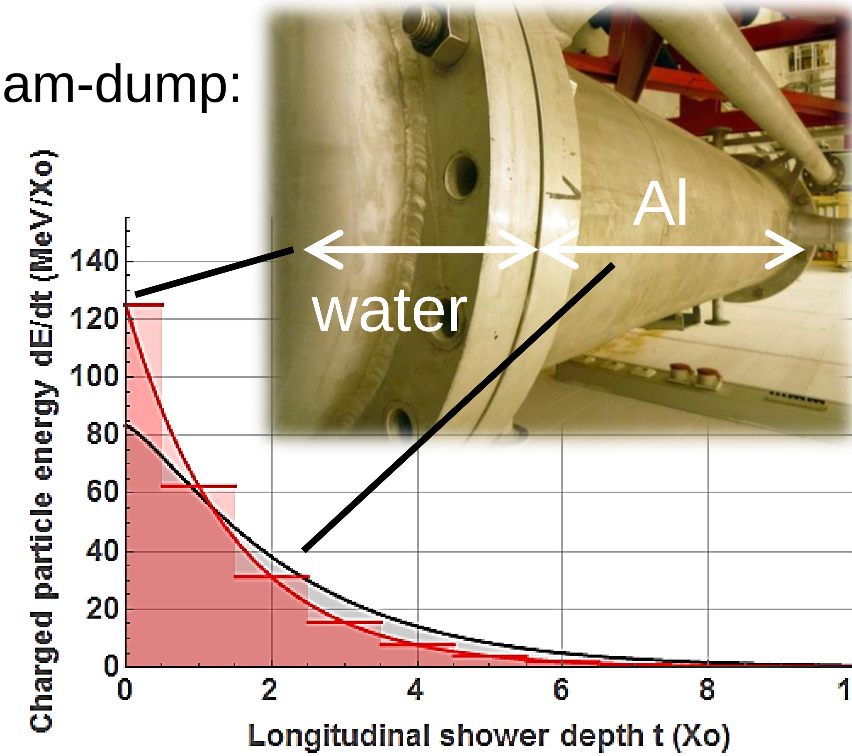
- beam energy ~ 130-138 MeV
- beam power ~ 20 kW
- lateral beam width ~ dump size
- main absorber material: 20 Xo Al
- in 10 000 h of operation:
  - ~ 3 x 10^{22} electrons
  - ~ 5400 C charge dumped



Bremsstrahlung in Beam-Dump

- first 155 mm of material in beam-dump are water
- mean first interaction point occurs at depth Xo, i.e. inside Al absorber
- longitudinal shower leakage: 2 x 10^{-5}
- energy and particle distributions in beam-dump:

