Dark Photon Searches at Mainz

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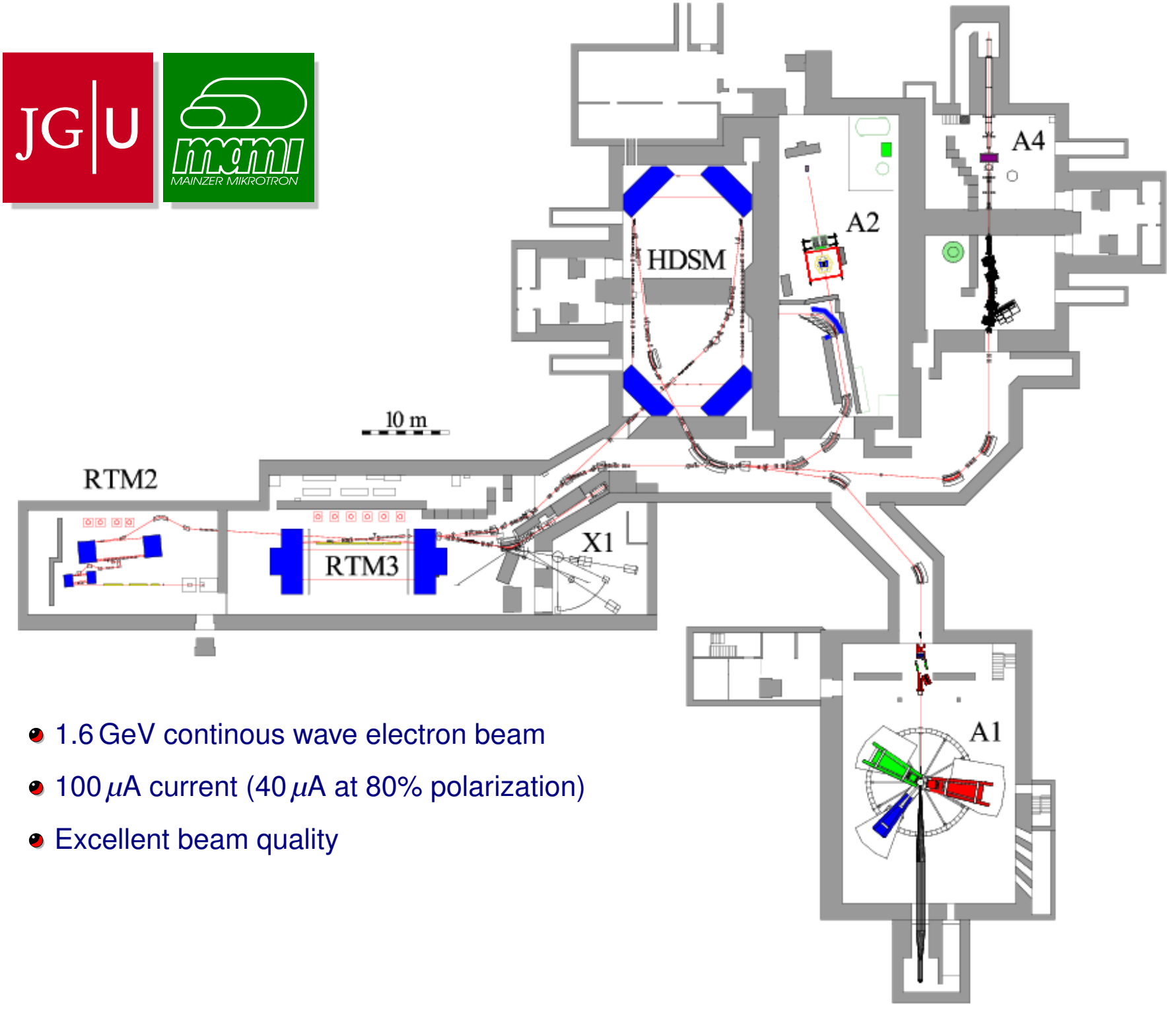
New Vistas in Low-Energy Precision Physics

