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

Achim Denig
October 20, 2023

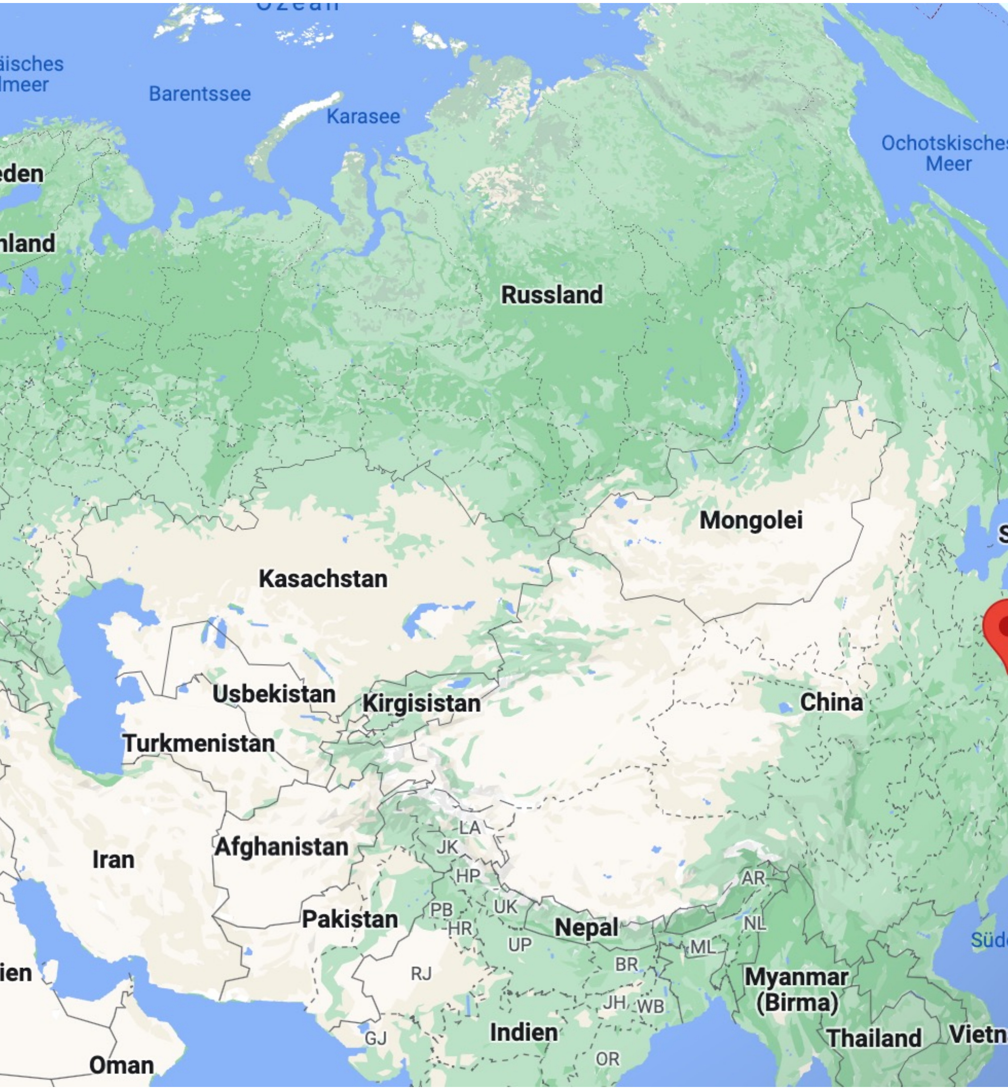
Status of the DarkMESA Experiment

Workshop on multi-front exotic phenomena
in particle and astroparticle physics (MEPA2023)
Hefei, China

Mainz


Mainz


MENU conference this week

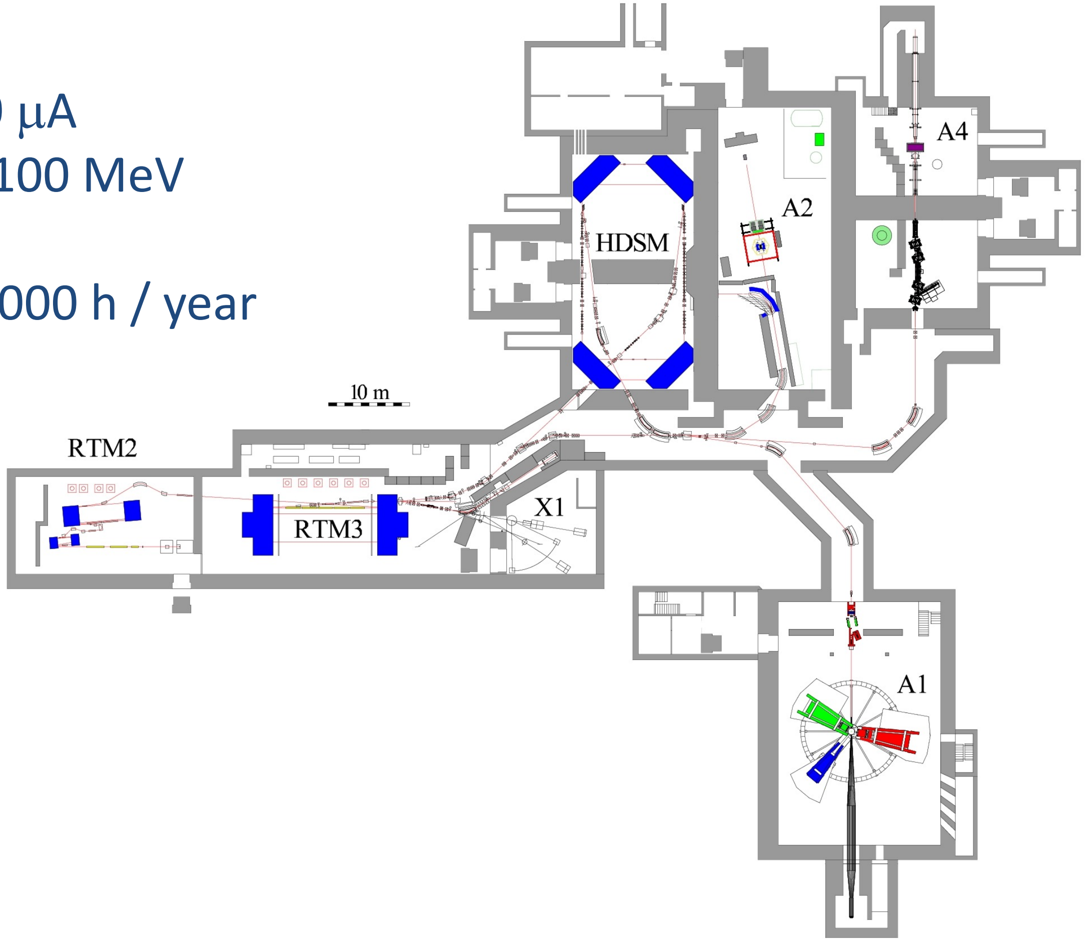

Island
Europäisches Nordmeer
Barentssee
Karasee
Irland
Vereinigtes Königreich
Schweden
Finnland
Russland
Ochotskisches Meer
Polen
Belarus
Österreich
Japan
Mongolei
Südkorea
Kasachstan
chinesisches Meer
Usbekistan
Kirgisistan
China
Turkmenistan
Philippinensee
Niger
Ghana
Ägypten
Irak
Iran
Afghanistan
Nigeria
Tschad
Pakistan
Nepal
Sudan
Saudi-Arabien
Myanmar (Birma)
Indien
Gabun
Oman
Thailand


Hefei

The Mainz Microtron MAMI

Electron Accelerator E_{max} =1.6 GeV (CW)
operated at JGU Mainz
Hallmarks

- Intensity max. 100 μA
- Resolution σ_E < 0.100 MeV
- Polarization 85%
- Reliability: up to 7000 h / year



