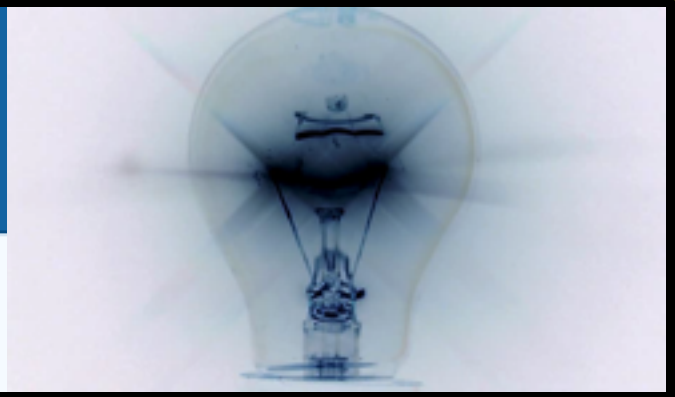
MU Programmtag 2016

12-13 December 2016
Helmholtz Institute Mainz



Dark Photon Searches at MAMI and MESA

Achim Denig, Mainz

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

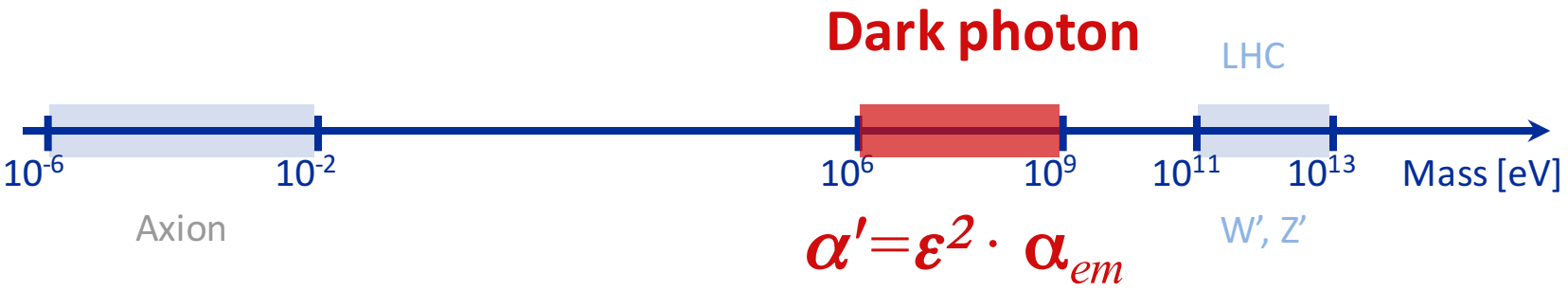
SFB 1044
THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

HIM
Helmholtz-Institut Mainz

JG|U

Dark Photon Search

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



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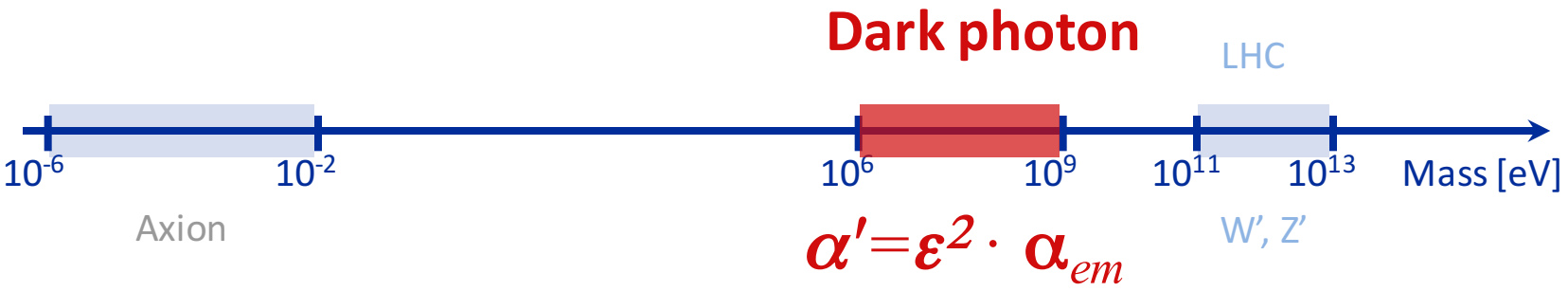


Search for the O(GeV/c^2) mass scale in a world-wide effort

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

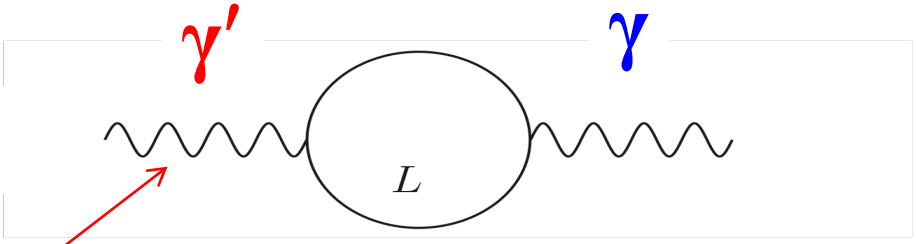
- Could explain presently seen **deviation of 3.6σ between $(g-2)_\mu$**
  Standard Model prediction and direct $(g-2)_\mu$ measurement
  Pospelov(2008)

Kinetic Mixing and Dark Matter

Holdom [1986]

A way to relate the dark sector to the SM (coupling ~ ε^2)

Dark Sector $U(1)_d$



Standard Model Sector U(1)

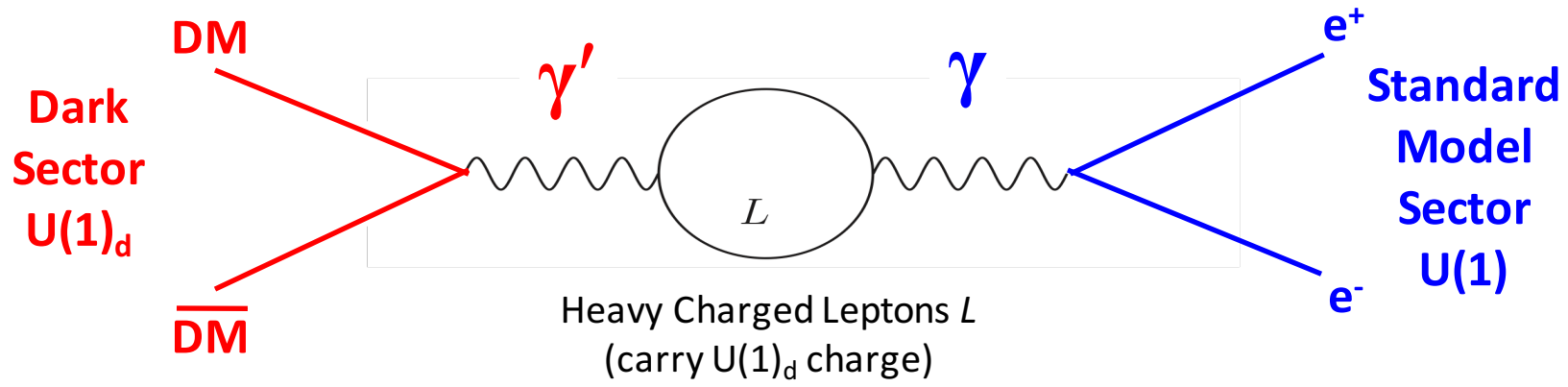
Dark Photon
(aka A′, U, Z_d, ...)

Heavy Charged Leptons *L*
(carry $U(1)_d$ charge)

Kinetic Mixing and Dark Matter

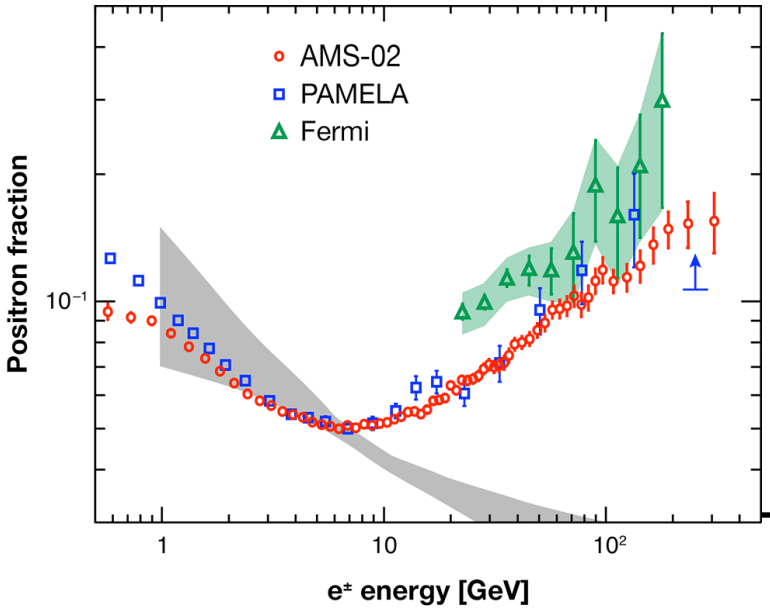
Holdom [1986]

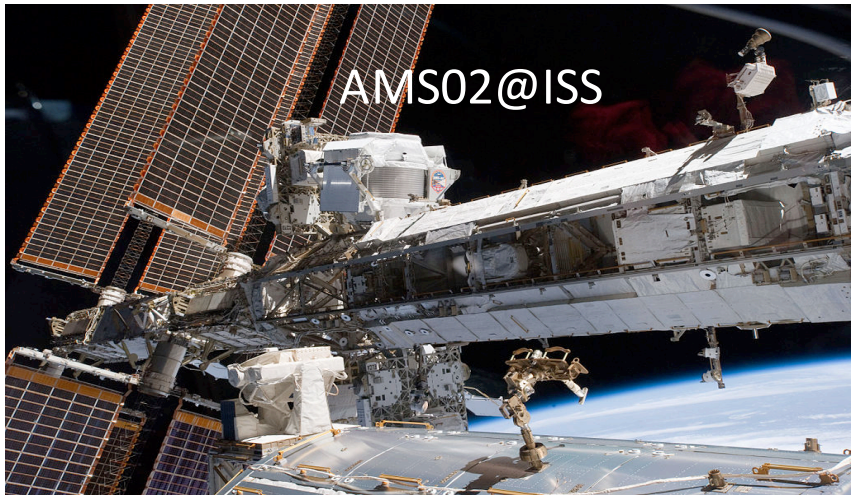
A way to relate the dark sector to the SM (coupling ~ ε^2)



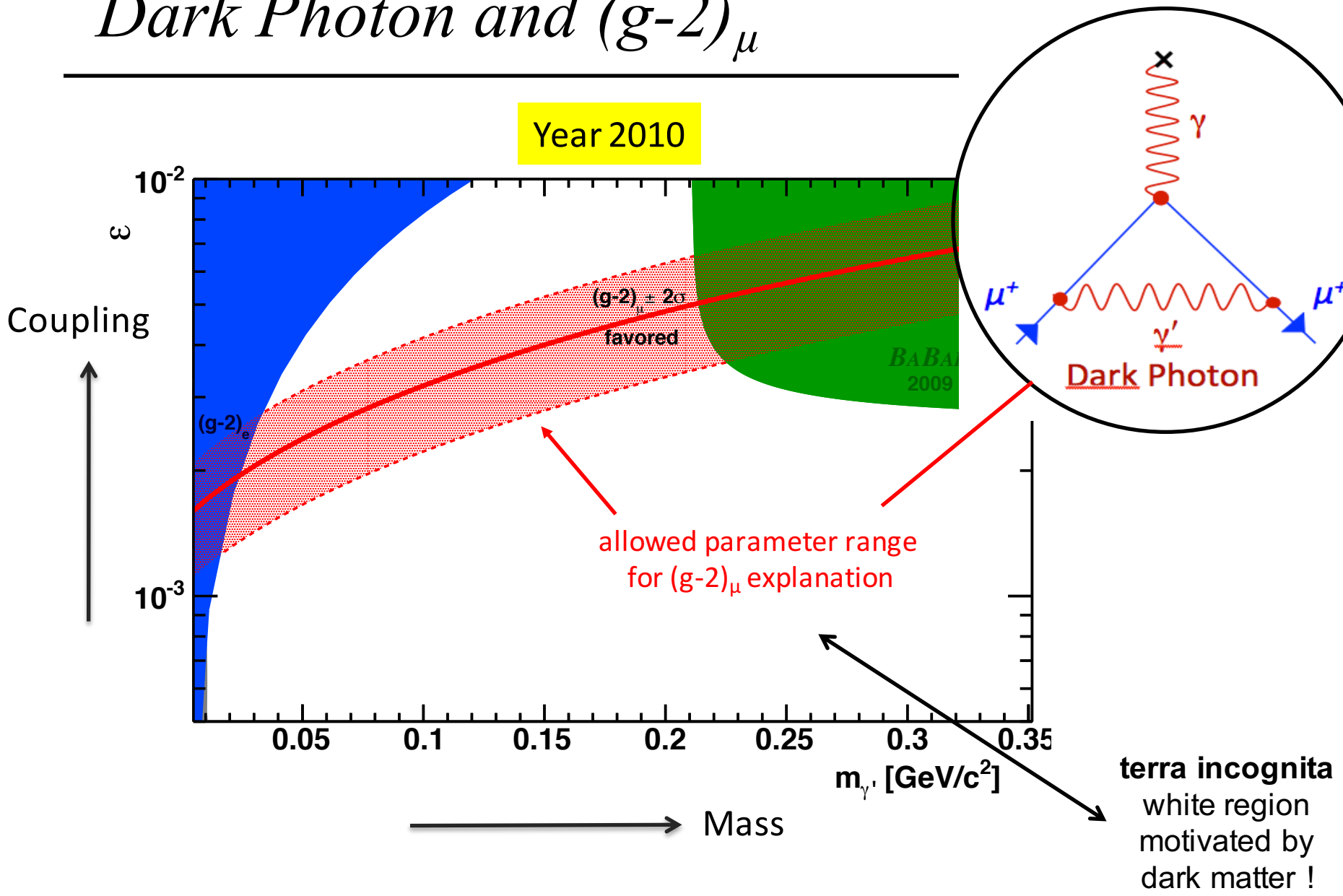
Heavy Charged Leptons *L*
(carry U(1)$_d$ charge)

Excess of positrons in cosmic ray spectrum due to Dark Matter annihilation?