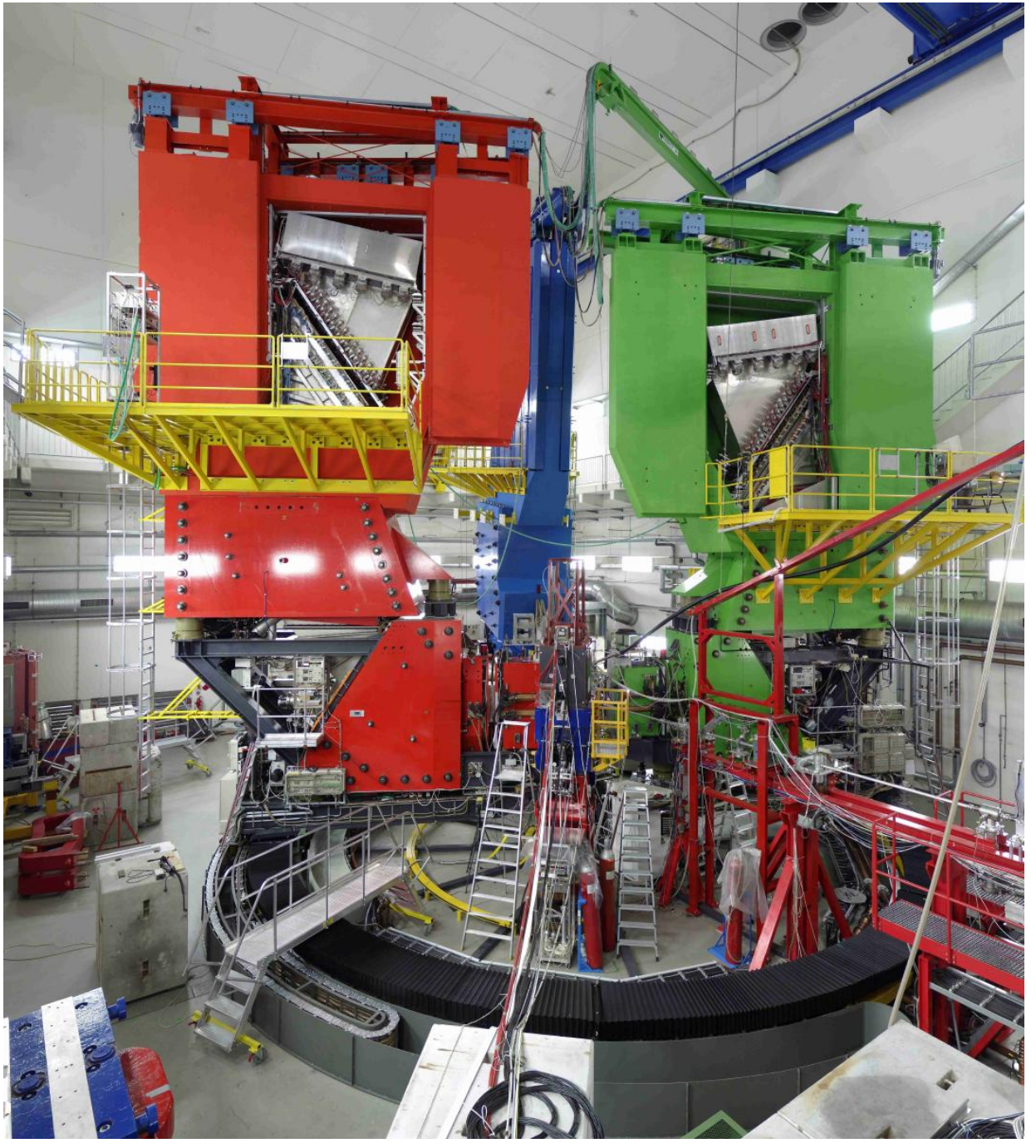
Mainz, April 5th, 2016

- Experiments at MAMI
  - Dark Photon searches with A1
- Experiments at MESA
  - “Classical” technique with MAGIX
  - Hidden Decay searches
- Possiblities for Beam-dump Experiments
  - Possibilites at MAMI
  - Possibilites at MESA



- 1.6 GeV continous wave electron beam
- 100 μA current (40 μA at 80% polarization)
- Excellent beam quality

A1: Spectrometer setup at MAMI



Spectrometer A:

$$\begin{aligned} \alpha &> 20^\circ \\ p &< 735\,\frac{\mathrm{MeV}}{c} \\ \Delta\Omega &= 28\,\mathrm{msr} \\ \Delta p/p &= 20\% \end{aligned}$$

Spectrometer B:

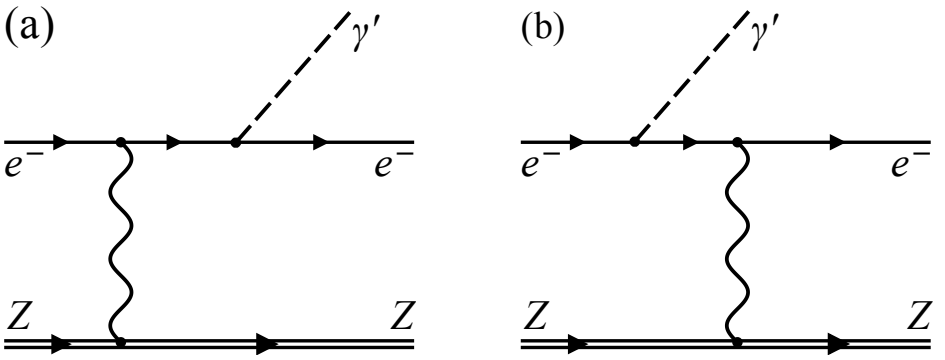
$$\begin{aligned} \alpha &> 8^\circ \\ p &< 870\,\frac{\mathrm{MeV}}{c} \\ \Delta\Omega &= 5.6\,\mathrm{msr} \\ \Delta p/p &= 15\% \end{aligned}$$

Spectrometer C:

$$\begin{aligned} \alpha &> 55^\circ \\ p &< 655\,\frac{\mathrm{MeV}}{c} \\ \Delta\Omega &= 28\,\mathrm{msr} \\ \Delta p/p &= 25\% \end{aligned}$$