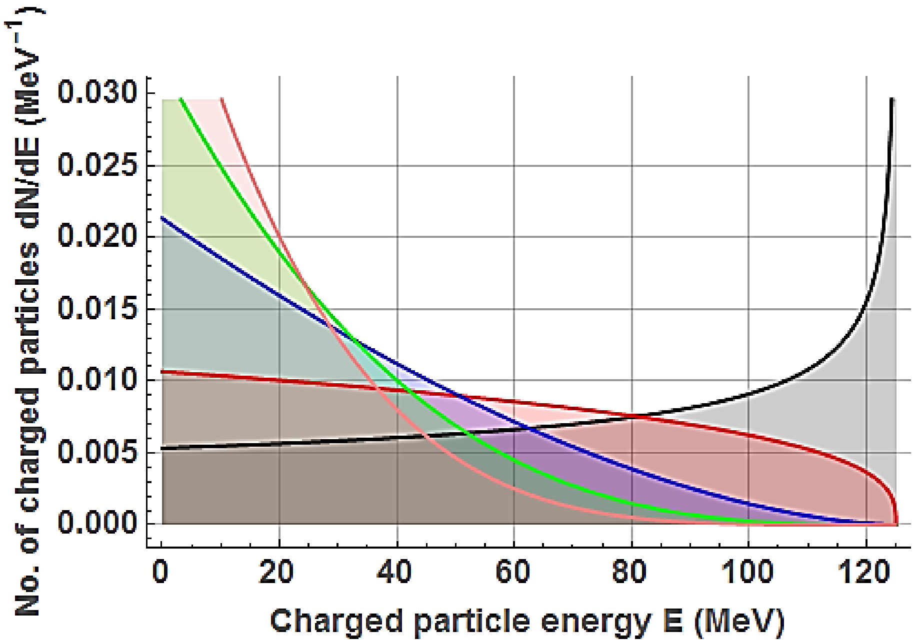




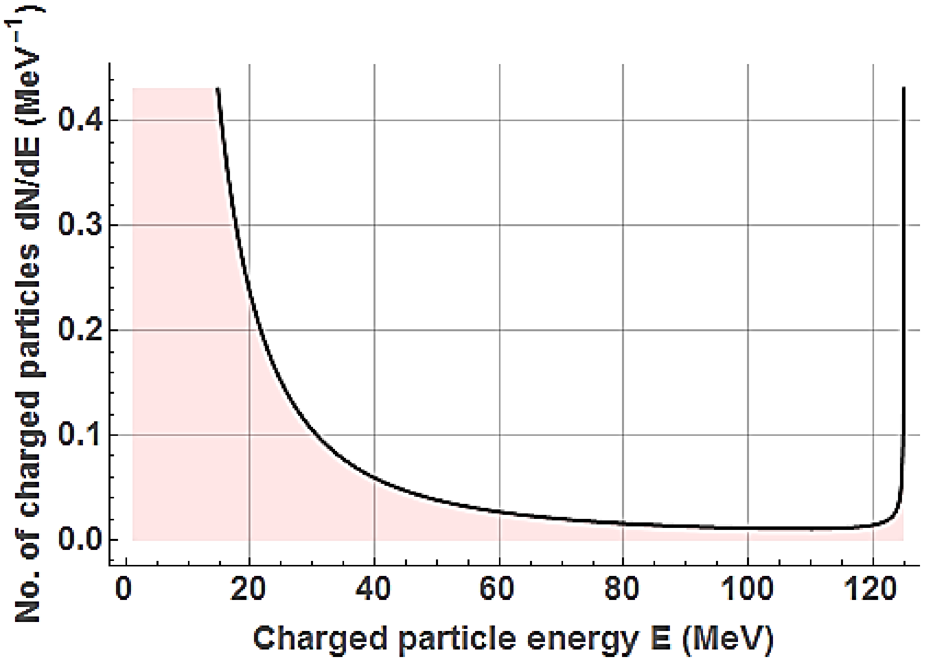
- shower maximum within first Xo
- on average ~ 3 charged particles per beam electron
- on average ~ 1 hard photon emission per beam electron

Available Energies in Beam-Dump

energy distribution
at different shower depths:



integral over complete shower:



beam-dump as possible dark matter source:

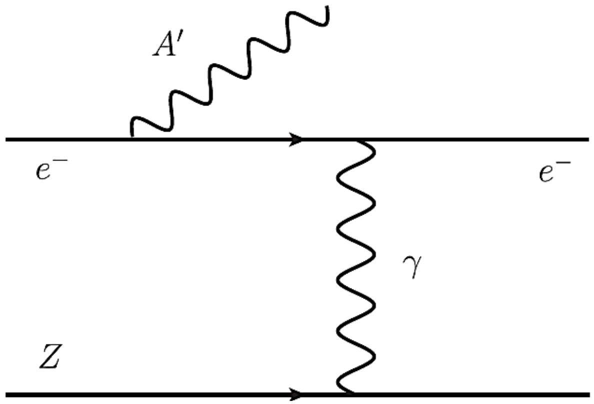
- DM production for m ~ 120 MeV can occur only within first Xo
- testing ground for DM production at m « 120 MeV

Model for A' Bremsstrahlung

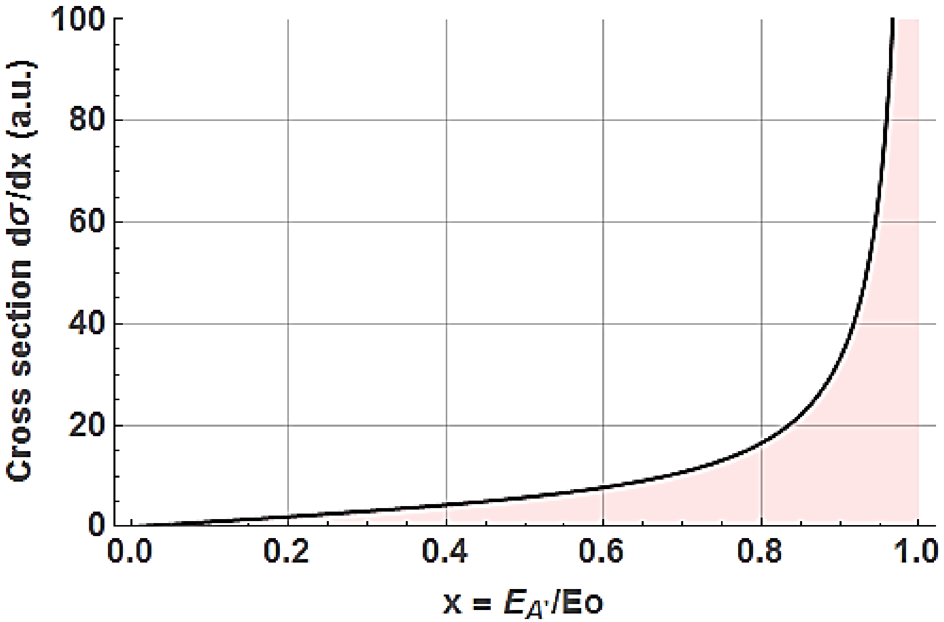
– unstable mediators appear in many Beyond Standard Model constructions