Dark Photon and $(g-2)_\mu$

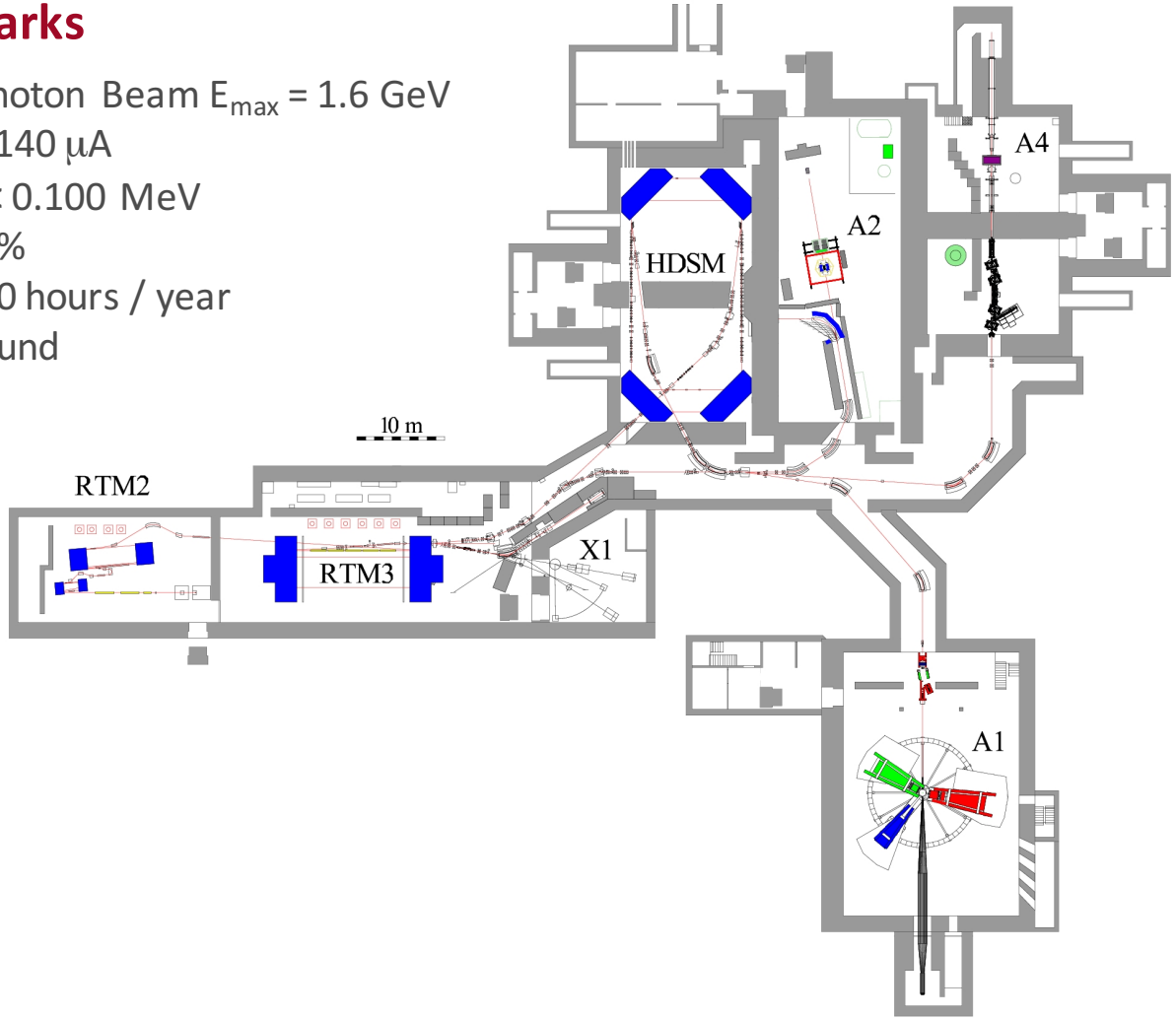


Dark Photon Search at MAMI

A1: High-Resolution Spectrometers

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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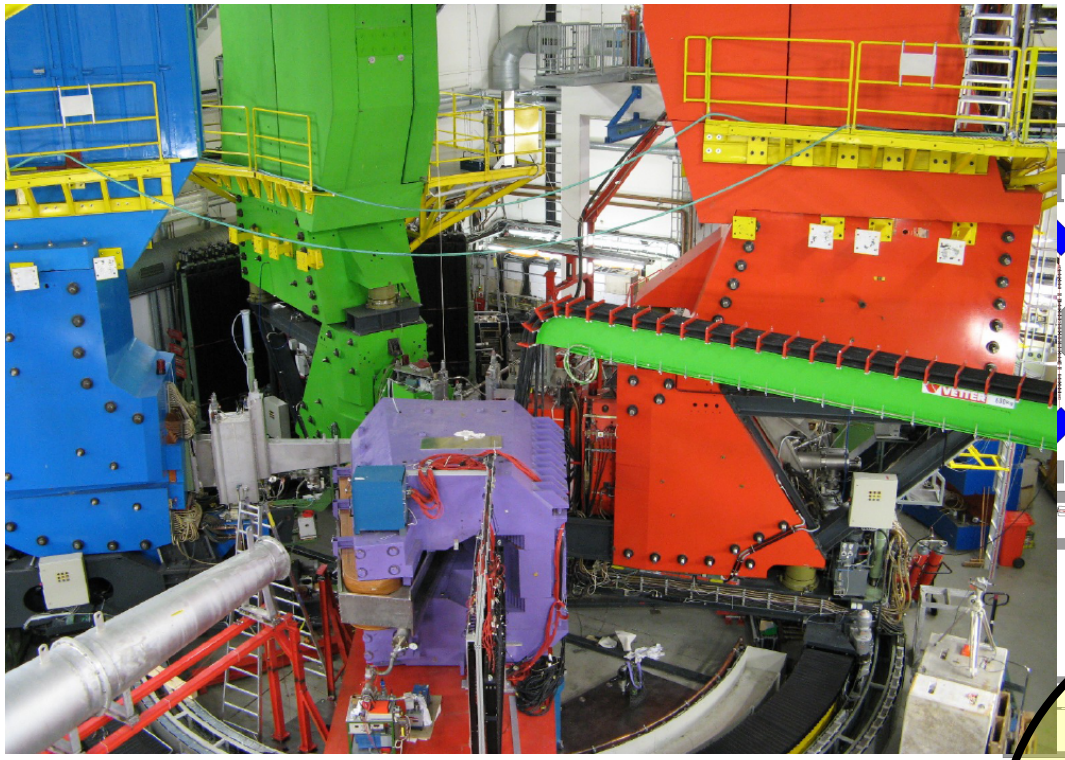
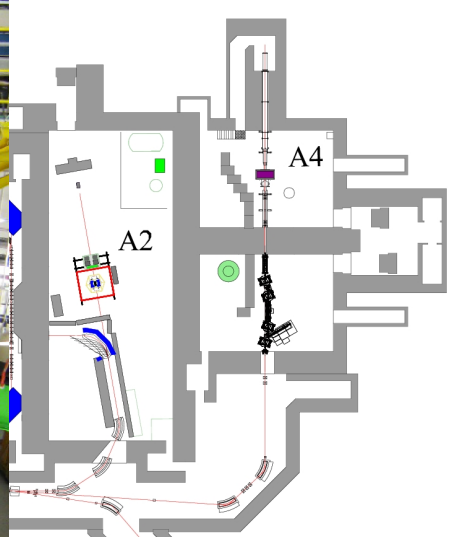
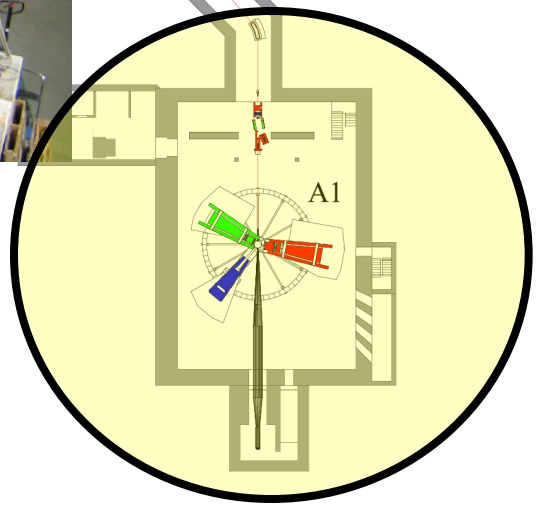






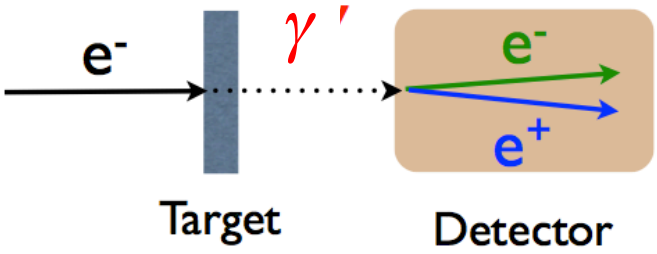
Experiment A1: Electron Scattering

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

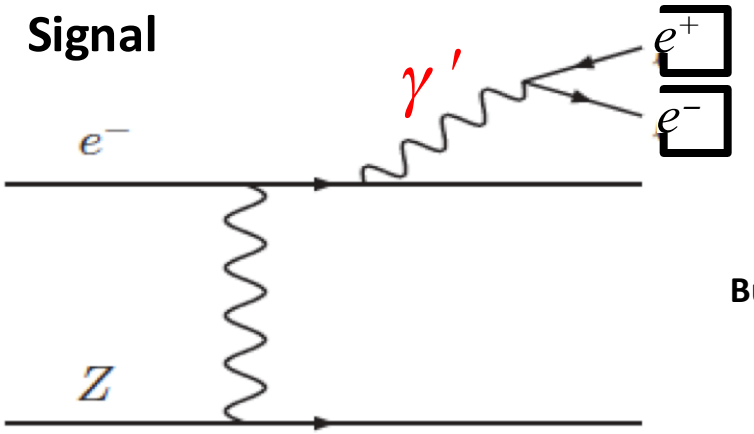
Results from A1 Pilot Run (2011)

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

Bjorken, Esssig, Schuster, Toro (2009)



Signal



Bump search!

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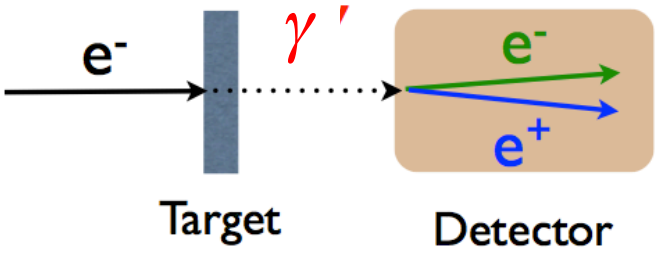
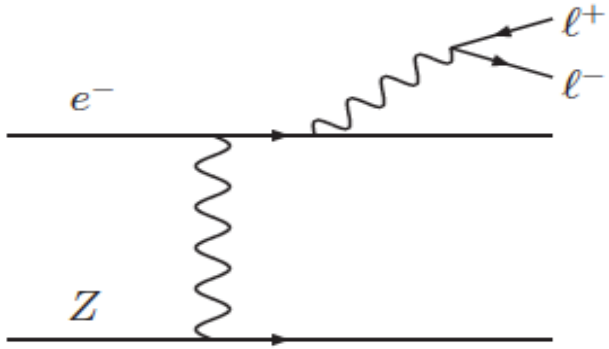
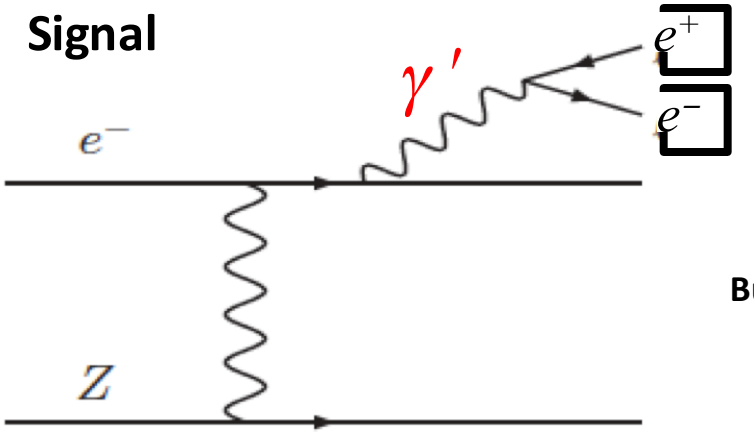