$$\delta p/p < 10^{-4}$$

The “classical” technique



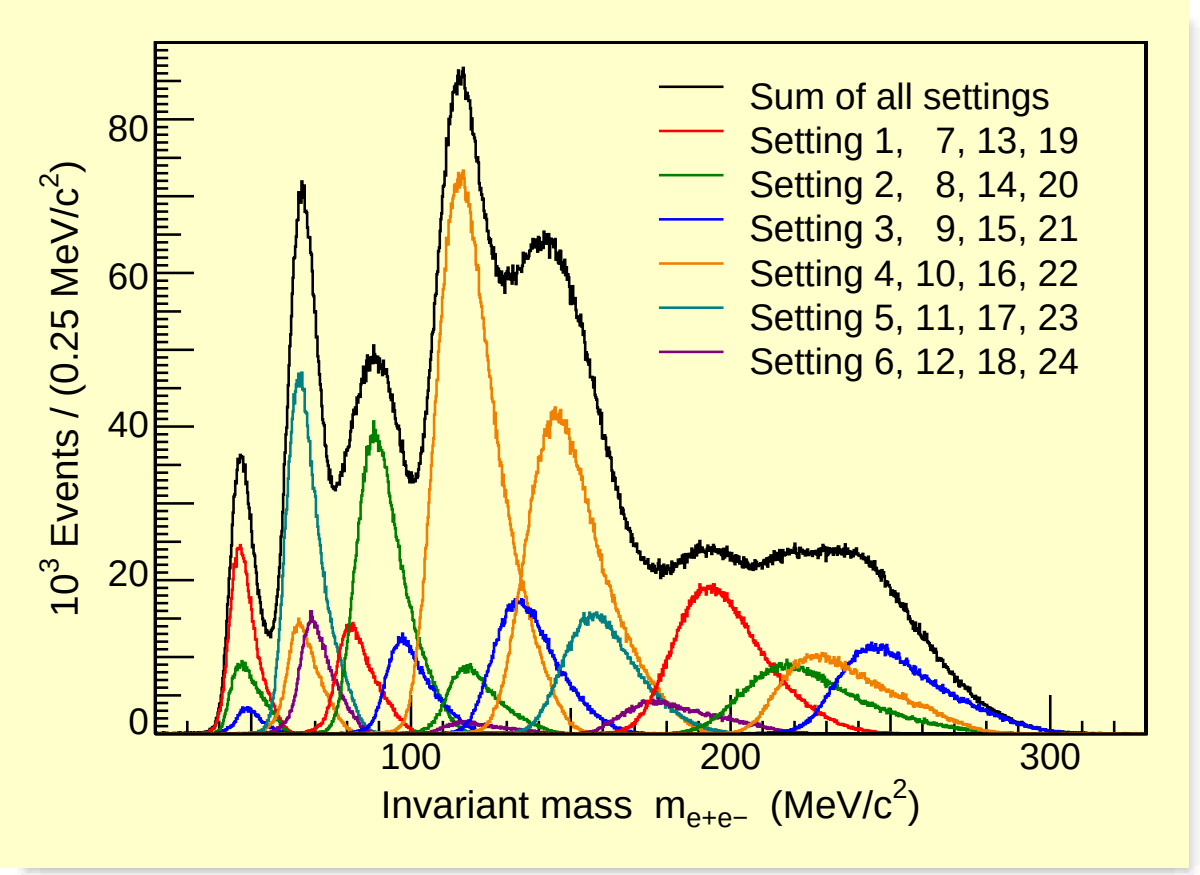
- Radiative production of a Dark Photon
- Detection of the decay to a lepton pair

$$e + Z \rightarrow e + Z + \gamma'$$
$$\hookrightarrow e^+ + e^- \quad \text{detected with High Resolution Spectrometers}$$

- Key features:
  - Huge luminosities are possible ($LZ^2 = 10^{39}\text{s}^{-1}\text{cm}^{-2}$)
  - But: Also huge background by Q.E.D. process
  - Sensitivity dominated by missing mass resolution

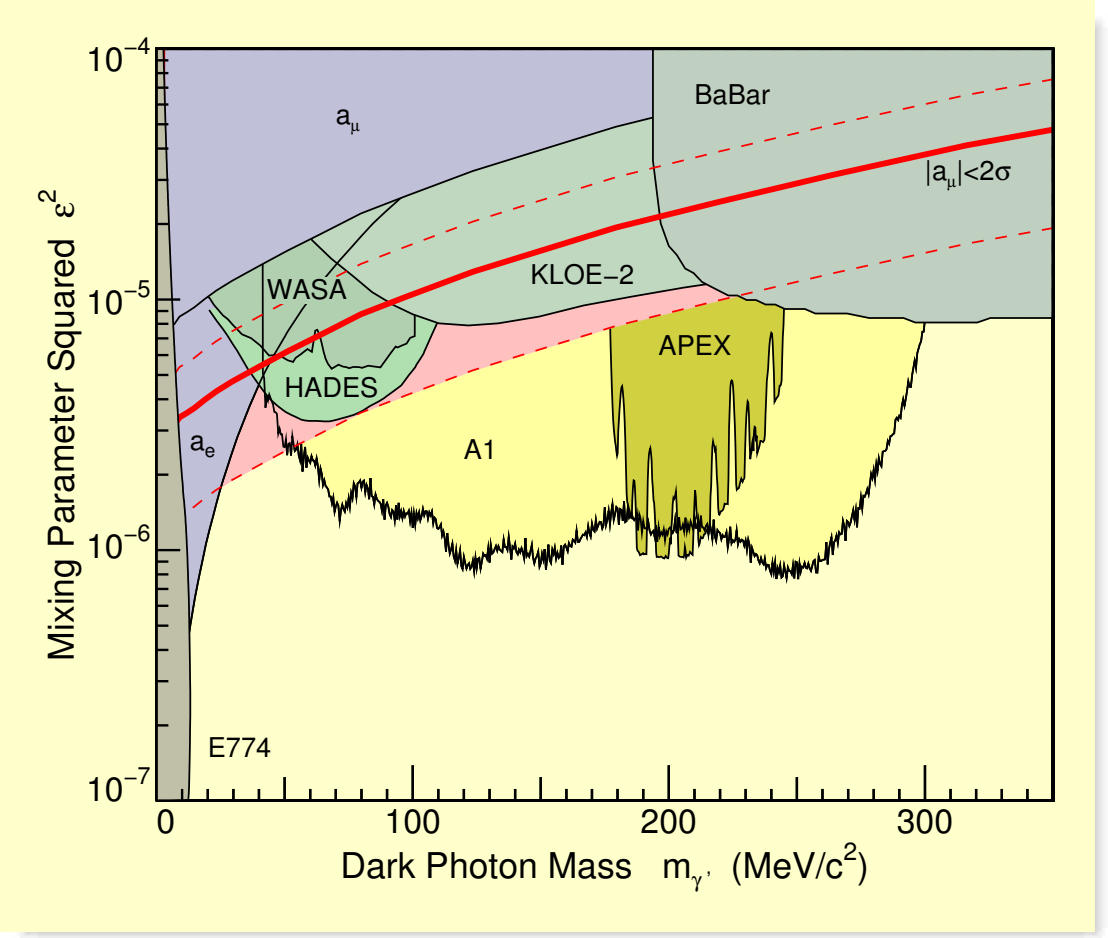
Bjorken et al. (2009)