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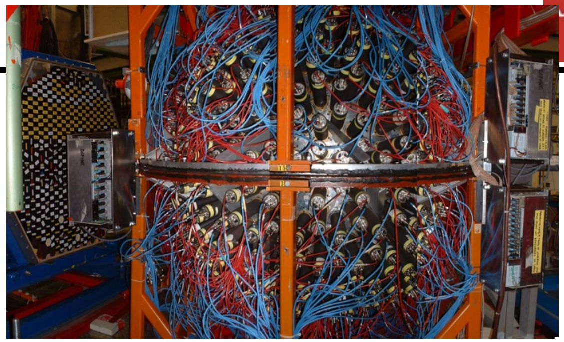
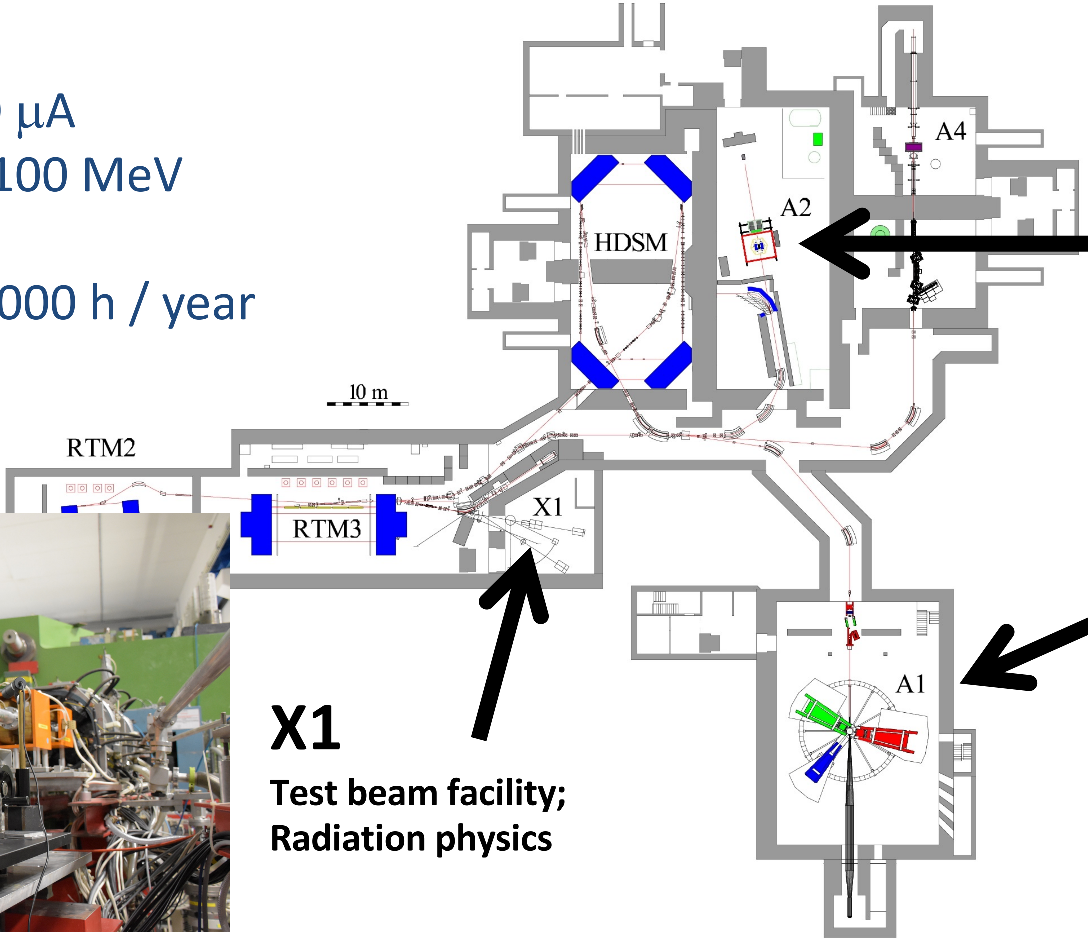
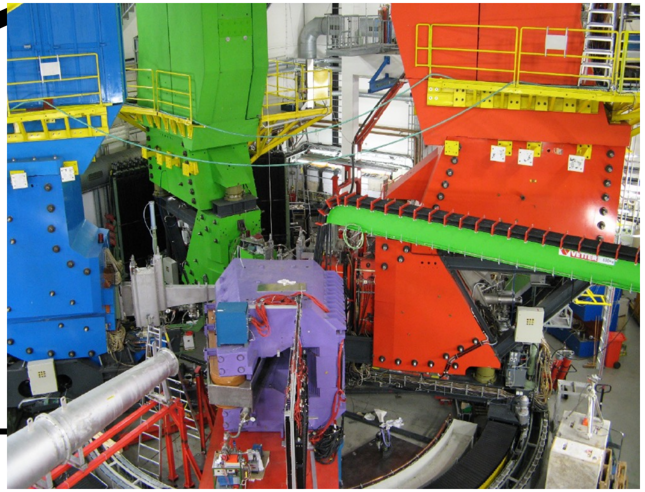


Photon scattering (A2 hall) (Crystal Ball / TAPS calorimeters; Polarized frozen-spin target → currently at Univ. Bonn)



Electron scattering (high resolution spectrometer setup)



X1

Test beam facility; Radiation physics

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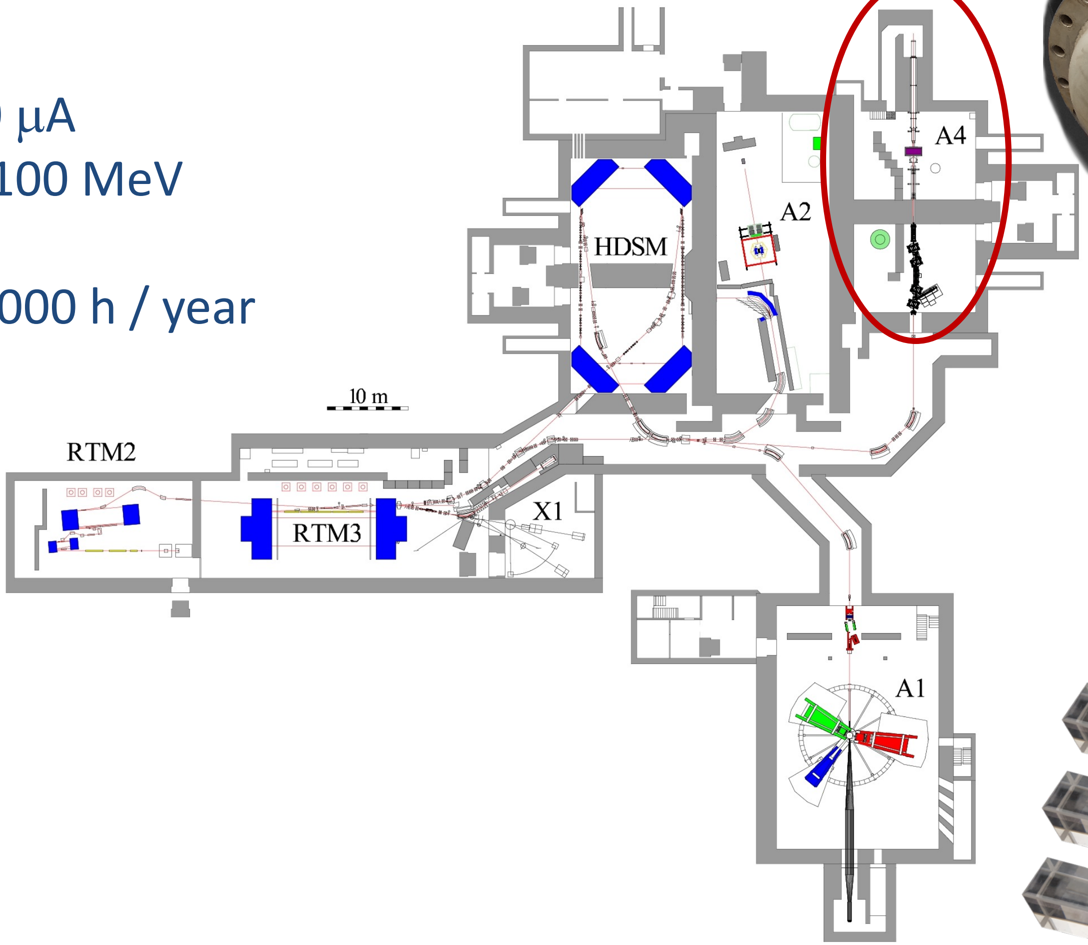
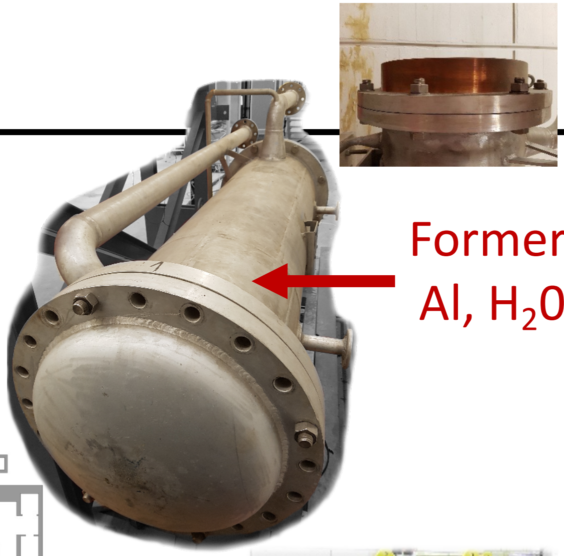
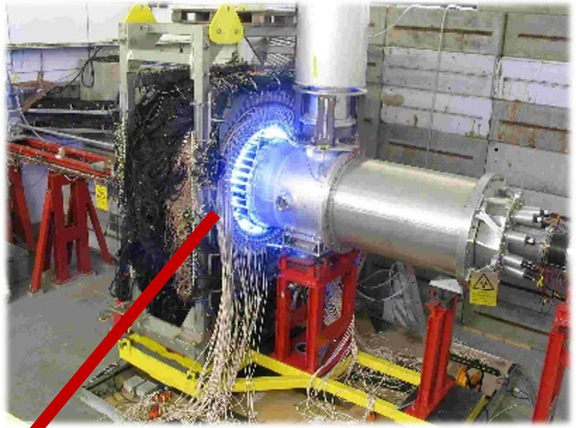
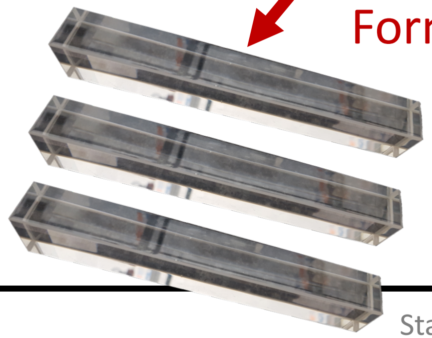




