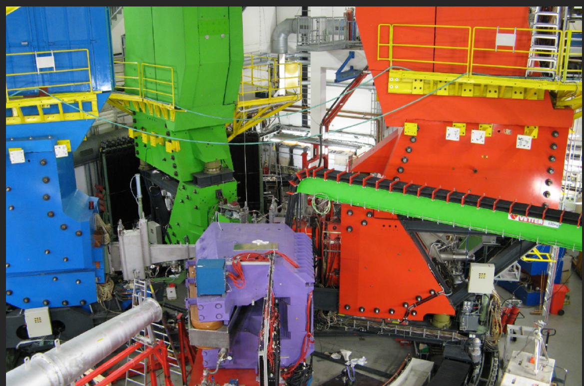
Achim Denig

Institute for Nuclear Physics
Johannes Gutenberg University Mainz

WORKSHOP ON DARK SECTORS 2016

Dark Photon Searches at MAMI and MESA / Mainz



Cluster of Excellence PRISMA

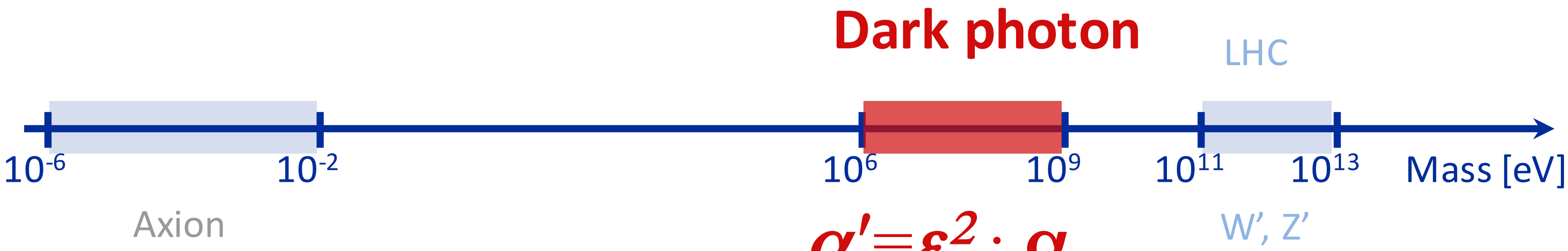
SFB 1044

THE LOW-ENERGY FRONTIER

JG|U

Dark Photon

New massive force carrier of extra $U(1)_d$ gauge group; predicted in almost all string compactifications



$$\alpha' = \varepsilon^2 \cdot \alpha_{em}$$

Search for the O(GeV/c²) mass scale in a world-wide effort

- Could explain large number of **astrophysical anomalies**
  Arkani-Hamed et al. (2009)
  Andreas, Ringwald (2010); Andreas, Niebuhr, Ringwald (2012)

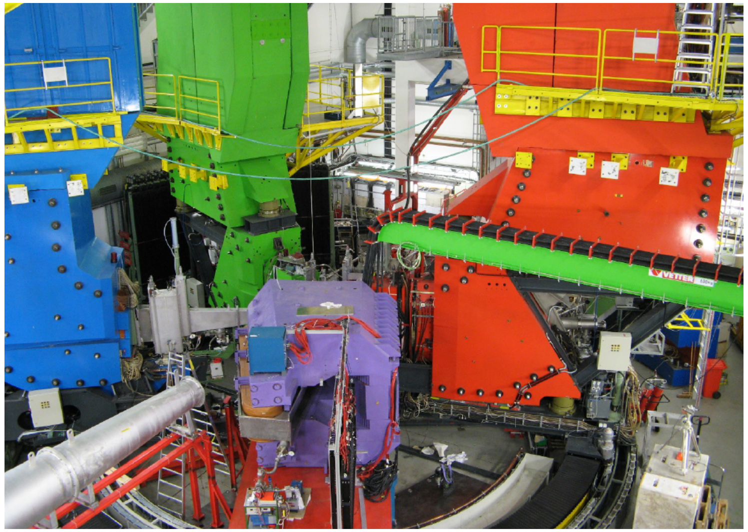
- Could explain presently seen **deviation of 3.6σ between $(g-2)_\mu$** Standard Model prediction and direct $(g-2)_\mu$ measurement
  Pospelov(2008)

Outline

- **Visible Dark Photon searches at the existing MAMI accelerator**
- **Perspectives for future MESA accelerators**
- **Possibilities for Beam Dump Experiments at MESA and MAMI (?)**

Dark Photon

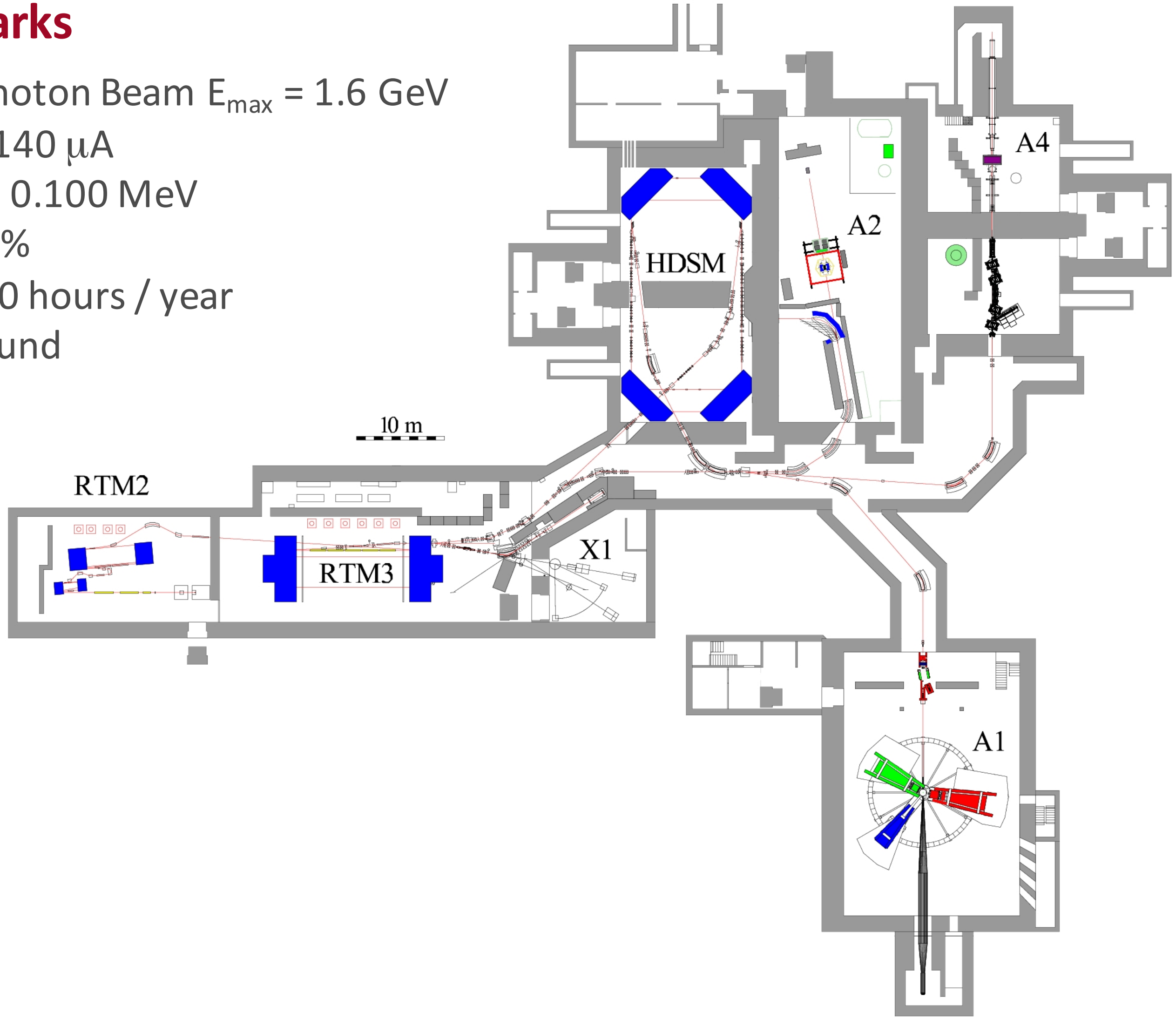
Searches at A1/MAMI



The Mainz Microtron MAMI

MAMI Hallmarks

- Electron and Photon Beam E_{max} = 1.6 GeV
- Intensity max. 140 μA
- Resolution σ_E < 0.100 MeV
- Polarization 85%
- Reliability: 7000 hours / year
- 11 m underground