All Settings



- Coverage in mass given by momentum acceptance
- Several settings necessary to extend range
- Different background conditions
- Summing up all settings...

Exclusion limits MAMI 2014



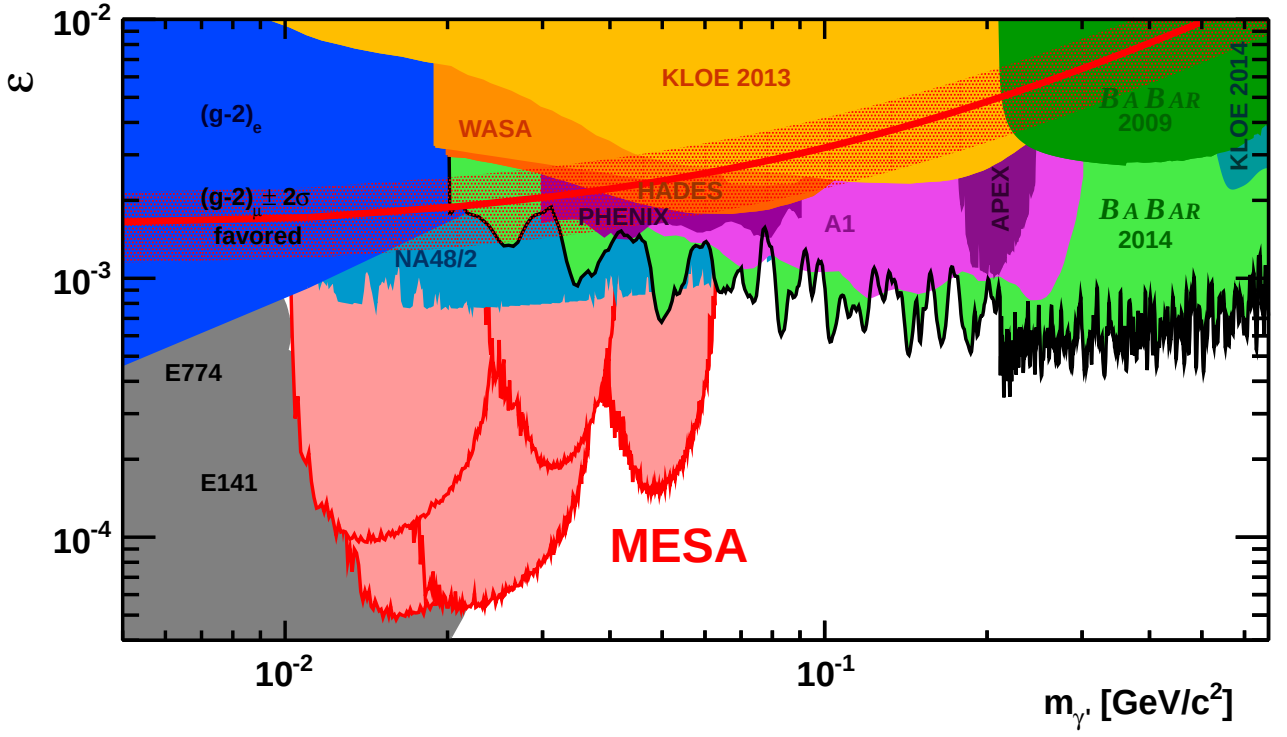
- 24 kinematical settings
- Including data from pilot experiment H.M. *et al.* PRL **106** (2011) 251802
- Sensitivity $\varepsilon^2 > 8 \cdot 10^{-7}$

H.M. *et al.*, Phys. Rev. Lett. **112** (2014)