Former A4 beam dump:
Al, $H_2$0, Cu → 20 X_0





Former A4 experiment:
1000 PbF_2 crystals
and PMTs

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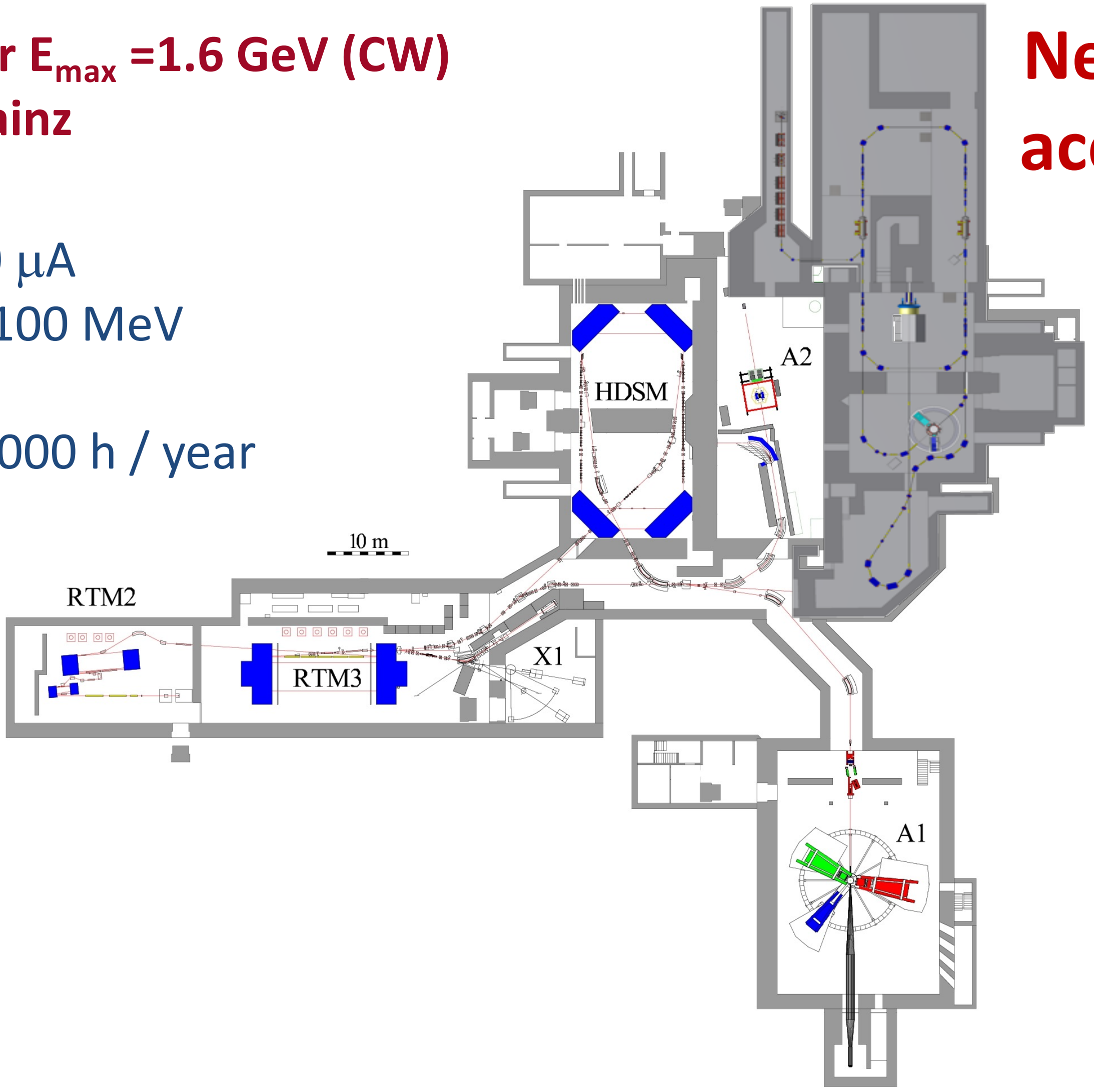

New MESA accelerator

New experimental hall

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and Structure of Matter

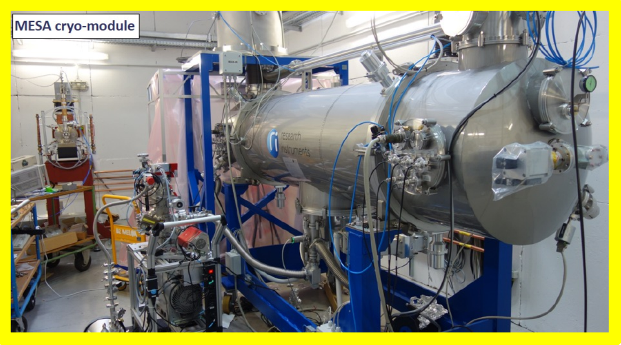
Mainz Energy-Recovering Superconducting Accelerator (MESA)

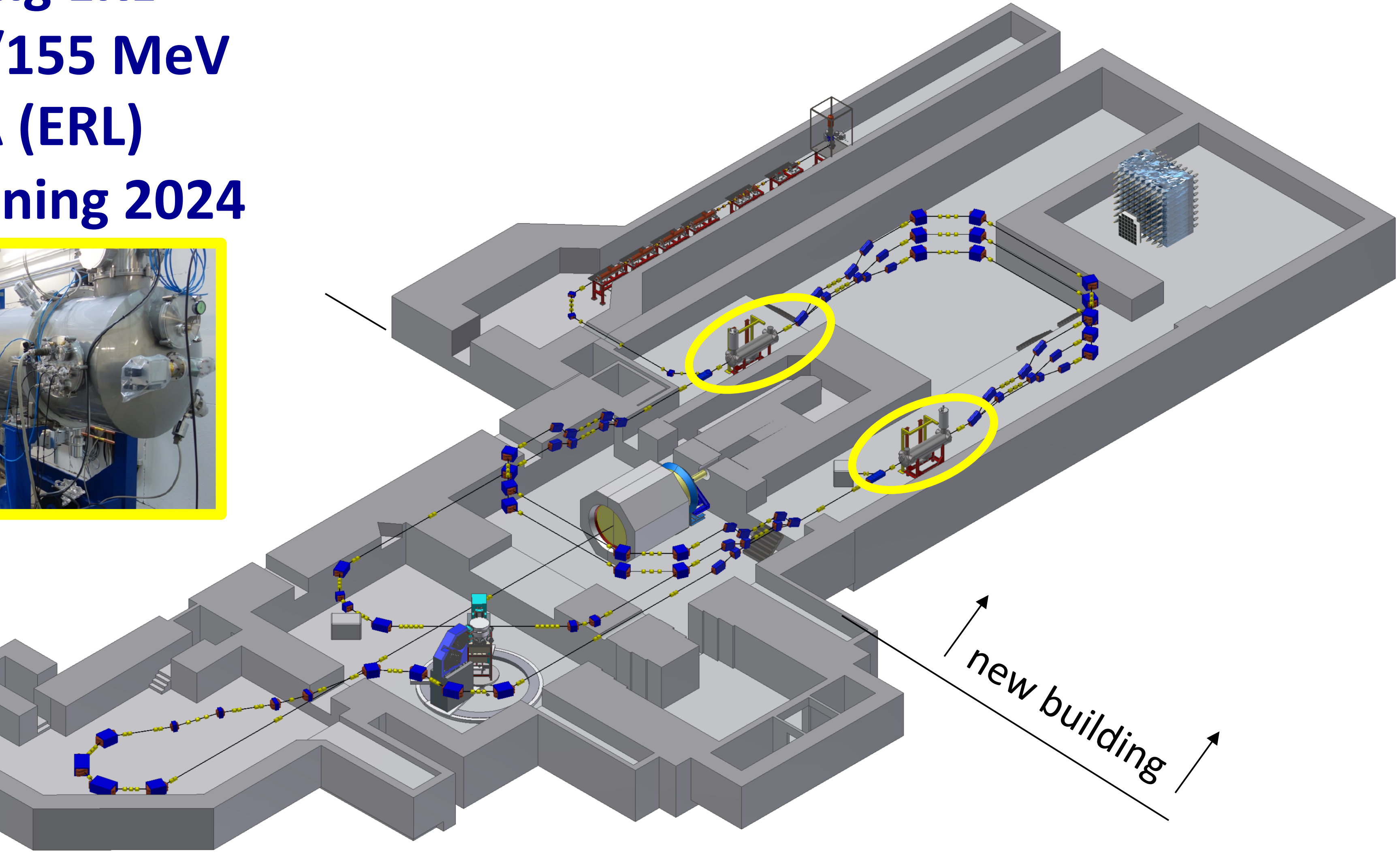
Recirculating ERL

E_{max} = 105/155 MeV

I_{max} > 1 mA (ERL)

Commissioning 2024





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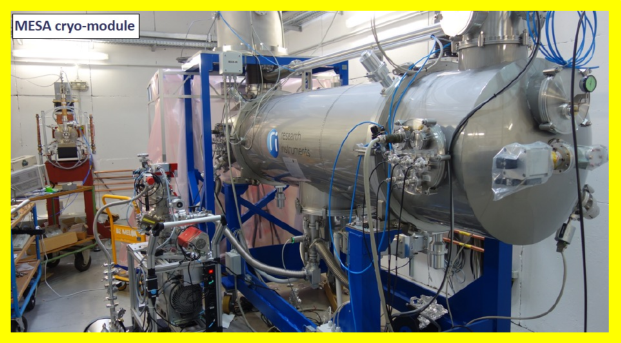