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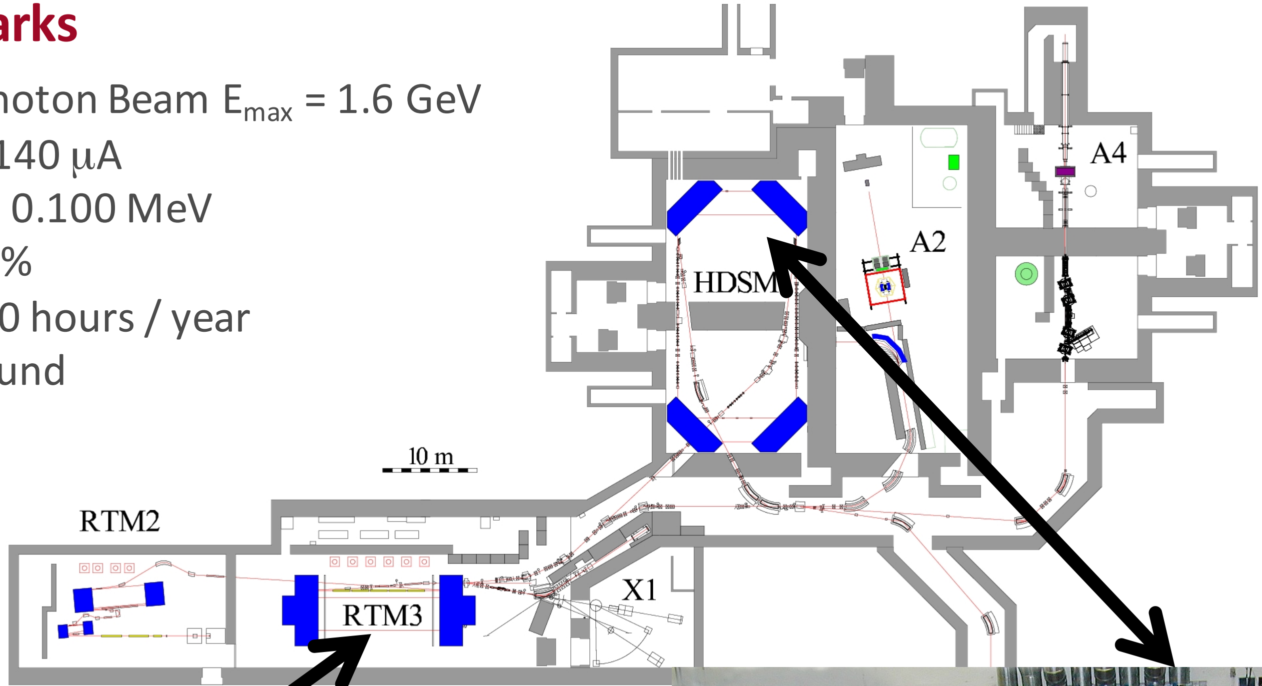
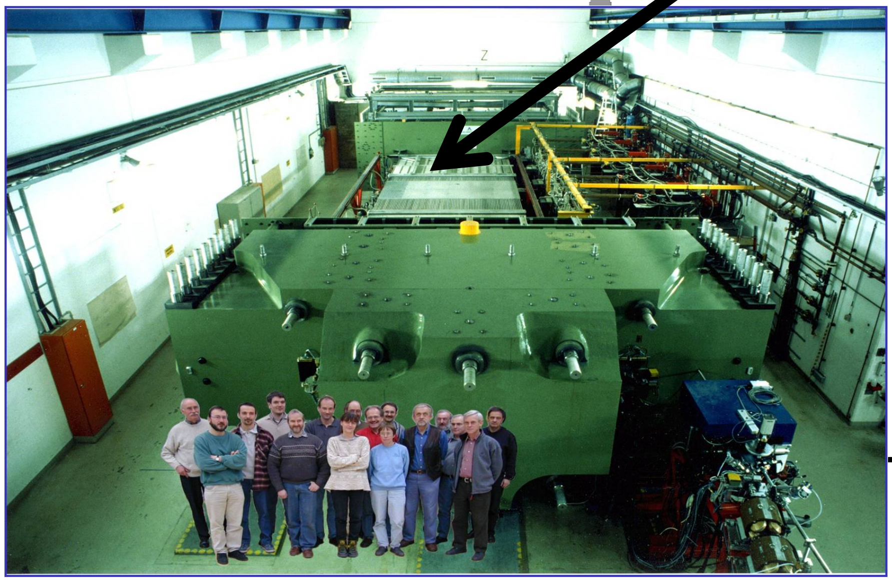
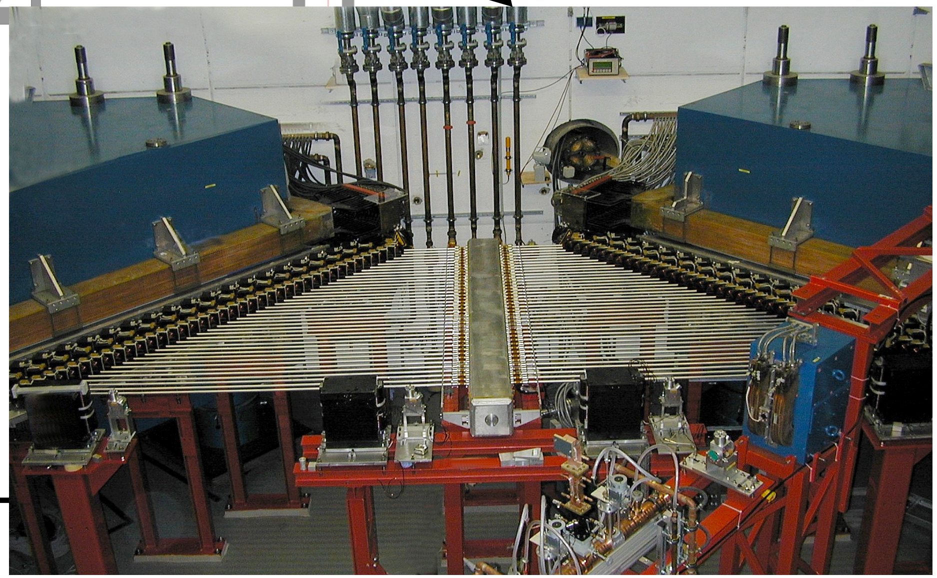
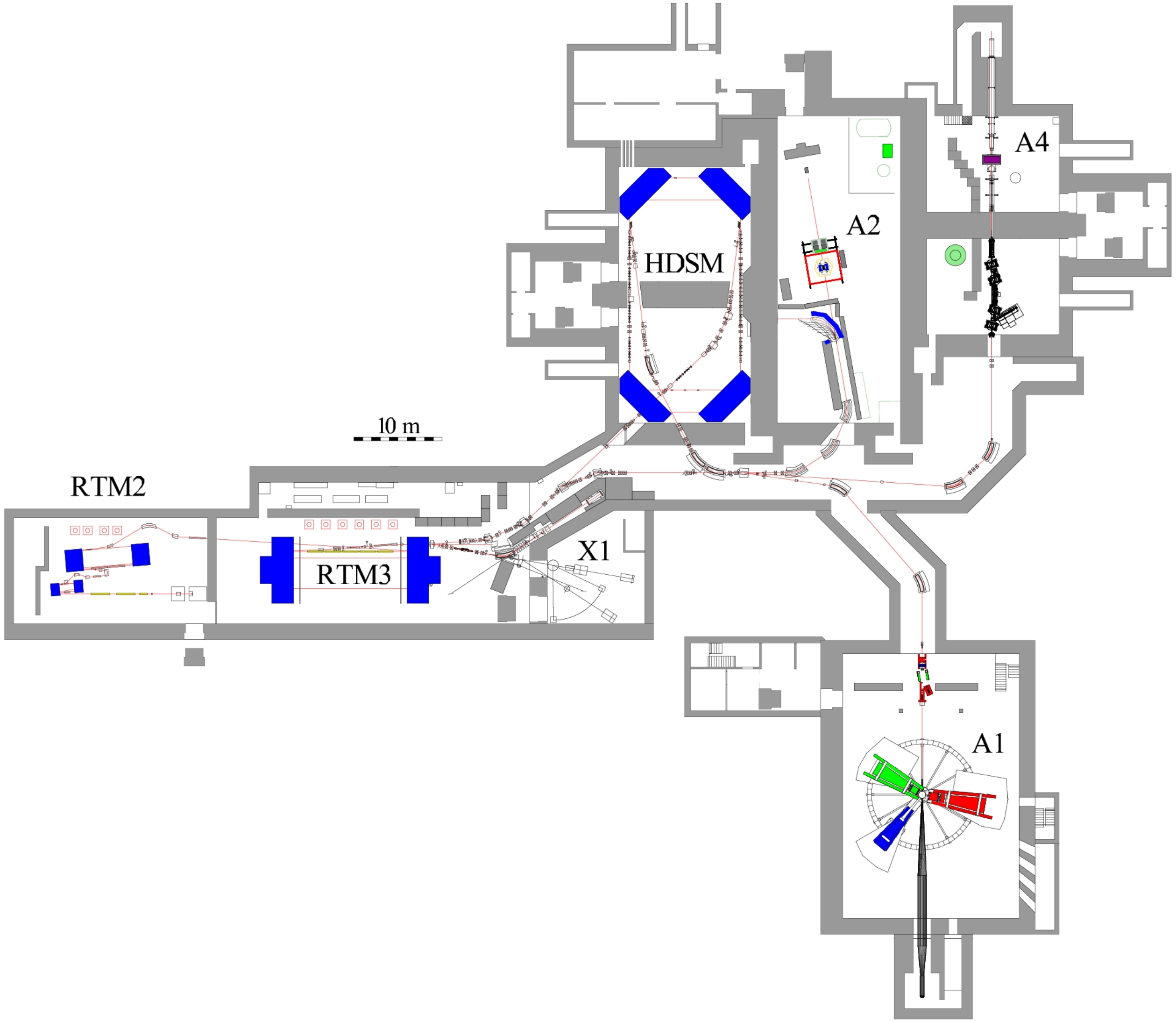






A1: High-Resolution Spectrometers



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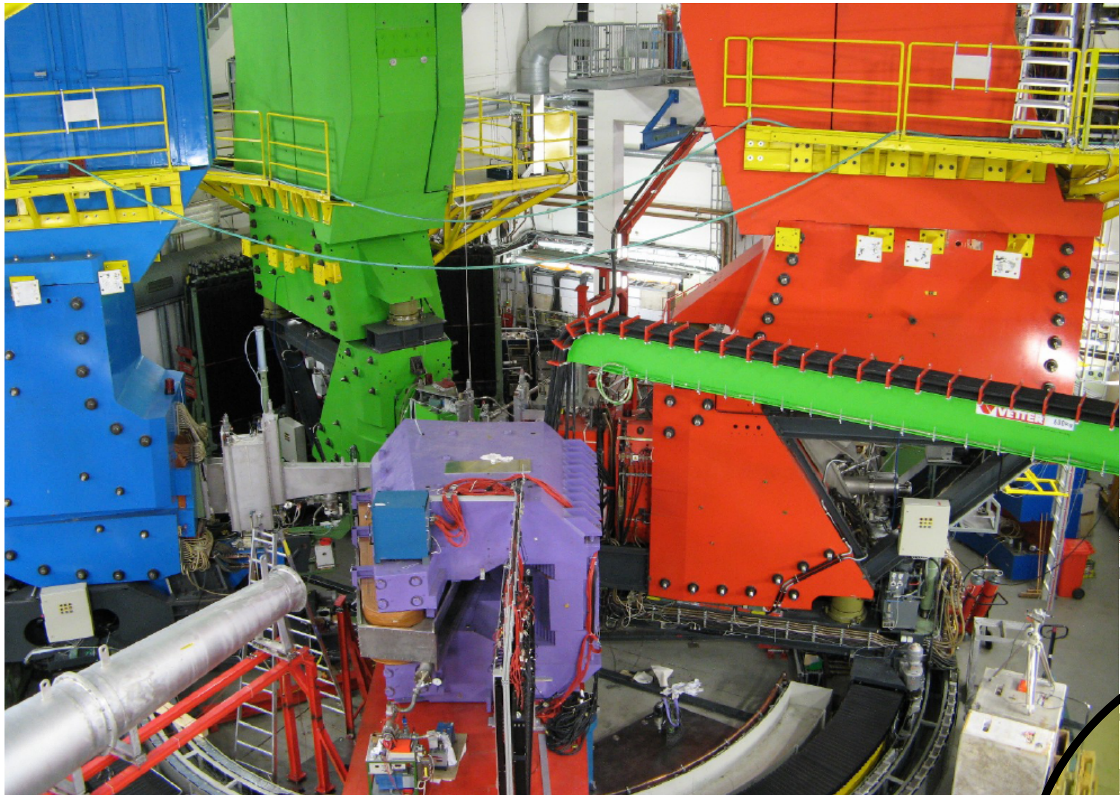
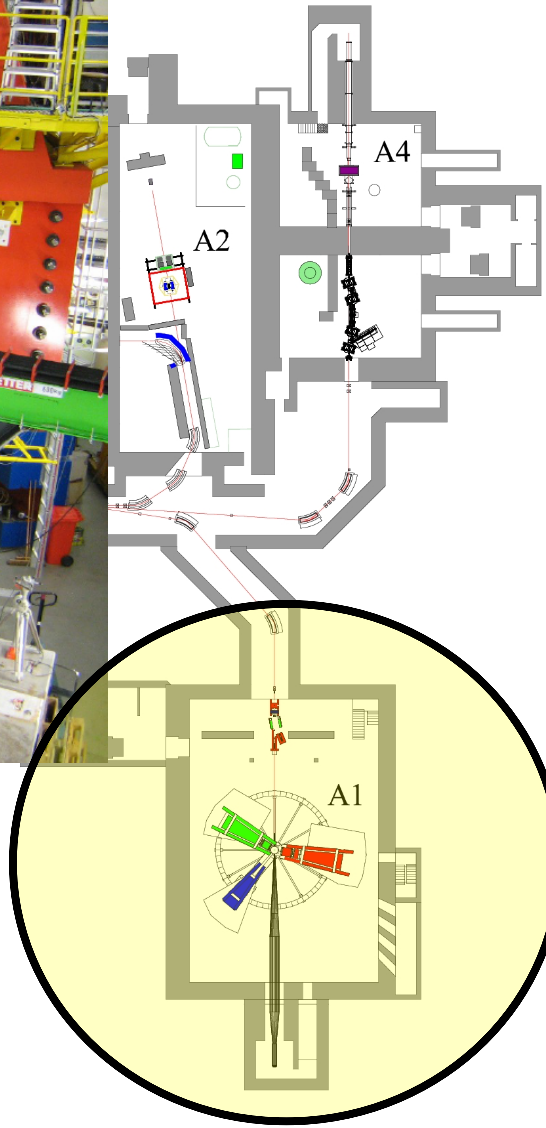




Experiment A1: Electron Scattering

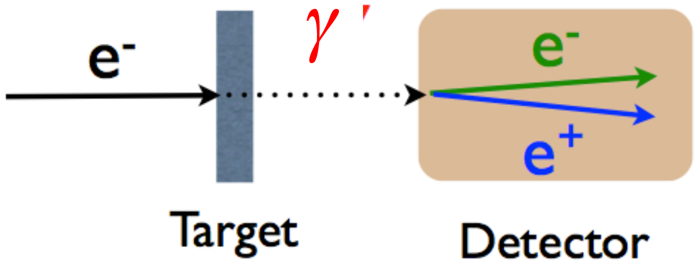
- 4 magnetic focussing spectrometers
- Resolution: $\delta p/p < 10^{-4}$
- Angular acceptance: <30 mrad