Backgroud



Signal



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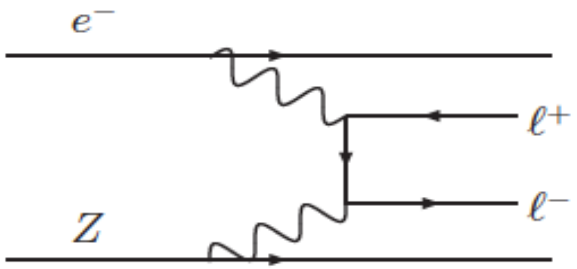
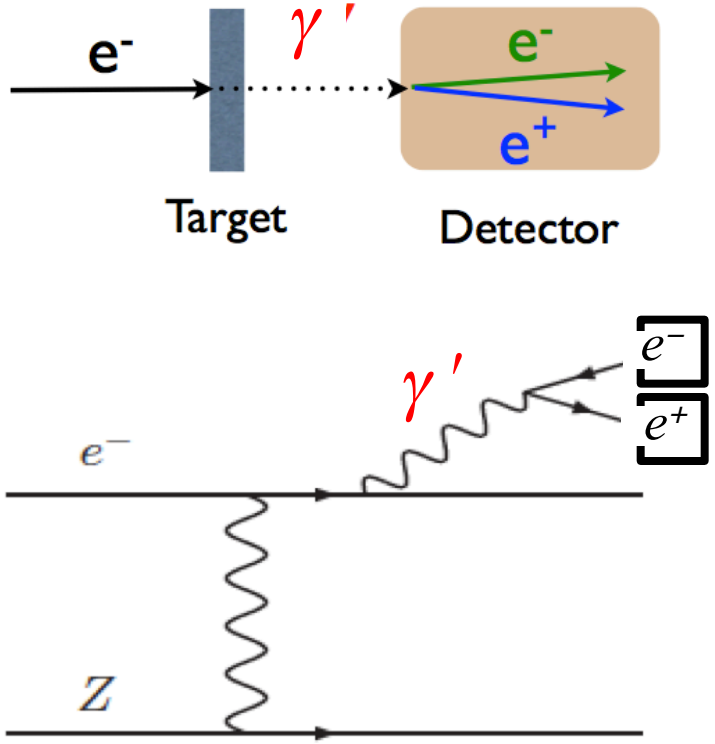


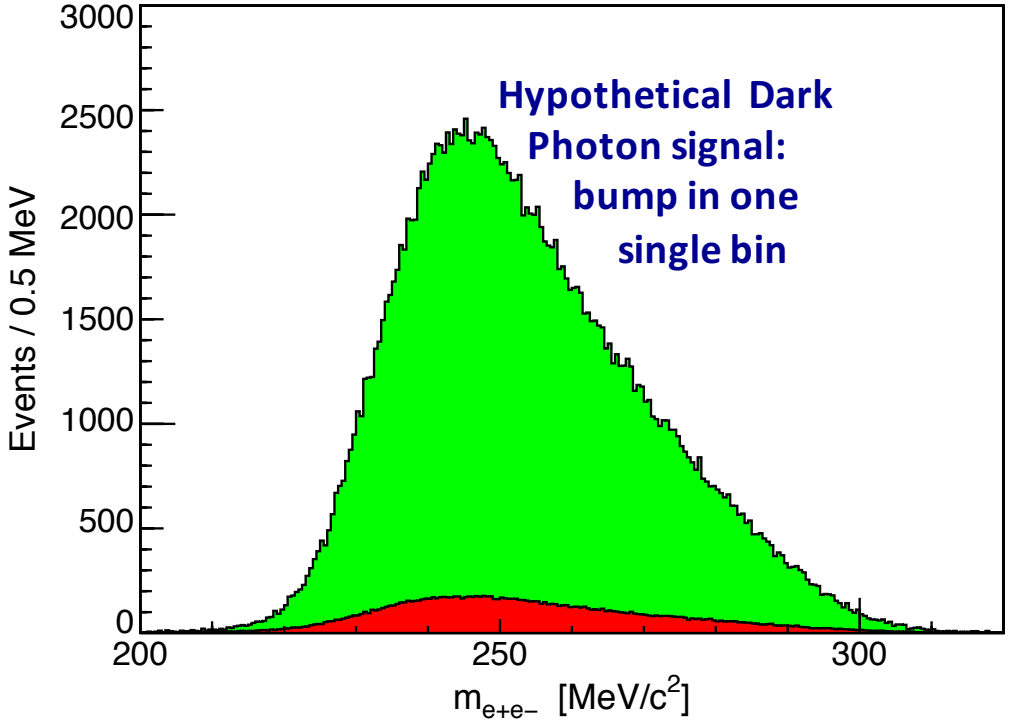
Results from A1/MAMI

Low-Energy Electr. Acceler. with high Intensity suited for DP search

Bjorken, Esssig, Schuster, Toro (2009)

Signal processes

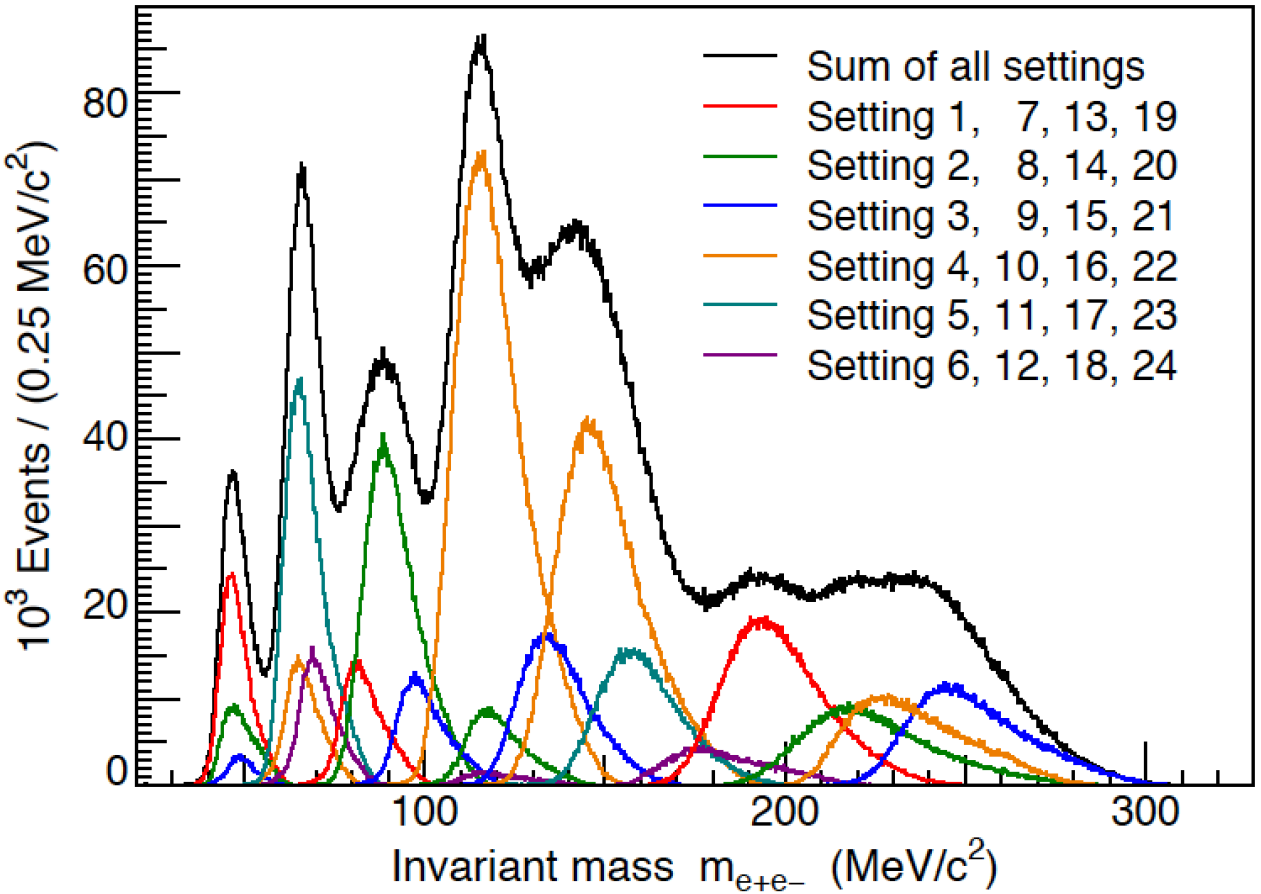




2010 test run
Invariant Mass of e+e-

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 $(g-2)_\mu$

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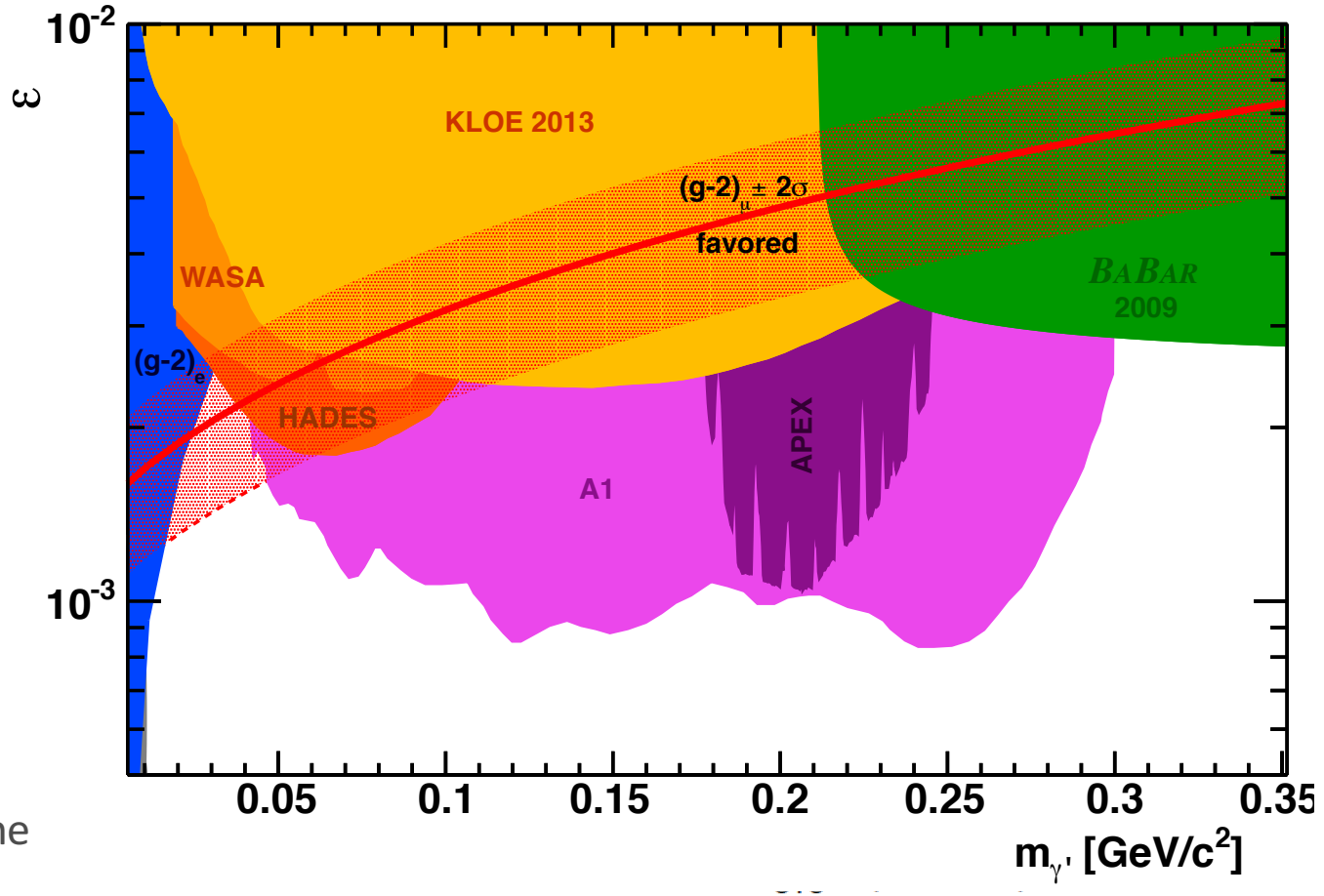

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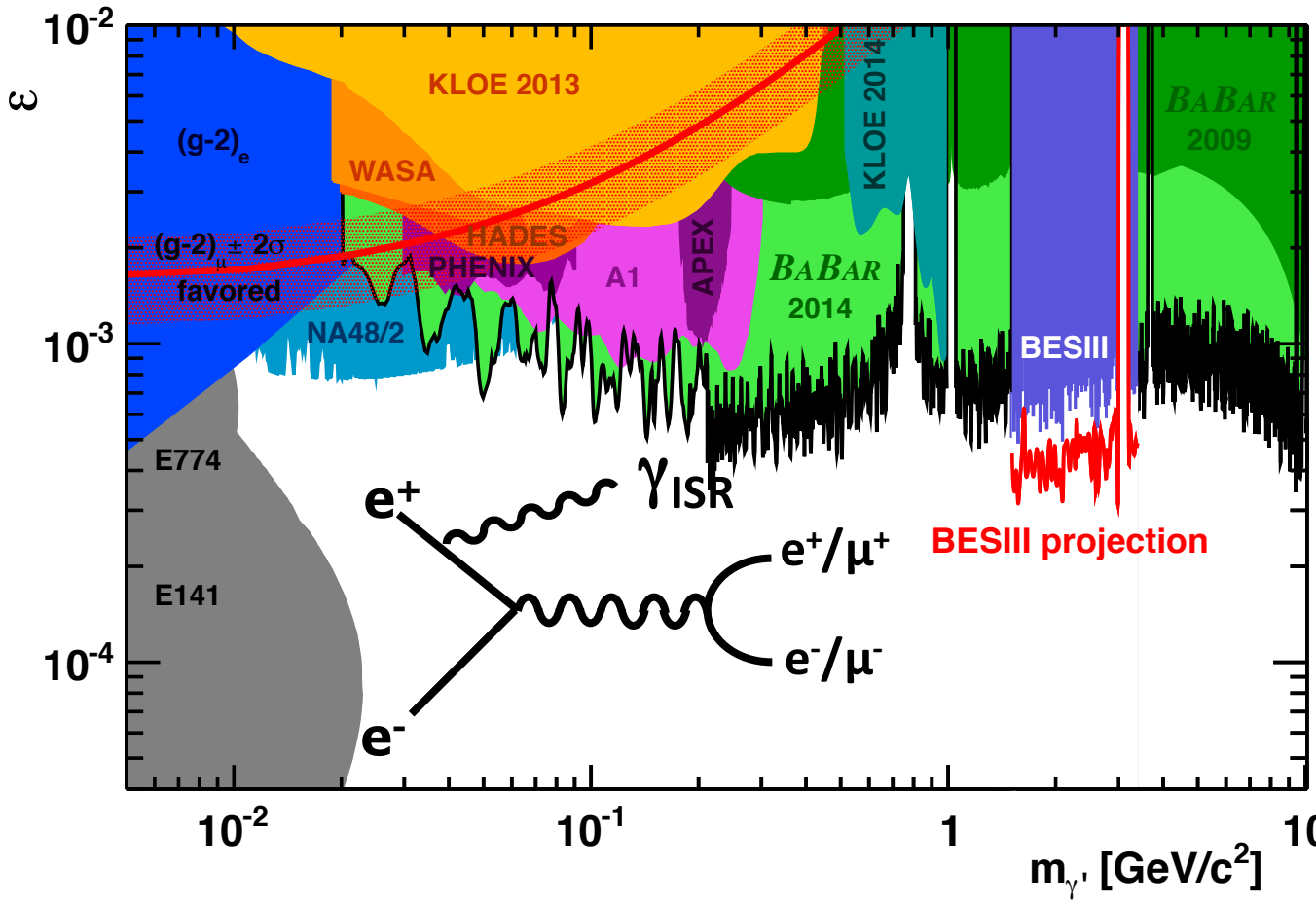

