SFB 1044

Cluster of Excellence Precision Physics, Fundamental Interactions and Structure of Matter PRISMA

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

JG|U

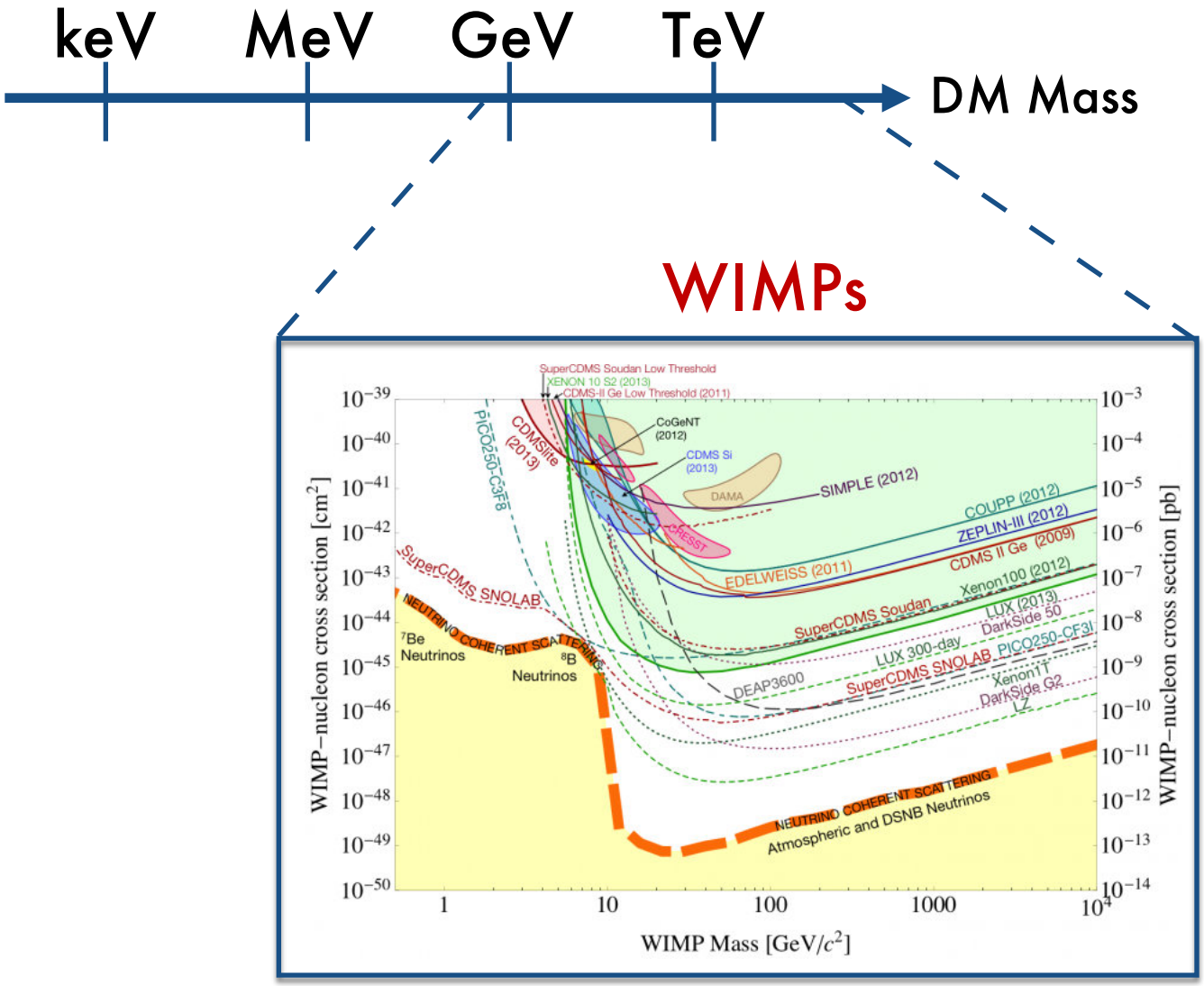
Dark Sector Searches at MAMI/MESA

Search for Long Lived Particles at the LHC, 4th Workshop LHC LLP

Amsterdam, October 24, 2018

Achim Denig

Dark Sector Searches



Dark Sector Searches

LDM

Dark Photon - Messanger

New massive force carrier of extra $U(1)_d$ gauge group

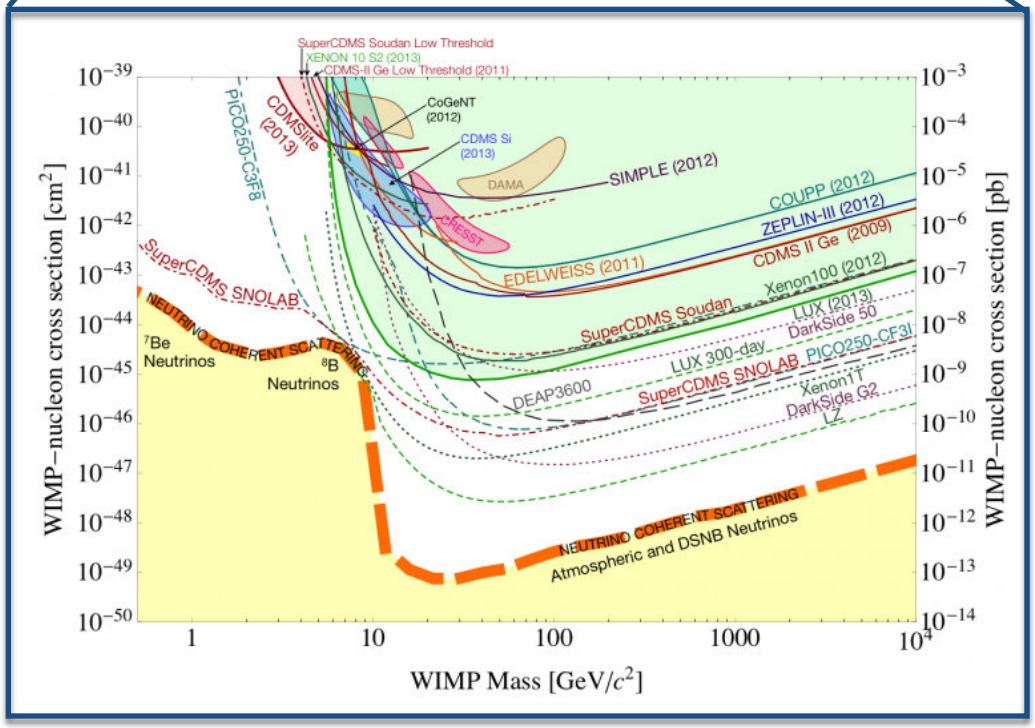
- Could explain large number of **astrophysical anomalies**

  Arkani-Hamed et al. (2009)
  Andreas, Ringwald (2010);

- Could explain **deviation of 3.7σ between $(g\text{-}2)_\mu$** SM prediction and direct $(g\text{-}2)_\mu$ measurement

  Pospelov(2008)

WIMPs

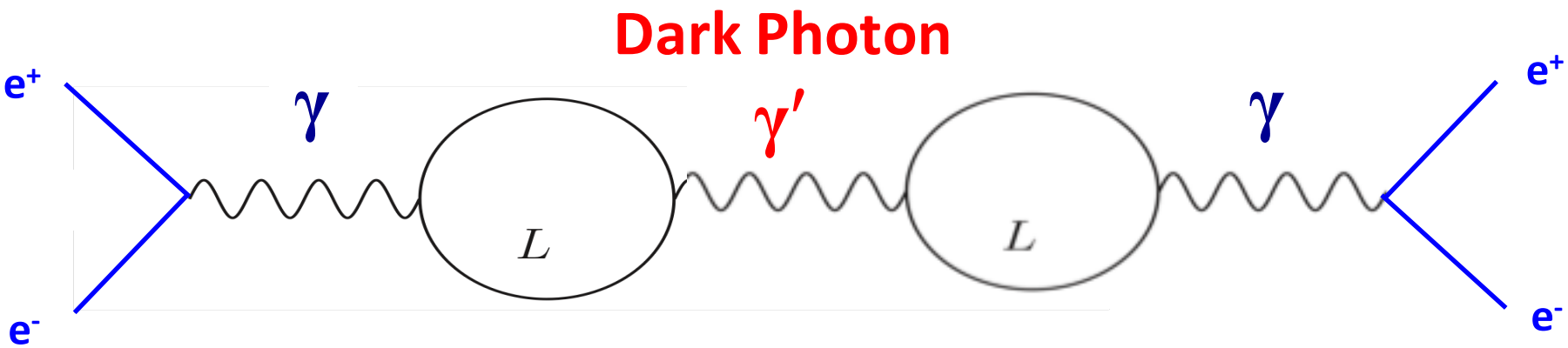


Dark Photon

Model 1: $m_{\gamma'} \ll m_{\mathrm{DM}}$

Holdom [1986]

Dark Photon decaying into SM particles – coupling ϵ

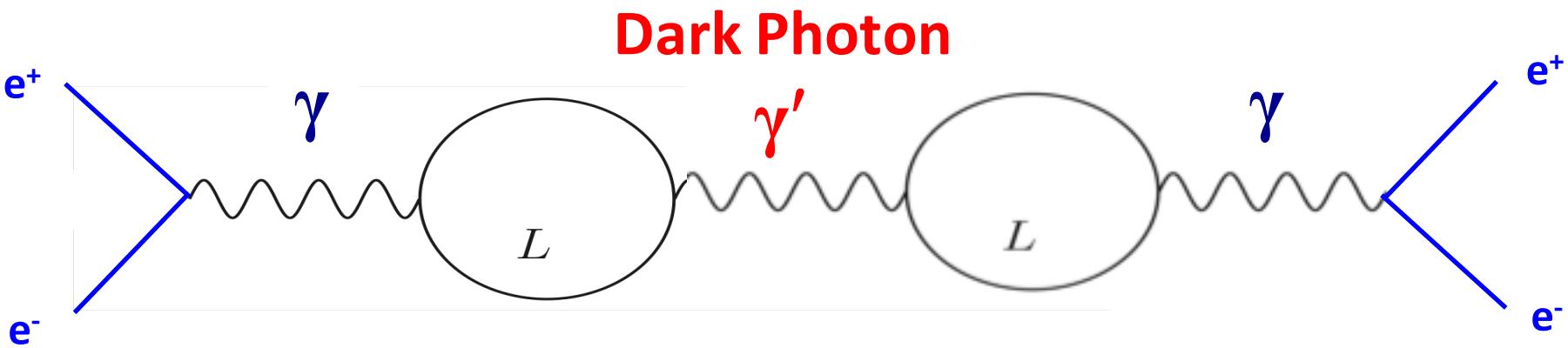


Dark Photon

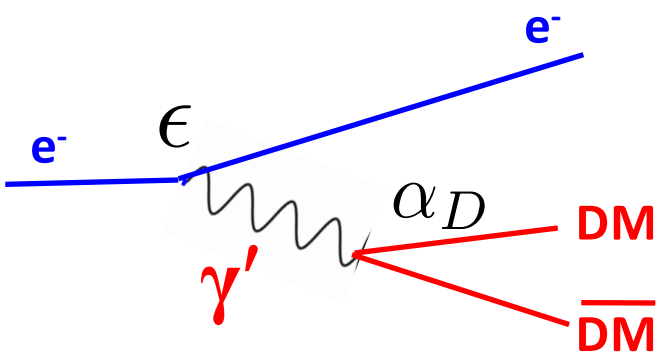
Model 1: $m_{\gamma'} \ll m_{\mathrm{DM}}$

Holdom [1986]