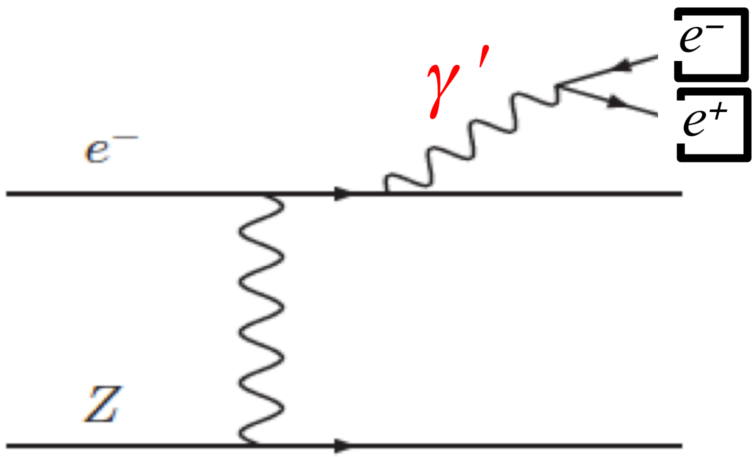
Results from A1/MAMI

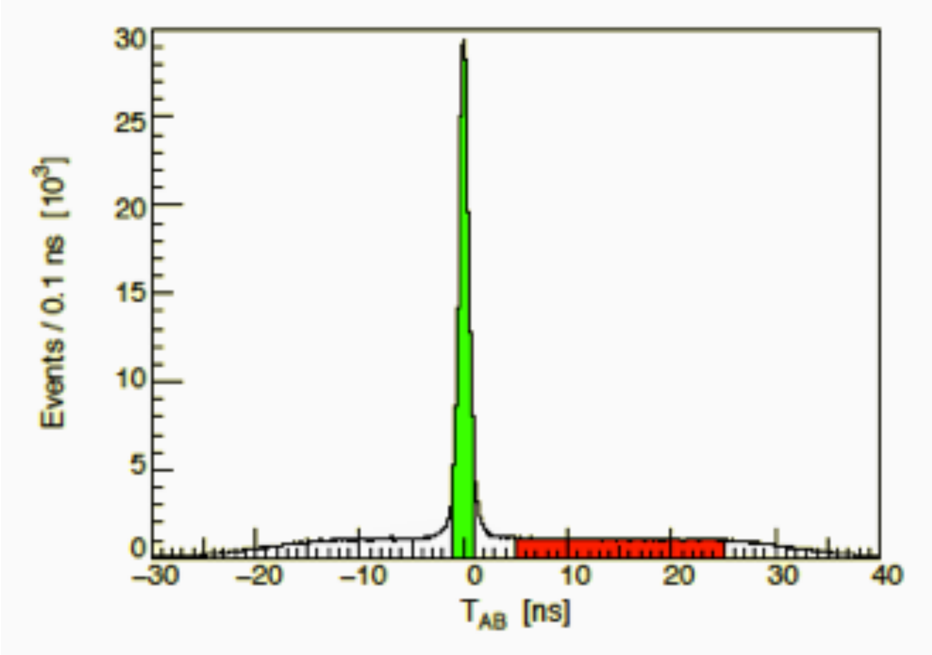
Low-Energy Electron Acceler. with high intensity suited for DP search

Bjorken, Esssig, Schuster, Toro (2009)

Signal processes







Time difference T_{AB} between both spectrometers

Results from A1/MAMI

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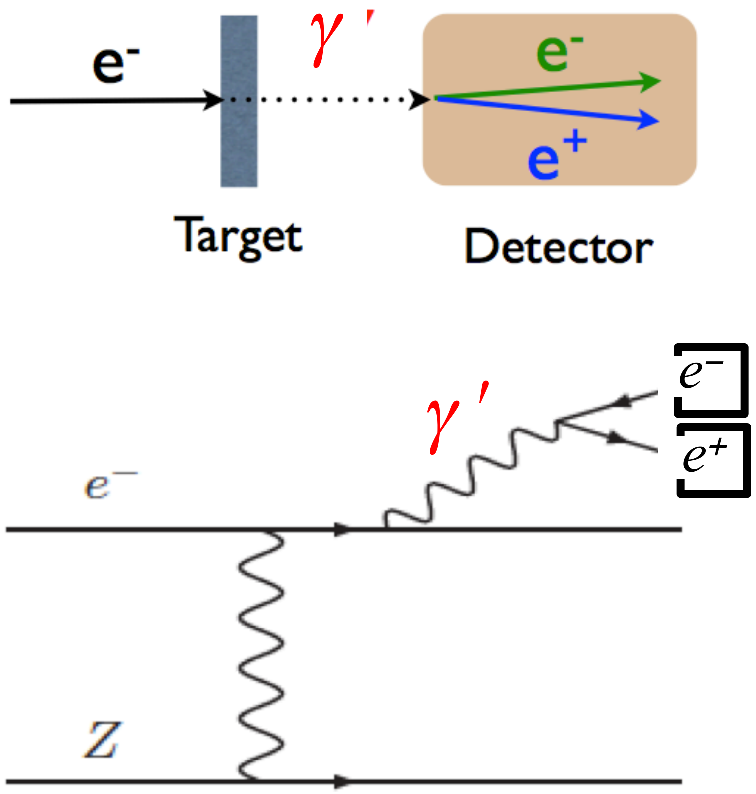
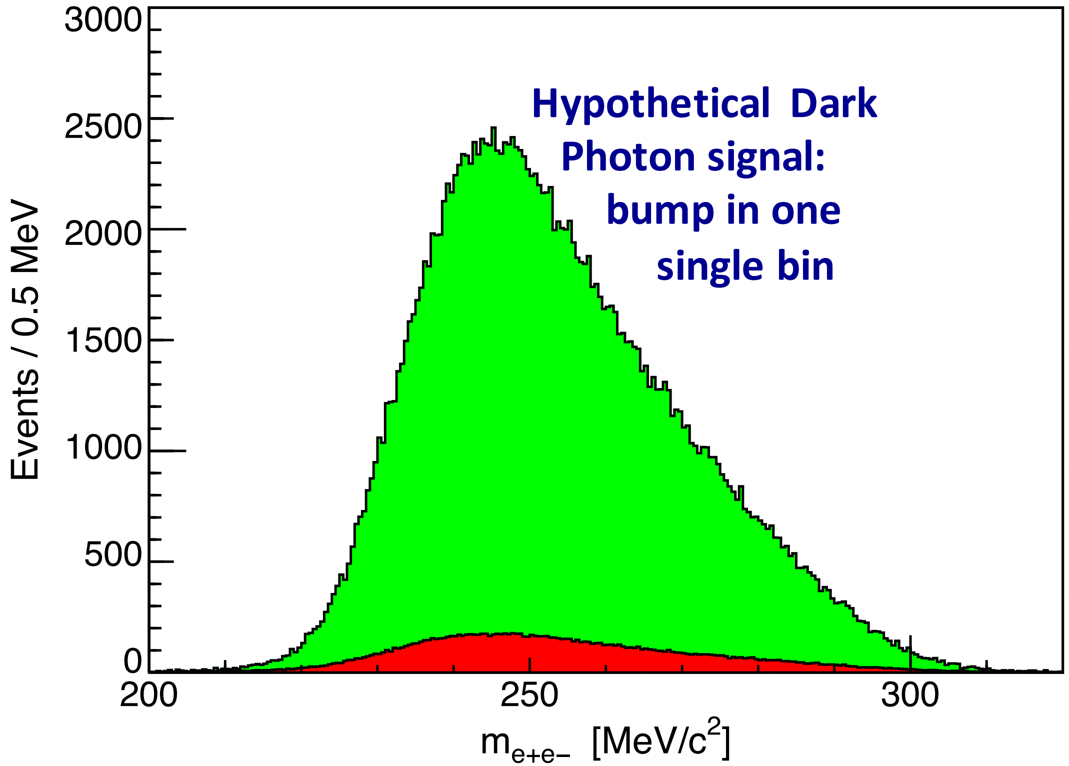
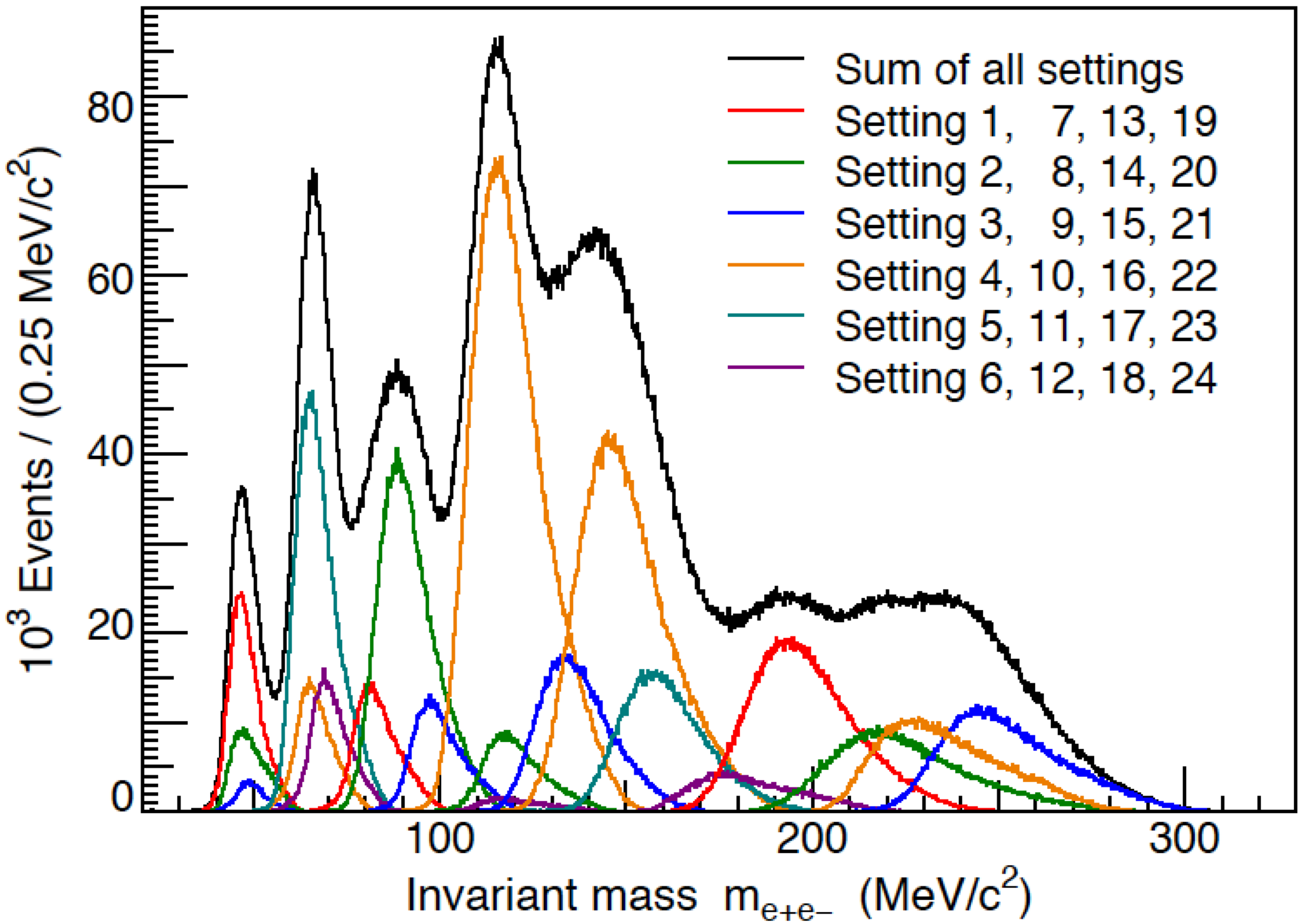




2010 test run
Invariant Mass of e+e-

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

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

Results from A1

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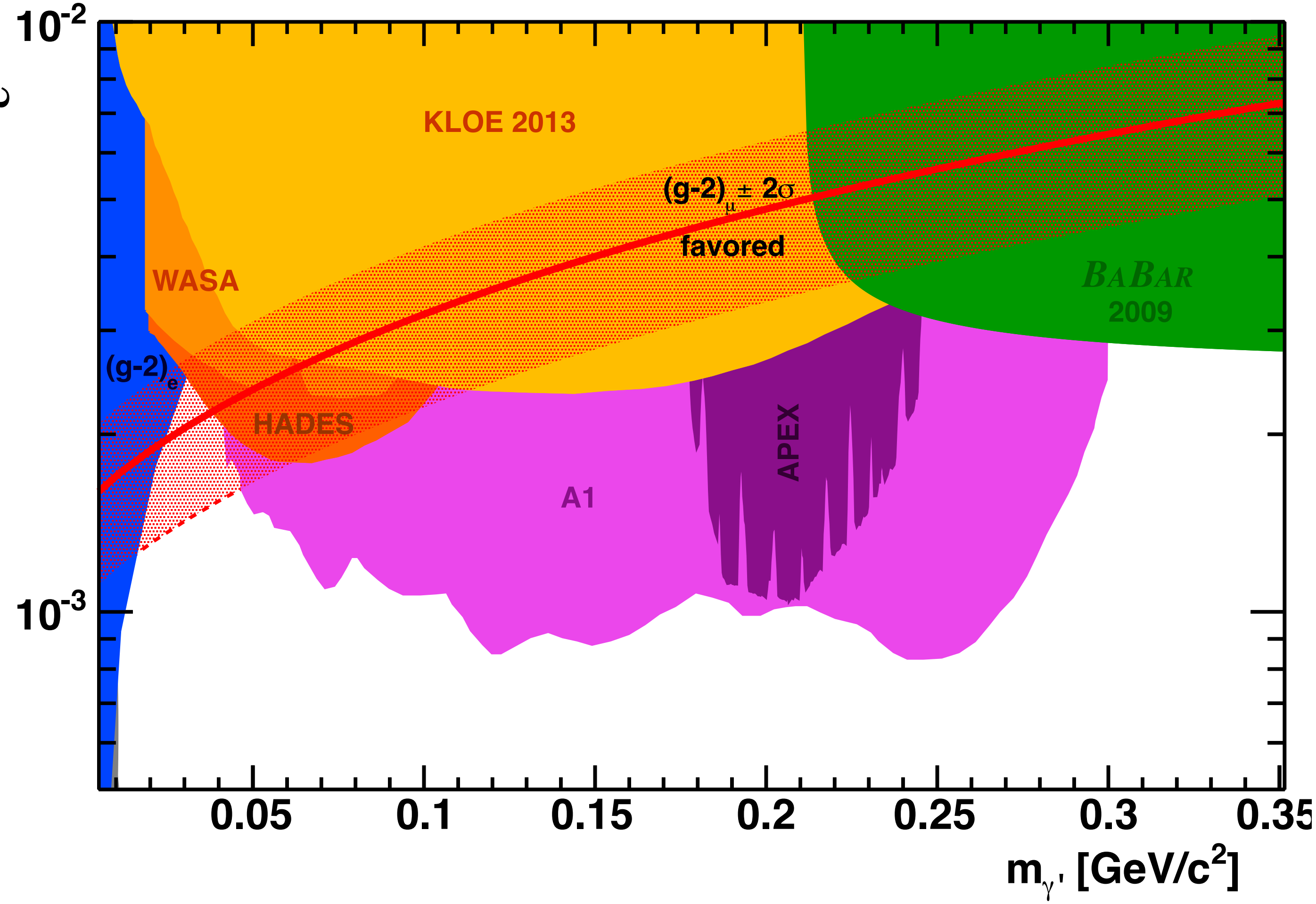