– radiative production of (massive) dark photon A' coupling with ε
– cross section peaked in forward direction
– subsequent (invisible) decay to dark matter pair coupling with α_D

cross section according to Bjorken et al., Phys. Rev. D80, 075018 (2009):



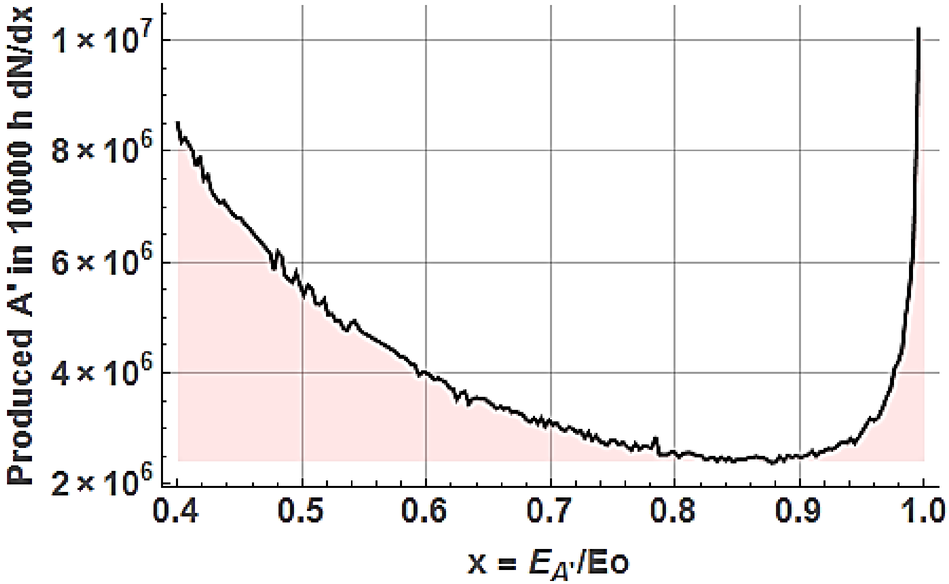
$$\frac{d\sigma}{dx} \approx \frac{8Z^2\alpha^3\epsilon^2 x}{m_{A'}^2}\left(1 + \frac{x^2}{3(1-x)}\right)\mathcal{L}og$$



Dark Beam Source

approx. total A' no. according to Bjorken et al., Phys. Rev. D80, 075018 (2009):

$$\frac{dN}{dx} = N_e \frac{N_0 X_0}{A} \int_{E_{A'}}^{E_0} \frac{dE_1}{E_1} \times \int_0^T dt I(E_1; E_0, t) E_0 \frac{d\sigma}{dx'} \Big|_{x'=E_{A'}/E_1}$$