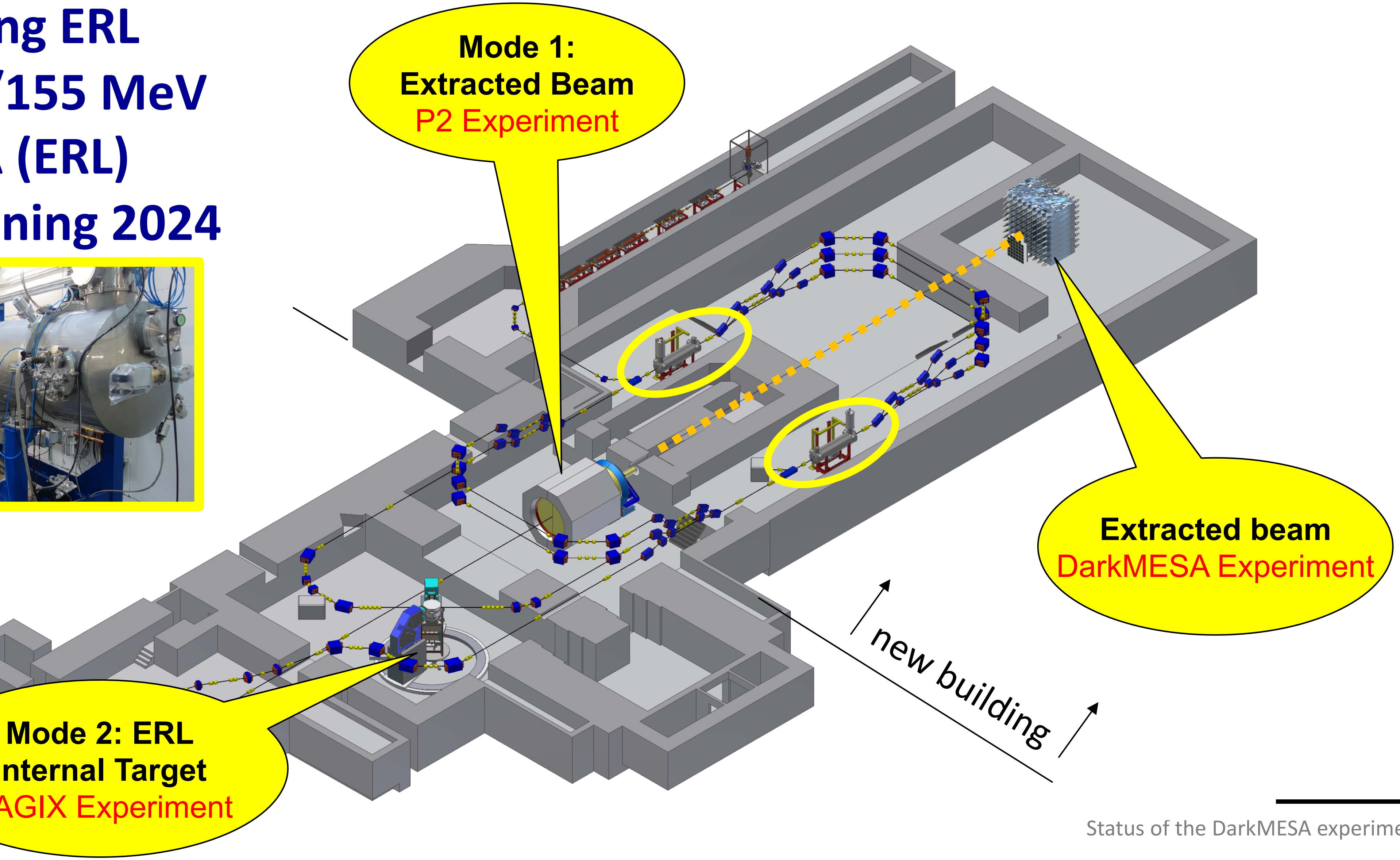

High-Resolution MAGIX Spectrometers

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

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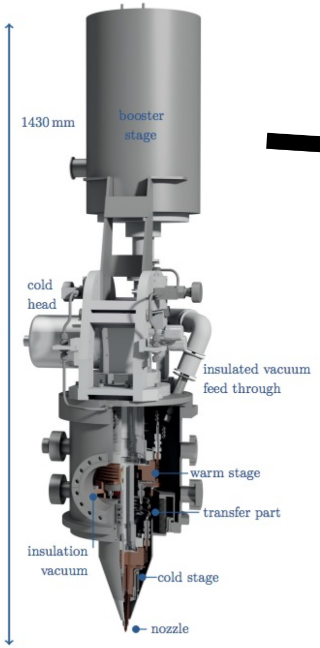
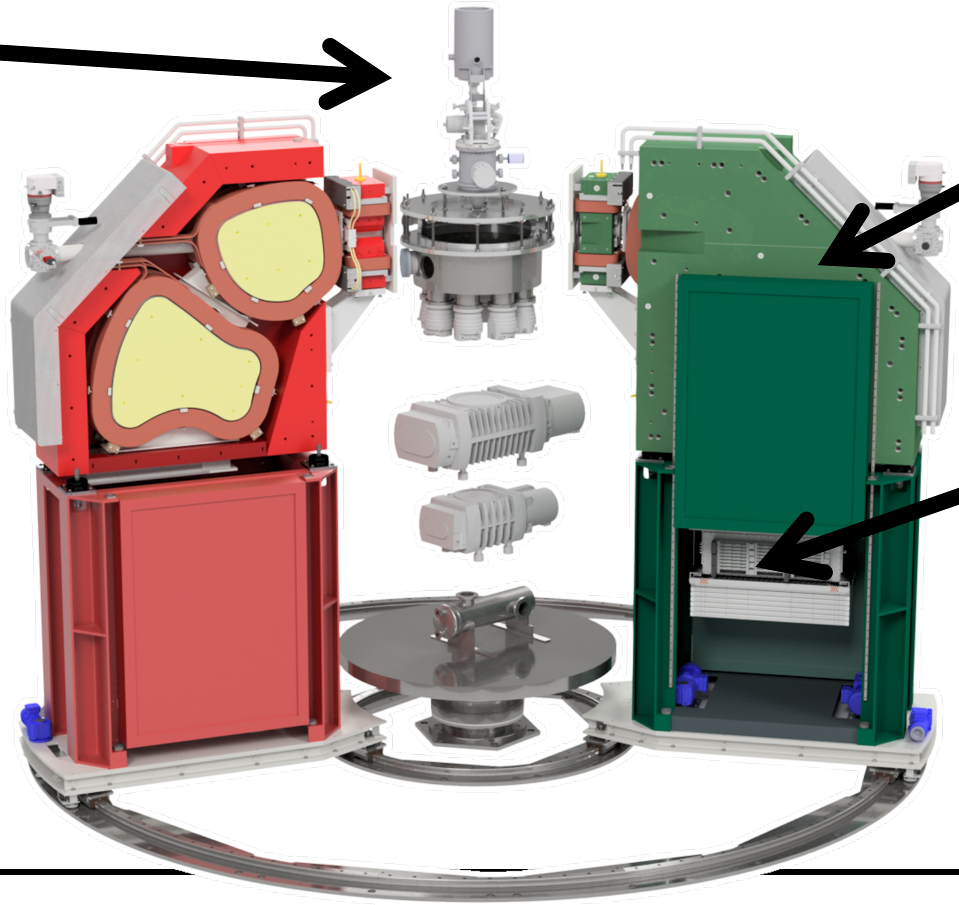
Operation of a high-intensity (polarized) ERL beam in conjunction with light internal target
→ a novel technique in nuclear and particle physics

NIM A1013 (2021)



Supersonic crygenic gas jet target

- Windowless environment
- Commissioned at A1/MAMI
- Design density $10^{19}/cm^2$



Two identical spectrometers

- Two dipoles each
- One quadrupole each

TPC-based focal plane detector

- 10^{-4} momentum resolution
- Requires spatial resolution of O(100 μm)
- Open field cage
- GEM readout

High-Resolution MAGIX Spectrometers

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in conjunction with light internal target
→ a novel technique in nuclear and particle physics

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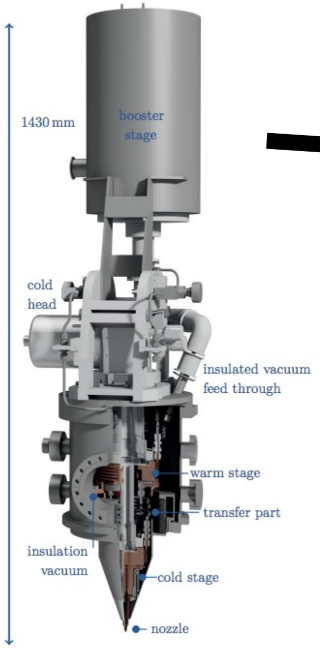