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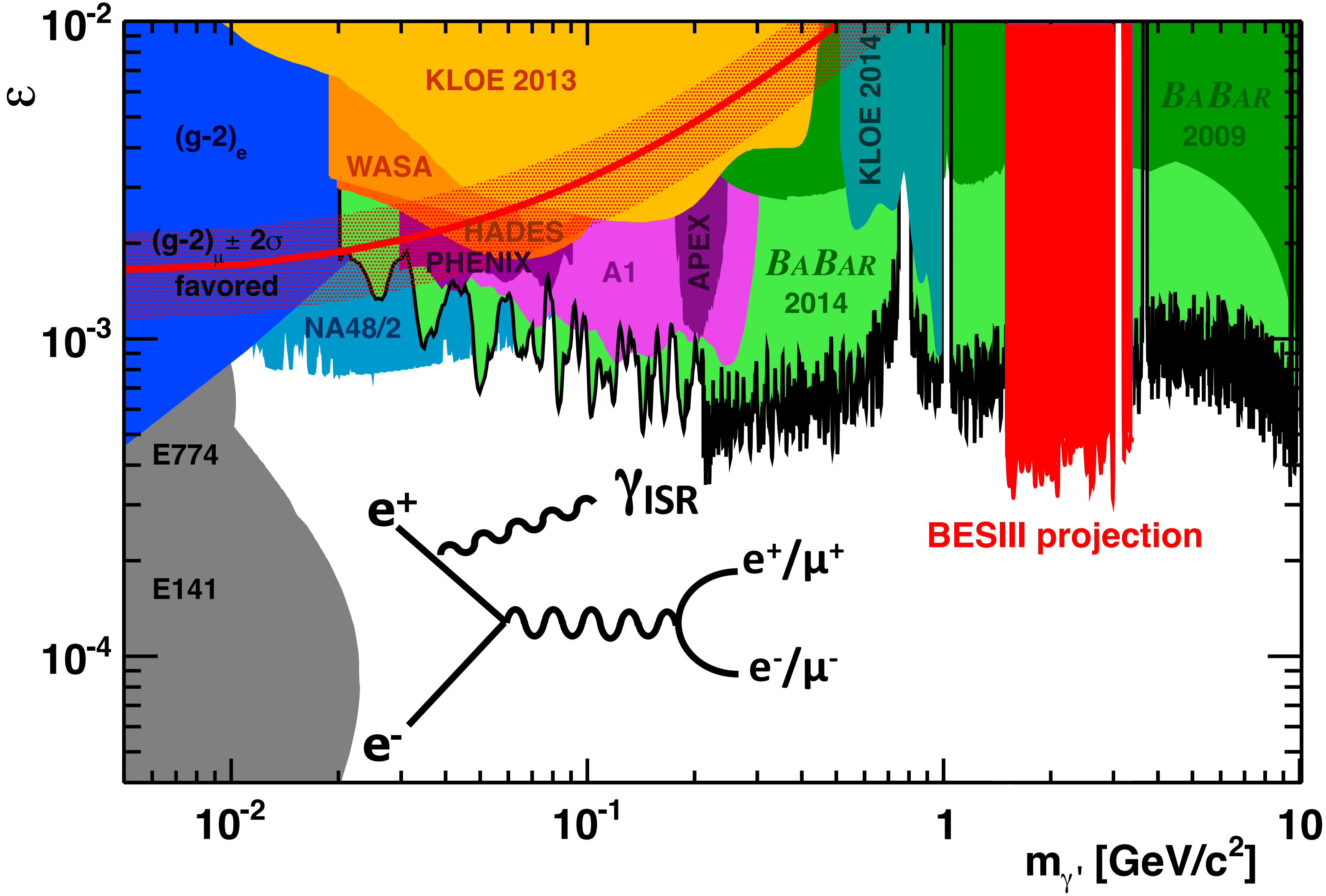
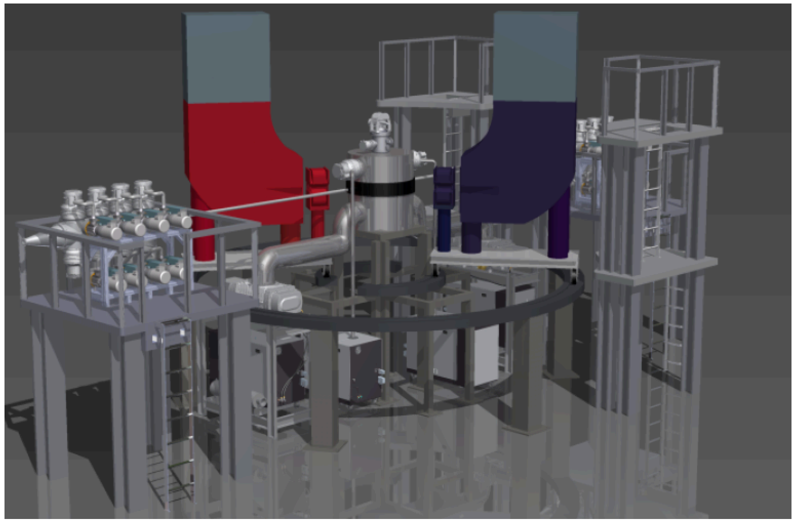
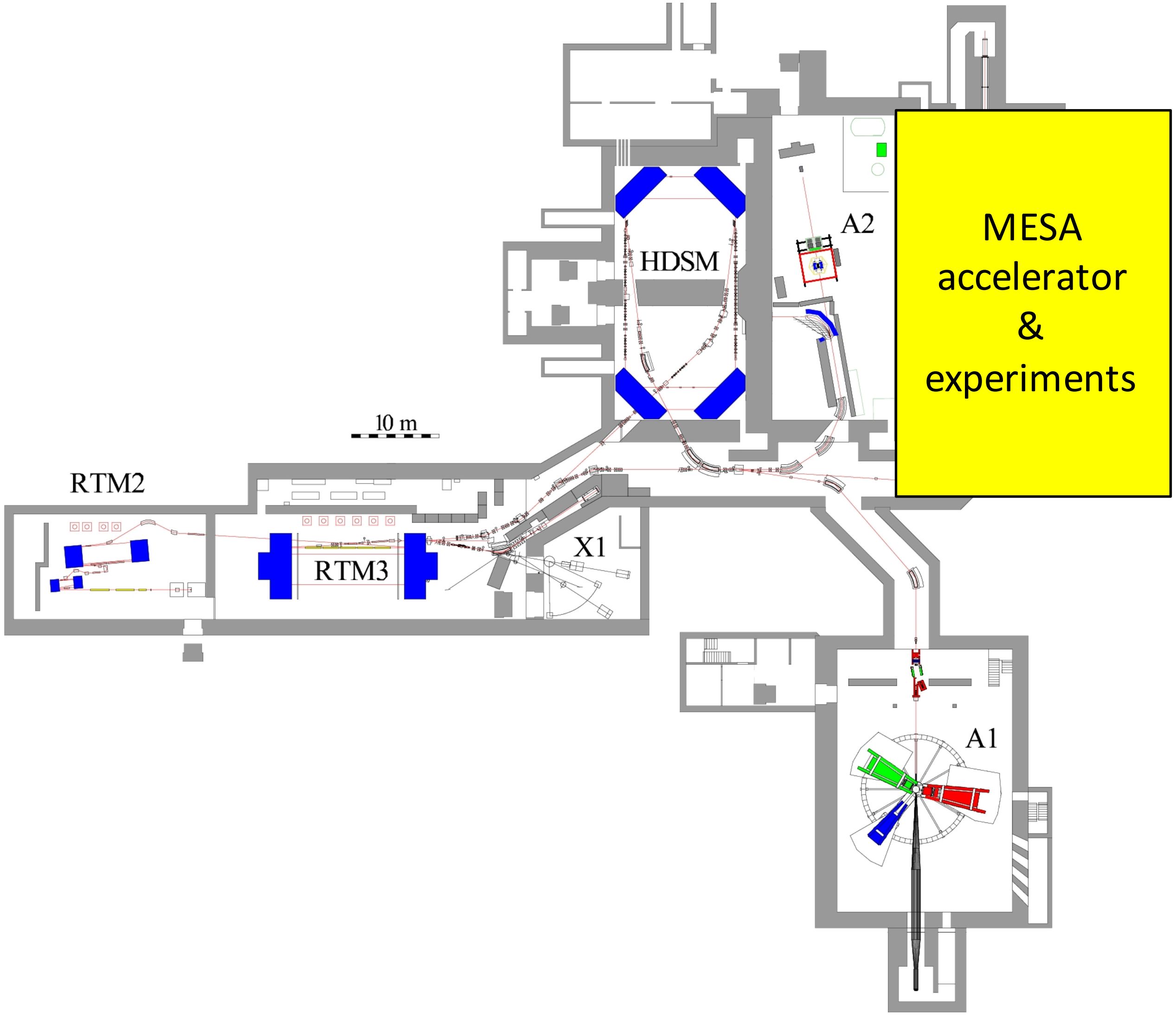
Situation as of today