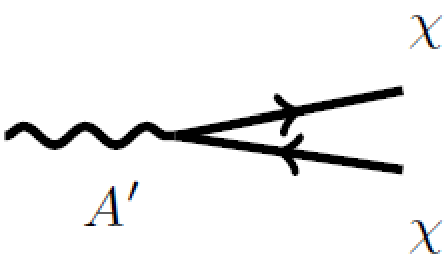


<u>example calculations</u>

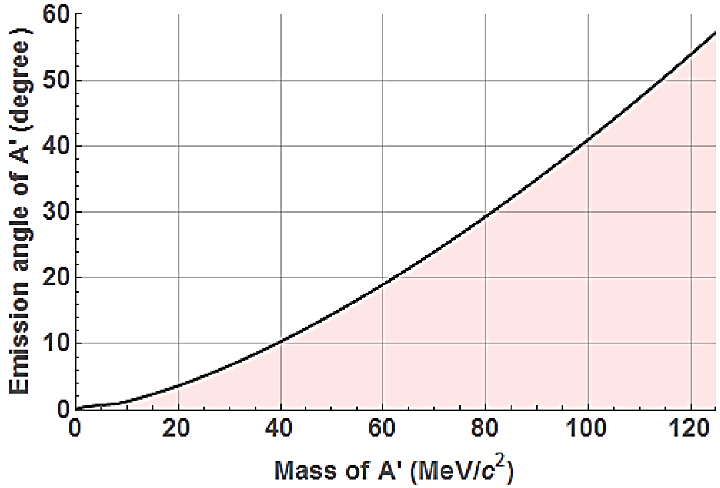
for $m_{A'}$ = 50 MeV/c^2 and $\epsilon = 10^{-4}$

– x-integrated total A' no.: 2 x 10^6

for 2 $m_X < m_{A'}$ and not too small α_D prompt decays into DM pairs in dump:

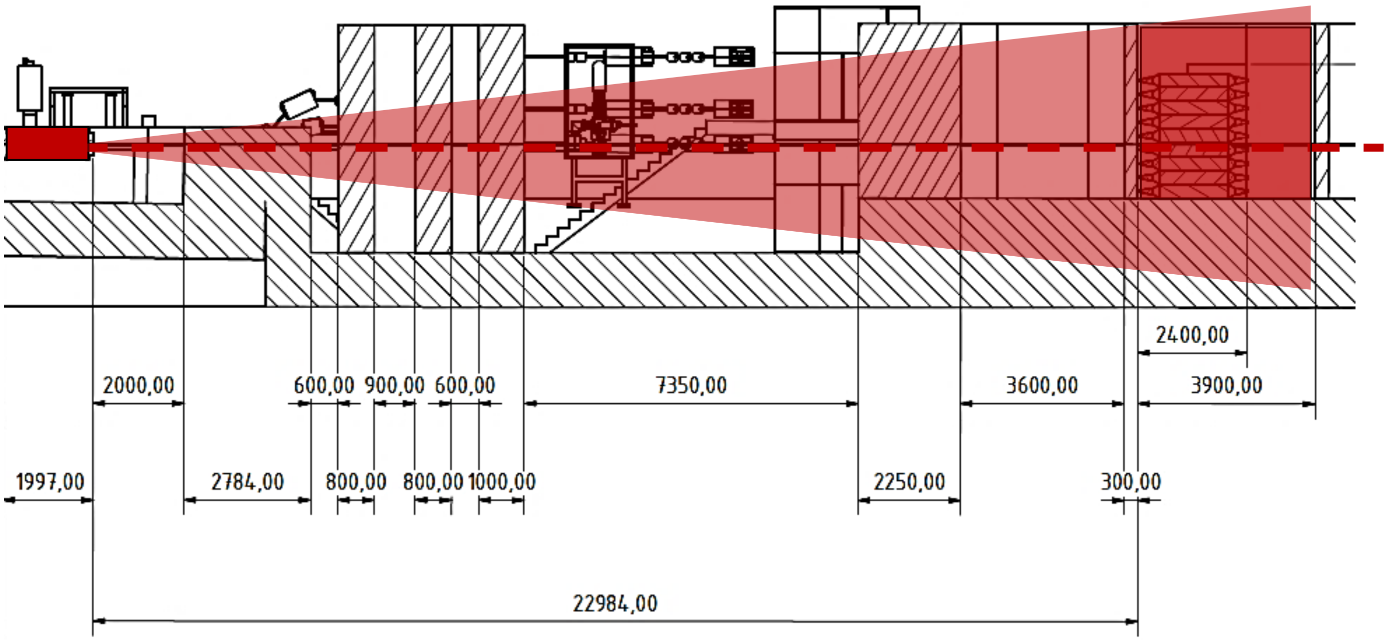


$$\theta_{A'\,\max} \sim \max\left(\frac{\sqrt{m_{A'} m_e}}{E_0}, \frac{m_{A'}^{3/2}}{E_0^{3/2}}\right)$$