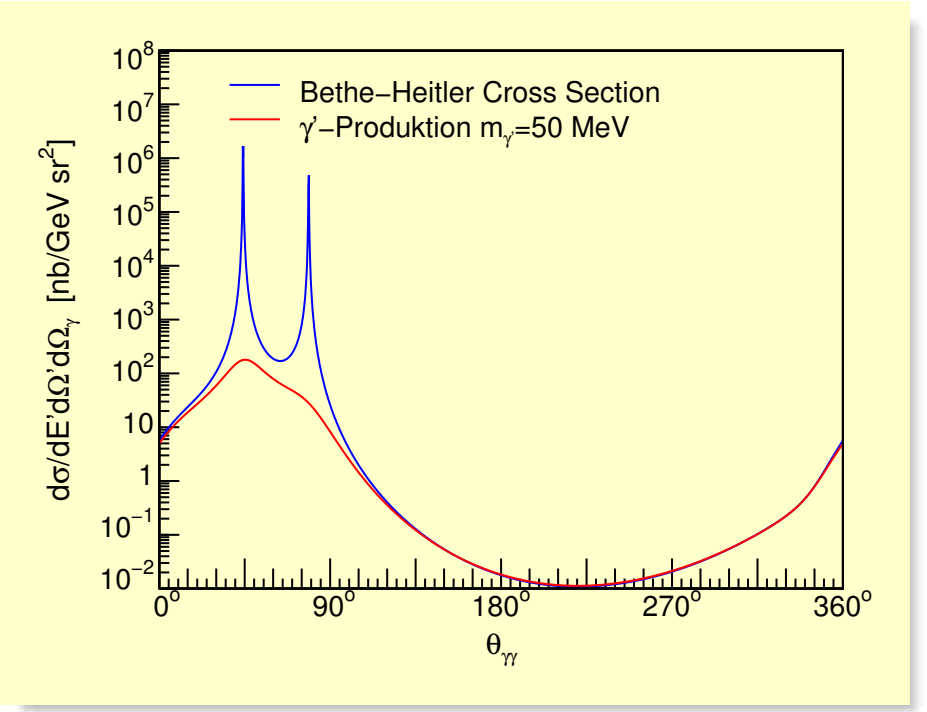
Dark Photons at MESA: Classical technique

$$e + Z \rightarrow e + Z + \gamma'$$
$$\hookrightarrow e^+ + e^- \quad \text{detected with MAGIX spectrometers}$$

- Low beam energy to extend mass range to lower masses
- Using the high resolution of the MAGIX spectrometers
- Gas target: Xenon? Thin foil?



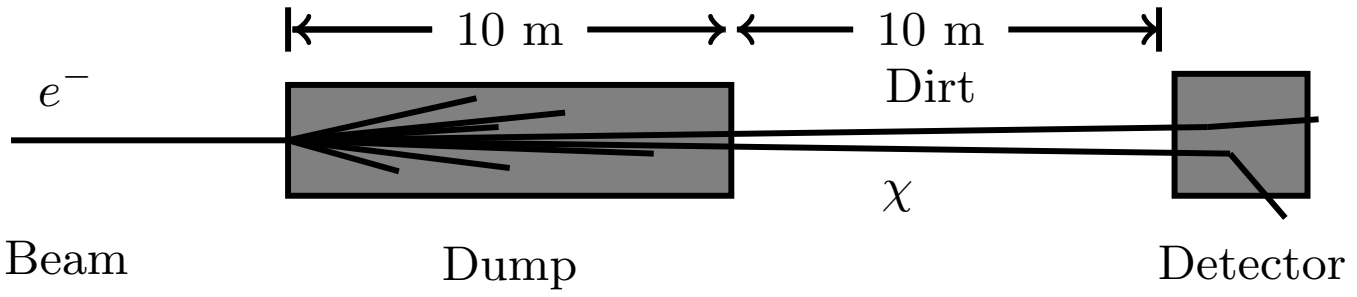
Dark Photons at MESA: Invisible Decay



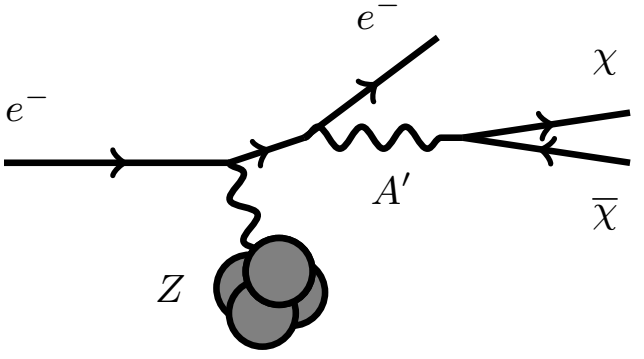
$$e + p \;\rightarrow\; e' + p + \gamma' \qquad \gamma' \hookrightarrow e^+ + e^-$$

- γ' detection via missing mass $m^2_{\gamma'} = (e + p - e' - p')^2$
- No restriction by decay
- Background: virtual Compton scattering: $e + p \rightarrow e' + p + \gamma$ + radiative tail
- Vertex identification with high suppression factor $(10^8 \ldots 10^{10})$ necessary
- Detector development: e.g. HVMAPs