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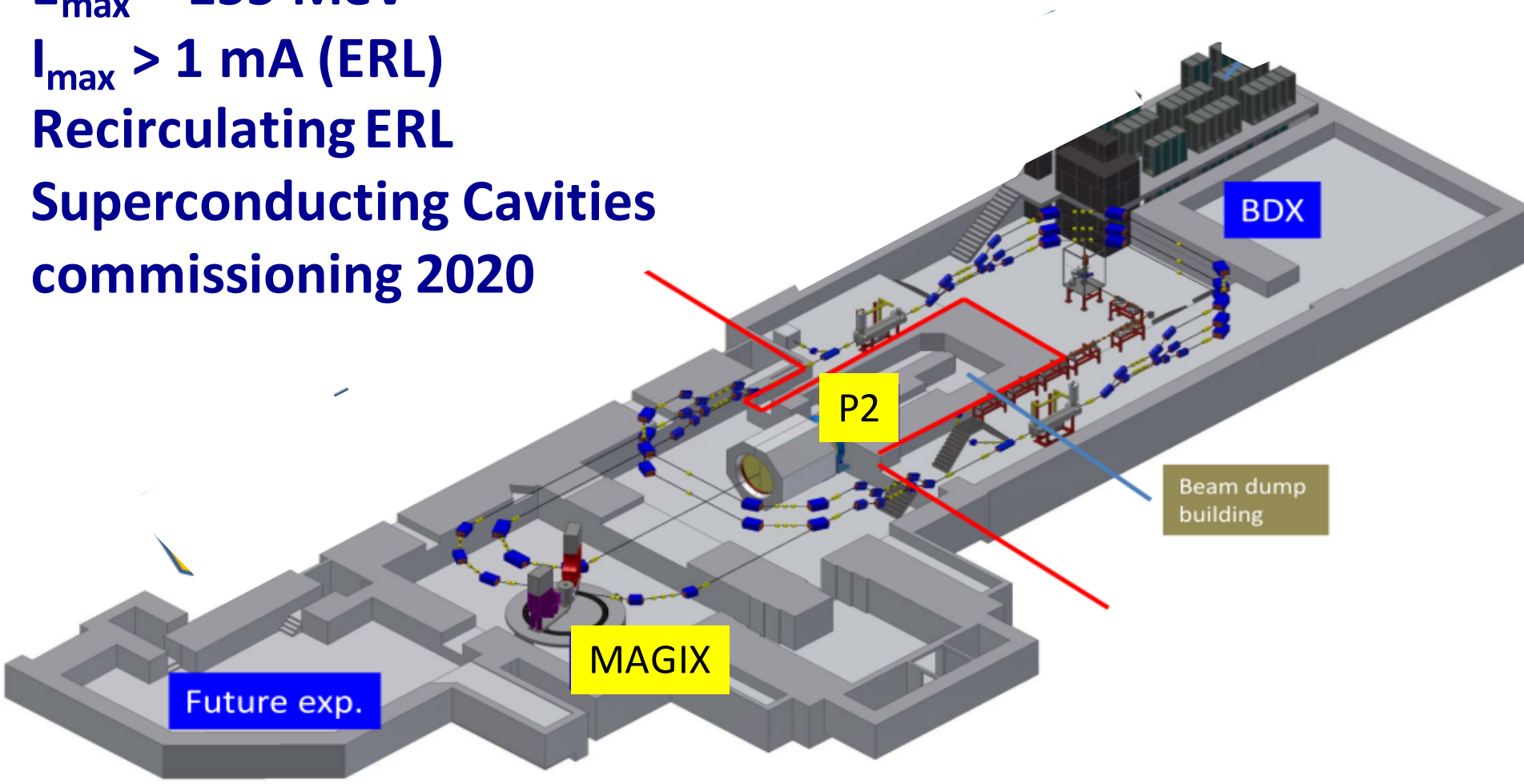
Dark Photon Search at MESA

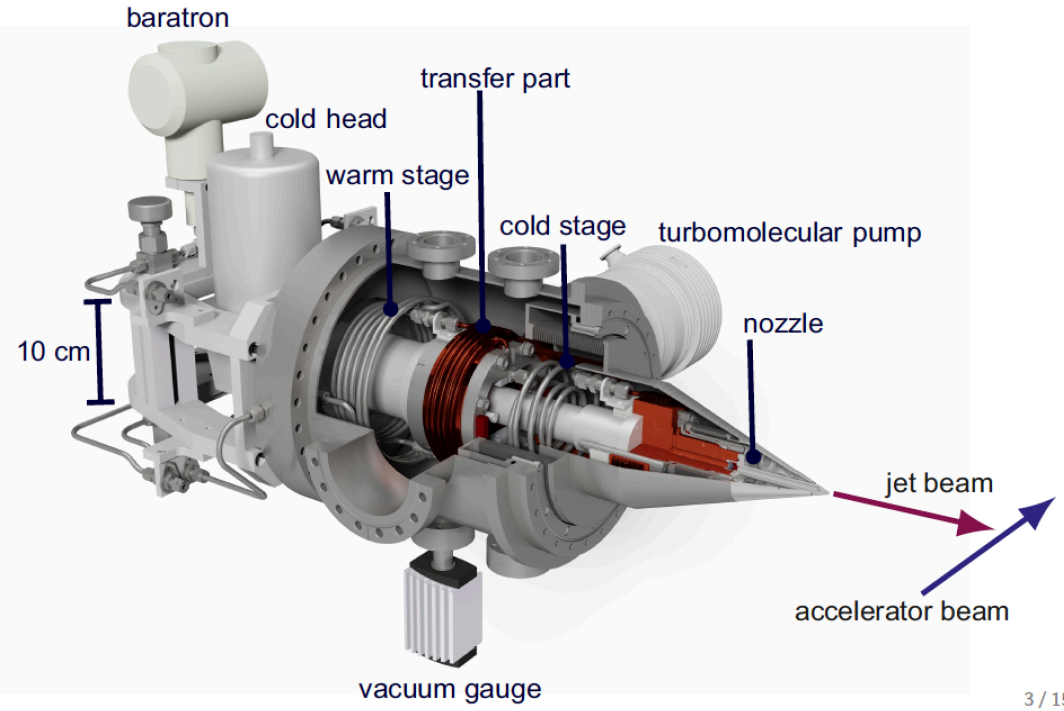
New Tool for Low-Precision Physics: MESA

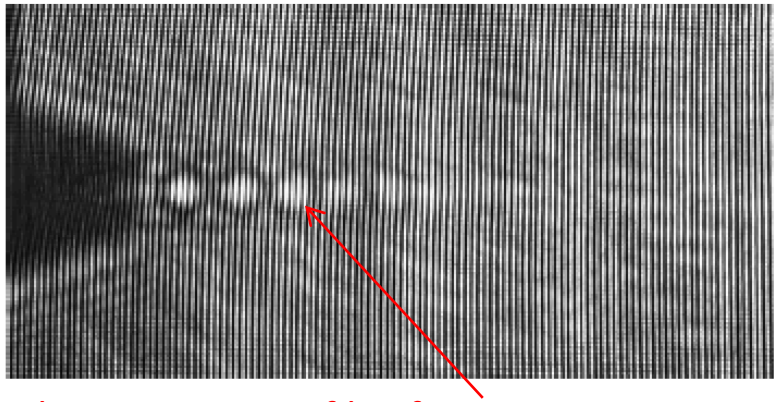
Mainz Energy-Recovering Superconducting Accelerator

E_{max} = 155 MeV
I_{max} > 1 mA (ERL)
Recirculating ERL
Superconducting Cavities
commissioning 2020



Internal Gas Jet Target



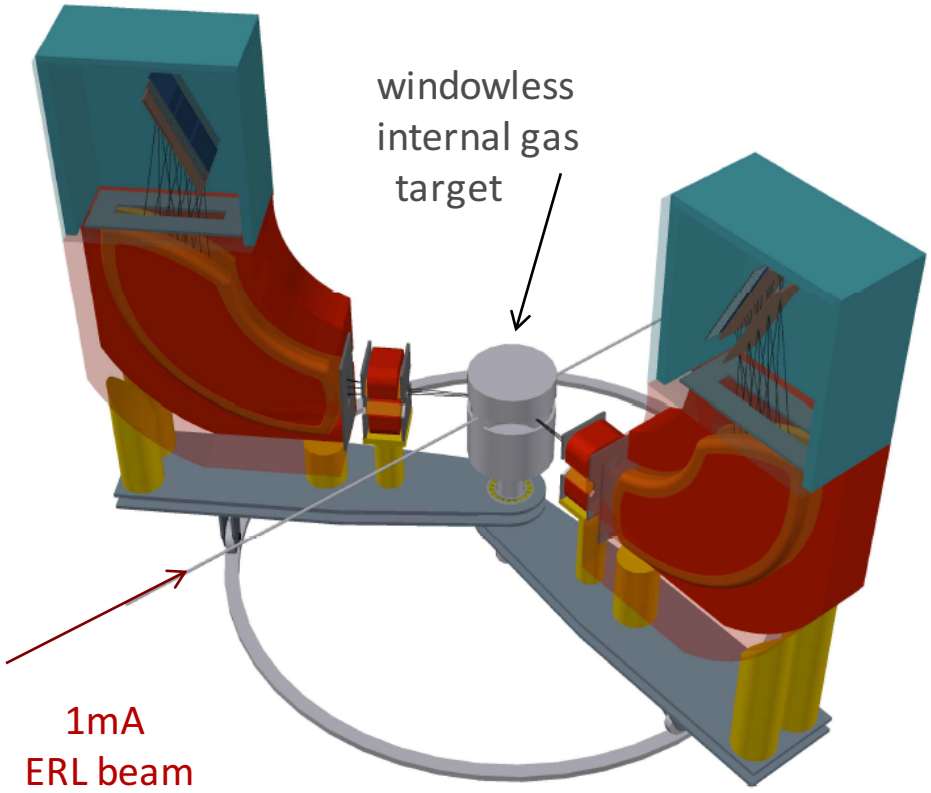


Characteristic profile of a supersonic gas jet

- 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 !