Dark Beam-Line

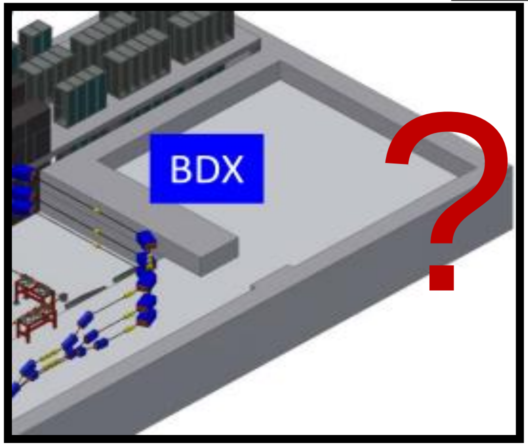
- 20 Xo beam-dump, 70 Xo (~ 8 m) barite concrete
- total length of 23 m including several shielding walls
- practically no surviving neutrons at detector site
- practically free of beam-dump related background



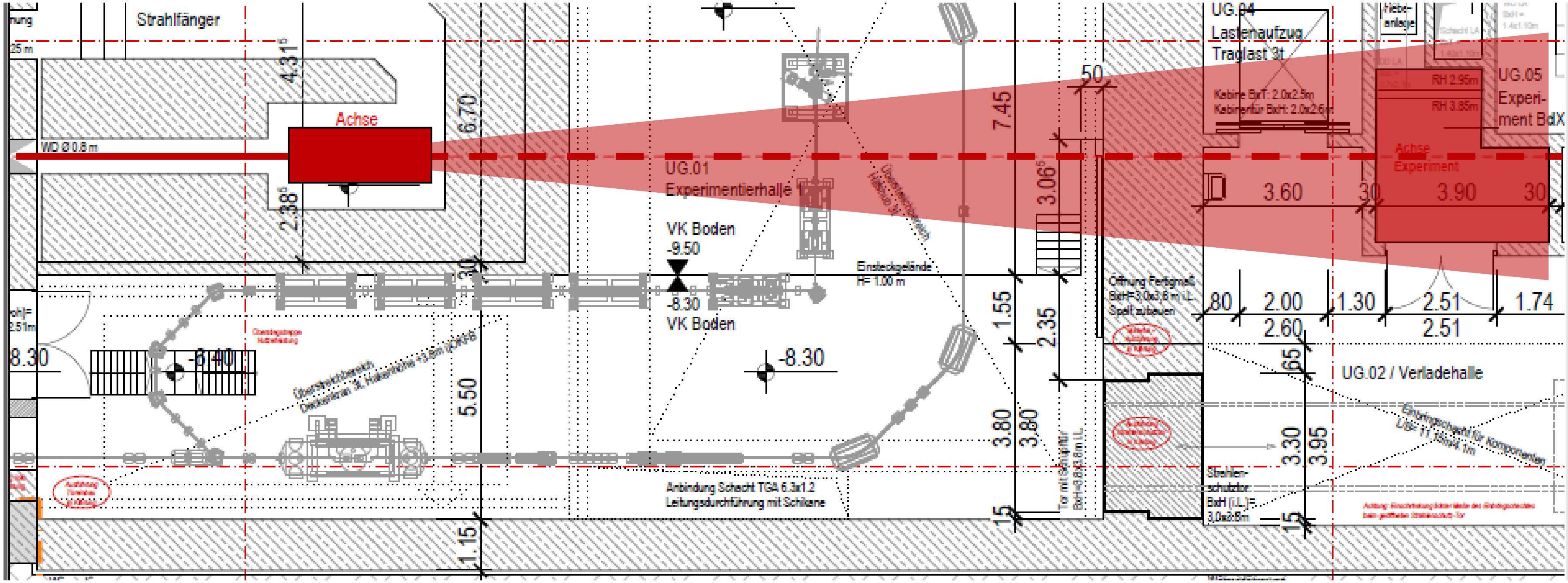
- multiple scattering of electron in first radiation length of beam-dump:

$\sqrt{\langle\theta^2\rangle}$ = Es/Eo ~ 10° ⇨ cone at detector site opens to ± 400 cm