Beam-Dump Experiments: Idea

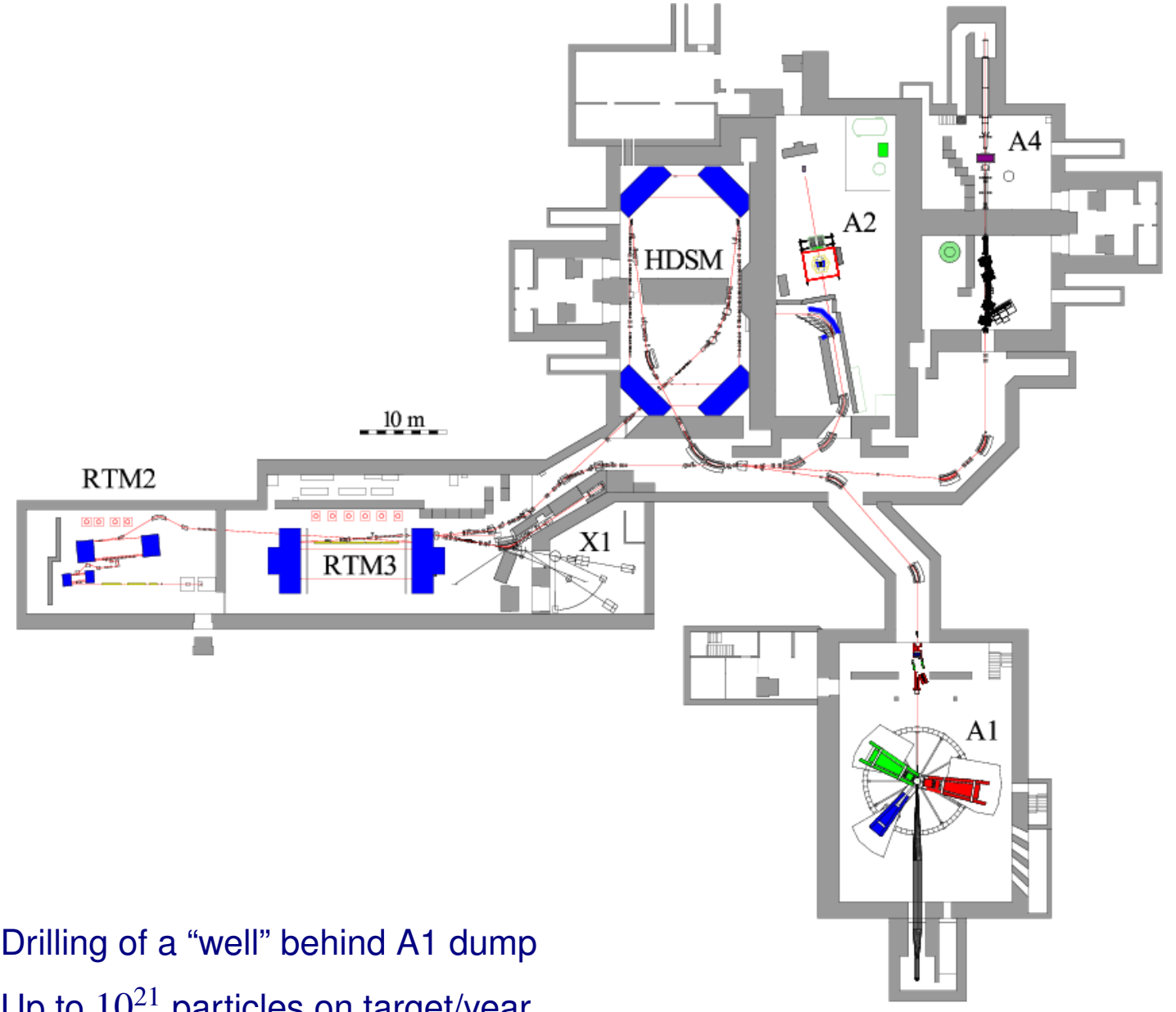


- Production in beam dump, *e.g.* via pair production



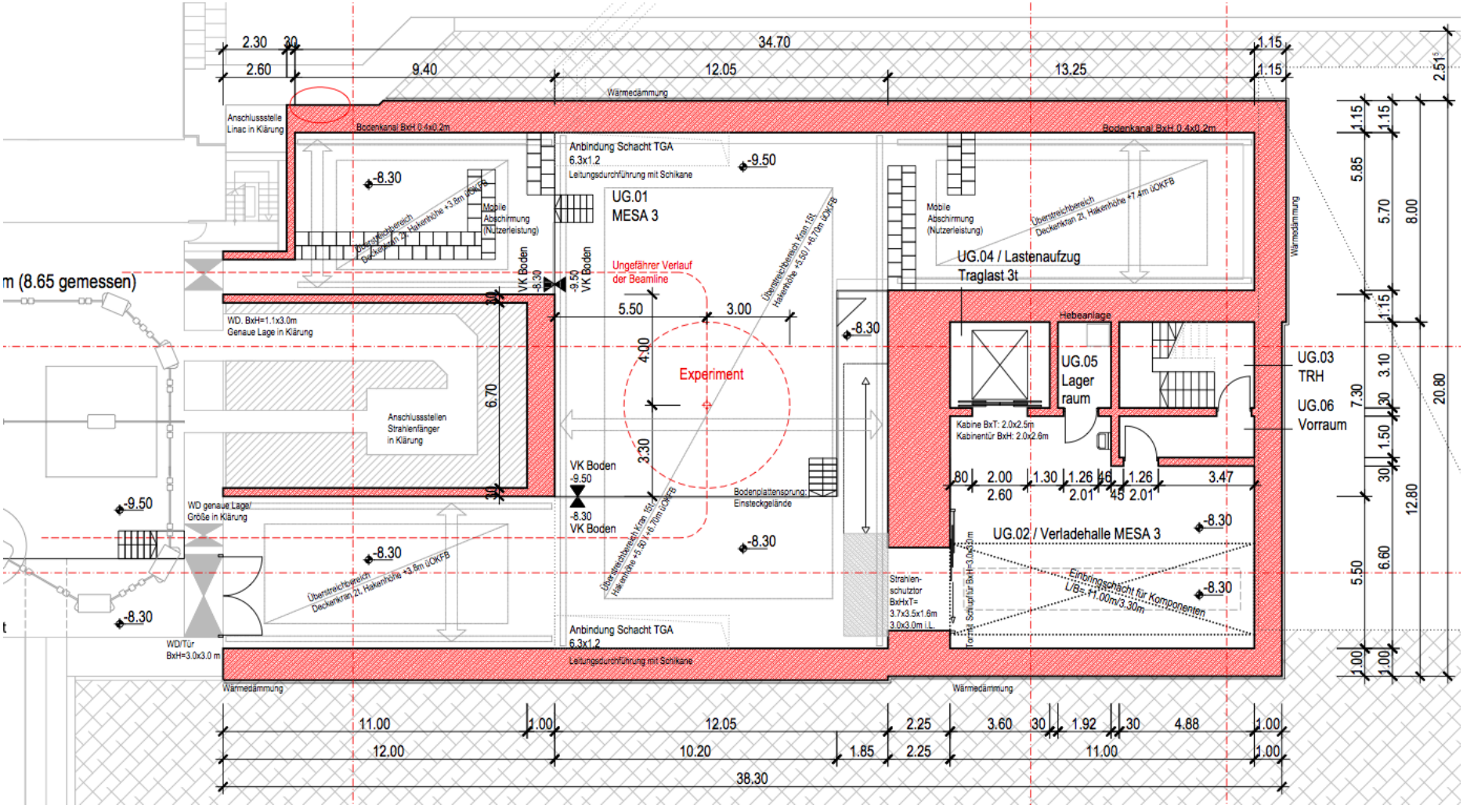
- Don't care about production mechanism!
- Dark Matter particles have MeV-scale energy (not eV!)