Dark Photon decaying into SM particles – coupling ϵ



Model 2: $m_{\gamma'} > 2m_{\mathrm{DM}}$



Dark Photon decaying into Dark Matter

→ invisible decay experiments

→ LDM detection

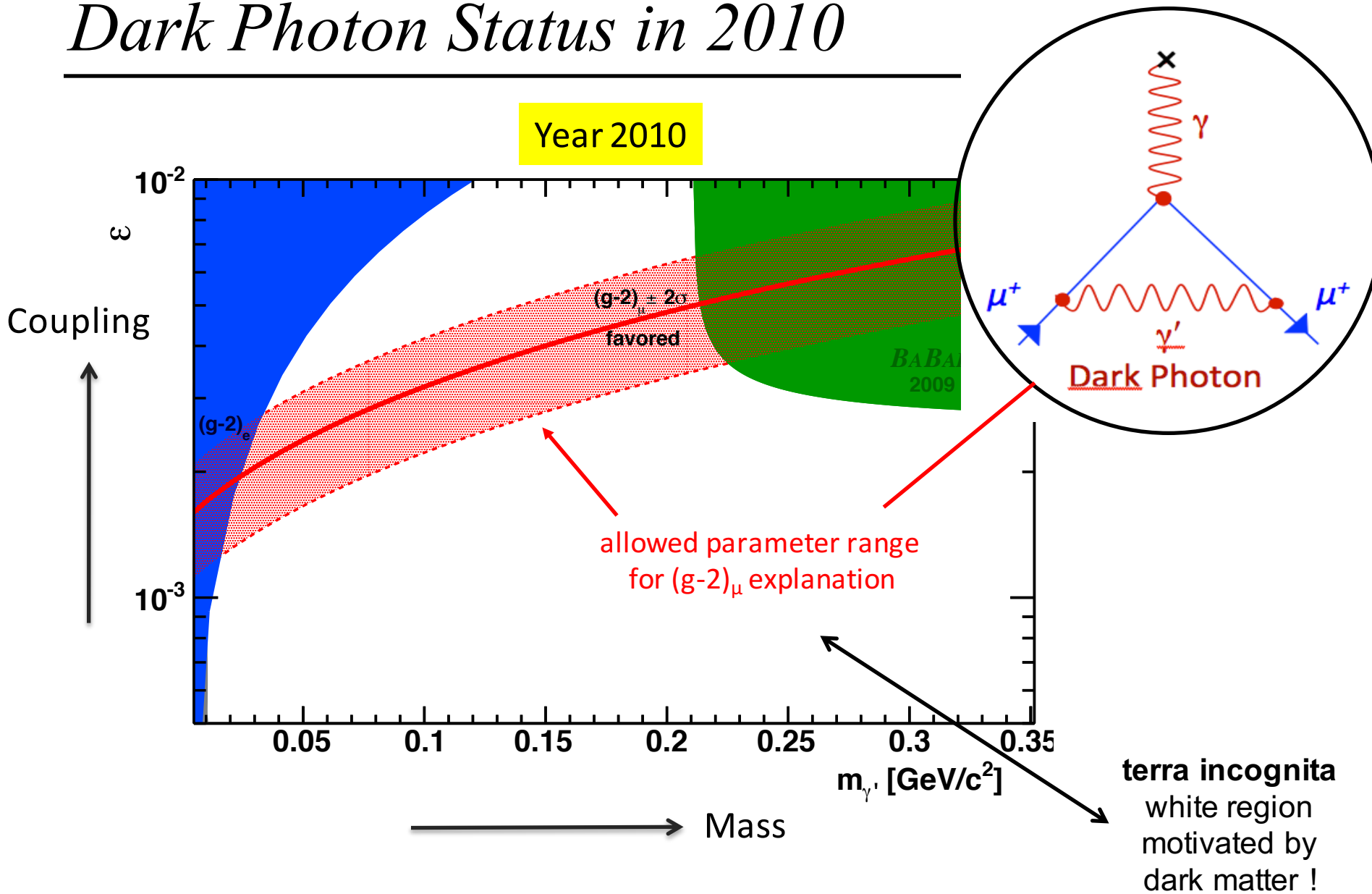
Dark Photon Searches at MAMI / MESA

(Model 1)

Light Dark Matter Search at MESA

(Model 2)

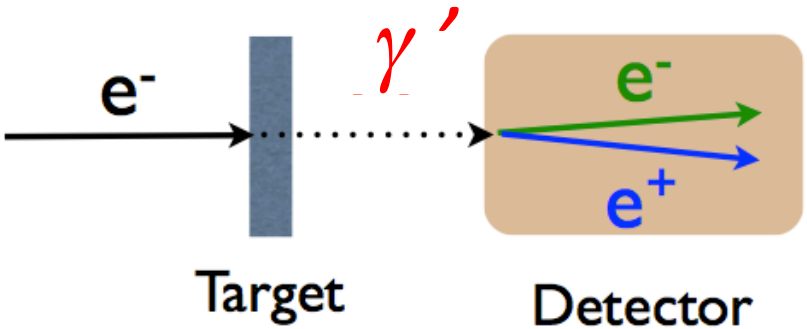
Dark Photon Status in 2010

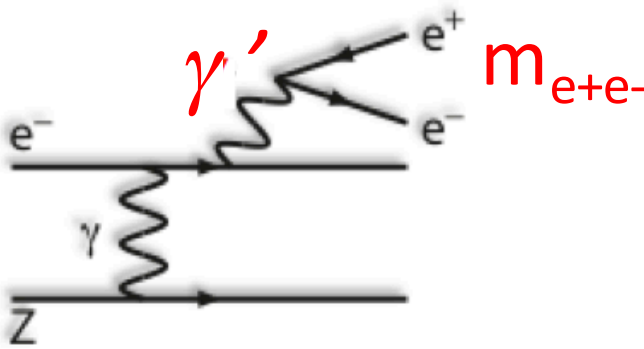


Searches using Fixed-Target Experiments

Bjorken, Essig, Schuster, Toro (2009)

Low-energy, high-intensity accelerators on the GeV scale are ideally suited for Dark Photon searches





Bump hunting!

1. **High luminosity e- beam**
2. **Excellent mass resolution**
3. **Detection at small angles**