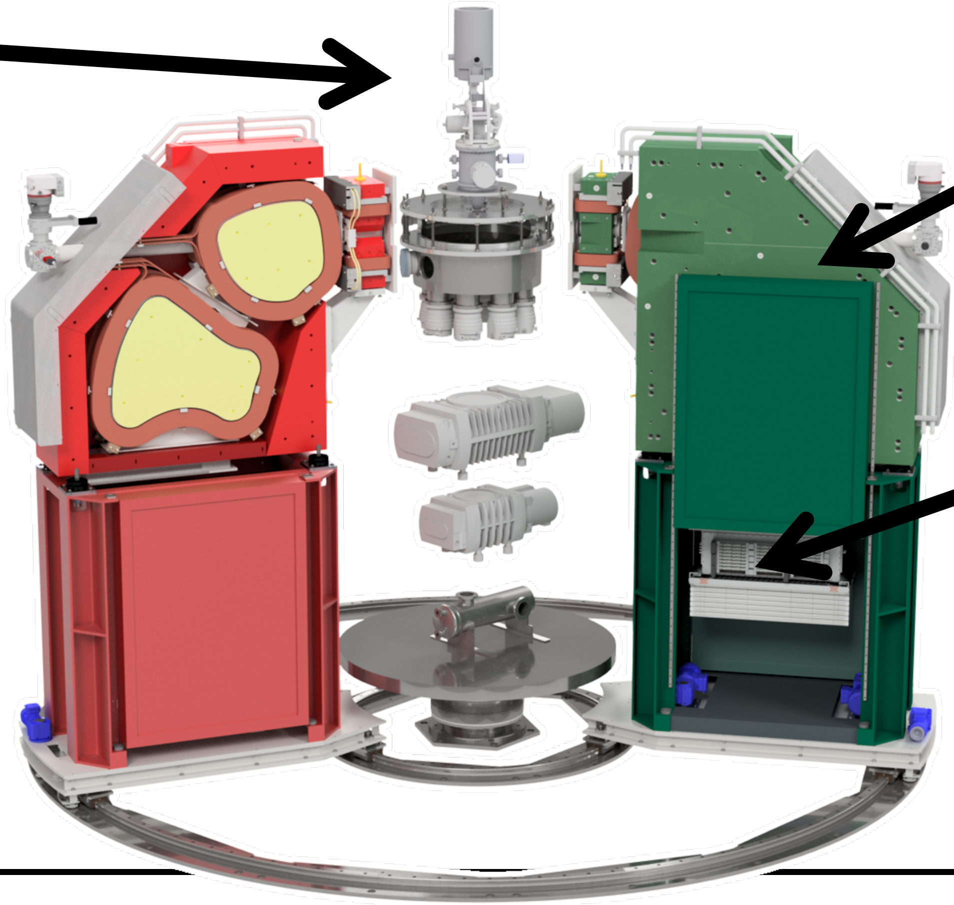

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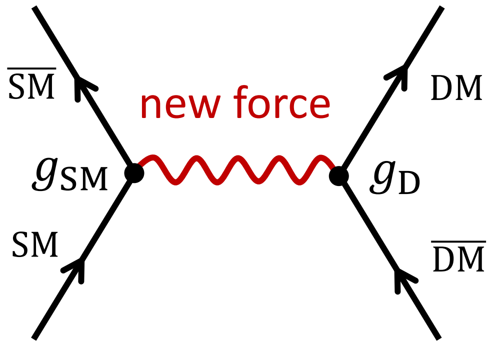
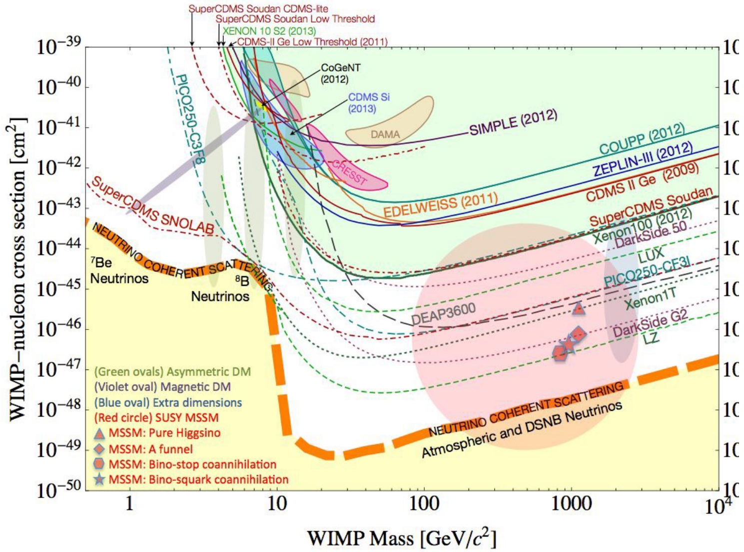
MESA Physics Programme

	ERL Mode MAGIX expt.	Extracted Beam Mode P2 expt.	Extracted Beam Mode DarkMESA.
Nucleon From Factors	✓		
EW Mixing Angle		✓	
Nuclear Astrophysics	✓ $^{12}C\ (\alpha,\gamma)\ ^{16}O$	neutron skin of nuclei ✓	
Few Body Physics	✓		
Light Dark Matter Search	✓		✓

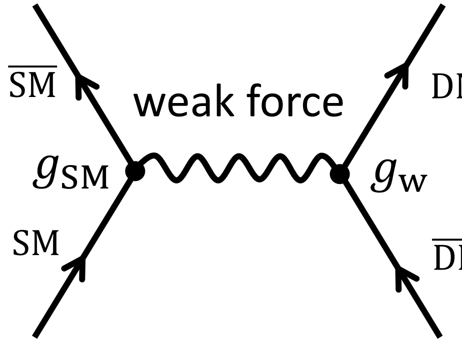
Light Dark Matter (LDM)

Light Dark Matter
MeV < m_{DM} < ~ GeV





WIMPs
GeV < m_{DM} < ~ TeV



- Thermal relic targets exist for the MeV-GeV mass scale
- LDM requires a beyond SM force
- Rich phenomenology of portals: vector, higgs, neutrino, axion

- Matching relic abundance for the electroweak mass scale
- WIMPs require only SM interaction
- No positive evidence after LHC and galactic DM searches

Vector Mediator: Dark Photon

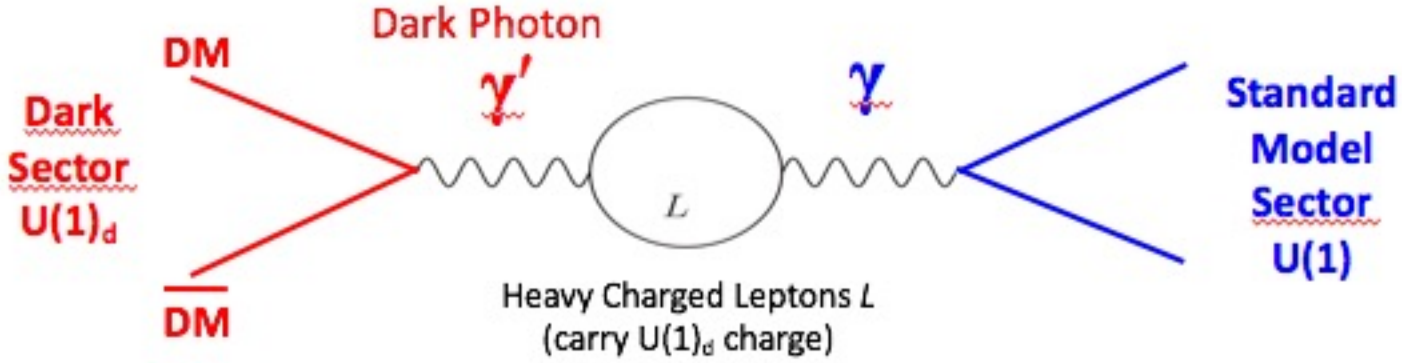
Model 1: $m_{\gamma'} \ll m_{\mathrm{DM}}$

$$\frac{1}{2}\epsilon_Y \, F^Y_{\mu\nu} F'^{\mu\nu}$$

Holdom [1986]