MAGIX Experiment @ MESA

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



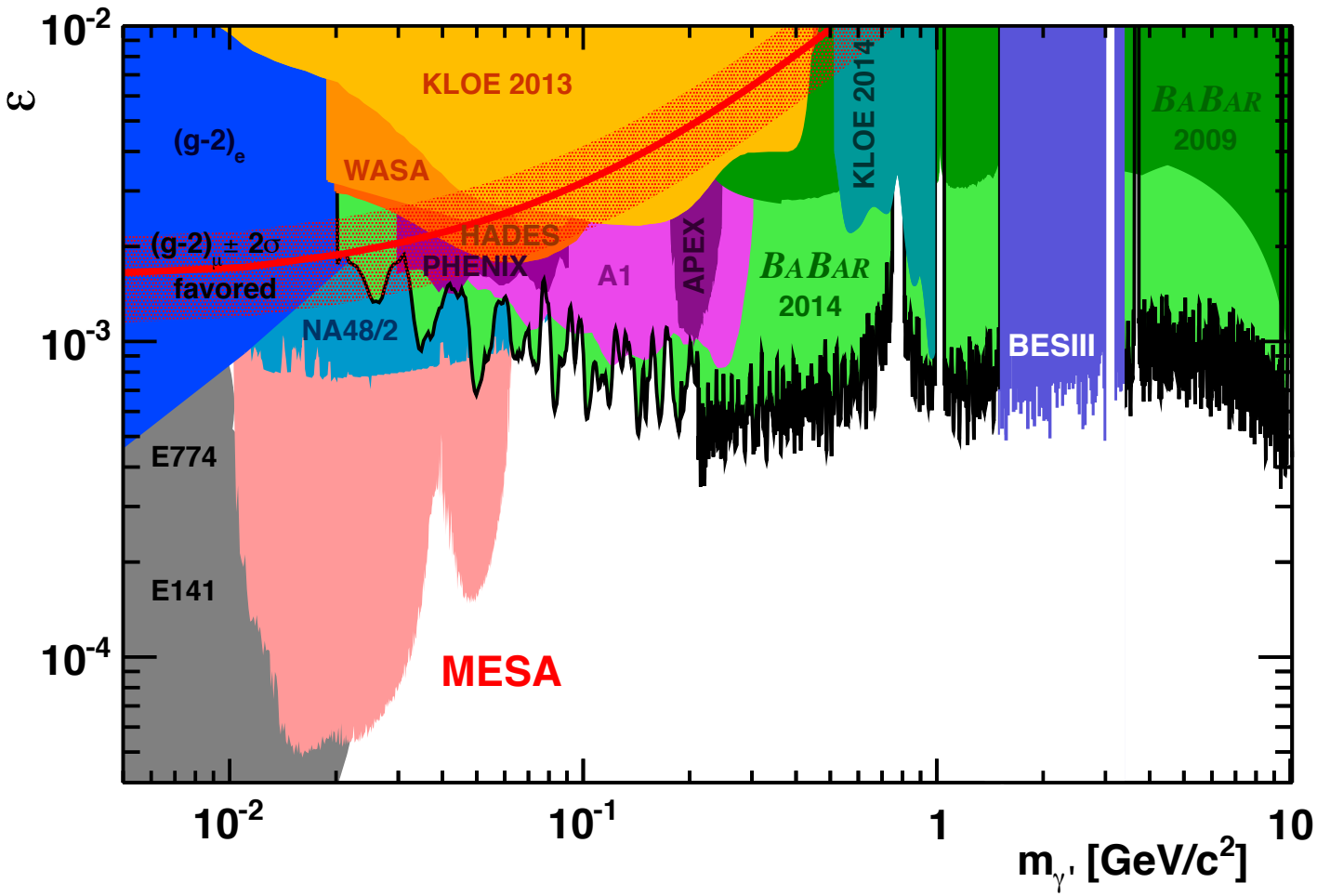
High resolution spectrometers MAGIX:

- 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

Dark Photon at MAGIX/MESA

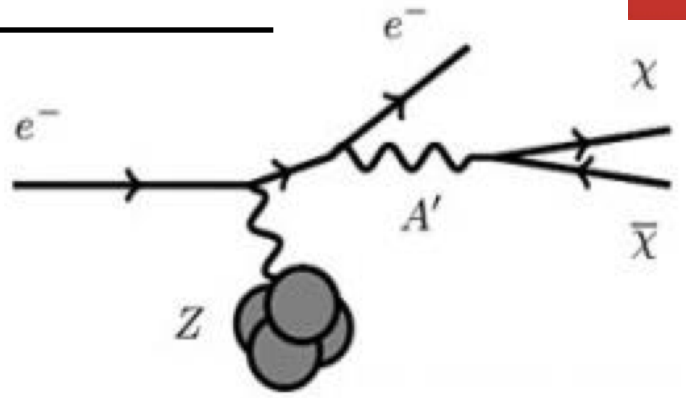
Features:

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



Invisible
Dark Photon Decays

Invisible Decay of Dark Photon

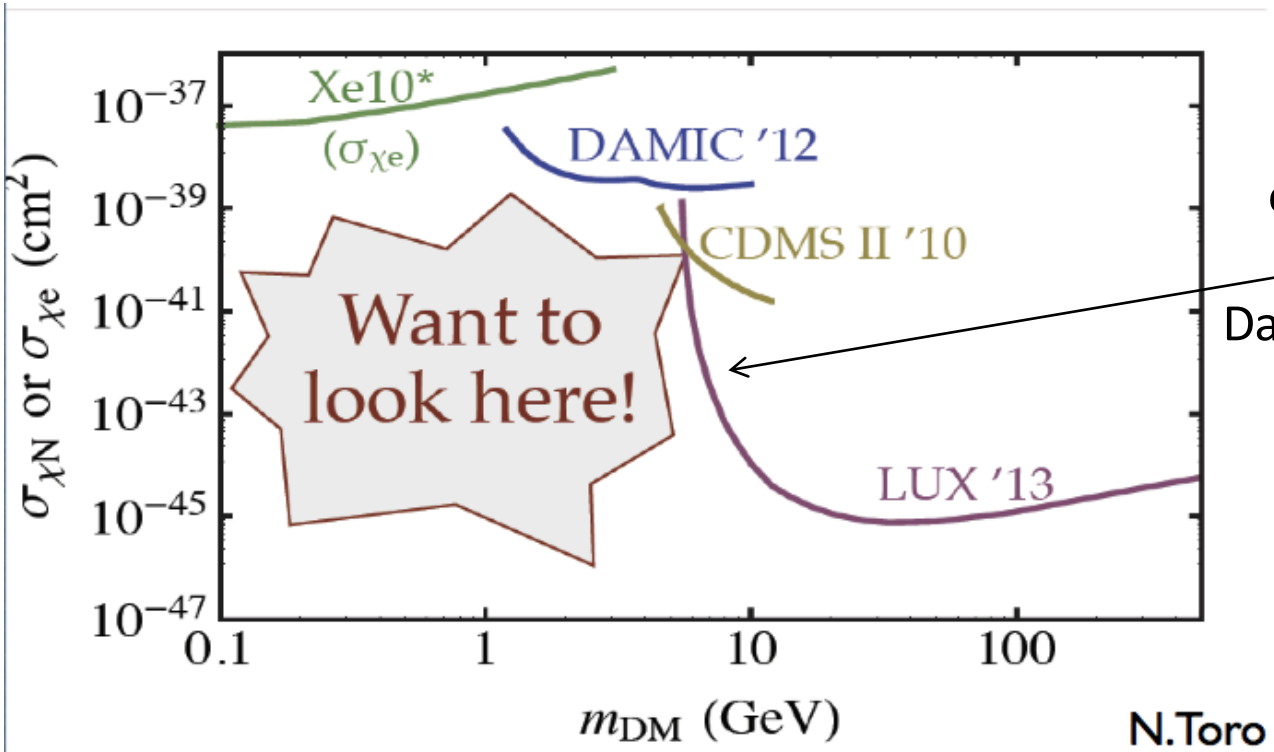


So far Kinetic Mixing: M(γ') < 2M(χ)

Consider now: M(χ) < 2M(γ')

Dark Photon decays dominantly into

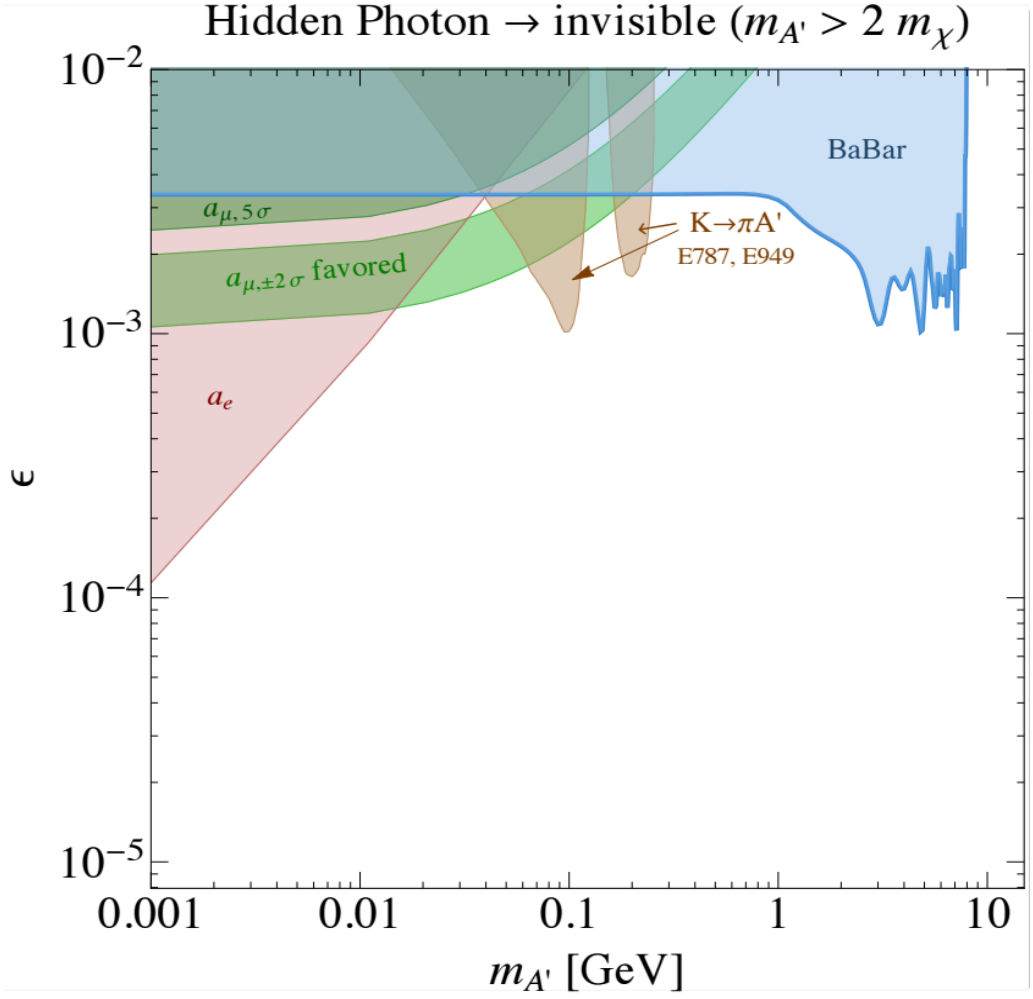
Light Dark Matter (LDM), which is not yet constraint experimentally!

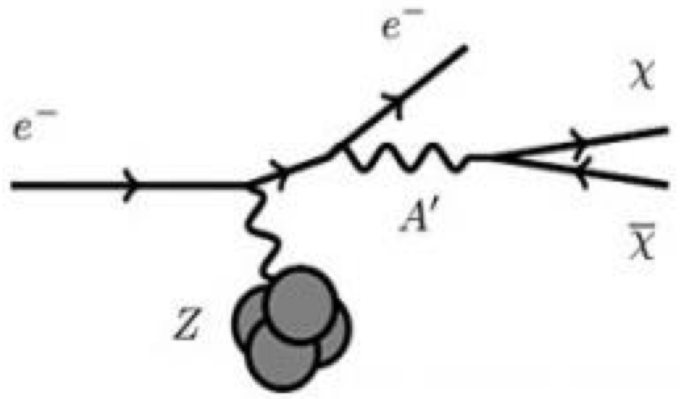


exclusion limits from classical Dark Matter experiments (nuclear recoil) not sensitive to LDM

N.Toro

Invisible Decay of Dark Photon





- Dark Matter particle not seen
- Few constraints
- Could again explain $(g-2)_\mu$

→ Missing energy / mass

→ Search for Dark Matter particle directly using dedicated low-background detectors

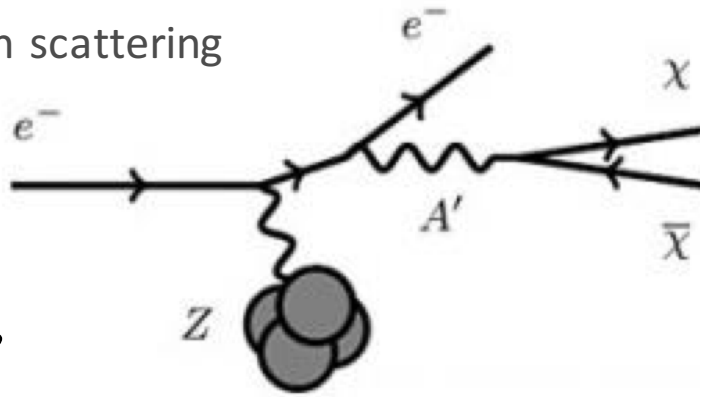
Dark Sector Searches at MAGIX

Model 2: Dark Photon coupling to Dark Matter

→ could still explain $(g-2)_\mu$ discrepancy

→ exploit excellent momentum resolution of MAGIX (proton recoil!)

→ Main background: Virtual Compton scattering



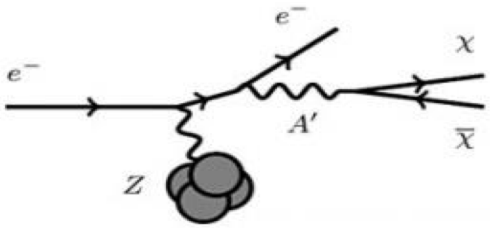
$$e + p \rightarrow e' + p + \mathrm{X}$$

$$\hookrightarrow \textit{invisible}$$

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

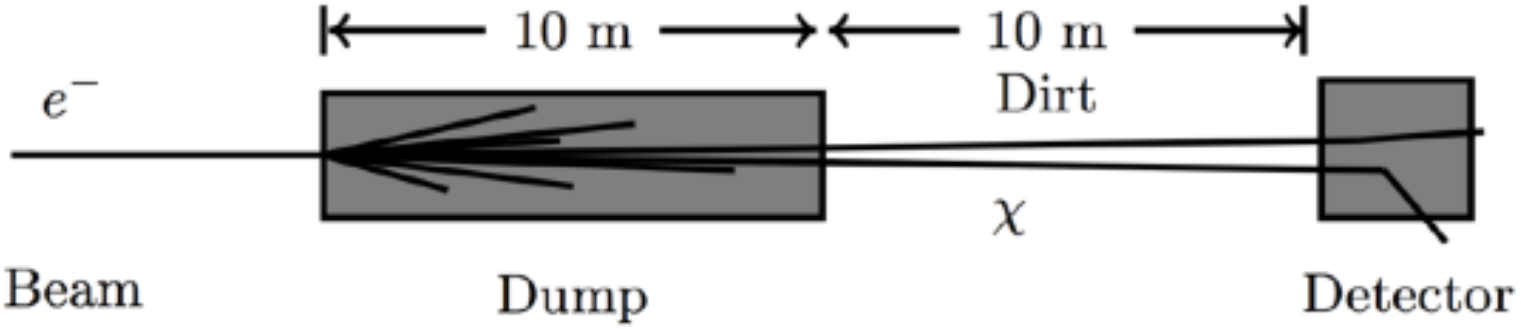
Sensitivity at MAGIX currently calculated within a bachelor thesis (use of thin HVMAPS detectors for proton recoil under study)

Beam Dump Experiment (BDX)



Electron Scattering on Beam Dump

→ Collimated and boosed (!) pair of Dark Matter particles !