→ MAMI / JLAB
→ Spectrometers

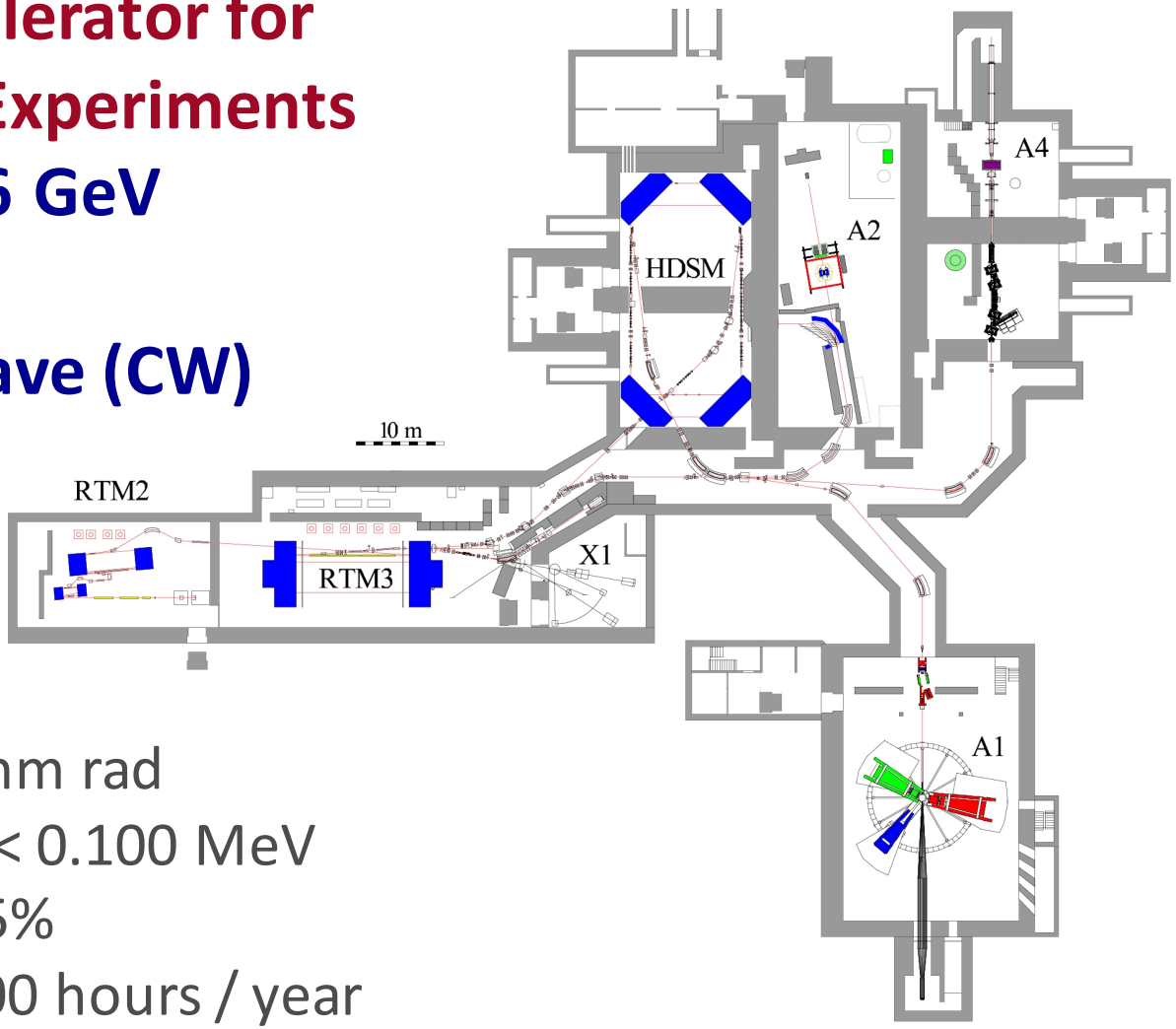
Mainz Microtron MAMI

Electron Accelerator for Fixed Target Experiments

E = 0.185 - 1.6 GeV

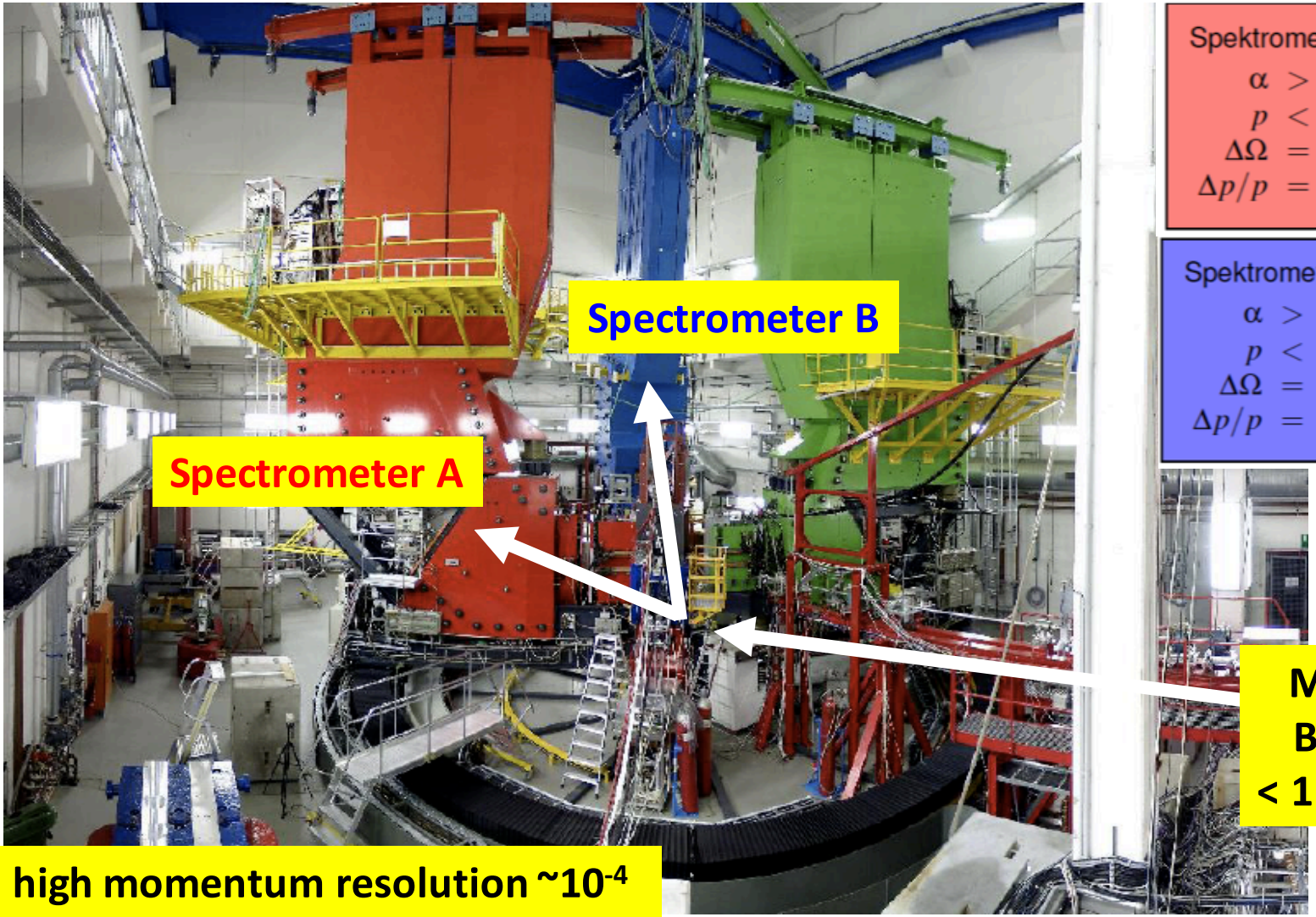
I_{max} ~ 100 µA

Continous Wave (CW)



- Emittance 25 nm rad
- Resolution σ_E < 0.100 MeV
- Polarization 85%
- Reliability: 7000 hours / year

A1 High Resolution Spectrometers



Spektrometer A:

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

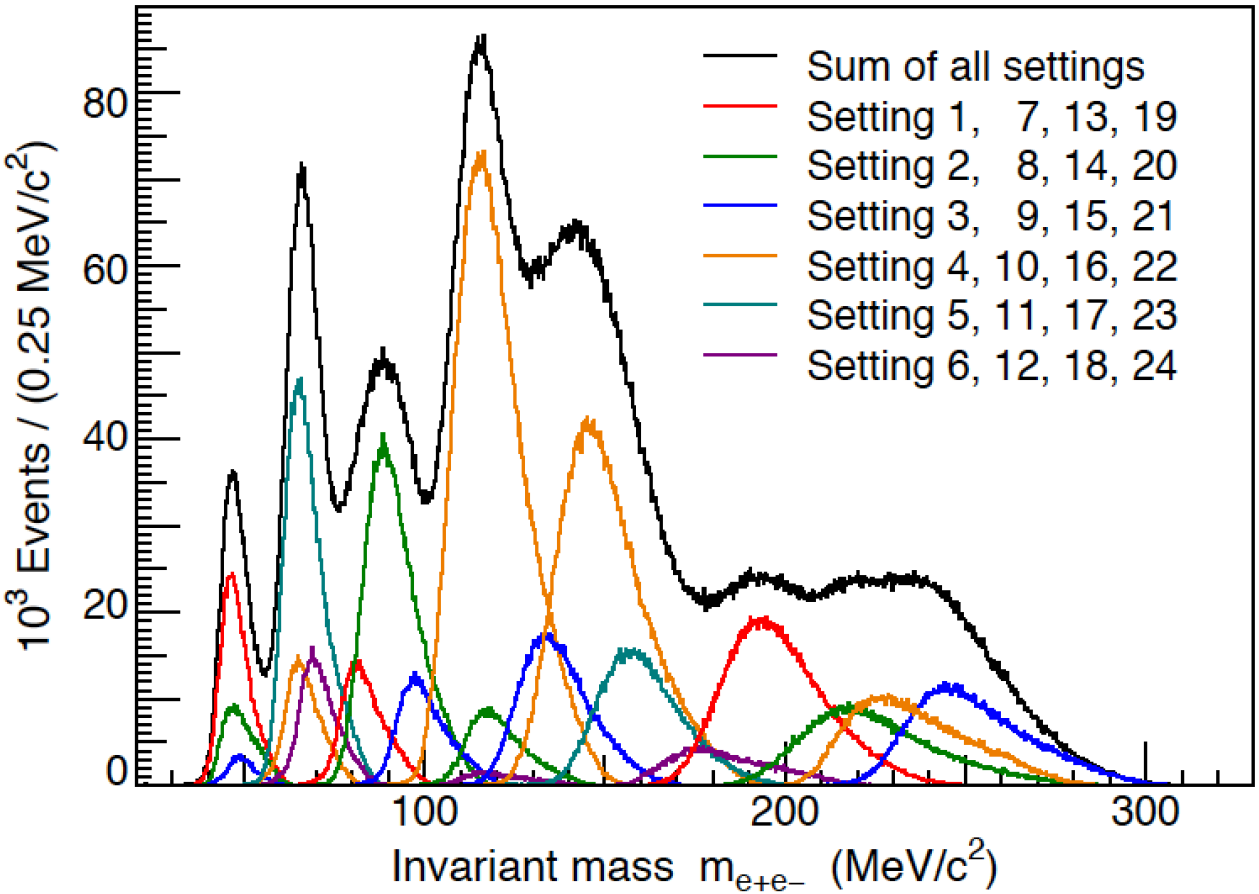
Spektrometer B:

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

high momentum resolution ~10^{-4}

Results from A1

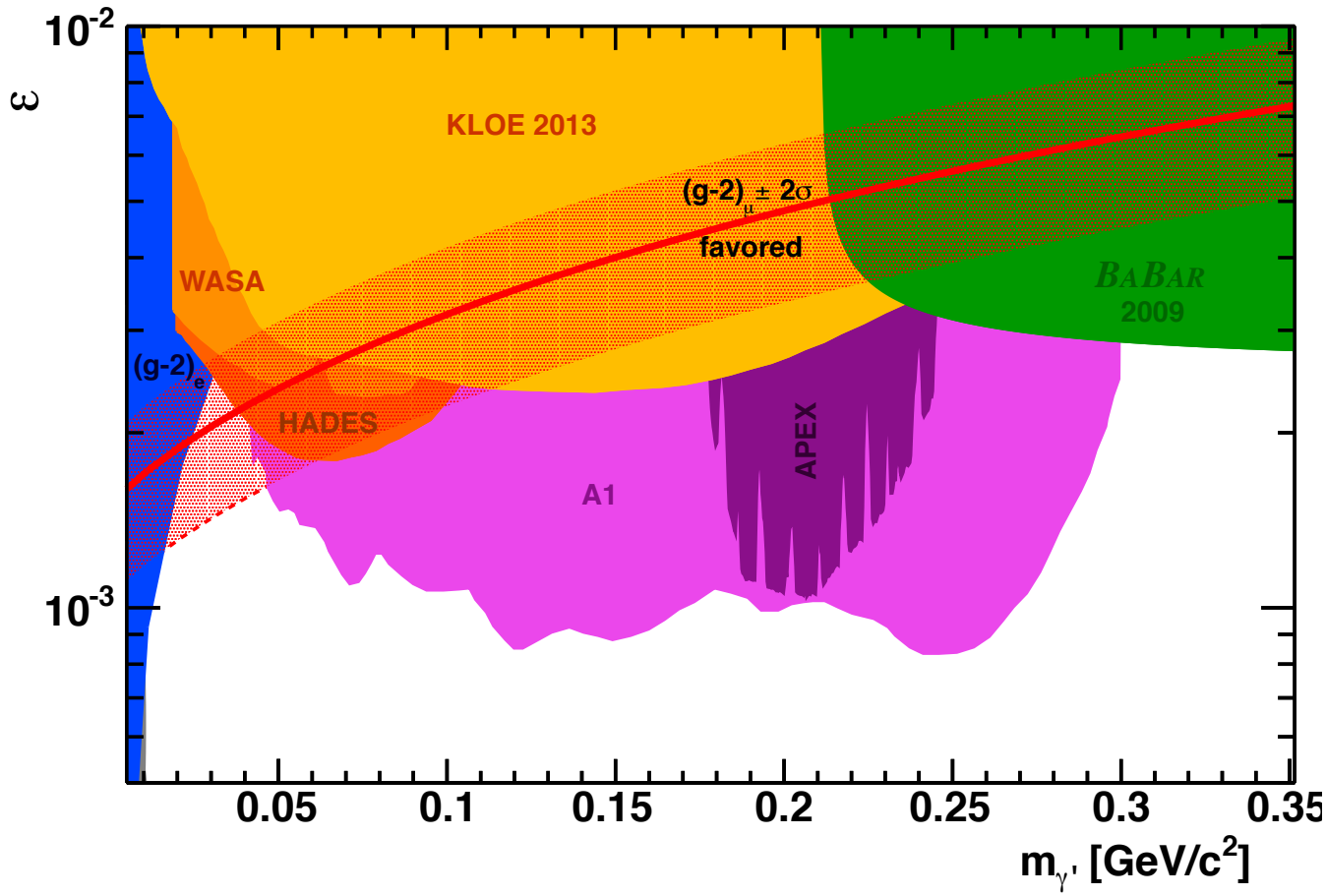
Merkel et al. [A1]
PRL '11
PRL '14



- E_{beam} 180 - 855 MeV
- 100 µA beam current
- Stack of Ta targets
- 22 kinematic settings
- O(1 month) of beam time