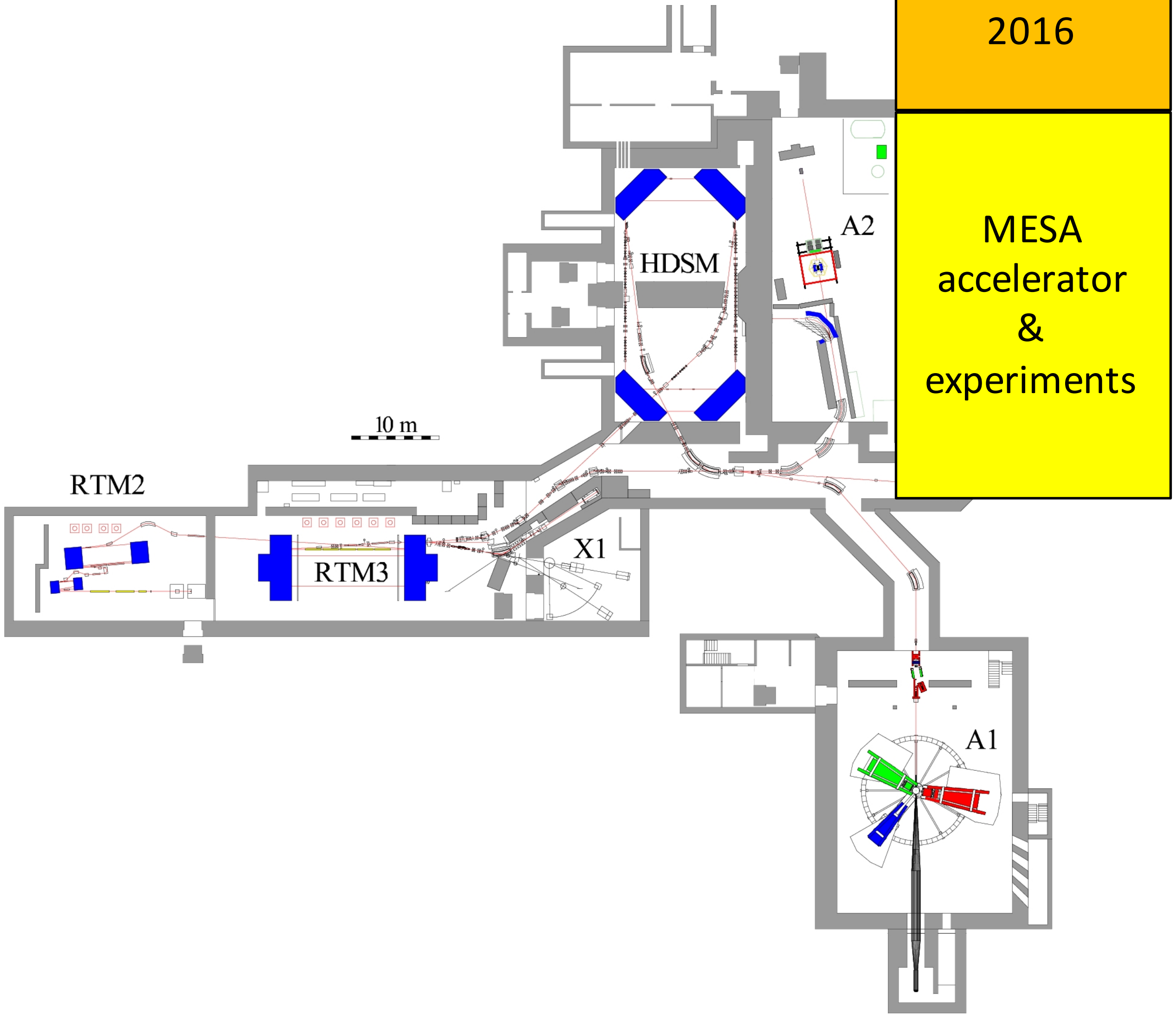
Dark Photon Search at MESA



Mainz Microtron MAMI



Mainz Microtron MAMI



New exptl. hall (CFP) funded in 2016

MESA accelerator & experiments

NEW: MESA Accelerator

Mainz Energy-Recovering Superconducting Accelerator

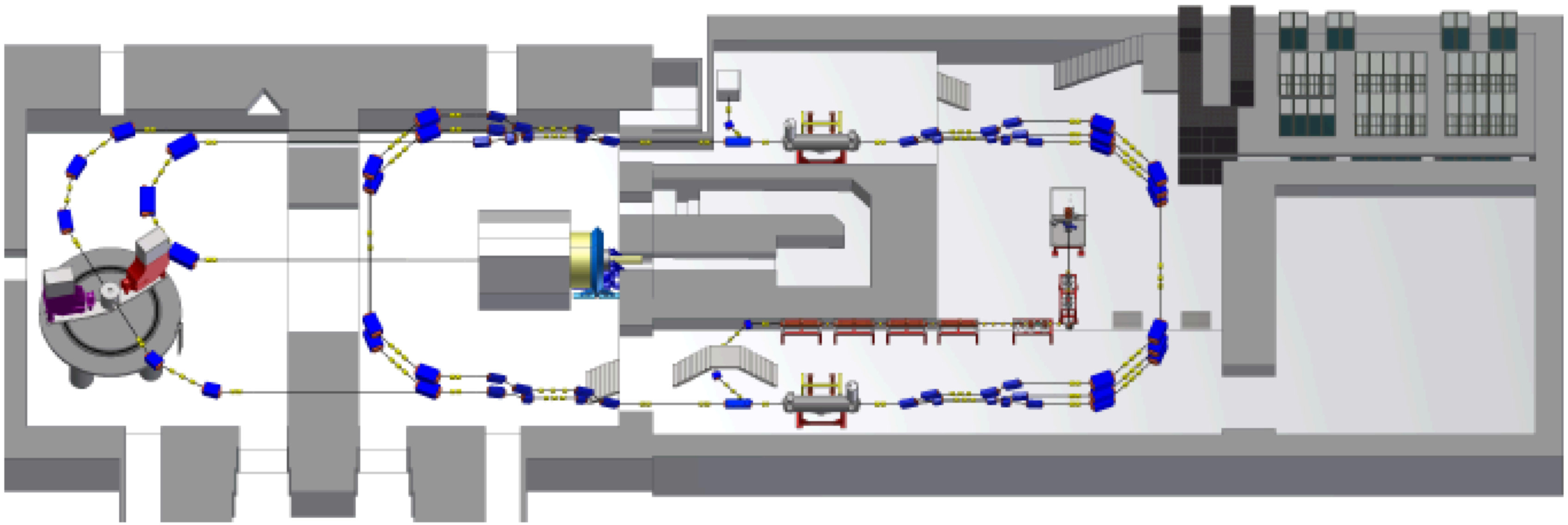
Recirculating ERL

E_{max} = 155 MeV

I_{max} > 1 mA (ERL)

commissioning 2020

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



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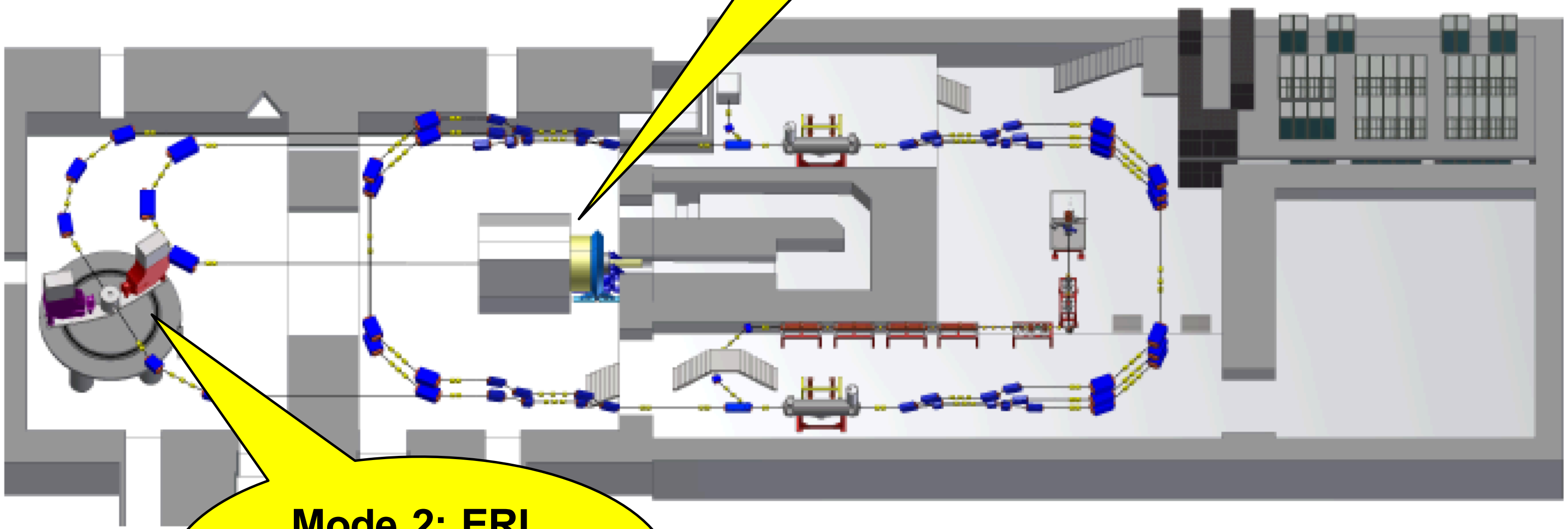
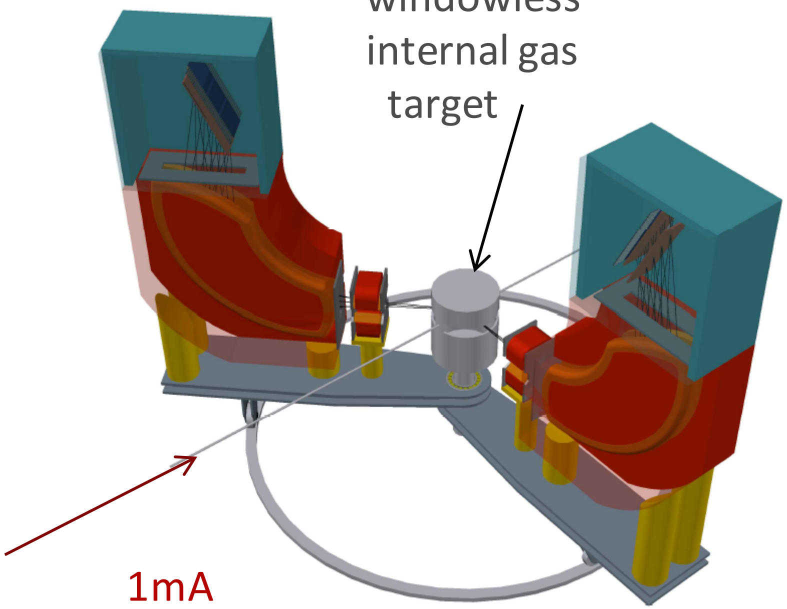


The MAinz Gas Internal EXperiment

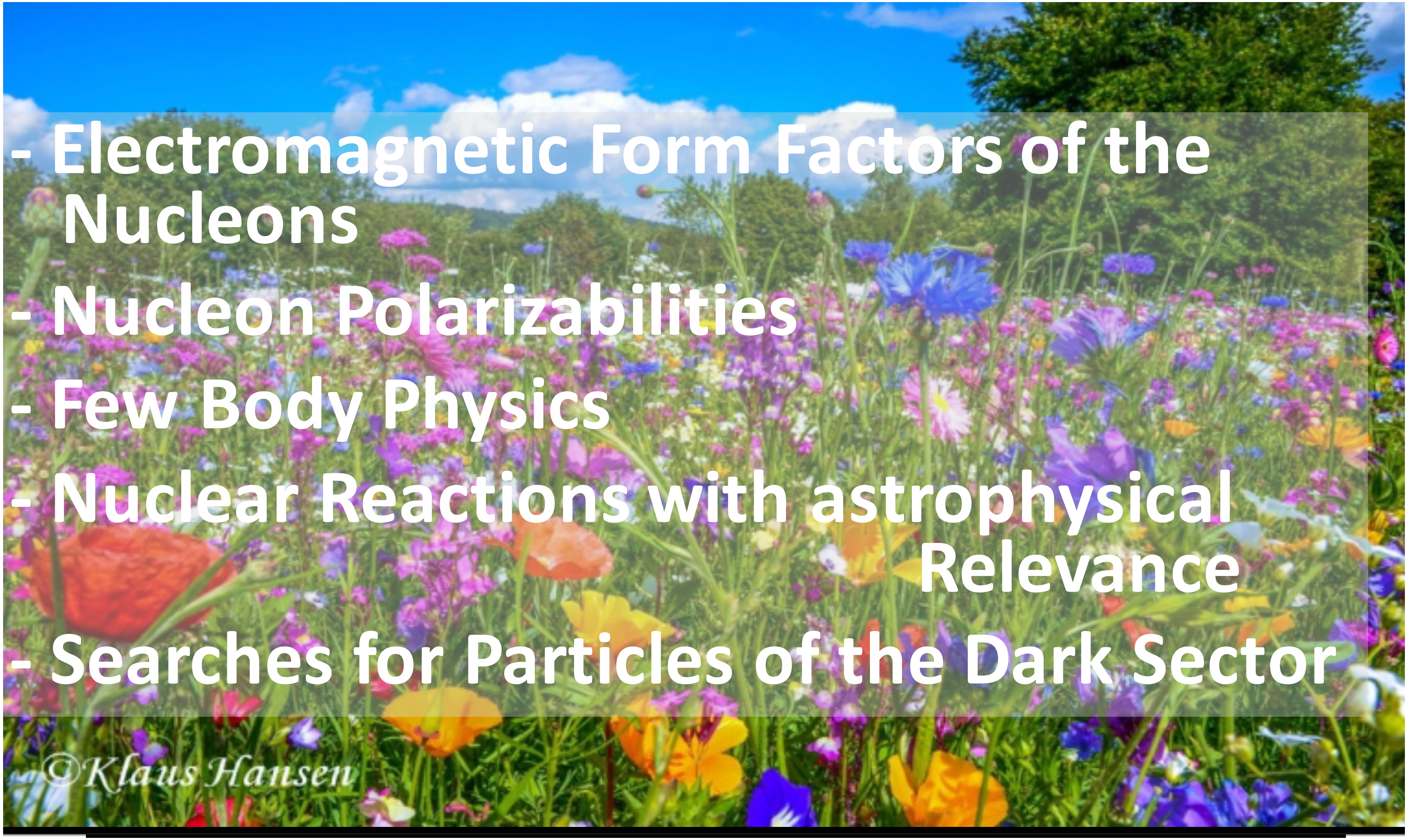
Operation of a high-intensity ERL beam
in conjunction with light internal target
→ a novel technique in nuclear and particle physics



High resolution spectrometers MAGIX:

- double arm
- compact design
- momentum resolution: $\Delta p/p < 10^{-4}$
- acceptance: ±50 mrad
- GEM-based focal plane detectors
- Gas Jet or polarized T-shaped target