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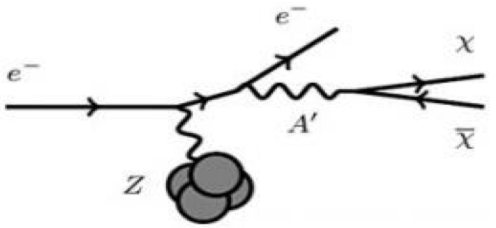

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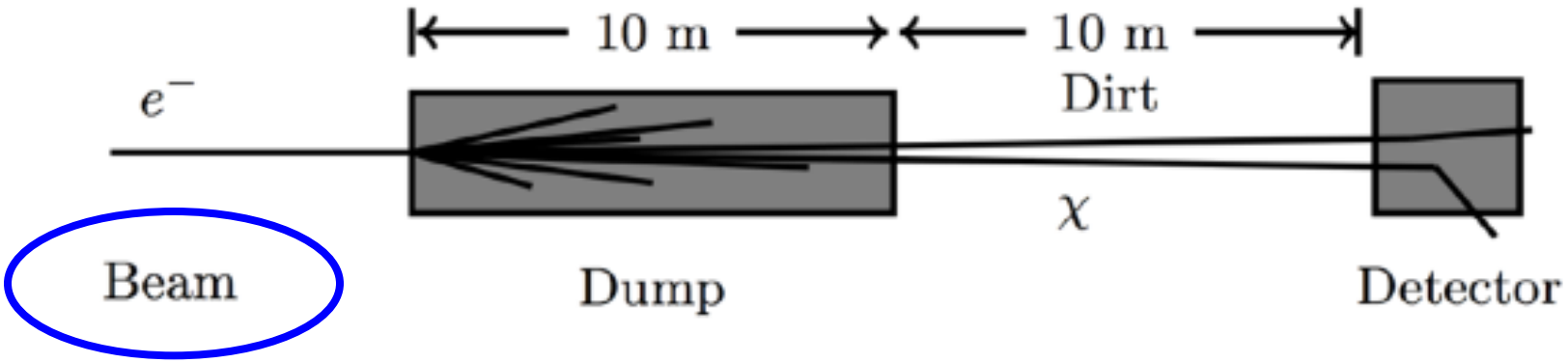

Beam:

- High intensity electron beam $O(10^{20} - 10^{22})$ EOT/year
- ~GeV energy scale
- Passive shielding and active vetos for background subtraction (μ, n, ν)
- Time structure for TOF measurement?

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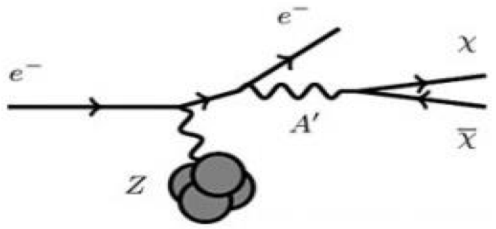

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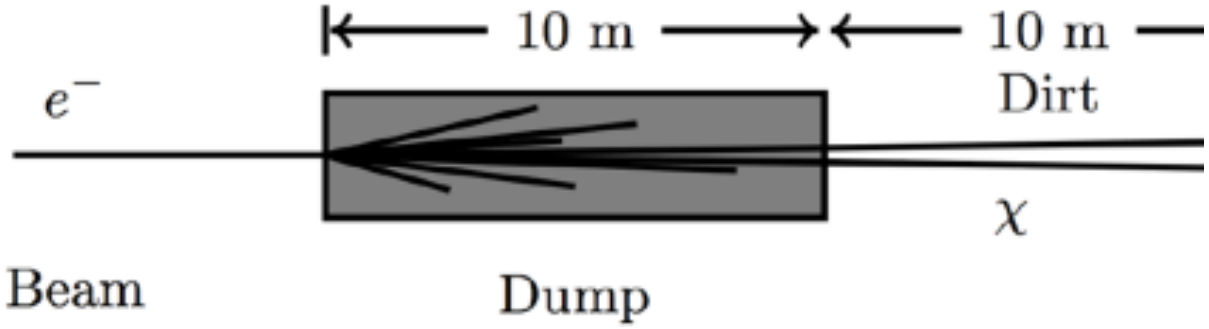
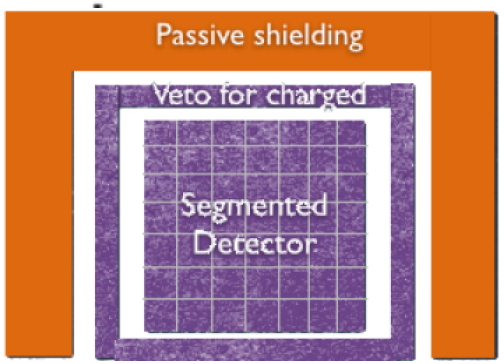
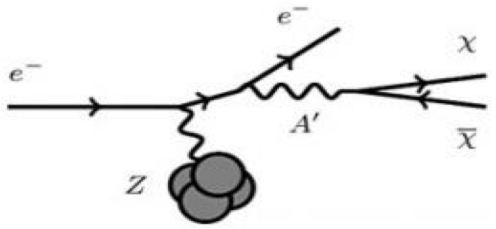




Detector:

- ~1 m^3 size detector (1-5 tons)
- High density to maximize event yield
- Low threshold for nucleon recoil detection (MeV) + EM shower detection
- CsI (Tl) crystals from BaBar EMC (?) High-tech for DM research considered

Beam Dump Experiment (BDX)



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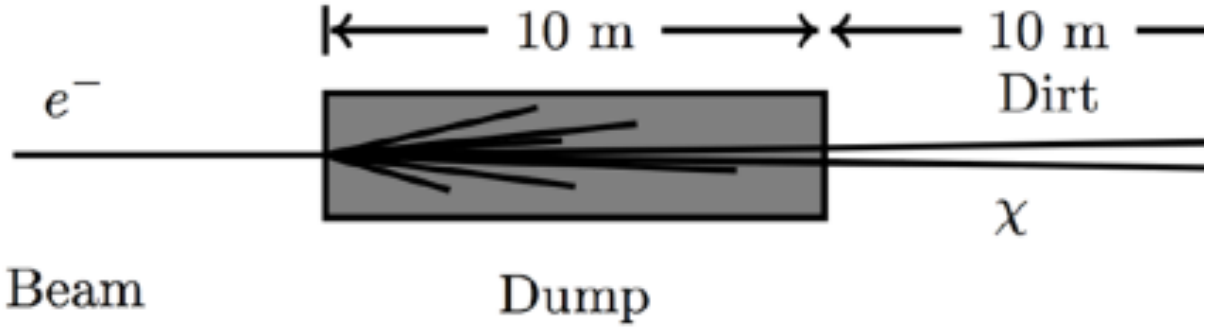

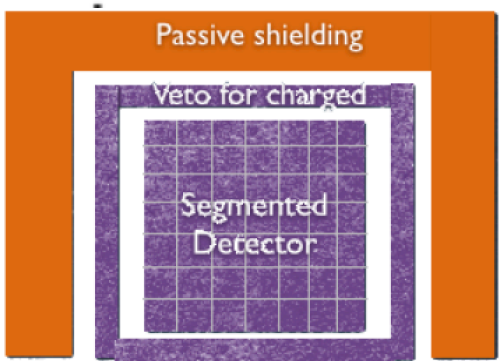

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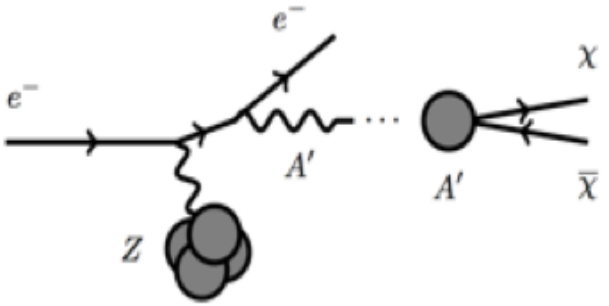
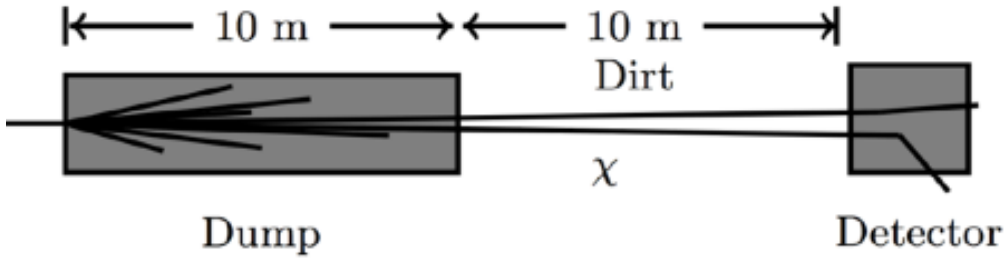
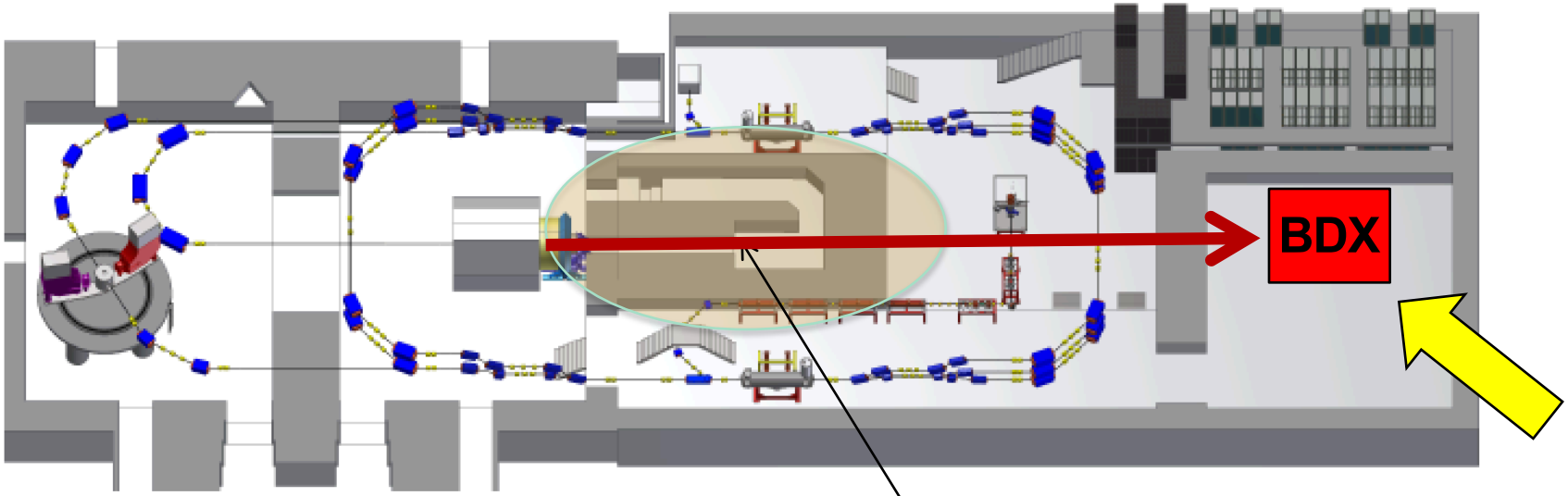
JLAB, Mainz, SLAC, Cornell