- Detection with simple detector, *e.g.* scintillator cube + active shielding
- ... or with sophisticated DM Detector ...

MAMI



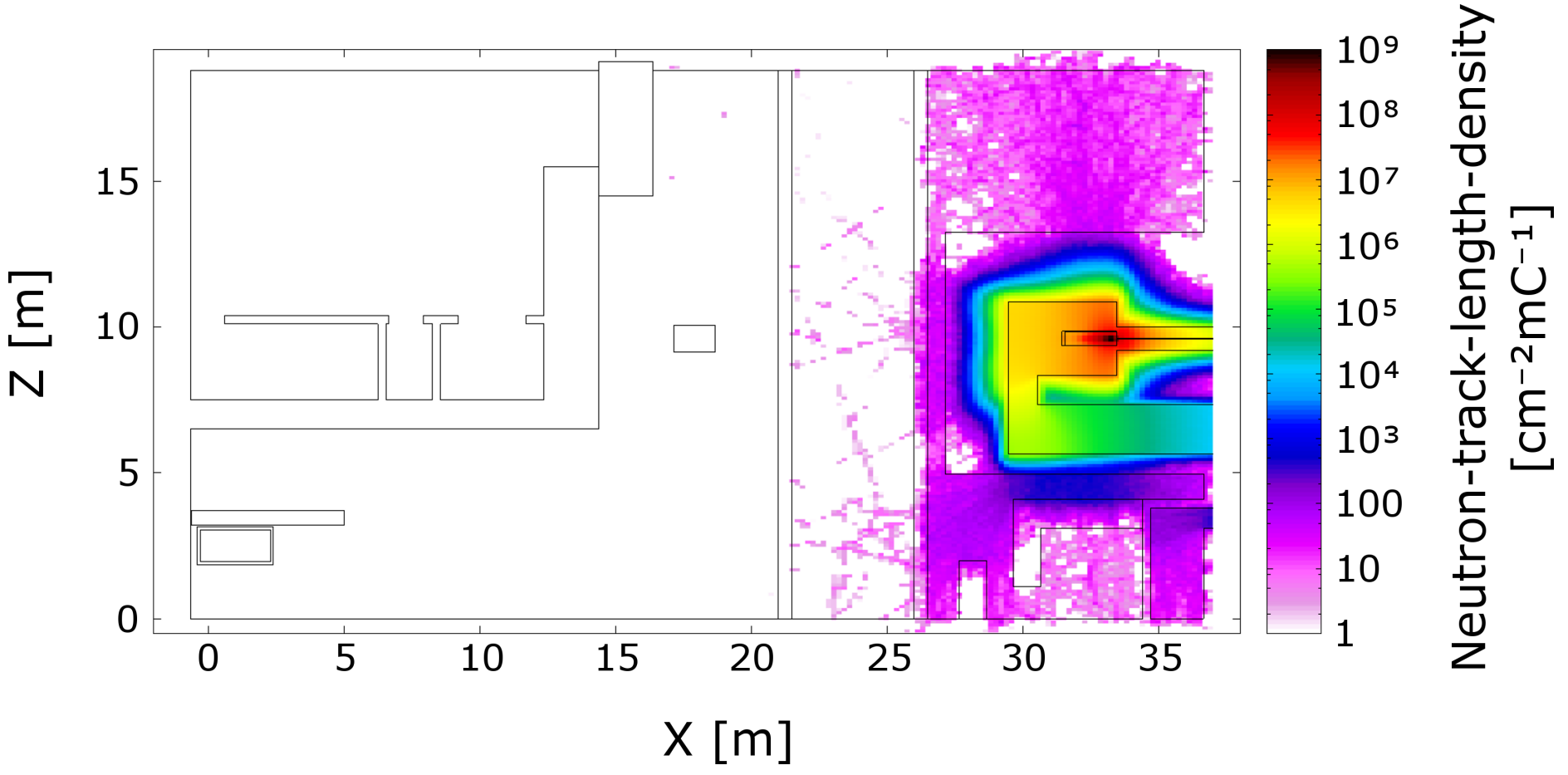
- Drilling of a “well” behind A1 dump
- Up to 10^{21} particles on target/year