MAGIX Physics Progam

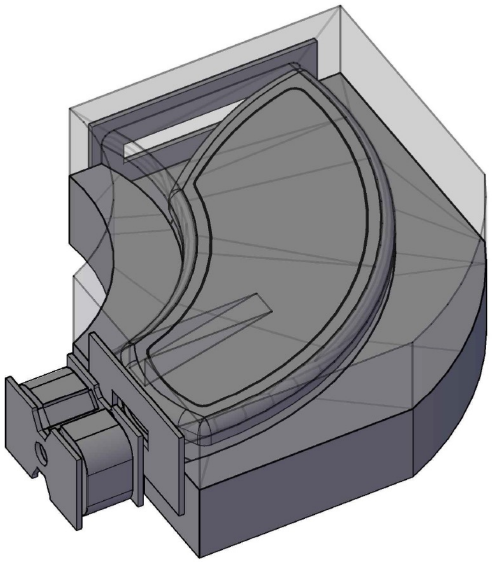


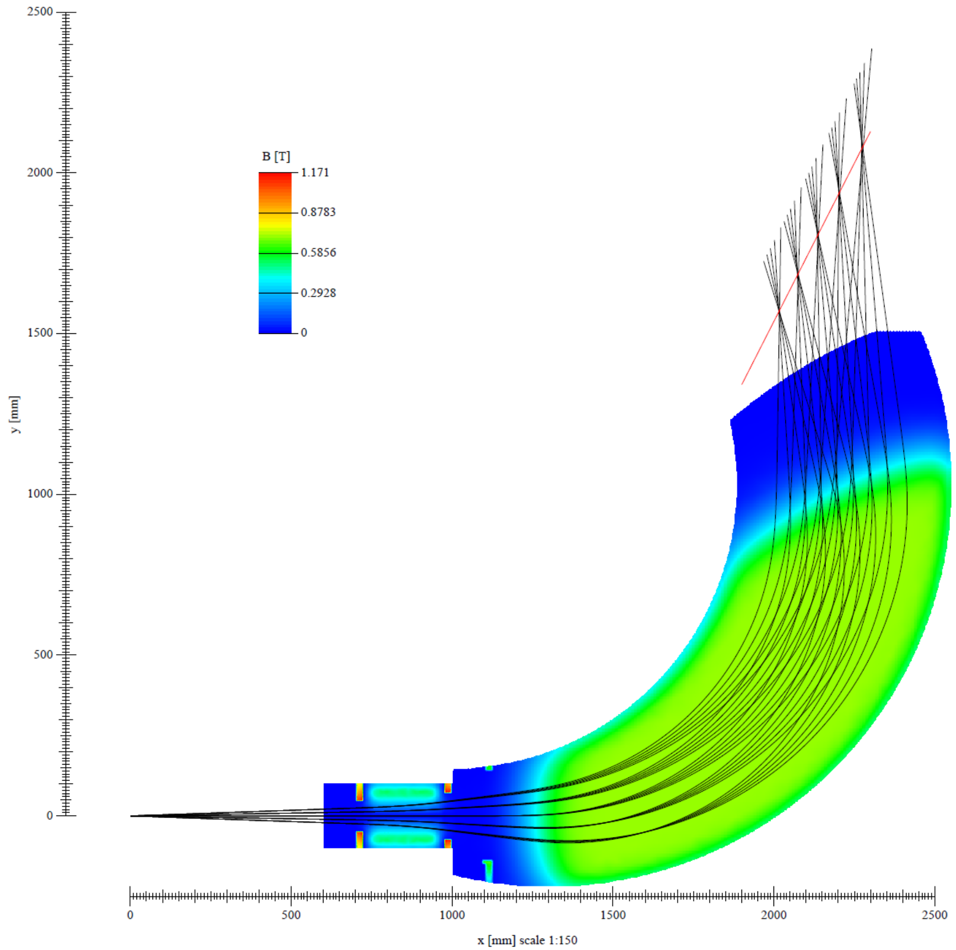
- Electromagnetic Form Factors of the Nucleons
- Nucleon Polarizabilities
- Few Body Physics
- Nuclear Reactions with astrophysical Relevance
- Searches for Particles of the Dark Sector

The MAGIX Spectrometers

Simple Design: Quadrupole + Dipole

- 200 MeV maximum momentum
- 90 MeV momentum acceptance @ 200 MeV

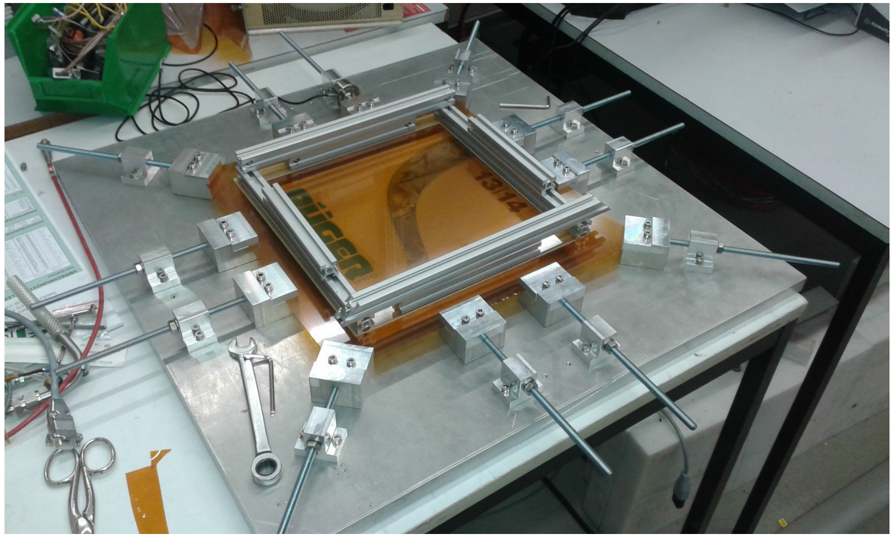




Finite-element simulations

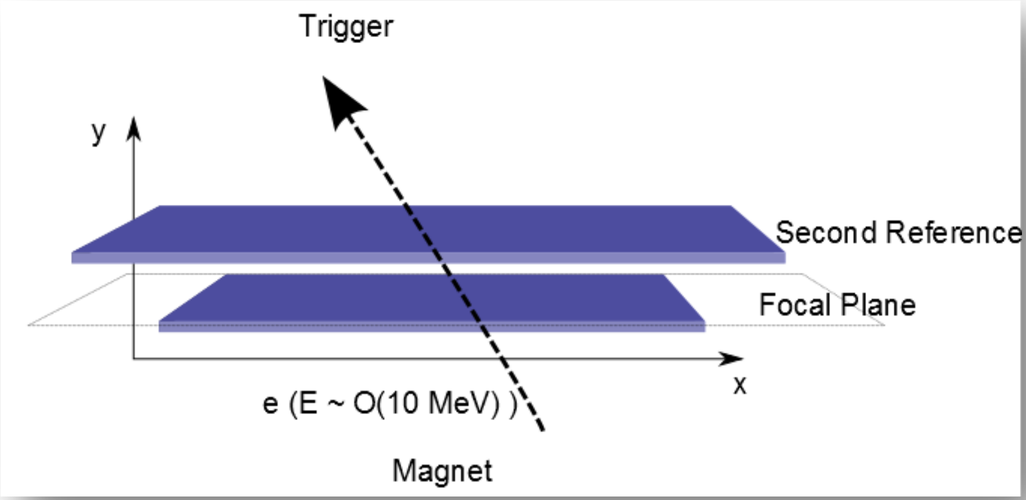
- 10^{-4} relative momentum resolution
- Assuming 50 µm resolution in the focal plane

The Focal Plane Detectors



2 Sensitive layers

- The first centered on the focal plane
- The second with a sizable lever arm to measure the angle
- 30 x 120 cm^2

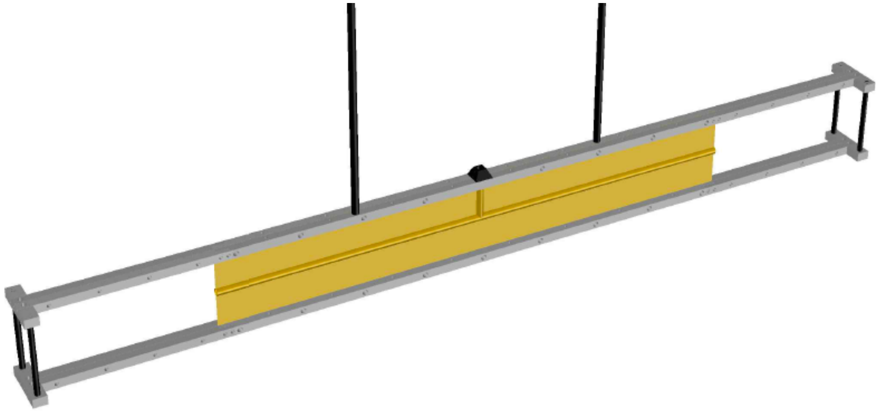


GEM Detectors

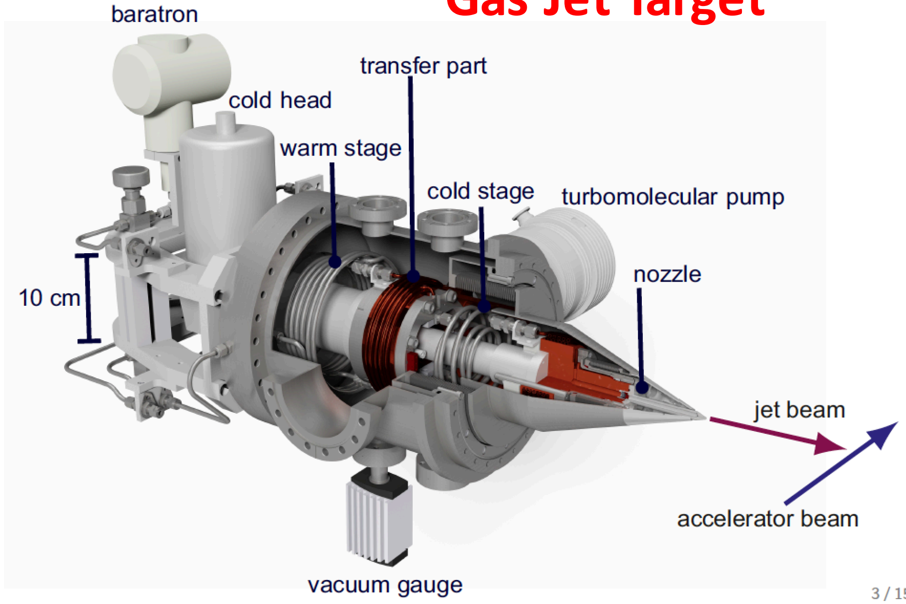
- 2D Strip readout
- 0.7% radiation length
- High rate capabilities
- Small TPC detector ???
- **Aim for 50 μm resolution**

Internal Gas Targets for MAGIX

Thin T-shaped foil



Gas Jet Target



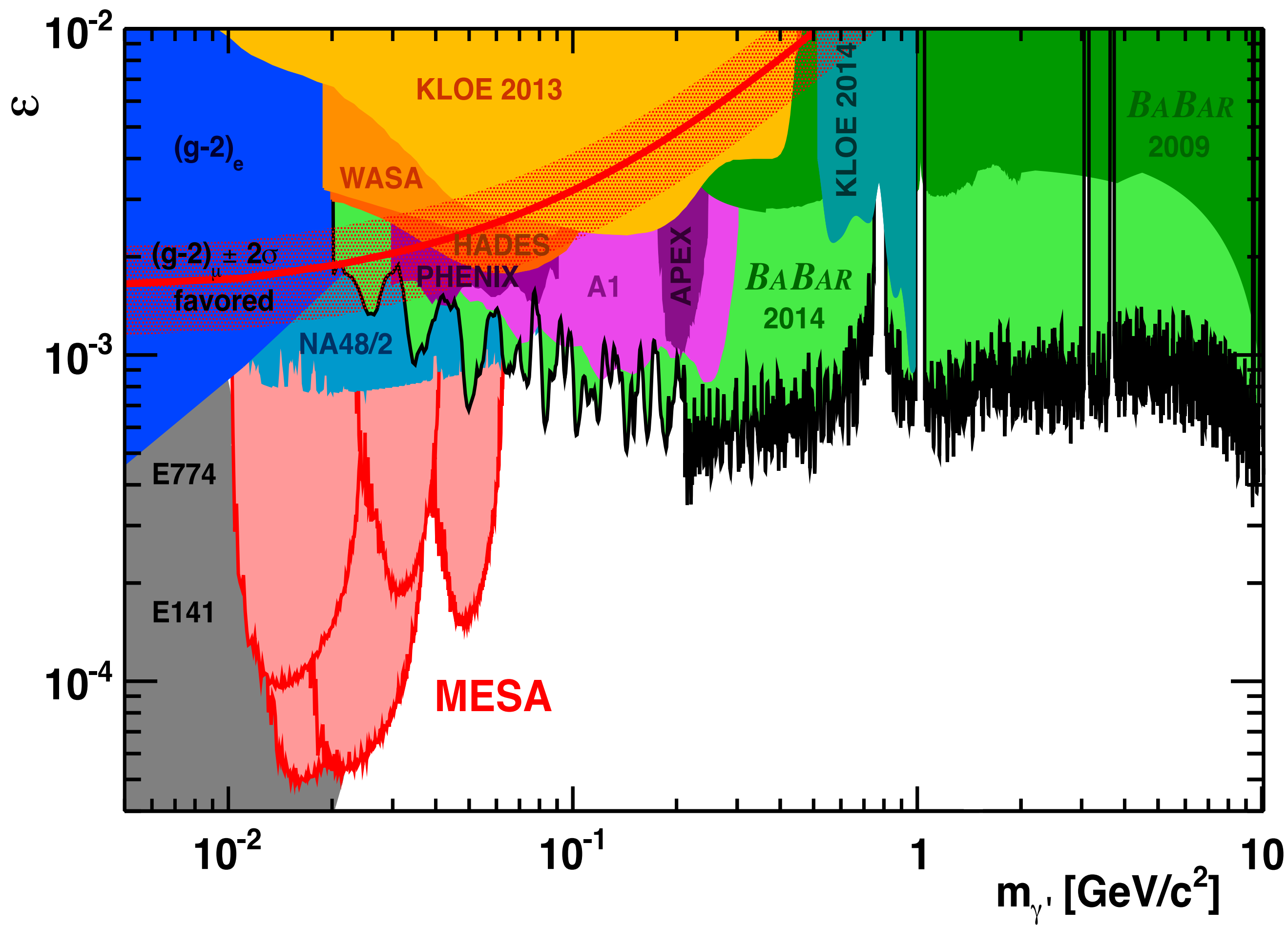
- Length (~ 30 cm)
- First prototype with mylar foil
- Can use polarized gases
- Estimated luminosity with polarized beam *O(>> 10^{32} cm^{-2} s^{-1})*