Results from A1

Merkel et al. [A1]
PRL '11
PRL '14

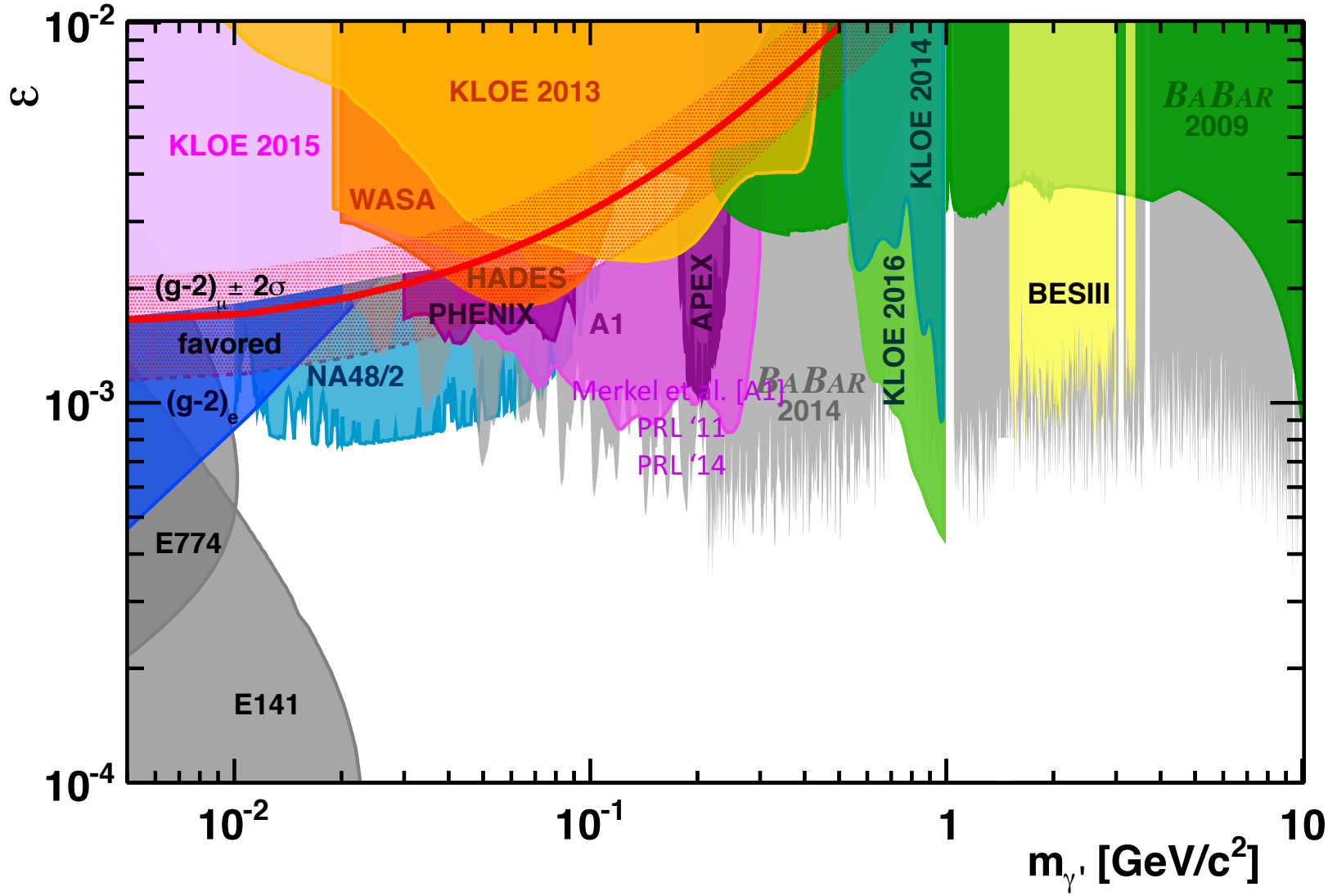


- E_{beam} 180 - 855 MeV
- 100 μA beam current
- Stack of Ta targets
- 22 kinematic settings
- O(1 month) of beam tim

→ **at time of publication most stringent limit ruling out major part of the parameter range motivated by $(g-2)_\mu$**

Situation as of today

Year 2017



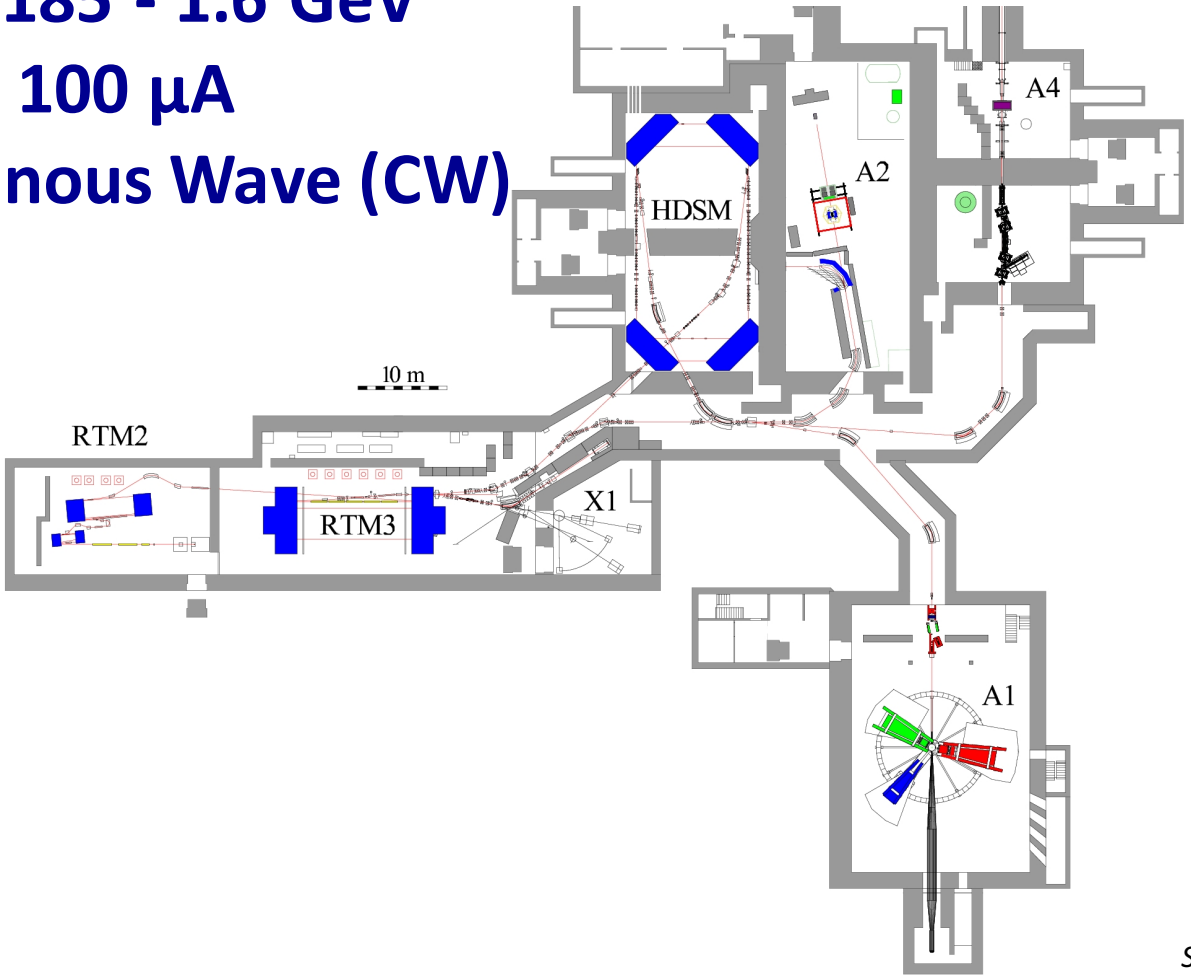
Mainz Microtron MAMI

Electron Accelerator for
Fixed Target Experiments

E = 0.185 - 1.6 GeV

I_{max} ~ 100 µA

Continous Wave (CW)



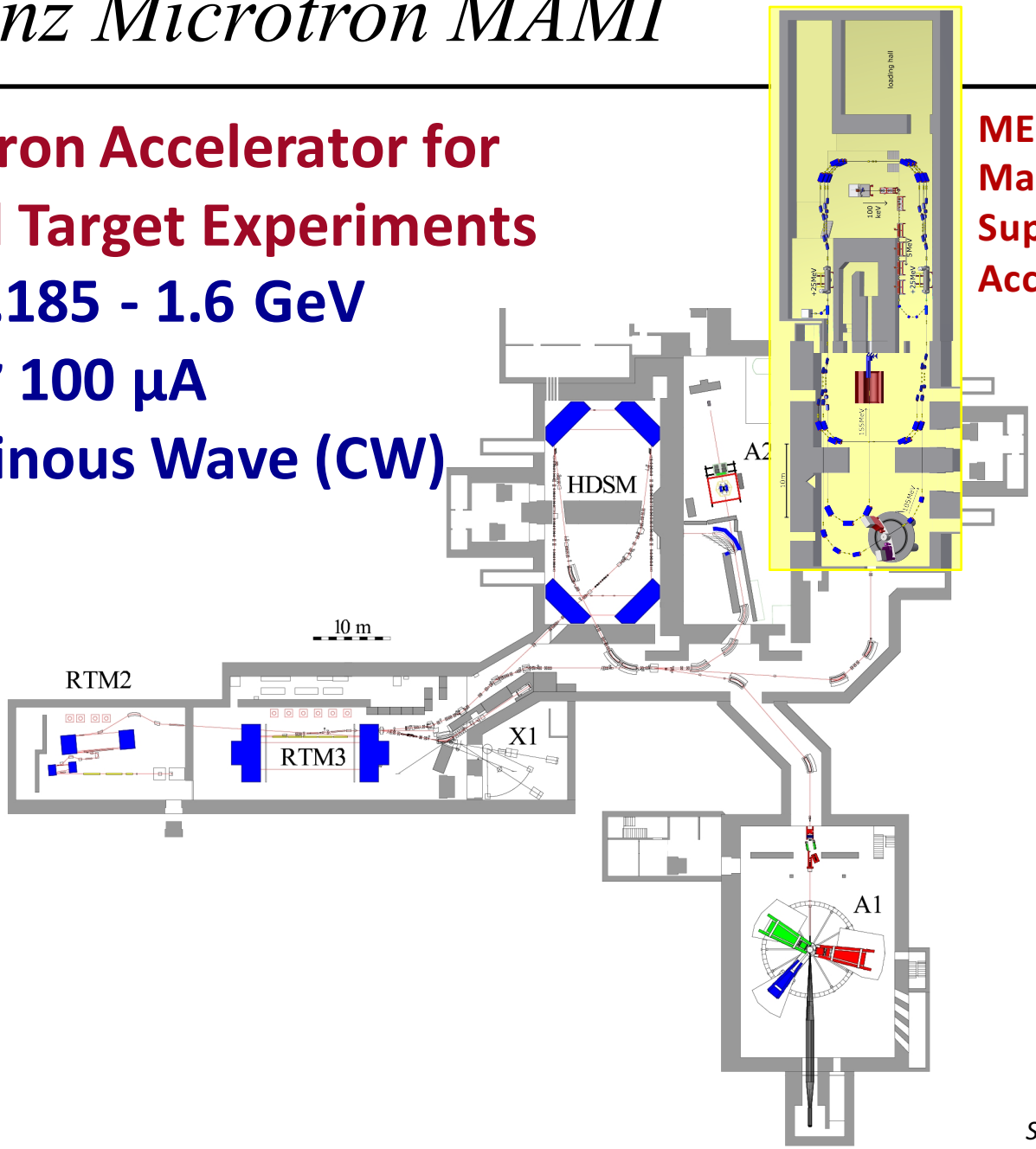
Mainz Microtron MAMI

Electron Accelerator for Fixed Target Experiments

E = 0.185 - 1.6 GeV

I_{max} ~ 100 µA

Continous Wave (CW)