Beam Dump Experiment (BDX) @ MESA

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





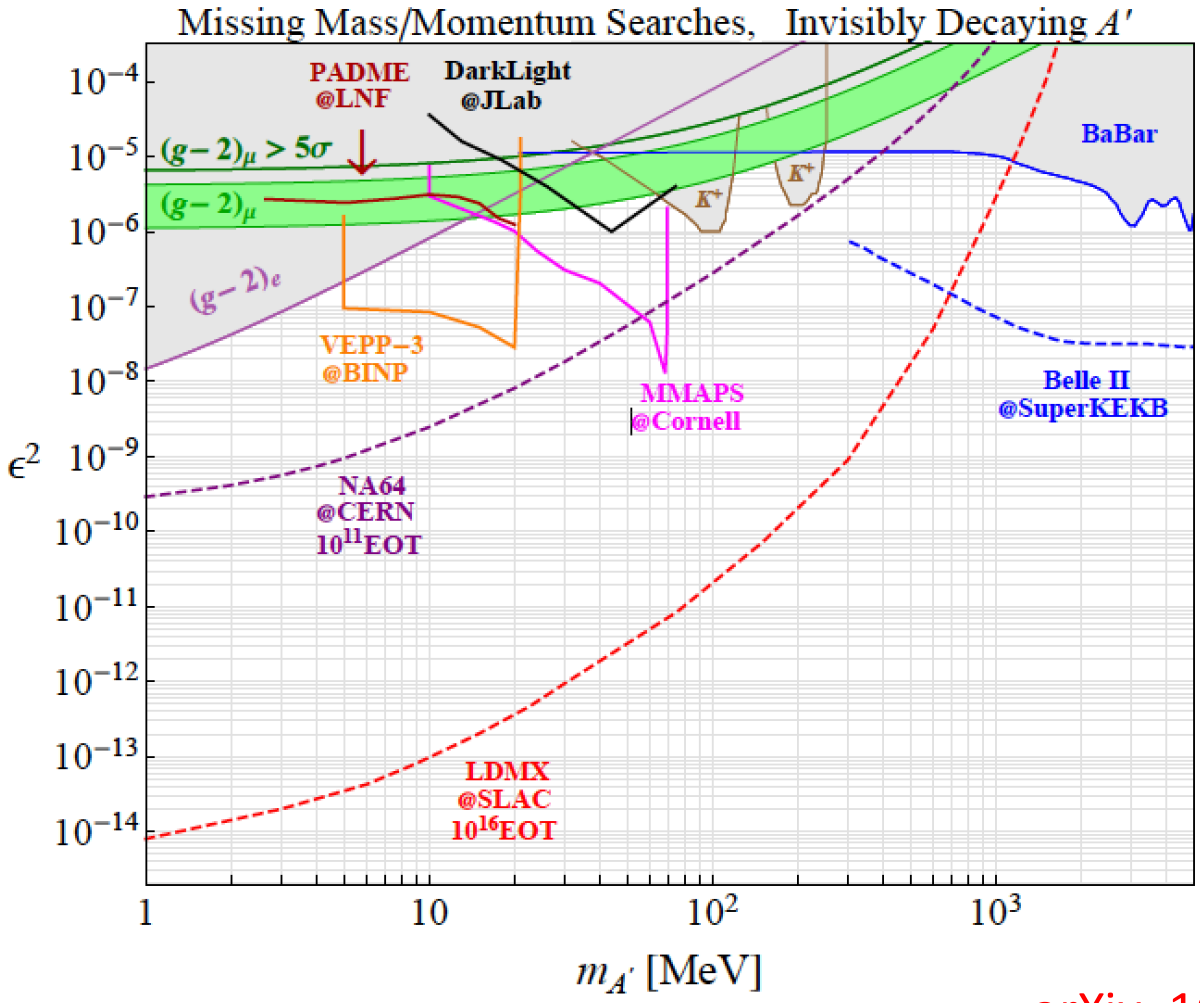


This existing beam dump is going to be the P2 beam dump

10,000 hours @ 150 µA

→ 10^{23} electrons on target (EOT)

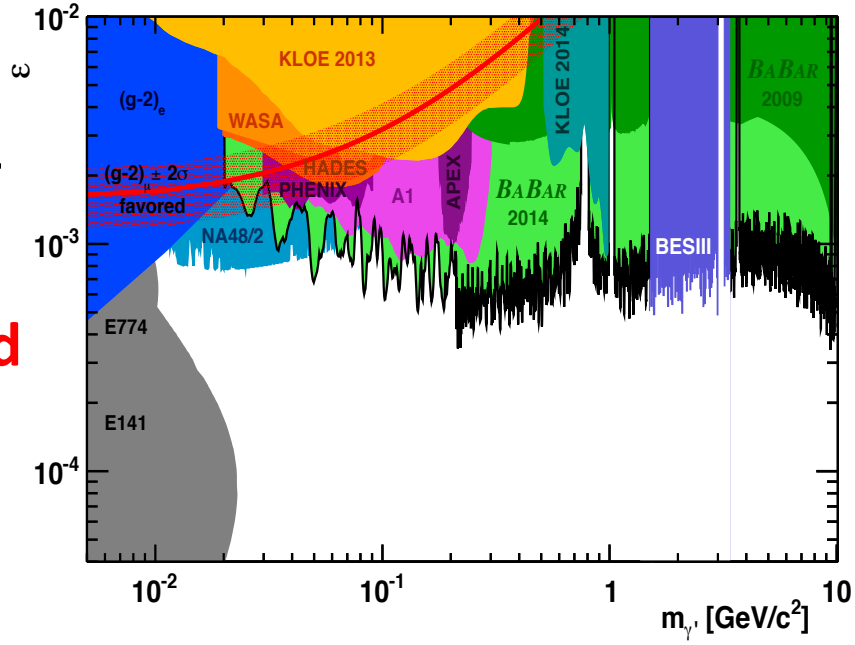
Future of Invisible Dark Photon Searches



arXiv: 1608.08632

Conclusions

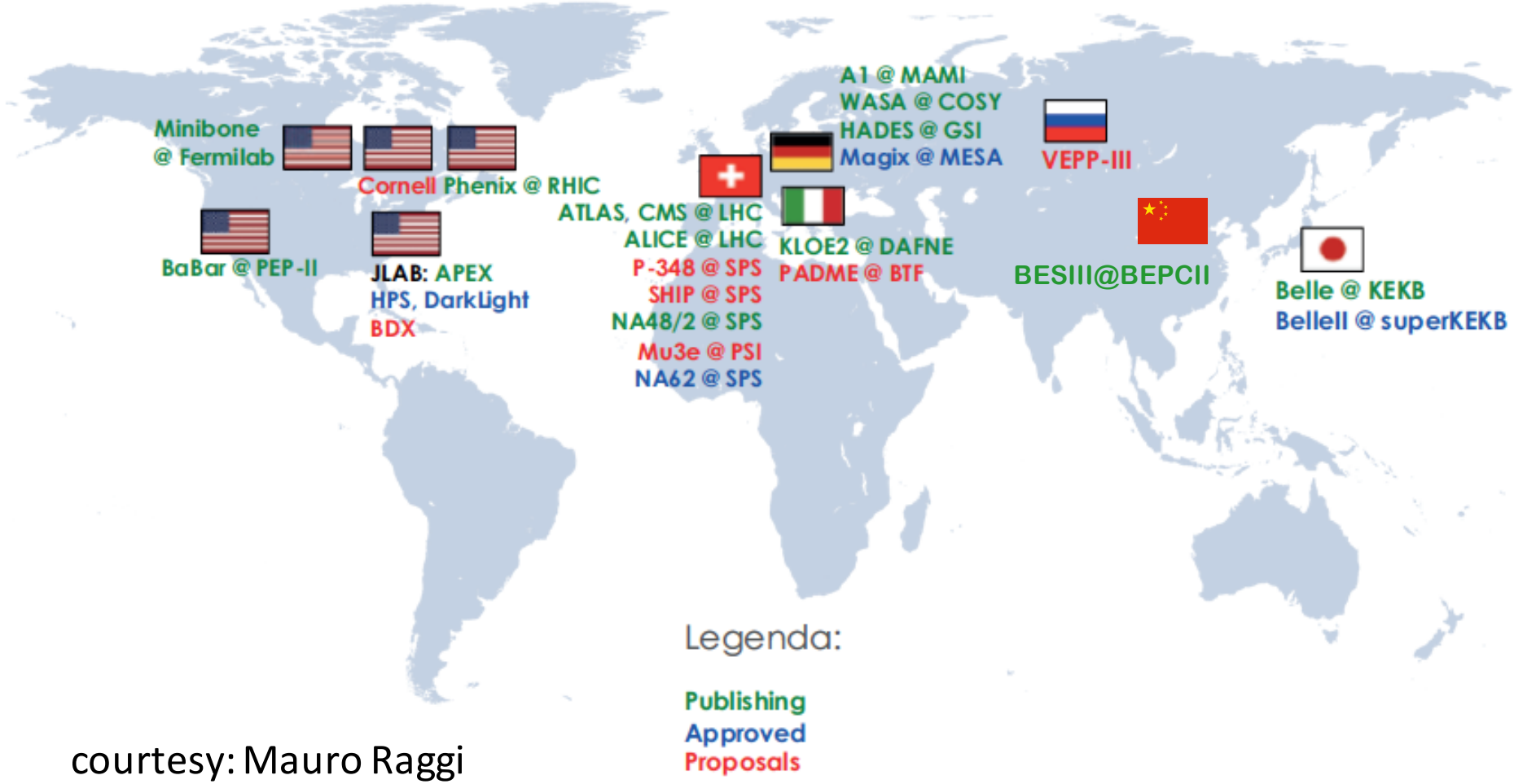
Take Home Message



- **Searches for Dark Photons motivated by Dark Matter and by $(g-2)_\mu$ puzzle**
- **Tremendous exper. progress seen**
- **Explanation for $(g-2)_\mu$ ruled out in simplest kinetic mixing model**
- **Dark Photon searches now making more and more direct connection to Dark Matter candidates itself (invisible decays)**
- **Thriving field and more to come in next 5 – 10 years**
- **Anomalous behaviour in ^{8}Be* --> ^{8}Be e+e- nuclear transition … Claim for a 17 MeV Dark Photon with ~7 sigma significance ….**

Krasznahorkay et al., PRL 116 (2016) 042501

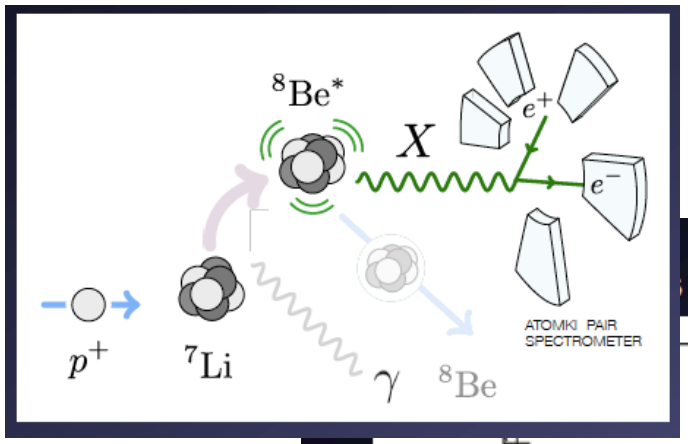
Thank you for your attention



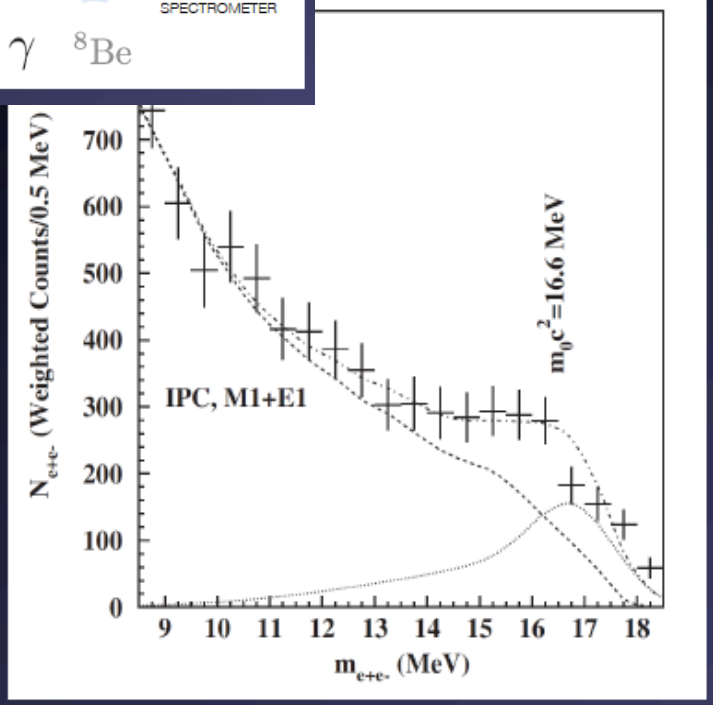
courtesy: Mauro Raggi

BACKUP

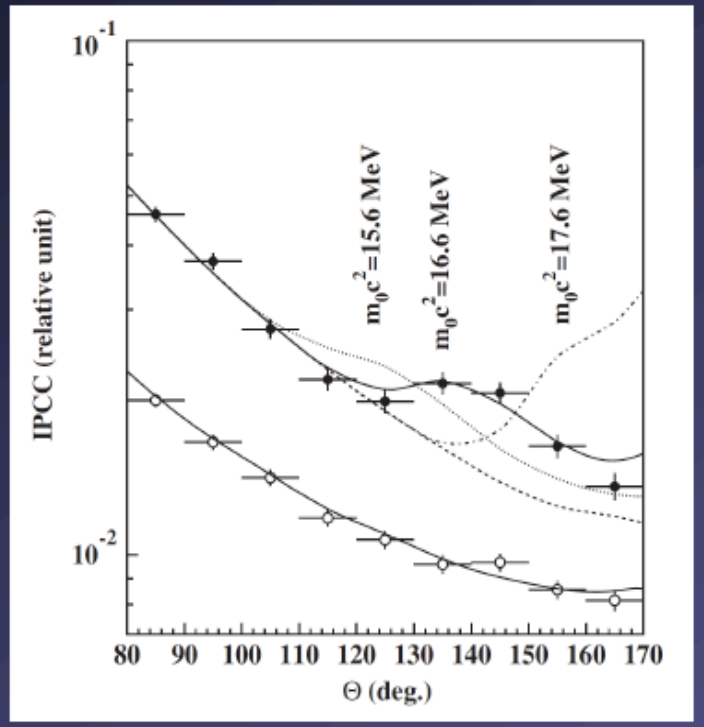
17 MeV Dark Photon ???