- Supersonic gas /cluster jet
- Higher gas density ($10^{19}/cm^2$)
- O(mm) target length
- Estimated luminosity *O(10^{35} cm^{-2} s^{-1})* @ $10^{19}/cm^2$
- Windowless !
- Ready in 2016 !

Dark Sector Searches at MAGIX

Features:

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



MAGIX / MESA

Model 1: Dark Photon coupling to SM particles

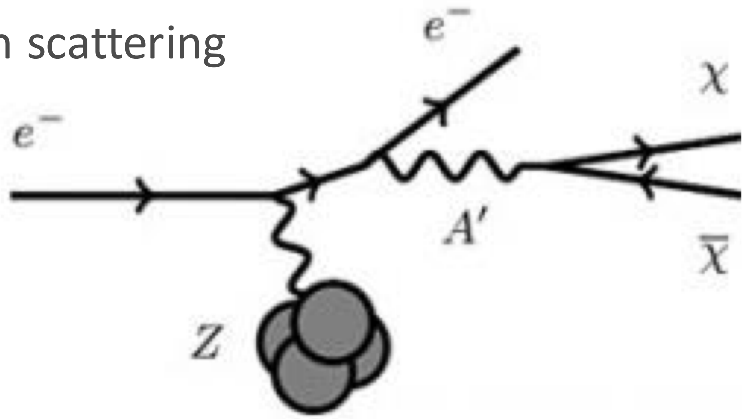
→ parameter range motivated by Dark Photon relation to Dark Matter

Dark Sector Searches at MAGIX

Model 2: Dark Photon coupling to Dark Matter

→ could still explain $(g\text{-}2)_\mu$ discrepancy
→ exploit excellent momentum resolution of MAGIX (proton recoil!)
→ Main background: Virtual Compton scattering

$$e + p \rightarrow e' + p + \mathrm{X}$$
$$\hookrightarrow \textit{invisible}$$

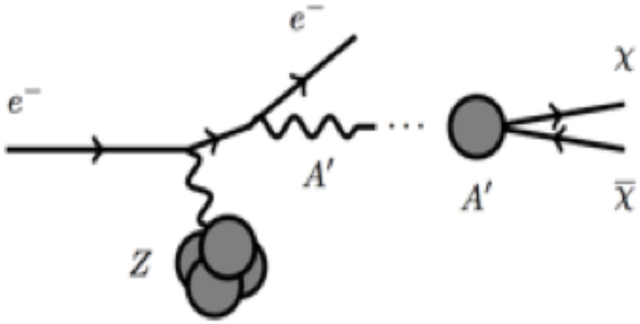


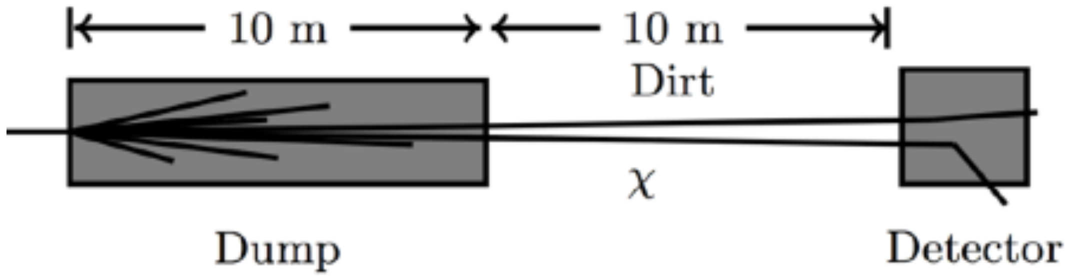
$$m_{\gamma'}^2 = (e + p - e' - p')^2$$

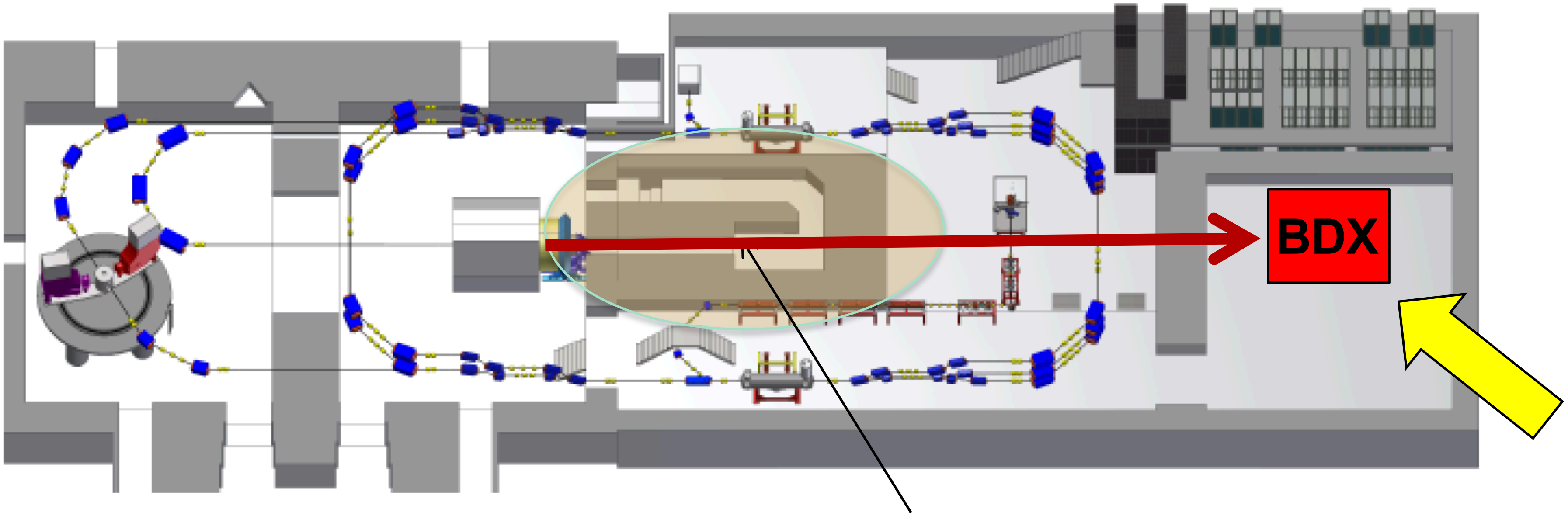
Sensitivity at MAGIX currently calculated within a bachelor thesis (use of thin HVMAPS detectors for proton recoil under study)

Beam Dump Experiment (BDX) @ MESA

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





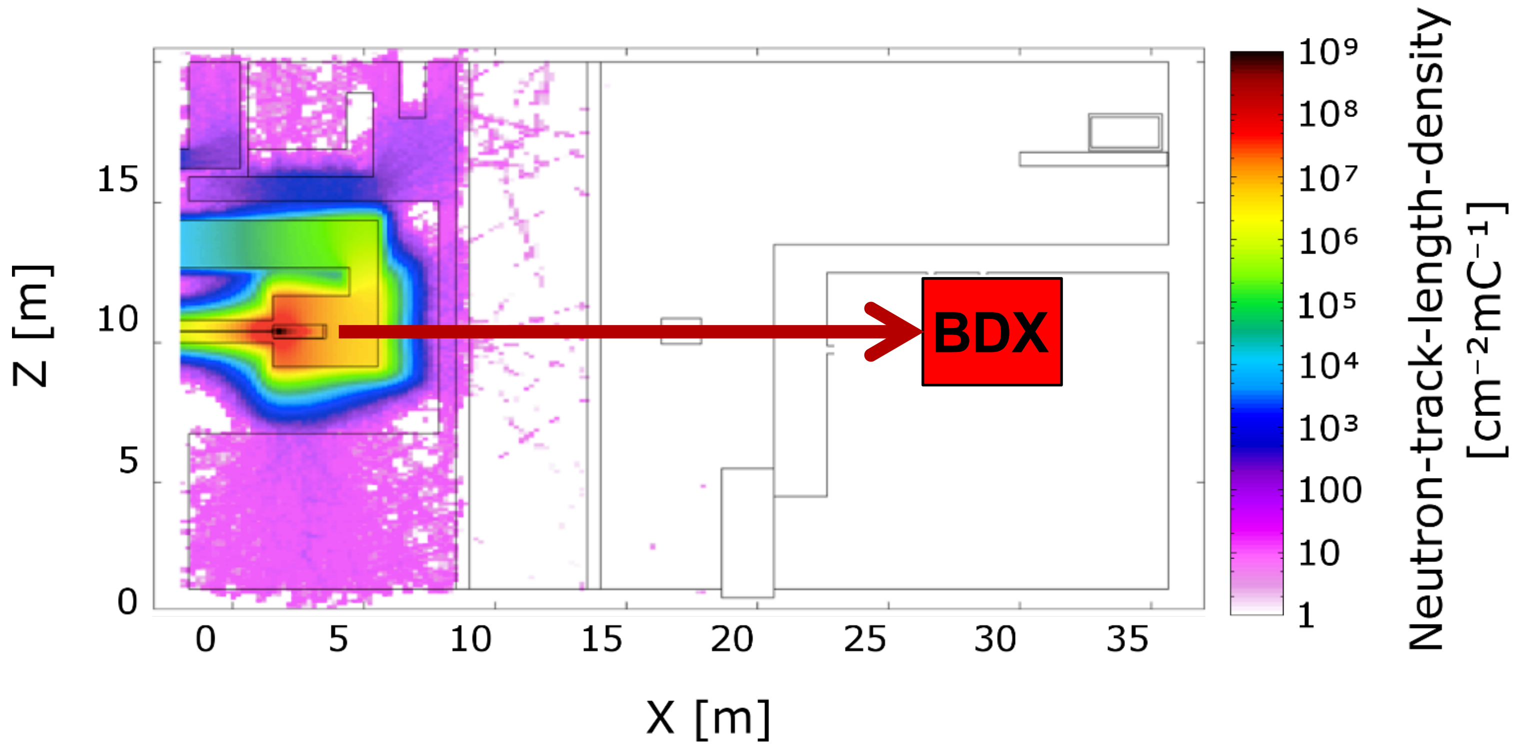


This existing beam dump is going to be the P2 beam dump

10,000 hours @ 150 µA

→ 10^{23} electrons on target (EOT)