New MESA Hall



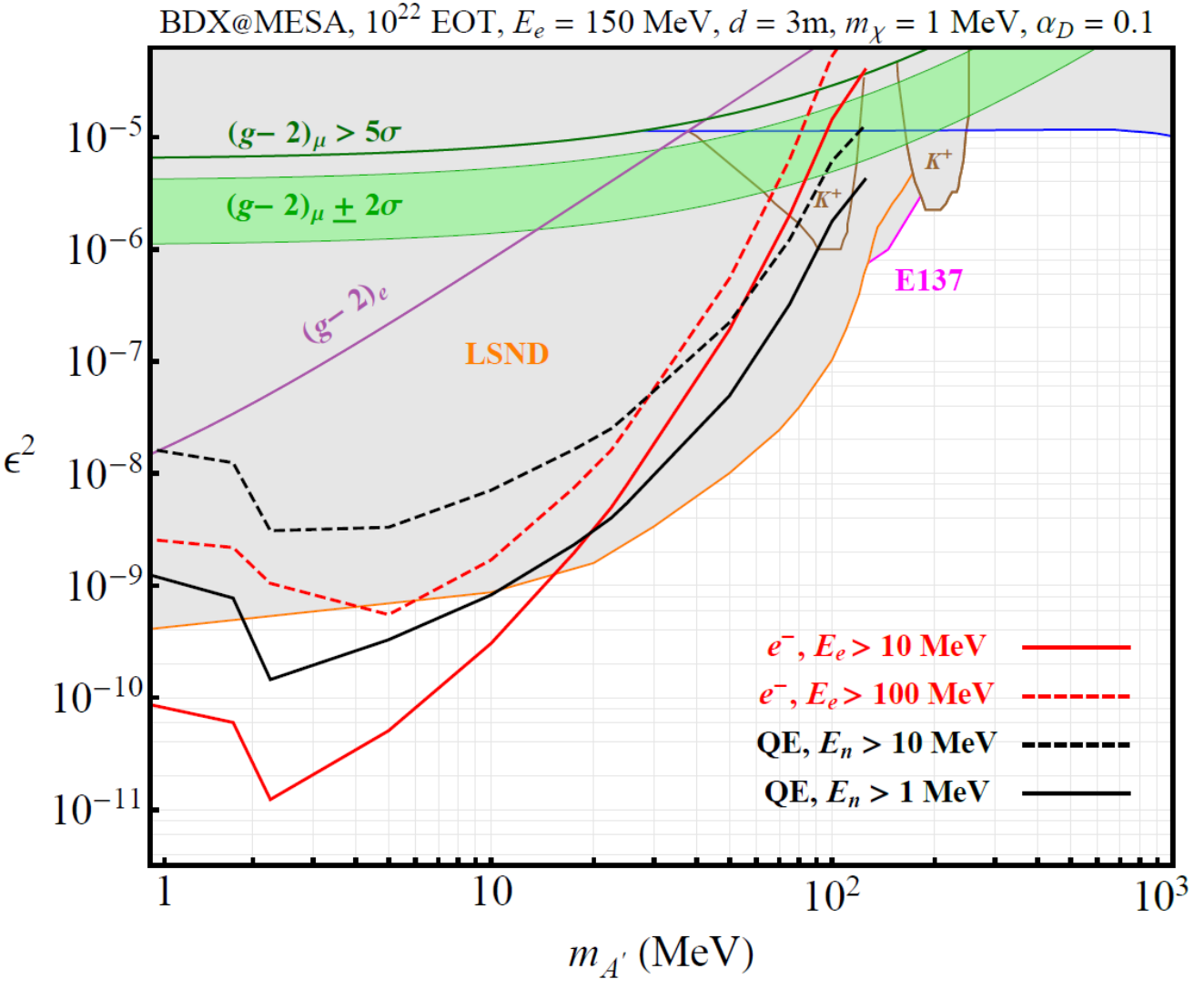
- Dedicated new hall for experiment
- Space for high resolution experiment
- Additional space for beam dump experiment: 150 μA beam on target for $50\%/a$

FLUKA Simulation



- Neutrons can be shielded
- Below pion threshold: negligible ν background
- Clean conditions, detailed layout of hall needed for further design
- Time structure of the beam possible

MAGIX Sensitivity



- Reasonable sensitivity for low mass region
- Multidimensional plot: Assumptions for dark photon mass, m_χ

Calculations: G. Krnjaic

Summary

MAMI:

- Limits for classical dark photon searches reached
- Further experiments are expensive

MESA:

- High Resolution Spectrometers
- Classical technique for low momenta
- Hidden decay channels

Beam Dump Experiments:

- A1 Hall behind beam-dump
- New MESA Hall