MESA
Mainz Energy-Recovering Superconducting Accelerator

MESA Accelerator

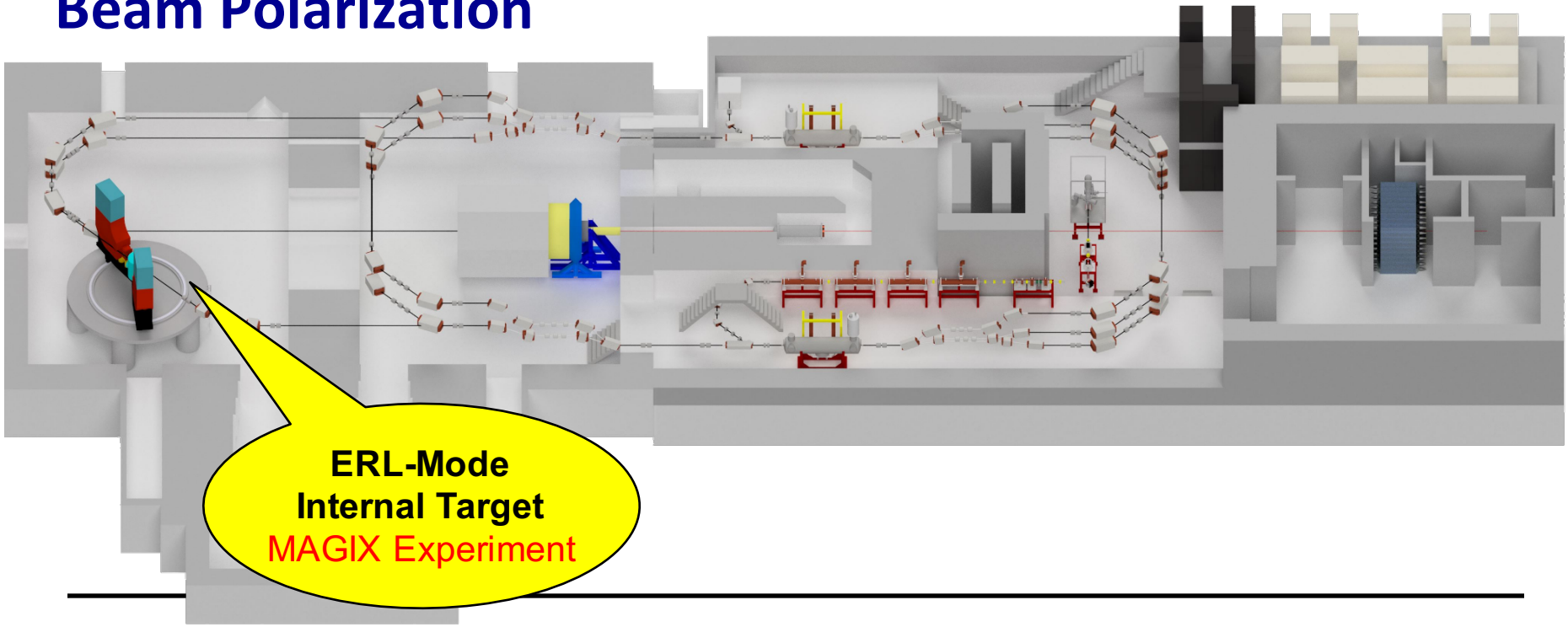
Mainz Energy-Recovering Superconducting Accelerator

Recirculating ERL Mode

E_{max} = 155 MeV

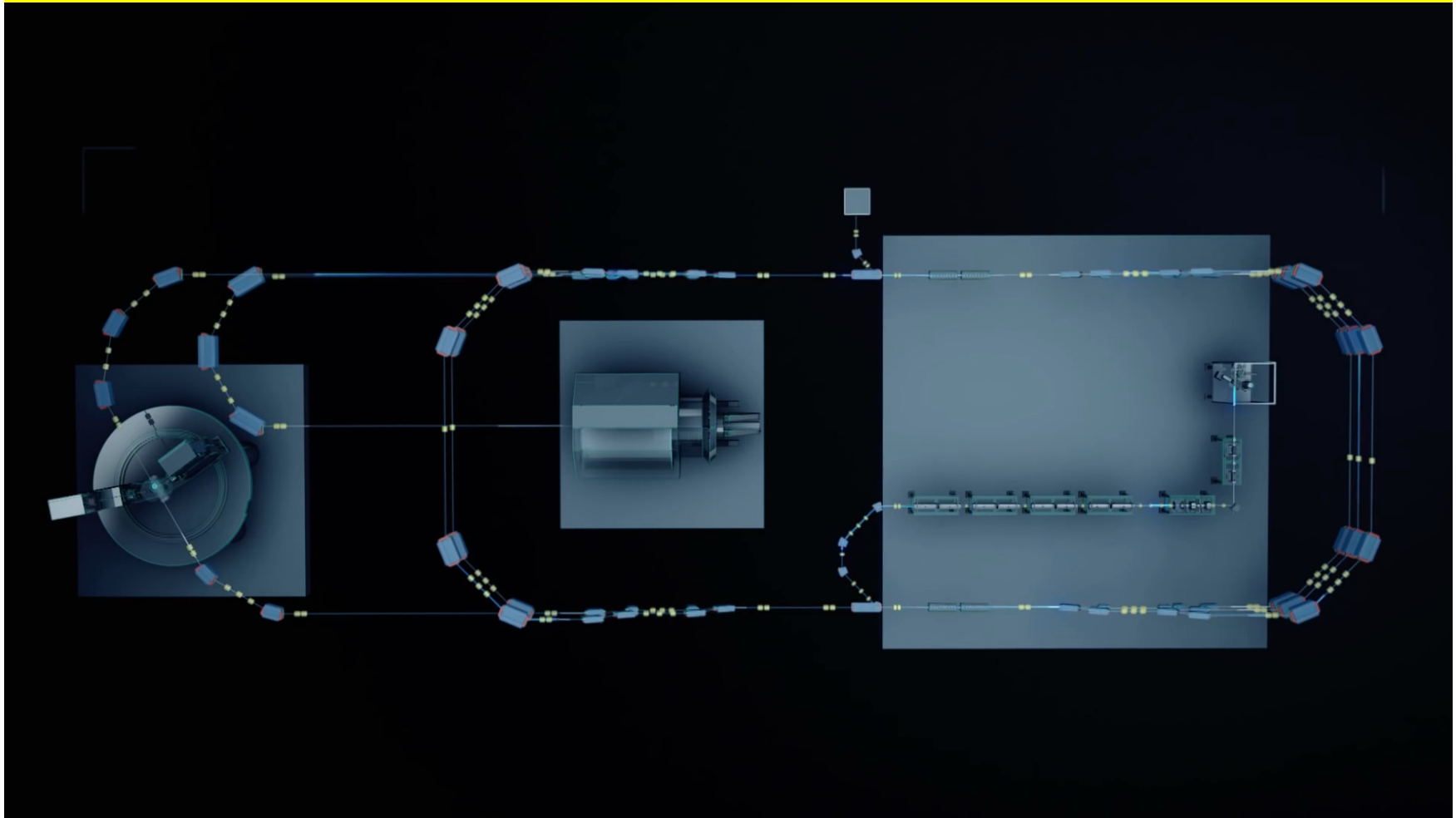
I_{max} > 1 mA

Beam Polarization



Internal Exper. MAGIX @ MESA ERL Mode

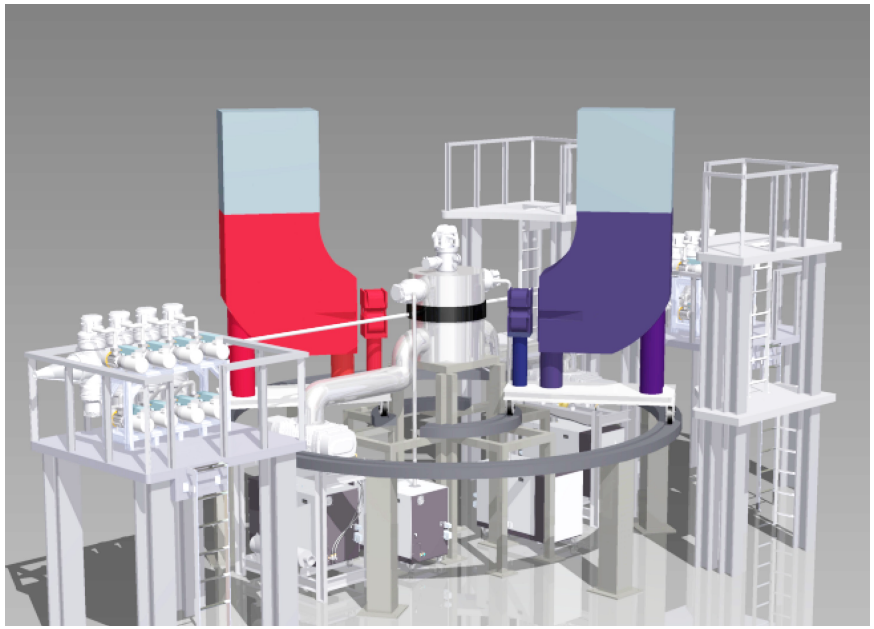
Operation of a high-intensity (polarized) ERL beam
in conjunction with light internal target
→ a novel technique in nuclear and particle physics
→ precise measurement of low momenta tracks at competitive luminosities

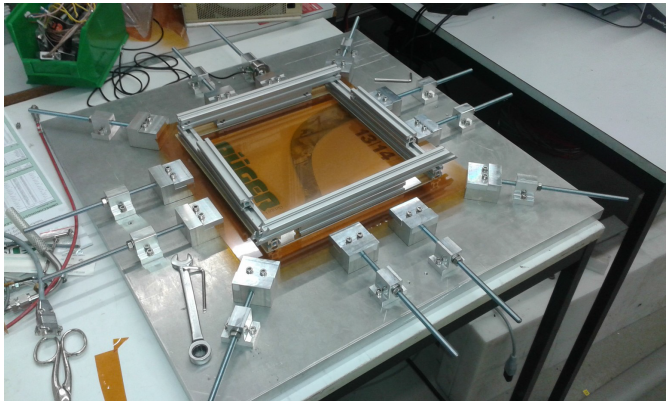


The MAGIX Spectrometers

High resolution spectrometers MAGIX:

- double arm, compact design
- momentum resolution: $\Delta p/p < 10^{-4}$
- acceptance: ±50 msr
- GEM- or TPC-based focal plane detectors





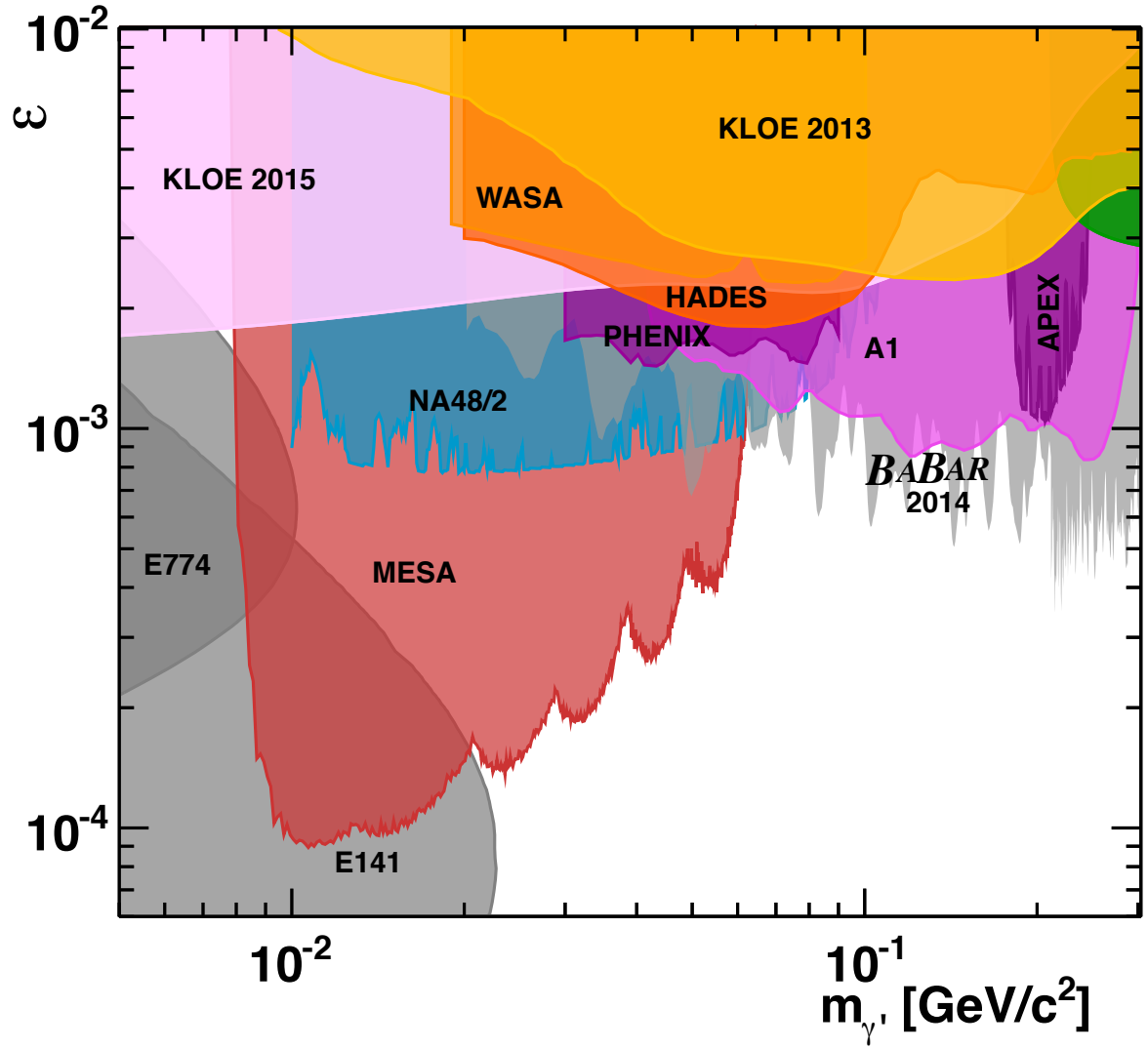
GEM technology for focal plane
Latest design: GEM-TPC