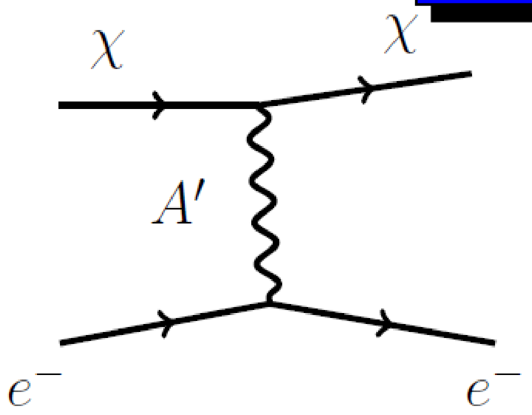
Dark Beam Detector Site

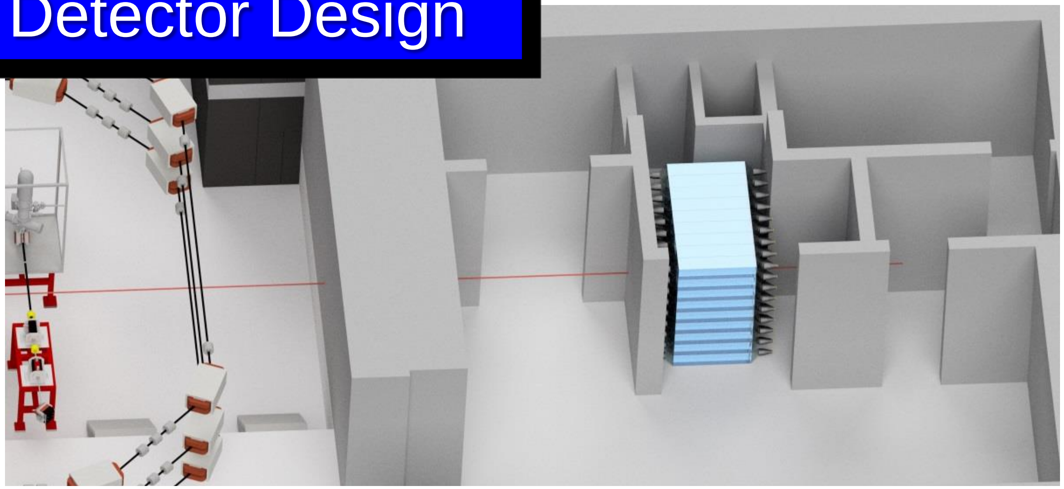


- no cooling power available
- max. 5 kW electric power
- regular access to chamber by workshop
- detector size limited by chamber floor: $3.90 \times 2.15\ m^2 + 2.40 \times 1.45\ m^2 = 12\ m^2$
- max. 2.4 m length in beam direction



Elements of Detector Design





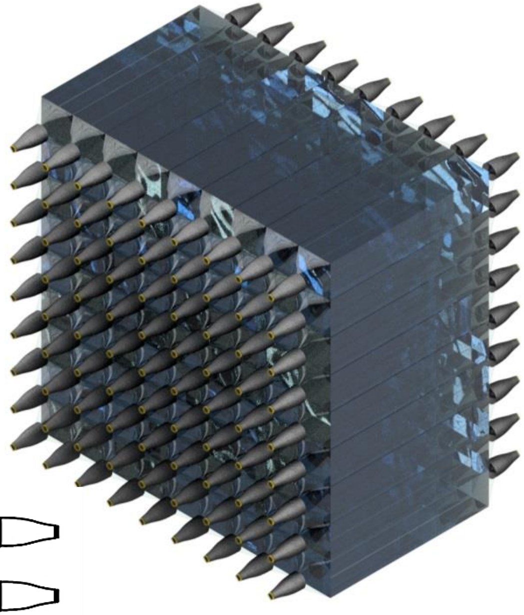
<u>geometry and choice of active medium</u>:

- because of large dark beam size: maximum active volume
- dark scattering signal: Cherenkov effect (electrons only)? Scintillation?
- use of directional information: Cherenkov effect? Tracking?

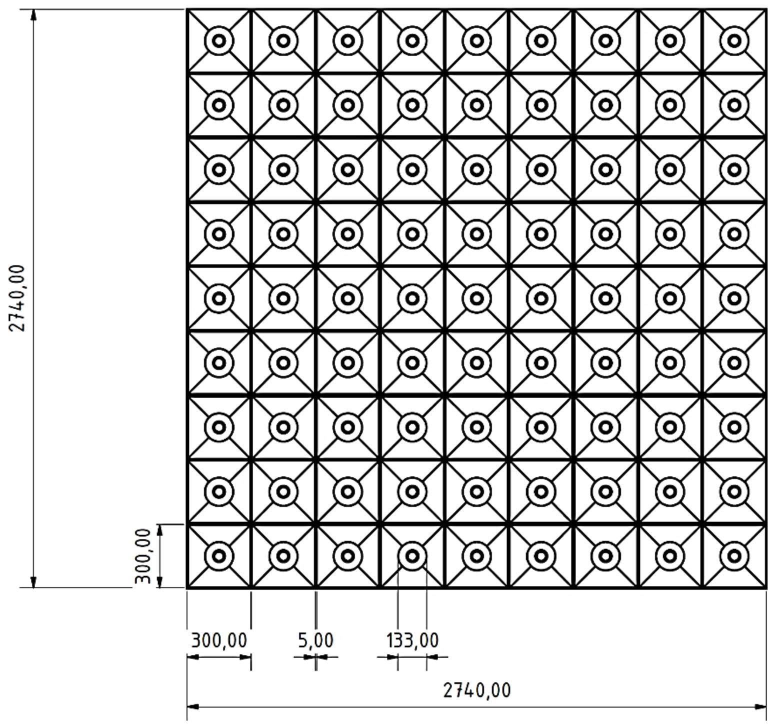
<u>background rejection</u>:

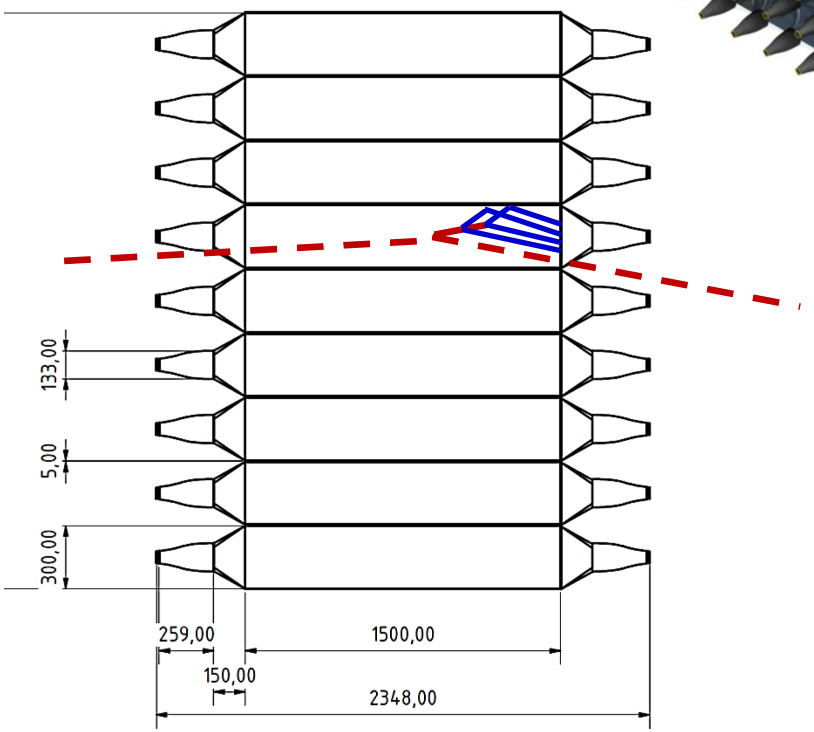
- use of beam on/off information: beam-time scheduling 50% / annum
- dark beam front-end and back-end read-out to access backgrounds?
- (annual) rotating of detector to access detector and read-out inhomogeneity?
- segmenting of detector read-out to allow for coincidences eliminating noise?
- use of a veto detector?

Draft of a Possible Detector



- 81 elements of 30 cm x 30 cm x 150 cm = 11 m^3
- 274 cm x 274 cm cross section
- use of 5 inch PMTs (Hamamatsu R1250)
- active material: lead glass blocks (high Z, short Xo)?
- validation of detector concepts possible at MAMI:
  3.5 MeV or 14 MeV test-beams, …