BDX @ MESA

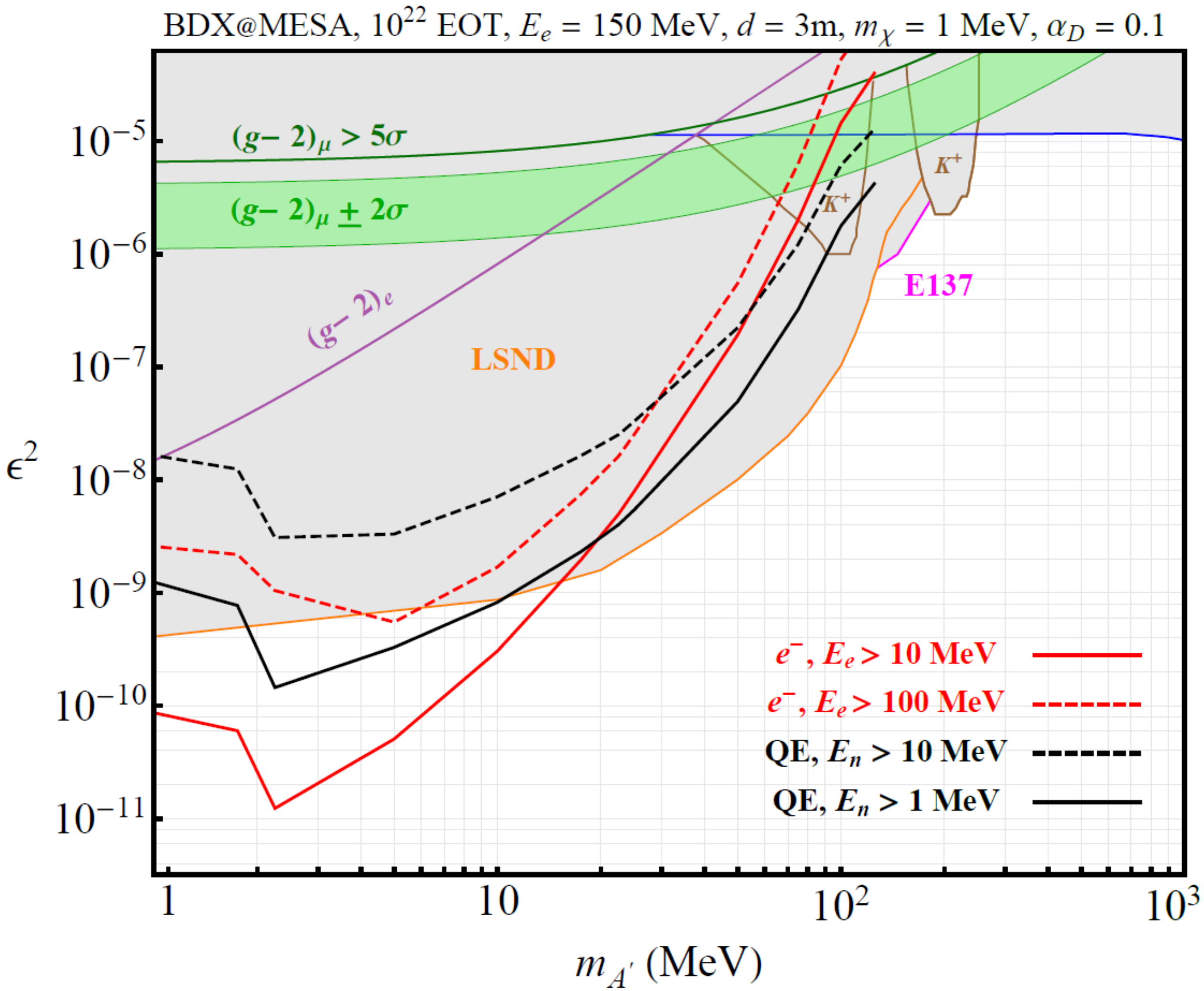


Background situation

- FLUKA simulation of neutron background promising (~10^{11} EOT)
- MESA running below pion production threshold → no neutrinos!

BDX @ MESA

Testing competititve parameter range



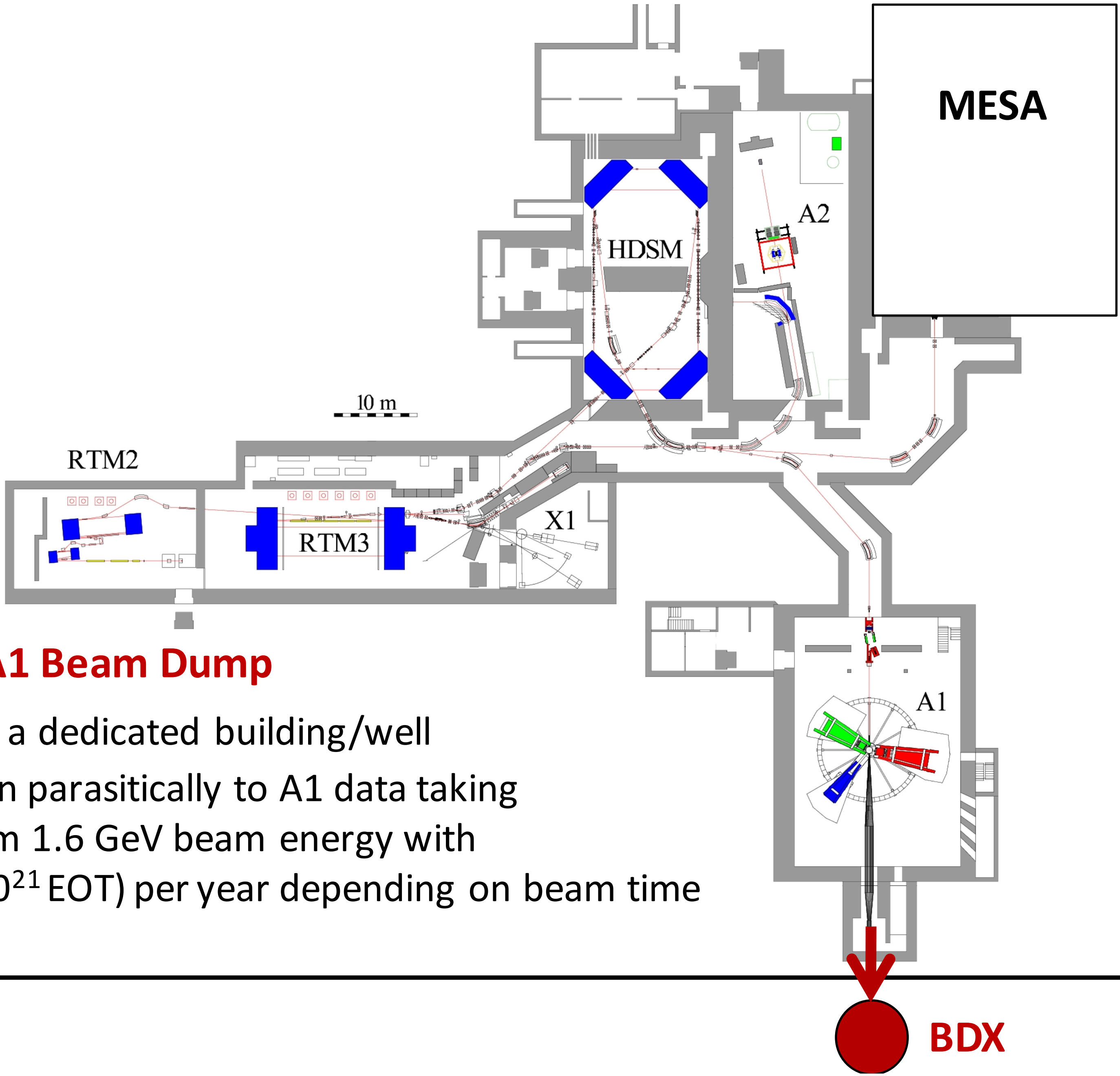
G. Krnjaic +
E. Izaguirre
Perimeter Inst.

But what about BDX at MAMI ?

Same intensity as MESA in extracted beam mode, but higher beam energy !!!

11 m underground !!!

BDX @ MAMI



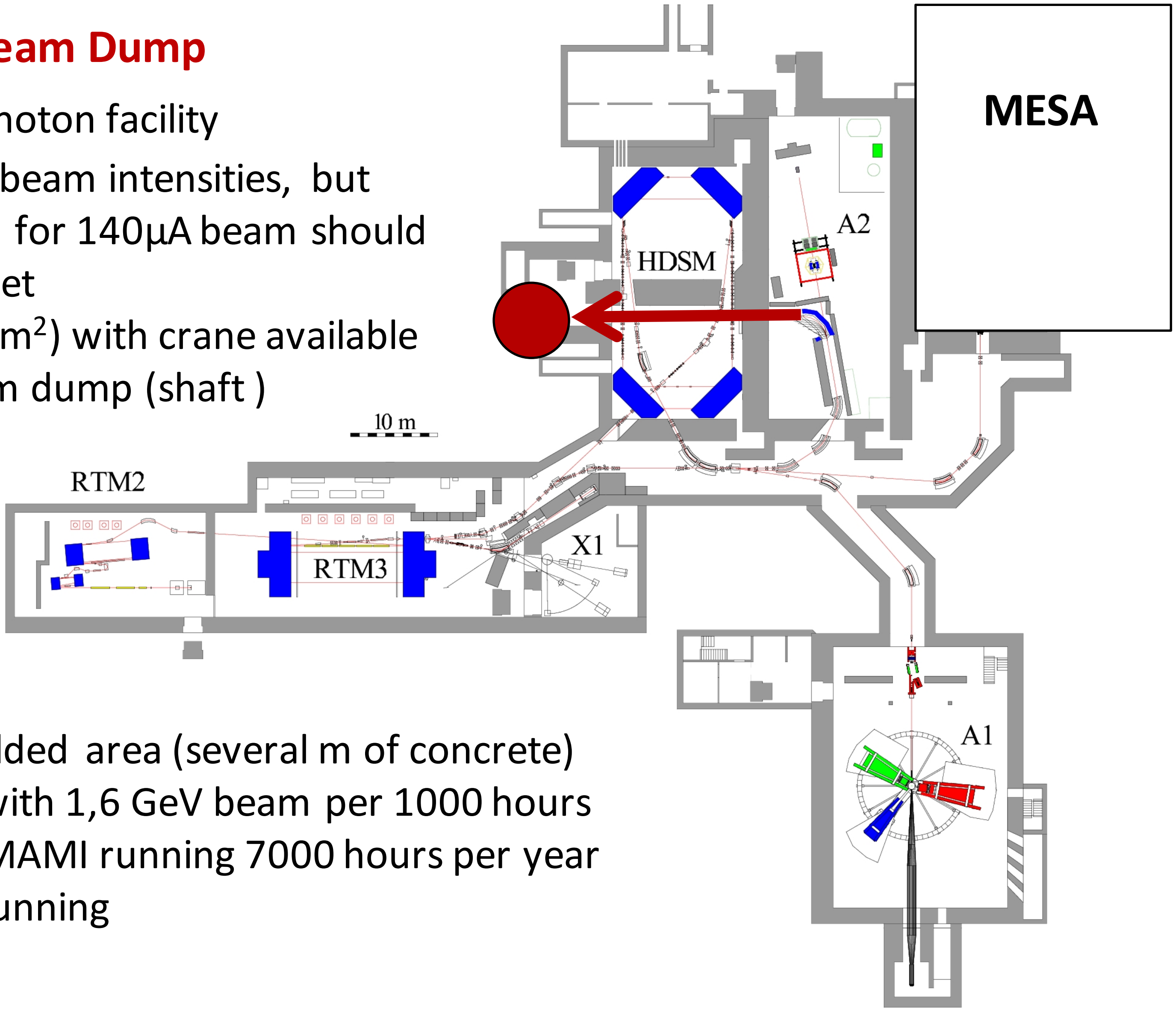
Option 1: A1 Beam Dump

- Requires a dedicated building/well
- Could run parasitically to A1 data taking
- Maximum 1.6 GeV beam energy with
  O(few 10^{21} EOT) per year depending on beam time

BDX @ MAMI

Option 2: A2 Beam Dump

- A2: Tagged photon facility
- Typically low beam intensities, but authorisation for 140µA beam should be trivial to get
- Space (many m^2) with crane available after A2 beam dump (shaft)



- Very well shielded area (several m of concrete)
- 3 x 10^{21} EOT with 1,6 GeV beam per 1000 hours (6 weeks) – MAMI running 7000 hours per year
- No parasitic running

BDX @ MAMI, Bunch-Structure

- Standard operation of MAMI with 2,45 GHz microwave frequency
  → bad for TOF purpose for BDX
- Recently single bunch tests carried out at MAMI
- Findings:
  - Bunch spacing can be varied almost arbitrarily
  - Drop of intensity
  - 12 ns bunch spacing @ 20 µA immediately achieved
  - 100 ns bunch spacing @ 3µA possible
- These numbers are conservativ estimates
  (A PhD student is working on this)

Conclusions

Conclusions

- **Competitive results achieved at A1/MAMI**

- **MESA will be operational ~2020**

  Great opportunities for Dark Sector physics and beyond; Experiences from Dark Light / JLAB !

- **Beam Dump Experiment at MESA and MAMI**

  - 10^{23} EOT parasitically to P2 data taking (0,155 GeV)
  - 10^{22} EOT in 3000 h of beam time (1,6 GeV)
  - Option to go for larger bunch spacing 12 ... 100 ns

  Dedicated beam time for BDX measurement .... ?!

MAGIX @ MESA