- Gas Jet or polarized T-shaped target for polarized target measurements

Dark Sector Searches at MAGIX

Features:

- Xe gas target
- Luminosity 10^{35} $cm^{-2}s^{-1}$
- 6 month of data taking



Dark Photon Searches at MAMI /MESA

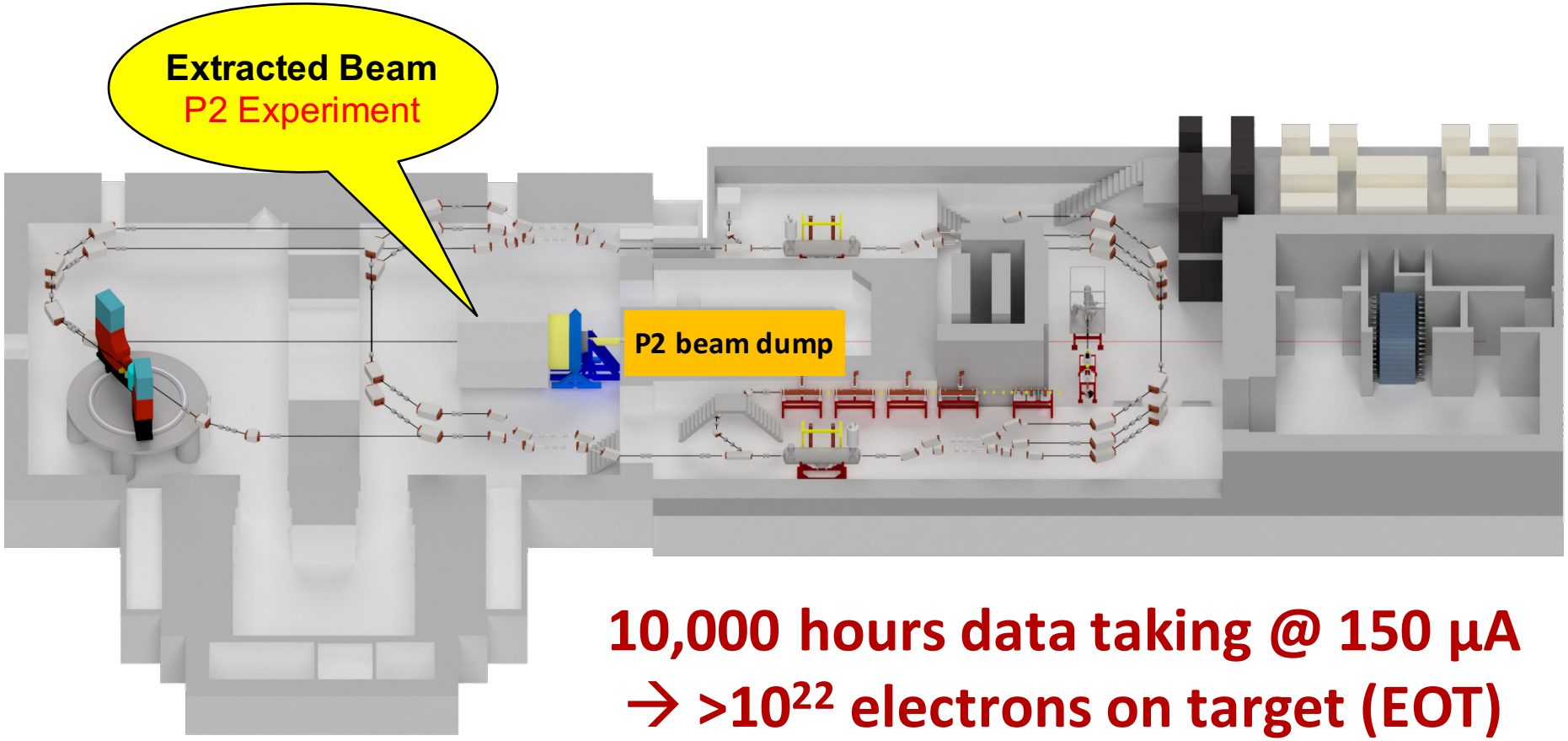
(Model 1)

Light Dark Matter Search at MESA

(Model 2)

Beam Dump Experiment (BDX) @ MESA

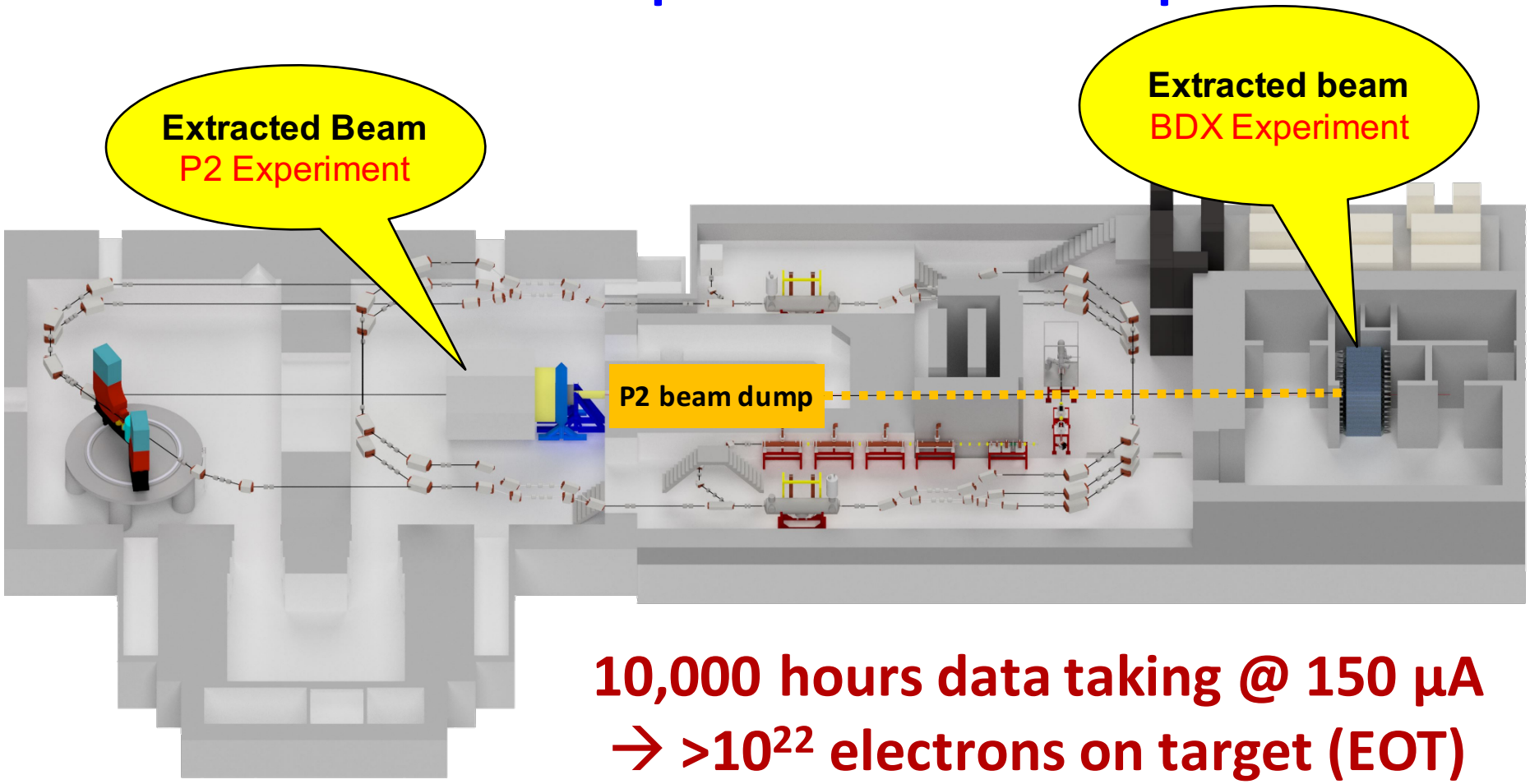
Electron Scattering (MESA) on Beam Dump
→ Collimated pair of Dark Matter particles !



10,000 hours data taking @ 150 µA
→ >10^{22} electrons on target (EOT)

Beam Dump Experiment (BDX) @ MESA

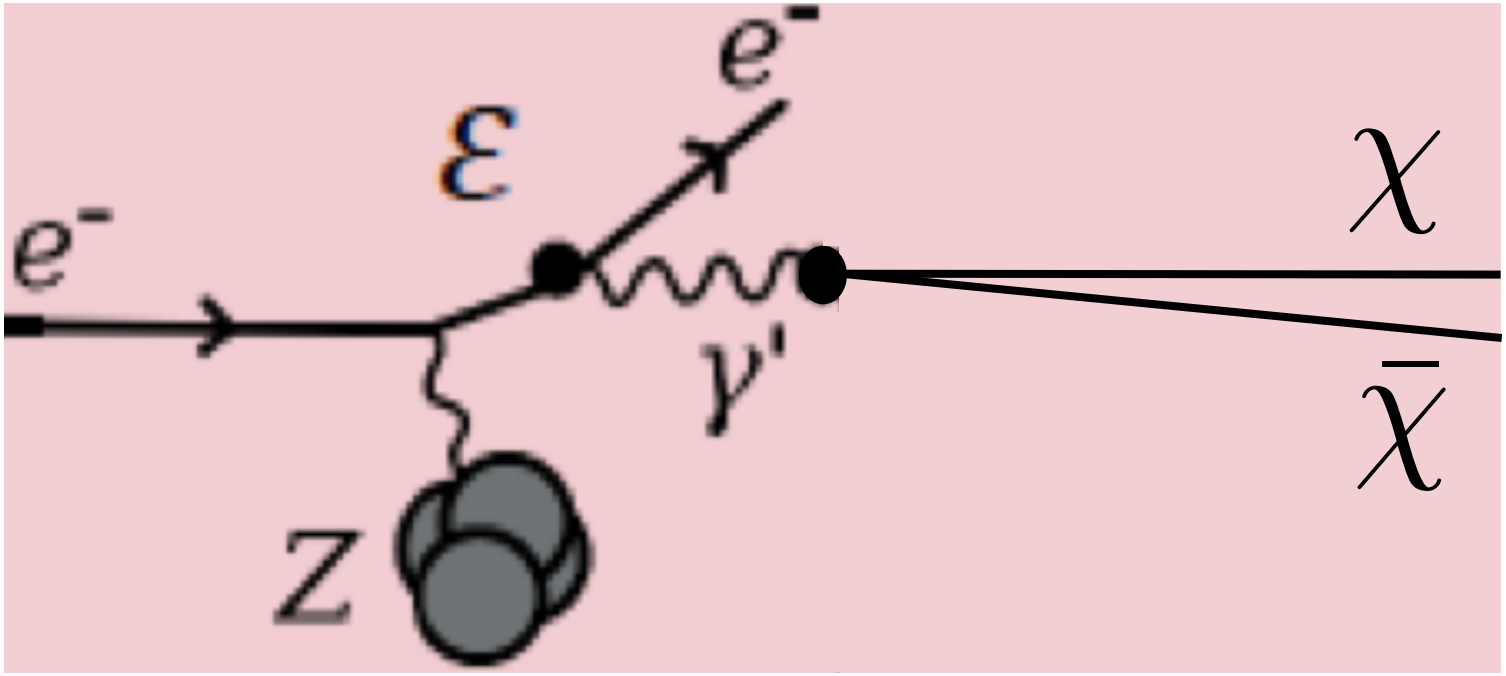
Electron Scattering (MESA) on Beam Dump
→ Collimated pair of Dark Matter particles !