Dark Photon decaying into SM particles – coupling ϵ

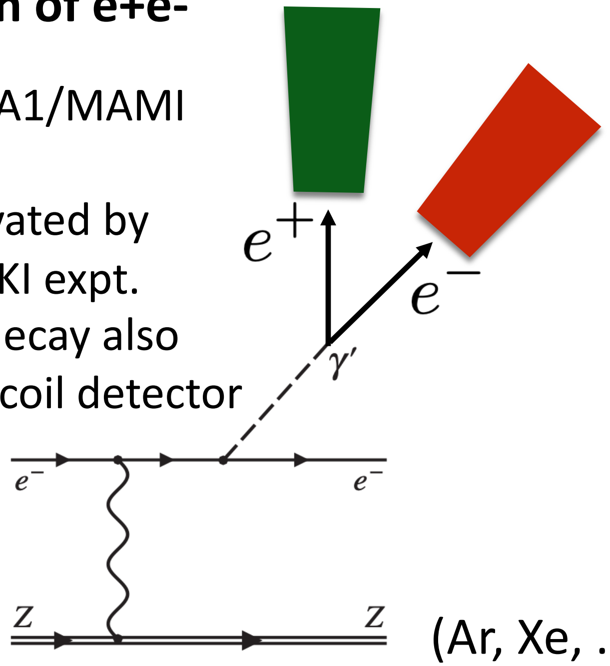
→ MAGIX



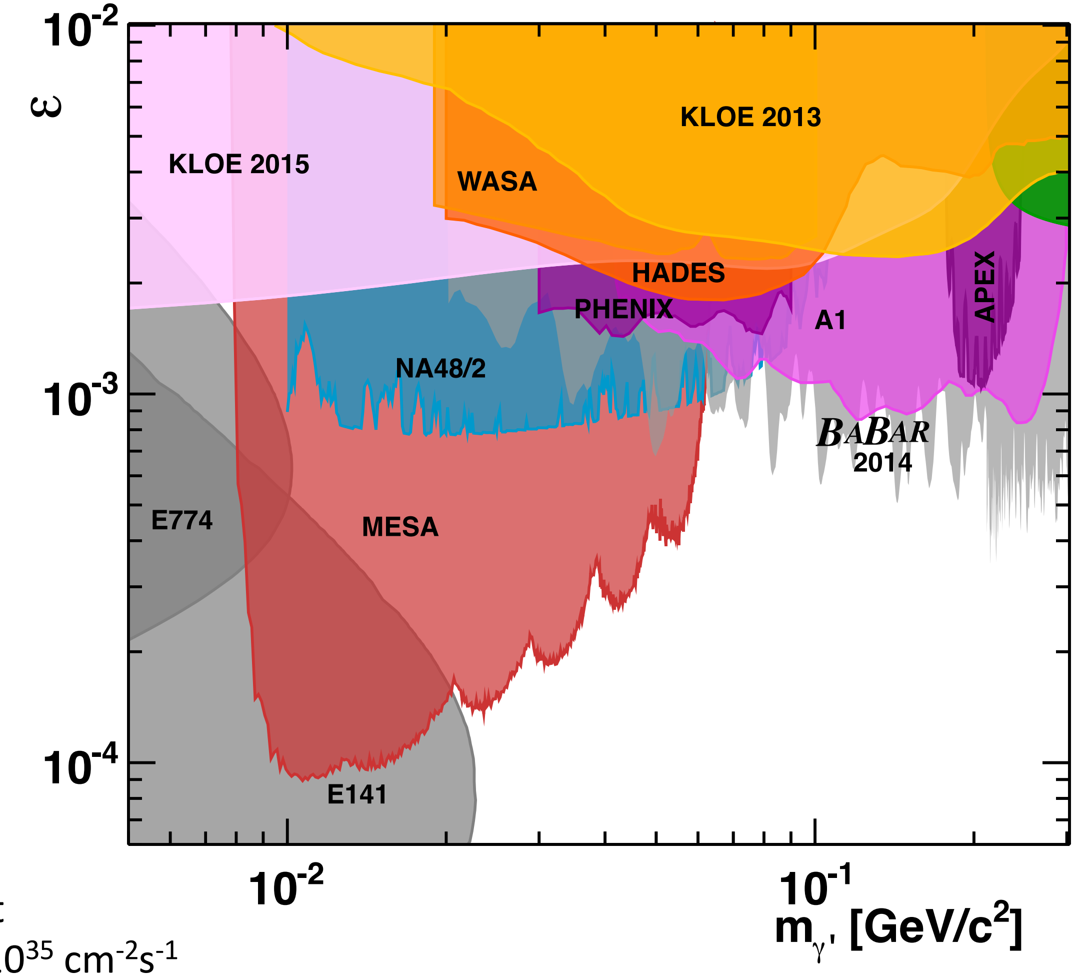
Dark Photon Search at MAGIX

Visible dark photon search
→ Coincident detection of e+e-

- Method pioneered by A1/MAMI and APEX/JLAB
- Parameter range motivated by X17 anomaly of ATOMKI expt.
- Invisible dark photon decay also possible thanks to Si recoil detector



(Ar, Xe, ...)



Features:

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

Vector Mediator: Dark Photon

$$\frac{1}{2}\epsilon_Y F^Y_{\mu\nu} F'^{\mu\nu}$$

Holdom [1986]

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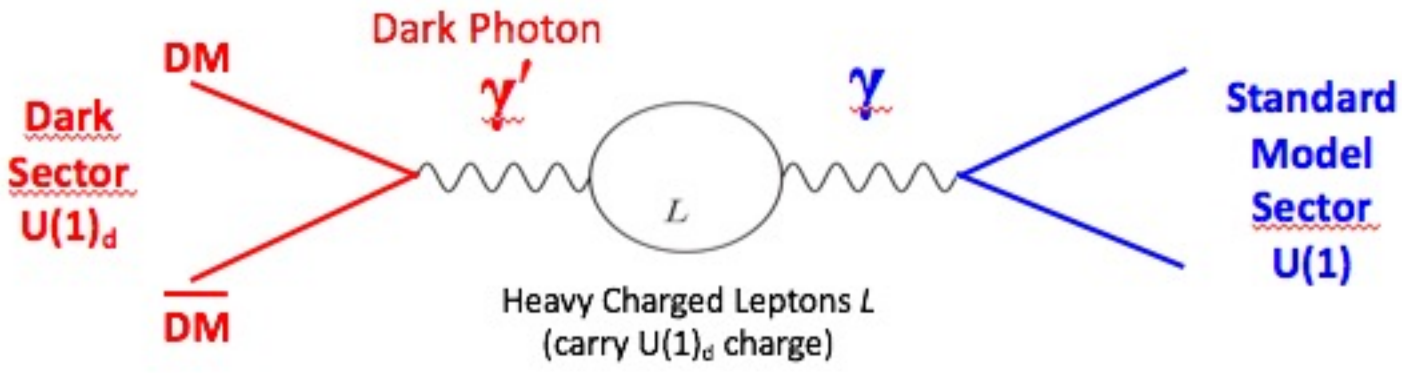
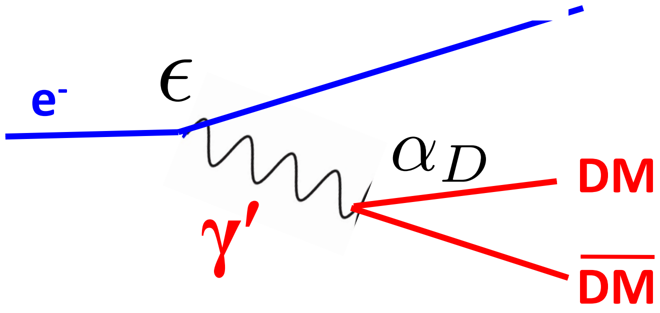
→ MAGIX visible decay

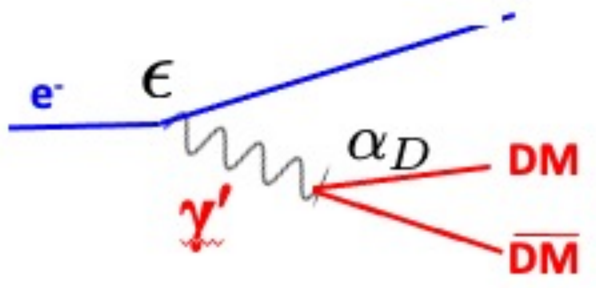


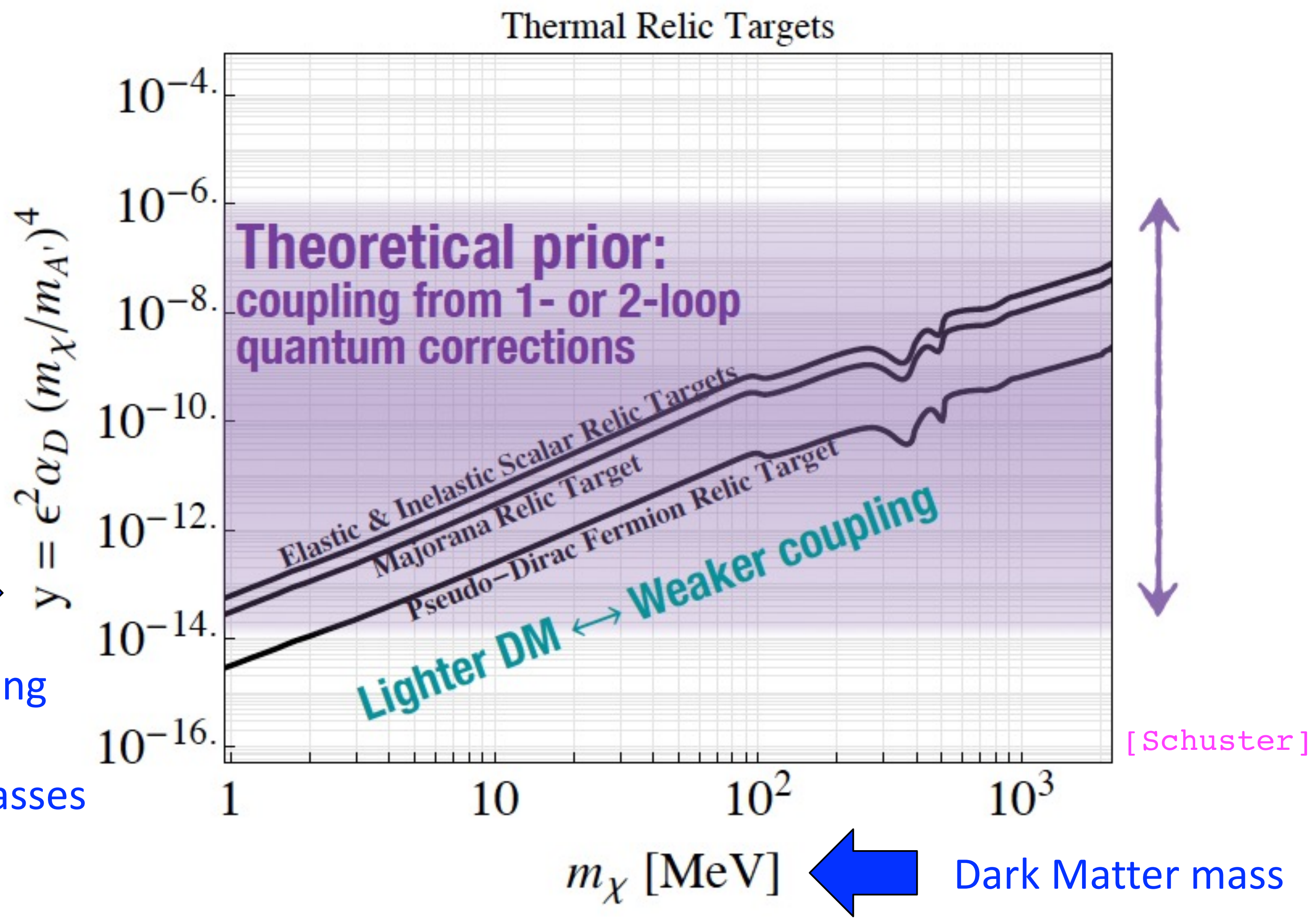
Model 2: $m_{\gamma'} > 2m_{\mathrm{DM}}$