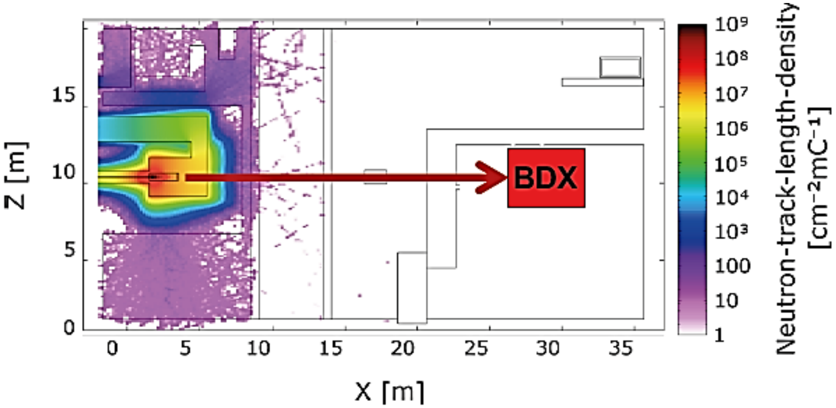
model and drawings by Mirco Christmann

Initial Projections for MESA

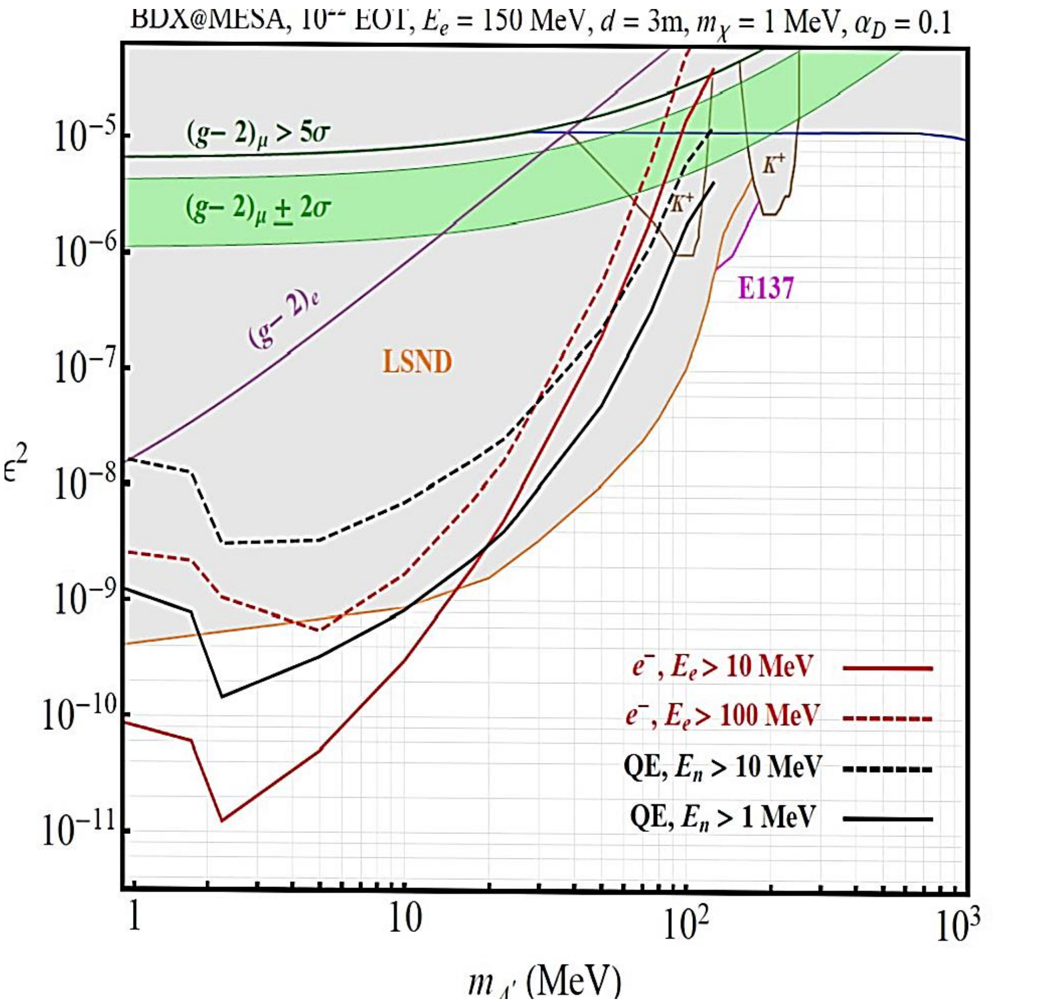
- assuming every dumped electron has one hard Bremsstrahlung emission
- acceptances from BDX@Jlab

- simulation of BDX@MESA under development

- FLUKA simulation of neutron background promising:



simulation by Steffen Heidrich



estimates by Gordan Krnjaic & Eder Izaguirre

communicated by M. Battaglieri (INFN Genova)

Conclusio

– electron beam-dump experiments significantly contribute to DM searches

– invisible decay searches reopen door to large regions of parameter space excluded by searches for decay electrons or muons

– beam-dump of extracted beam at MESA ideal
to explore light and weakly coupled new physics

1. very large luminosities
2. extremely stable beam conditions (*cf.* parity violation)
3. very low backgrounds
4. limited but dedicated floor space available
5. excellent infrastructure conditions

– MESA and its beam-dump experiments could go online by > 2020

Outlook: Search for Answers to the 5 Ws (and an H)