distribution of e^+e^-



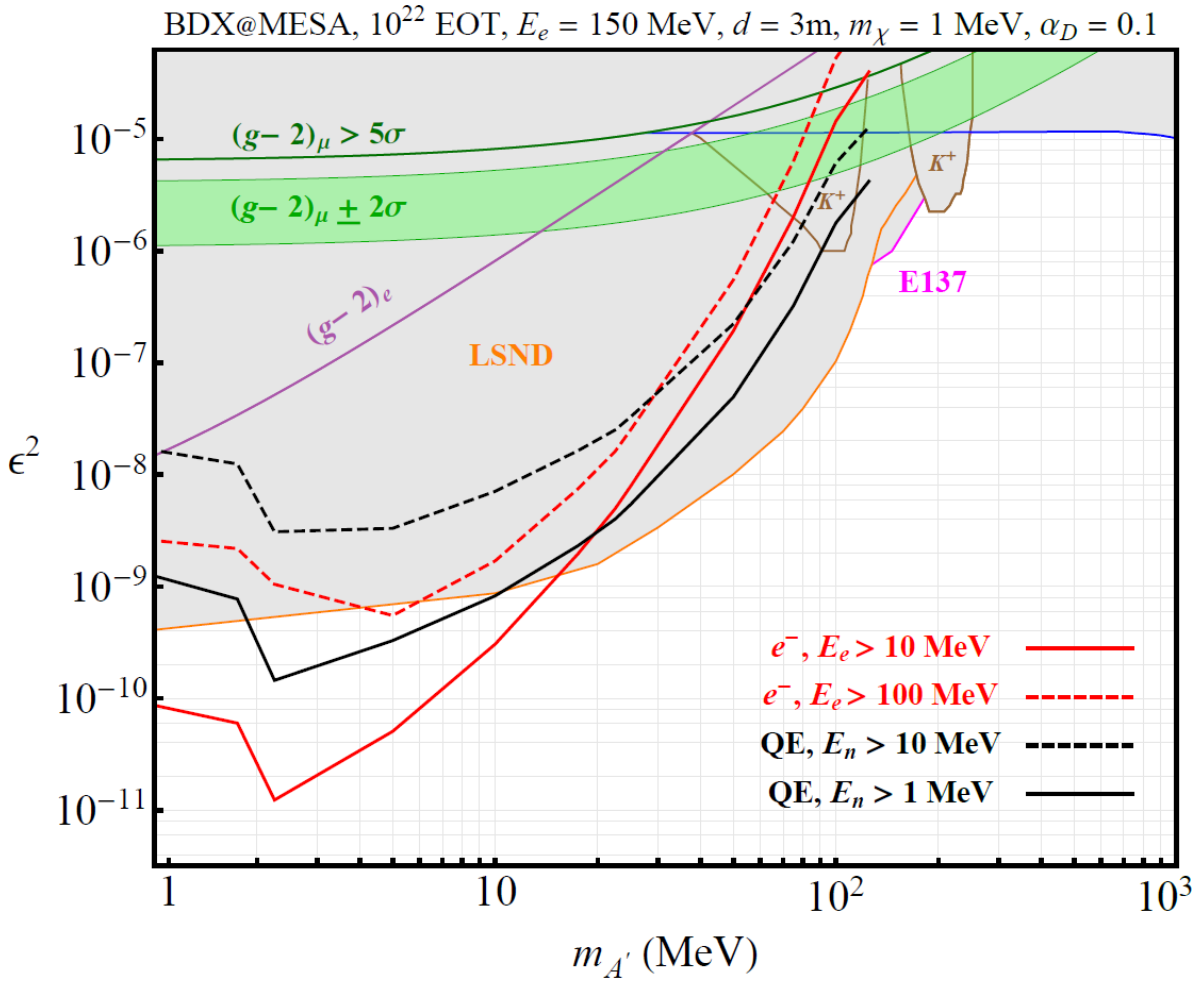
Angular correlation of e^+e^- pairs



Krasznahorkay et al., PRL 116 (2016) 042501

⟹ $m_X \approx 17$ MeV

Testing competititve parameter range



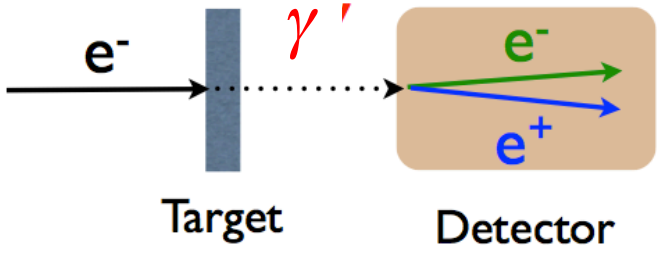
G. Krnjaic +
E. Izaguirre
Perimeter Inst.

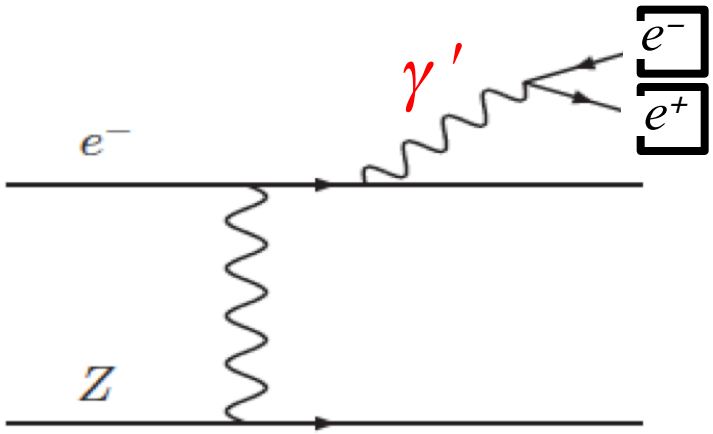
Results from A1/MAMI

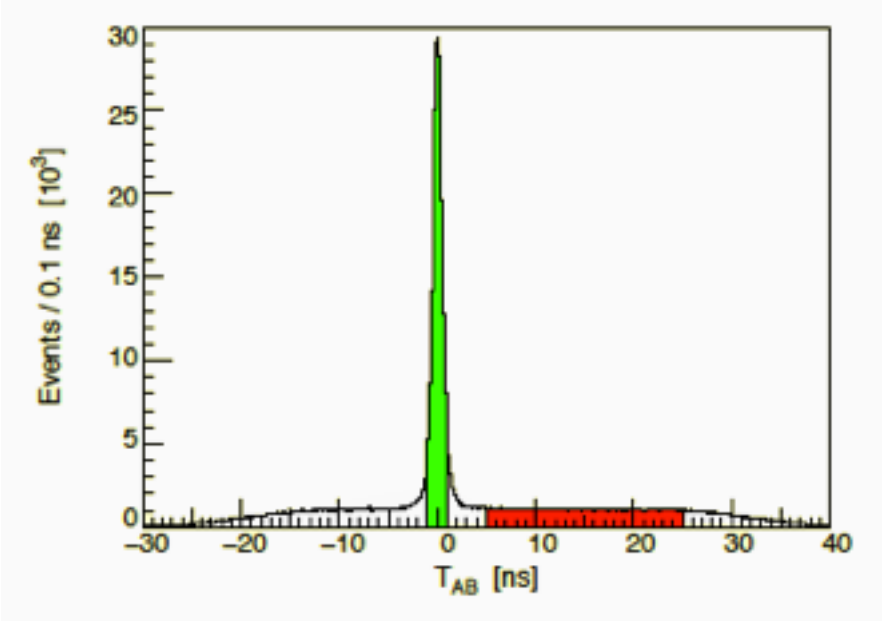
Low-Energy Electron Acceler. with high intensity suited for DP search

Bjorken, Esssig, Schuster, Toro (2009)

Signal processes

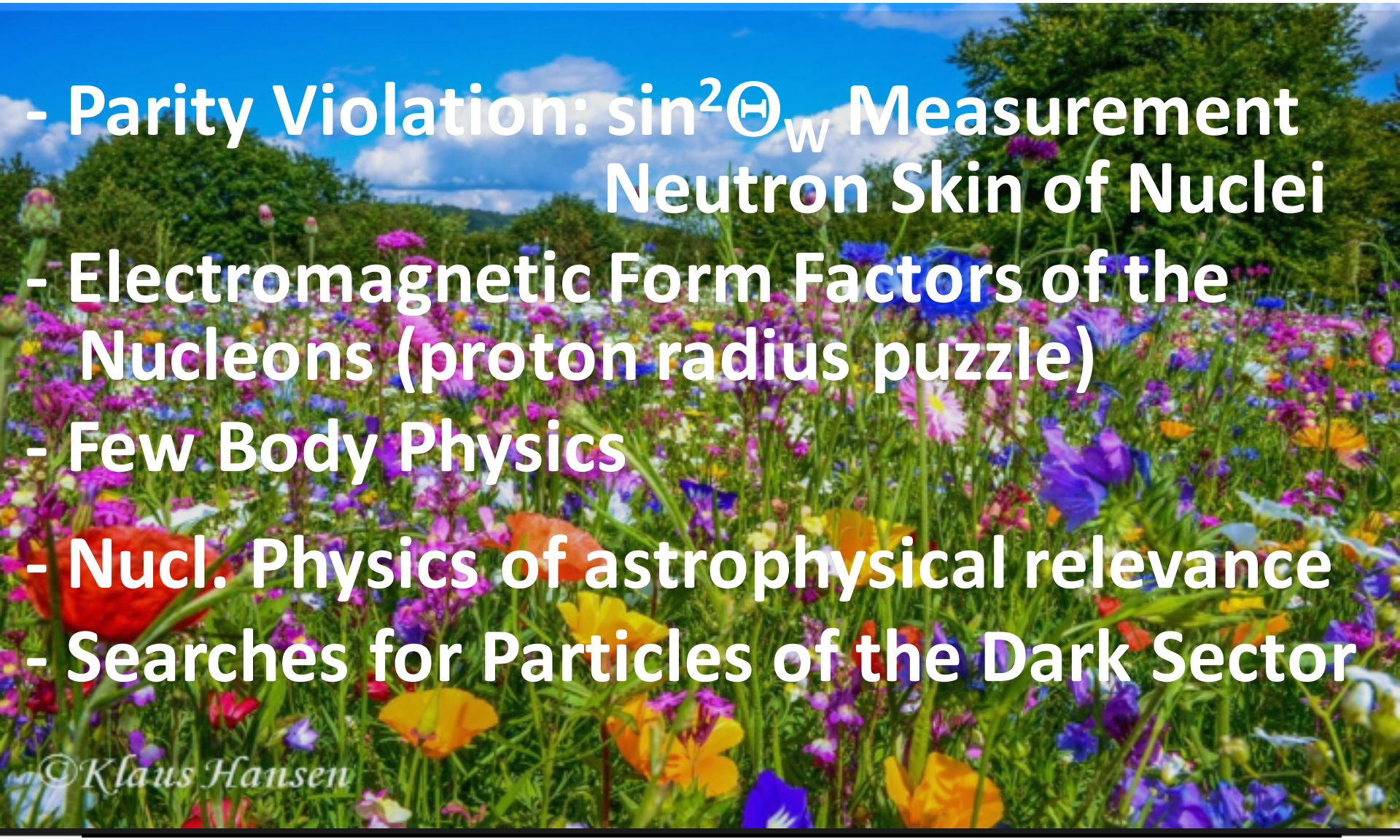




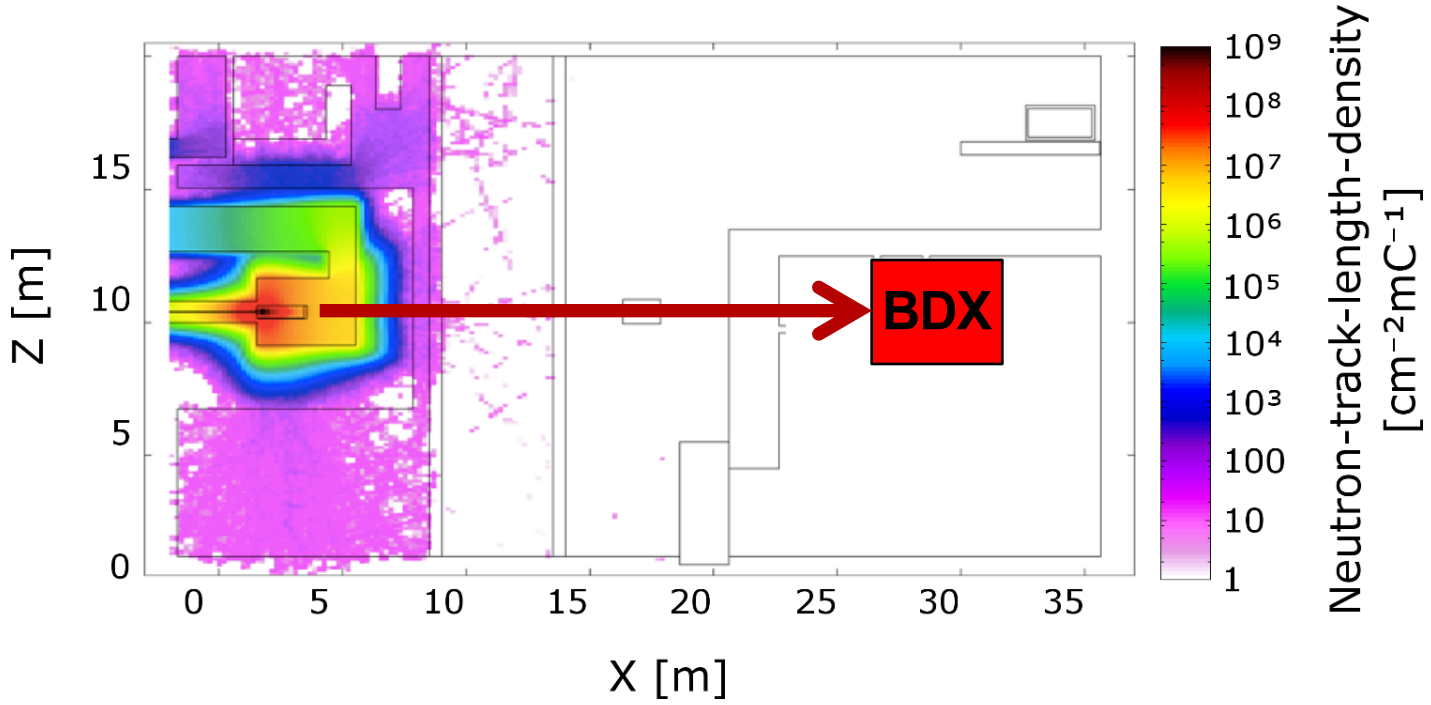


Time difference T_{AB} between both spectrometers

MESA Physics Progam



BDX @ MESA



Background situation

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

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