10,000 hours data taking @ 150 µA
→ >10^{22} electrons on target (EOT)

Beam Dump Experiment (BDX) @ MESA

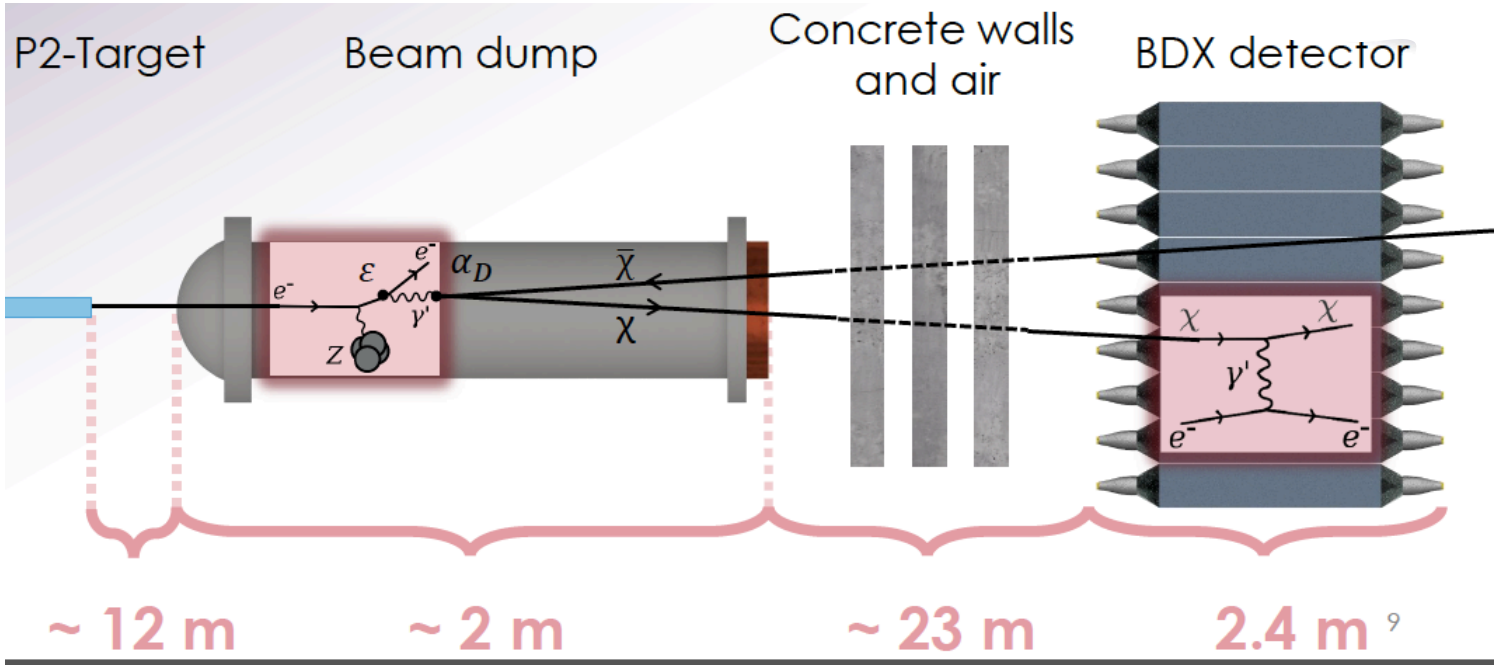
Electron Scattering (MESA) on Beam Dump
→ Collimated pair of Dark Matter particles !



10,000 hours data taking @ 150 µA
→ >10^{22} electrons on target (EOT)

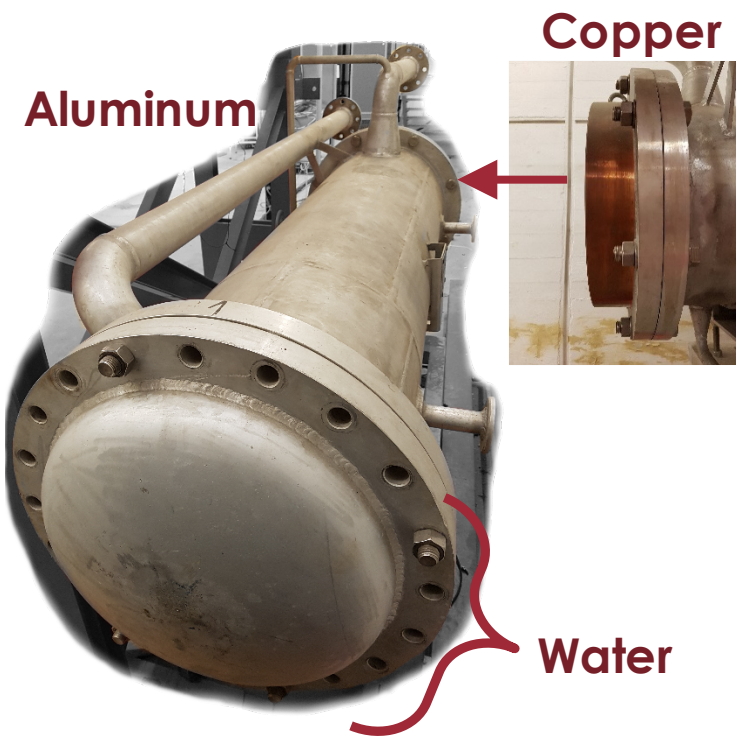
Beam Dump Experiment (BDX) @ MESA

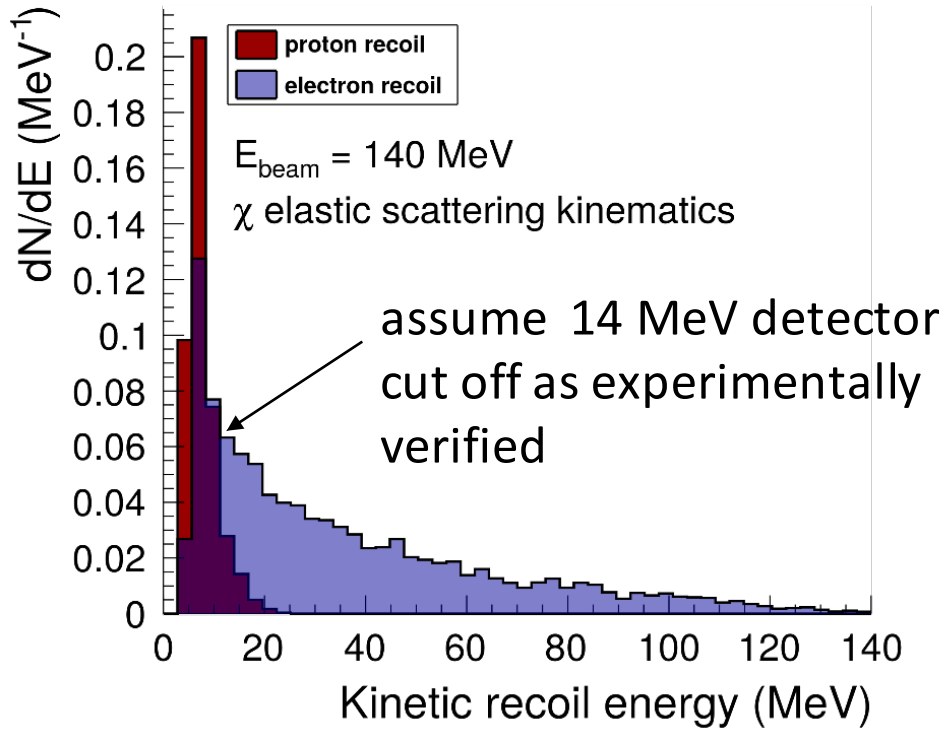
Electron Scattering (MESA) on Beam Dump
→ Collimated pair of Dark Matter particles !



Simulation BDX @ MESA

- Full GEANT4 simulation (P2 target, beam dump, BDX detector volume, walls etc.)
- Addition of 2.5 mm W plate before beam dump to increase (dark) photon rate?
- No neutrino background due to low beam energy, reduced neutron background



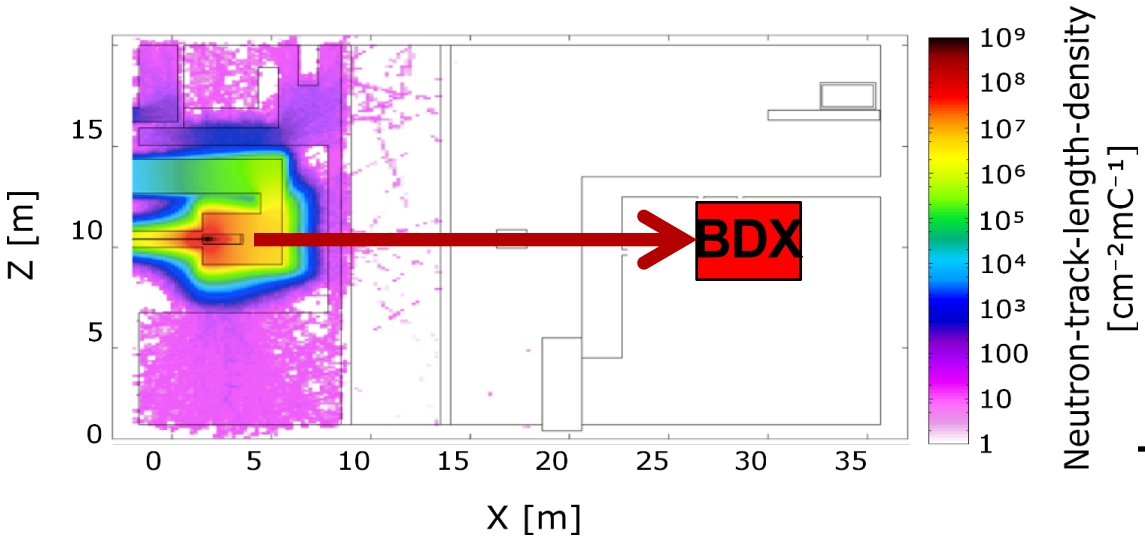


Detector Concept for BDX @ MESA

Ideal Requirements:

1. Large Surface (Acceptance)
2. Large thickness (Int. Prob.)
3. High density (Int. Prob.)
4. Reliability (long running time)
5. Background rejection

- Cosmics
- Natural Backgrounds
- Beam Backgrounds (Neutrons)