Dark Photon decaying into Dark Matter
→ MAGIX invisible decay and DarkMESA



LDM Portals – A rich Phenomenology



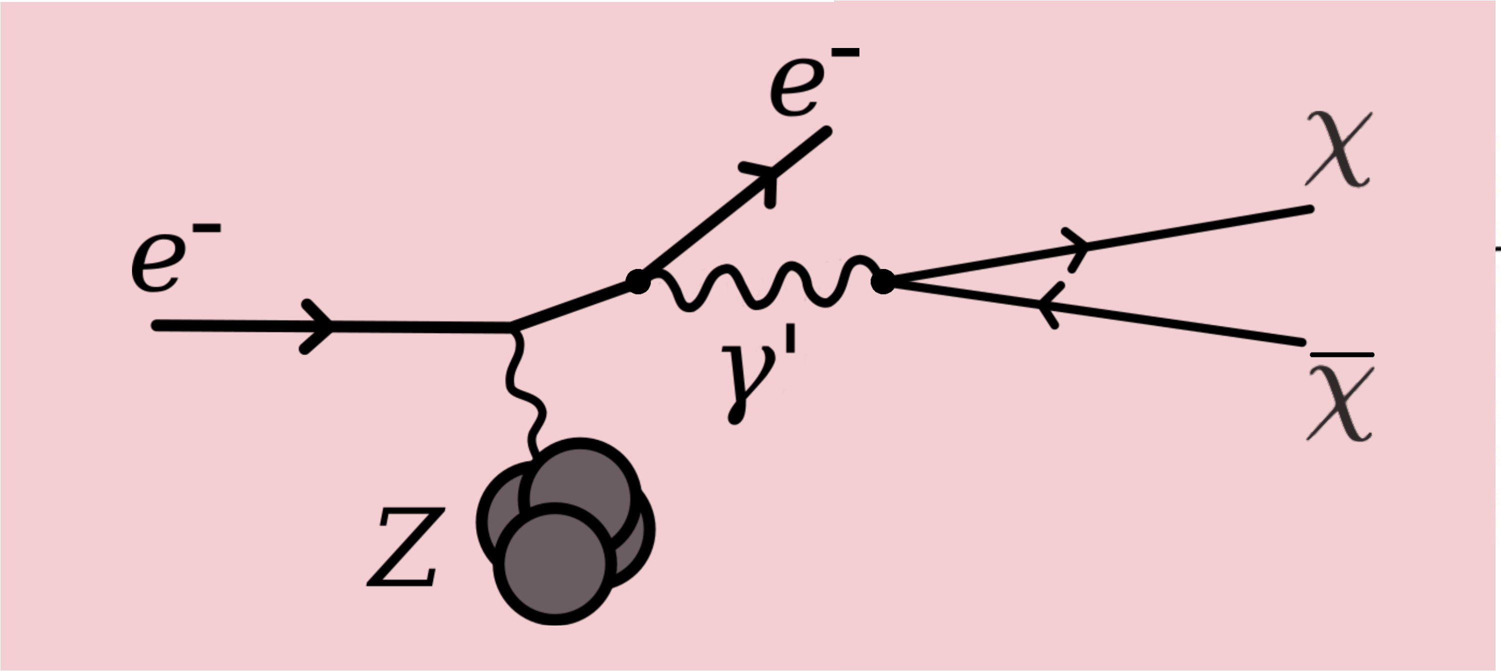


Combination of
- Dark photon -Electron coupling
- Dark photon – DM coupling
- Ratio of DM/Dark photon masses

Dark Matter mass

Beam Dump Experiment DarkMESA

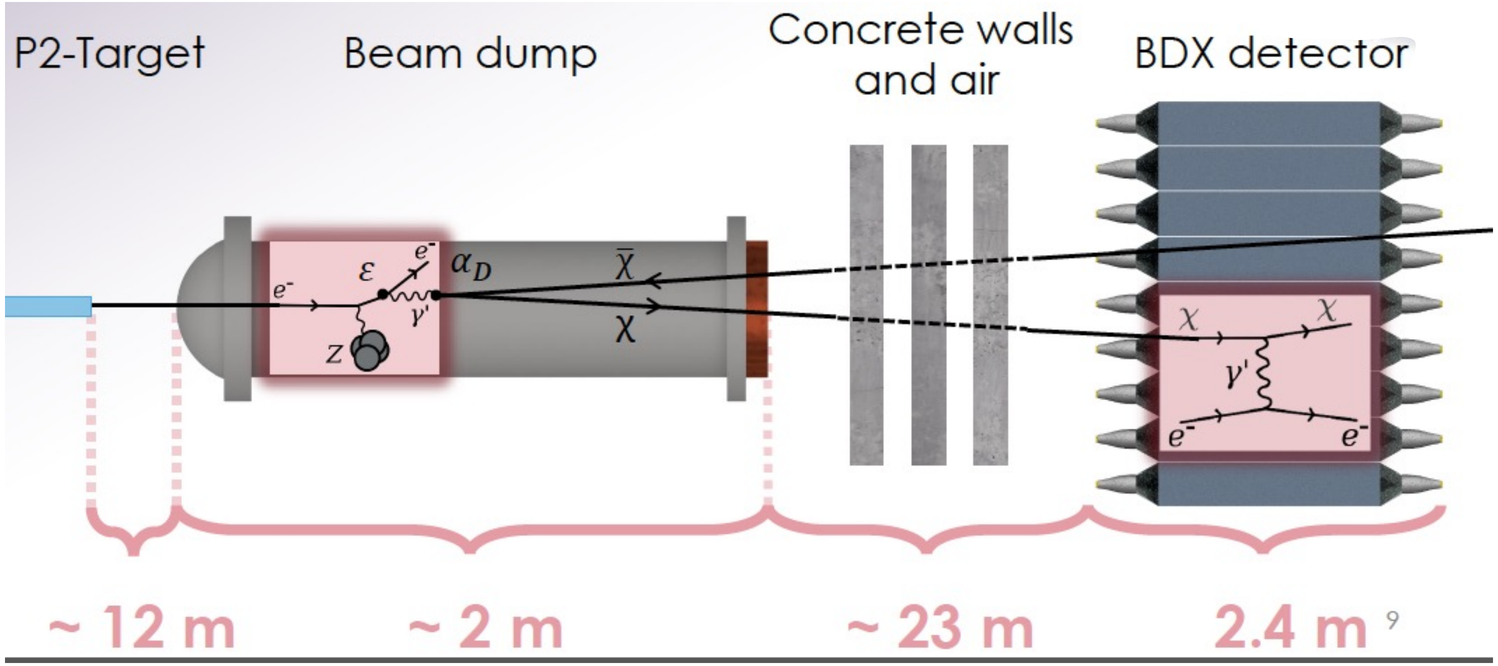
Model 2: $m_{\gamma'} > 2m_{\mathrm{DM}}$



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

Beam Dump Experiment DarkMESA

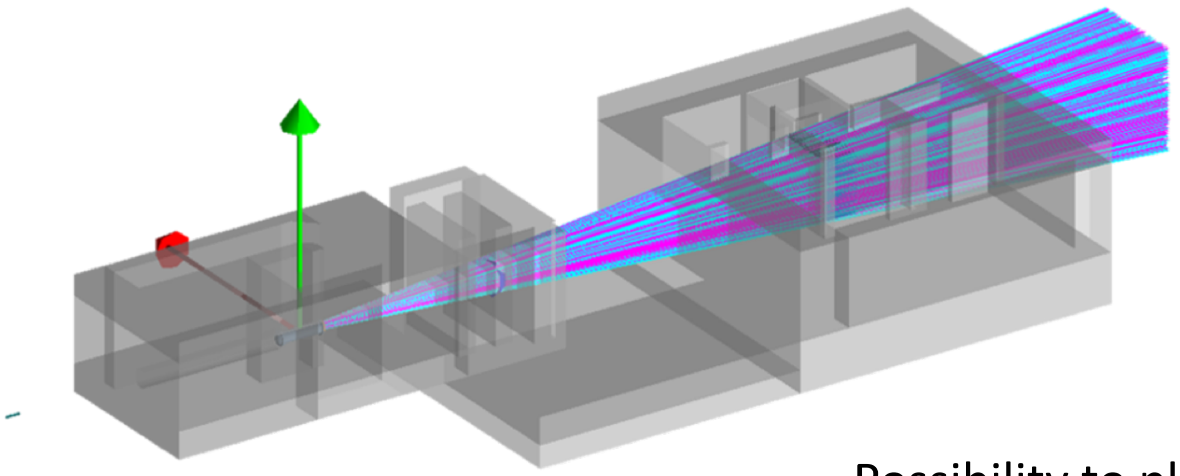
Model 2: $m_{\gamma'} > 2m_{\mathrm{DM}}$

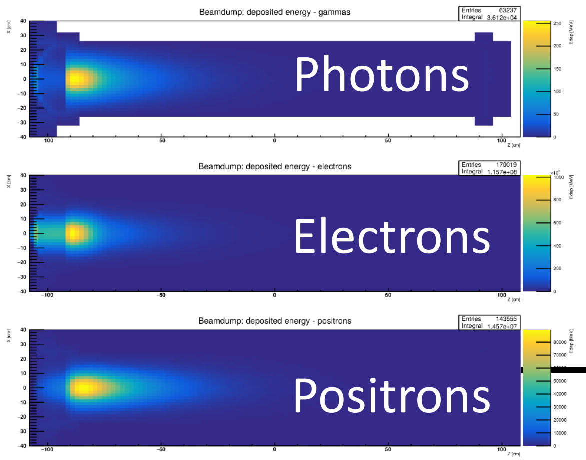


Electron Scattering (MESA) on Beam Dump
→ Collimated pair of Dark Matter particles !