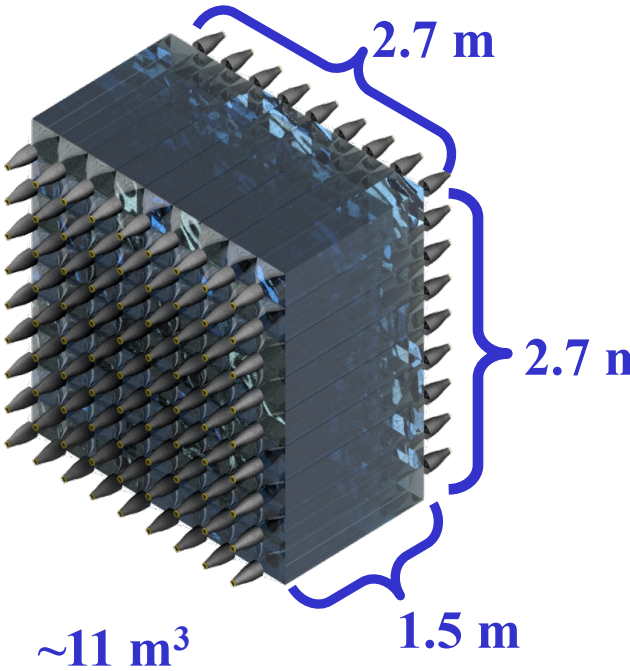


Detector Concept for BDX @ MESA

Ideal Requirements:

1. Large Surface (Acceptance)
2. Large thickness (Int. Prob.)
3. High density (Int. Prob.)
4. Reliability (long running time)
5. Background rejection

- Cosmics
- Natural Backgrounds
- Beam Backgrounds (Neutrons)

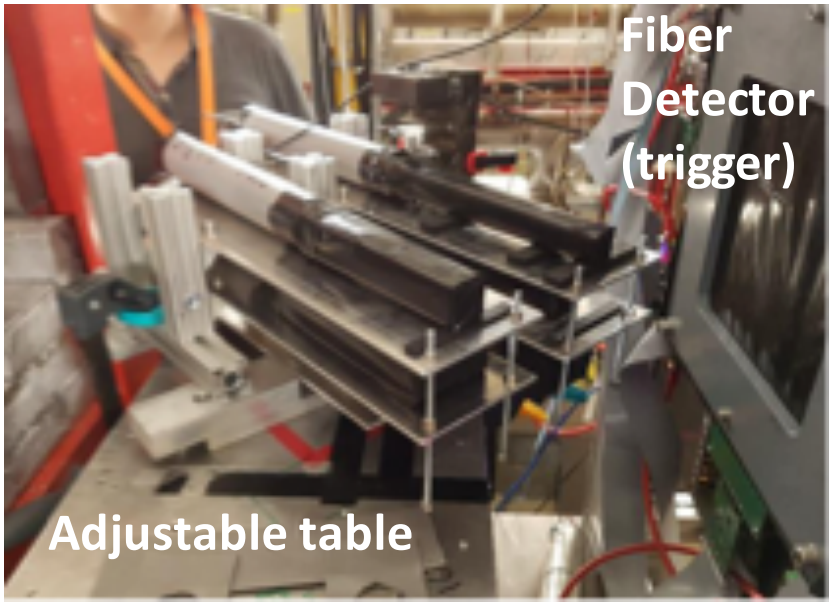


Baseline Concept

Inorganic crystal calorimeter (high density)

- Cherenkov (fast, no neutrons)
- Scintillator (higher light yield)

Test Beam BDX @ MESA



14 MeV

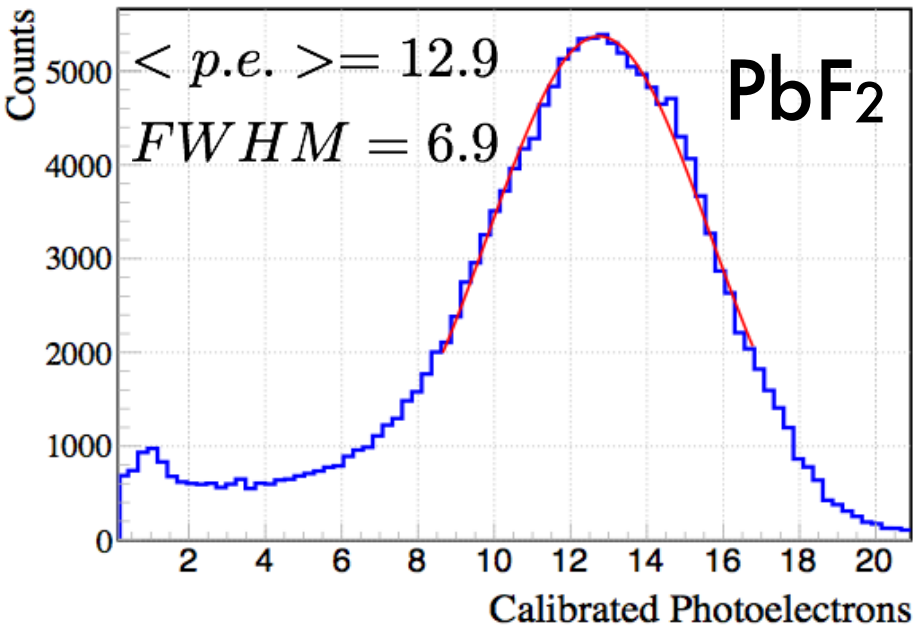
MAMI beam

Measurements:

Light Yield

Position dependence

PMT voltage scan



Crystals investigated

SF5 (Pb-Glass, Schott AG)

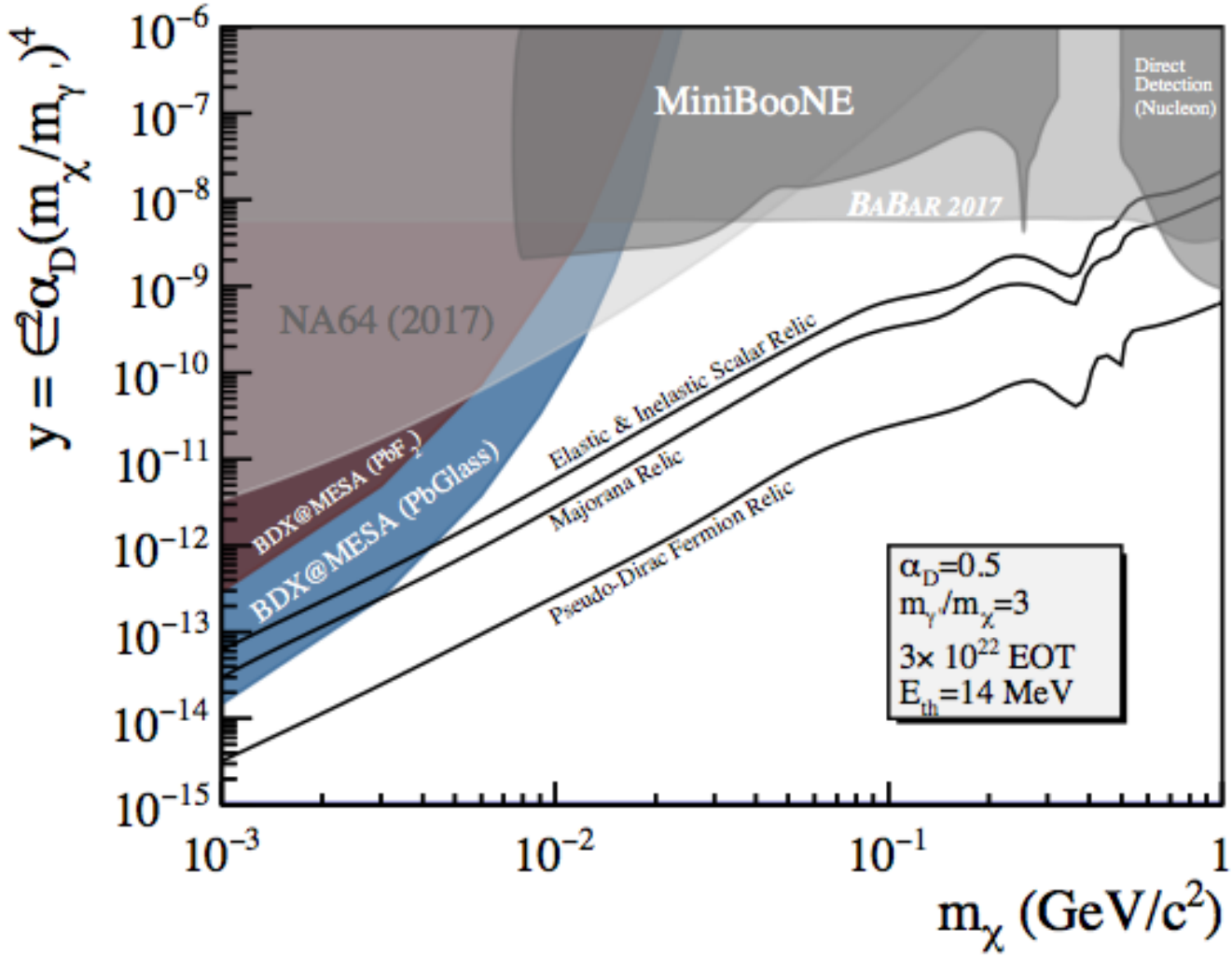
SF6 (Pb-Glass, Schott AG)

SF57HTultra (Pb-Glass, Schott AG)

BGO (from L3-LEP)

PbF_2 (from A4/MAMI)

Sensitivity BDX @ MESA



Dark Sector Searches at MAMI / MESA

- **GeV scale Dark Photon searches motivated by**
  - Astrophysical anomalies
  - $(g\text{-}2)_\mu$

- **Low-energy electron fixed-target accelerators ideally suited for Dark Photon searches**

- **Results from A1/MAMI and from JLAB**

- **New MESA accelerator < 155 MeV up to 1 mA beam current becoming operational in 2023**

- **MESA allows to cover low-mass region for Dark Photon**

- **Competitive Beam Dump Experiment (BDX) at MESA**

Dark Sector Searches at MAMI / MESA

- **GeV scale Dark Photon searches motivated by**
  - Astrophysical anomalies
  - $(g\text{-}2)_\mu$

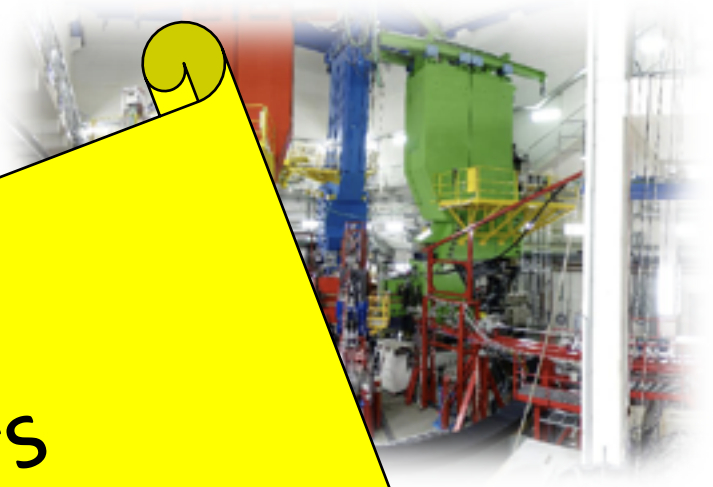
- **Low-energy electron fixed-tar**
  ideally suited for Darl

- **Results f**

- **New MESA**
  operationa

- **MESA allows**

- **Competitive Be Dump Experiment (BDX) at MESA**



New Collaborators welcome

current becoming

s region for Dark Photon