Beam Dump Experiment DarkMESA

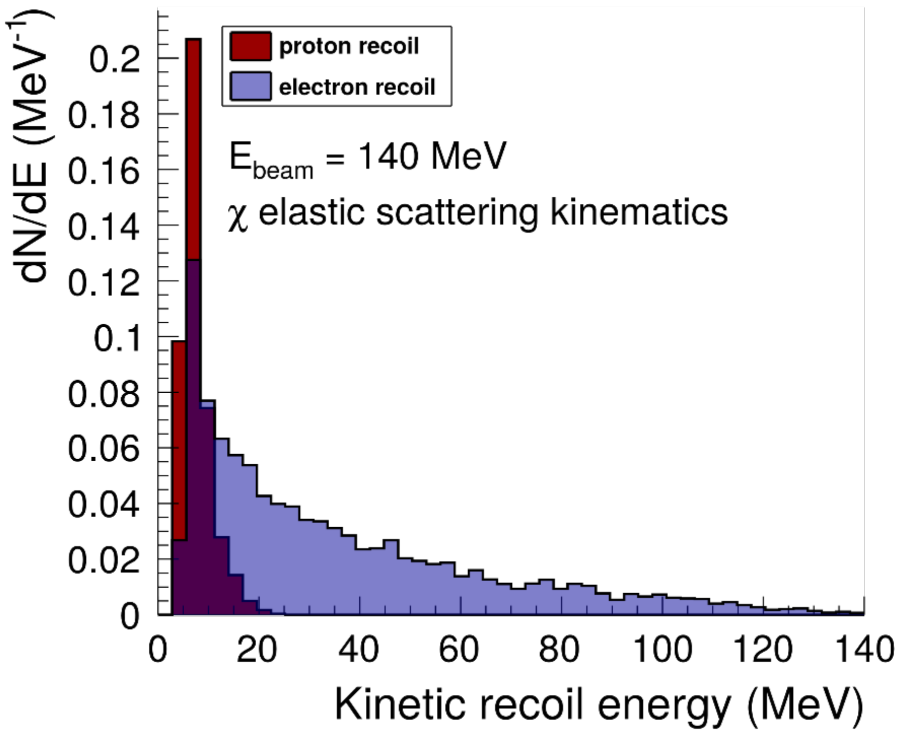
Full GEANT4 simulation:
P2 target, beam dump, BDX detector volume, walls etc.





Possibility to place a second detector off-axis

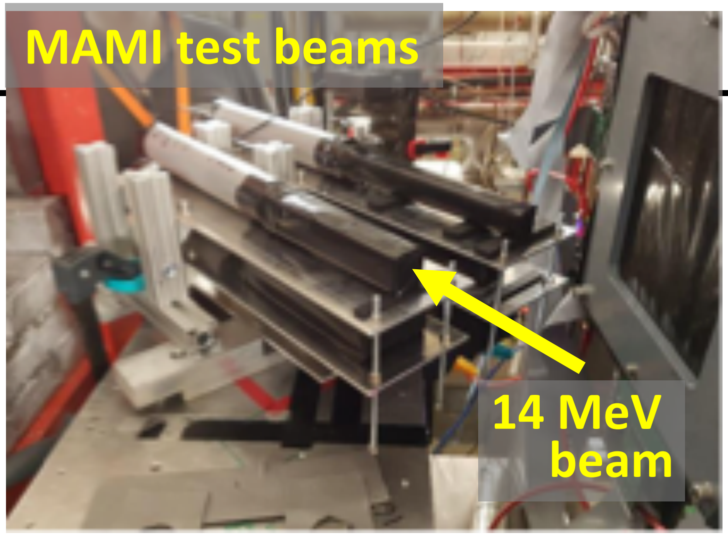
→ **LDM interaction with DarkMESA material (electron recoil)**

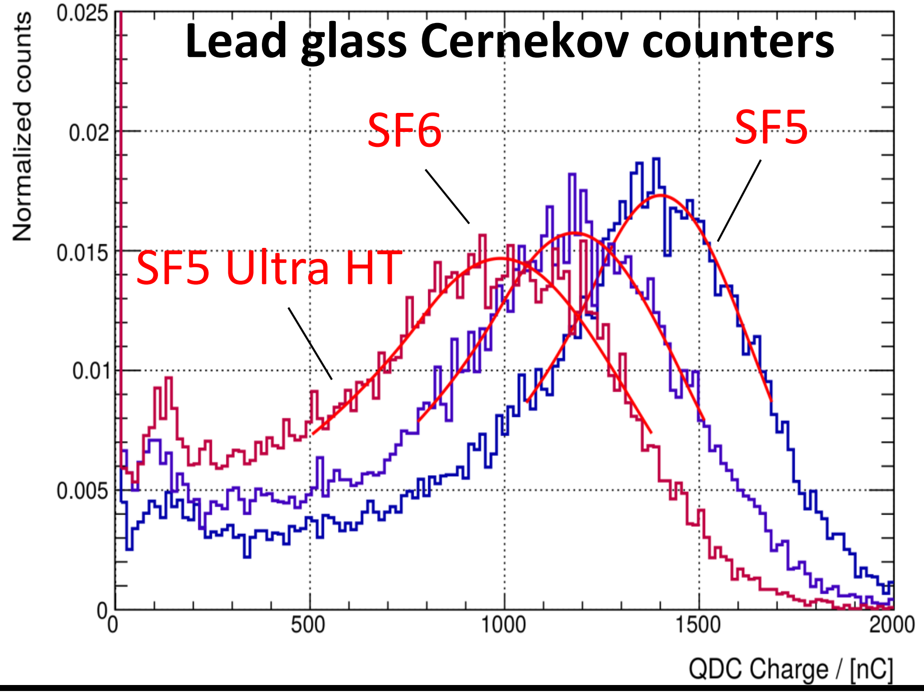


Detector Concept for DarkMESA

Ideal Requirements:
1. Electron Detection > few MeV
2. Large Surface (Acceptance)
3. Large thickness (Int. Prob.)
4. Reliability (long running time)
5. Background rejection
- Cosmics
- Natural Backgrounds
- Beam Backgrounds (n, ν)

Baseline Concept
Inorganic crystal calorimeter
- Cherenkov (fast, no neutrons)
- Scintillator (higher light yield)

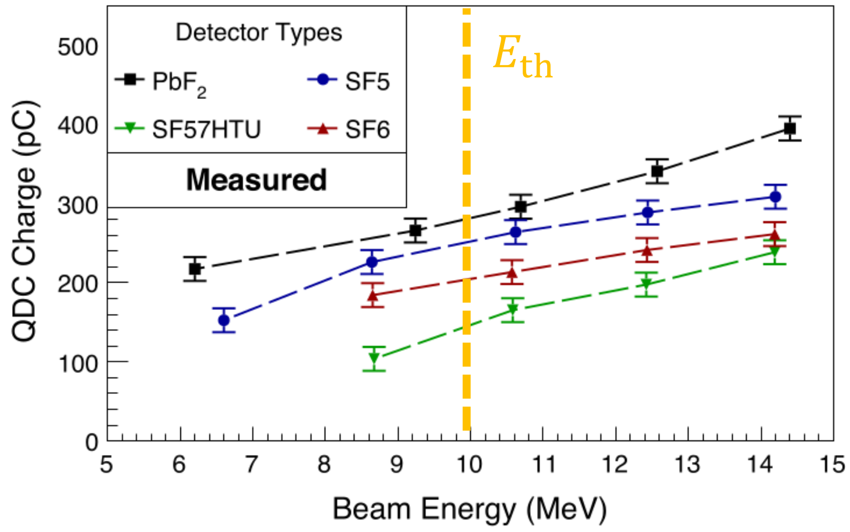




Detector Concept for DarkMESA

PbF_2 (old A4/MAMI crystals) and the Pb-glass SF5 offer proper electron sensitivity and neutron insensitivity

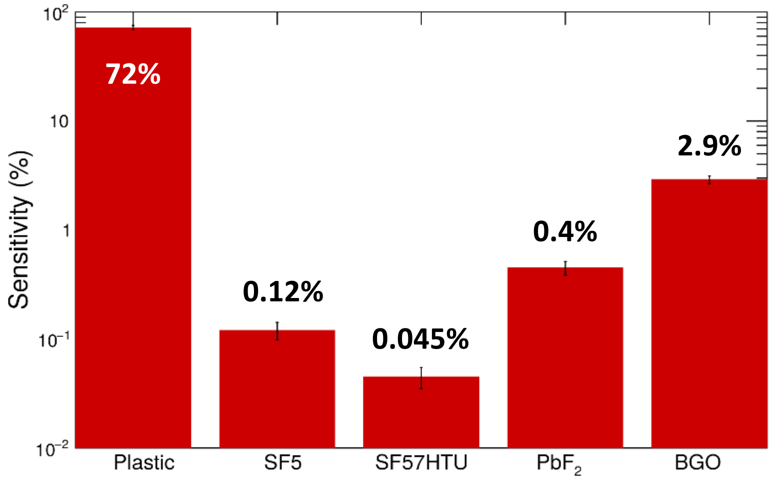
Electron sensitivity study



Electron beam tests
Mirco Christmann, et al.

- NIM A 958 (2020) 162398
- NIM A 960 (2020) 163665

Neutron sensitivity study

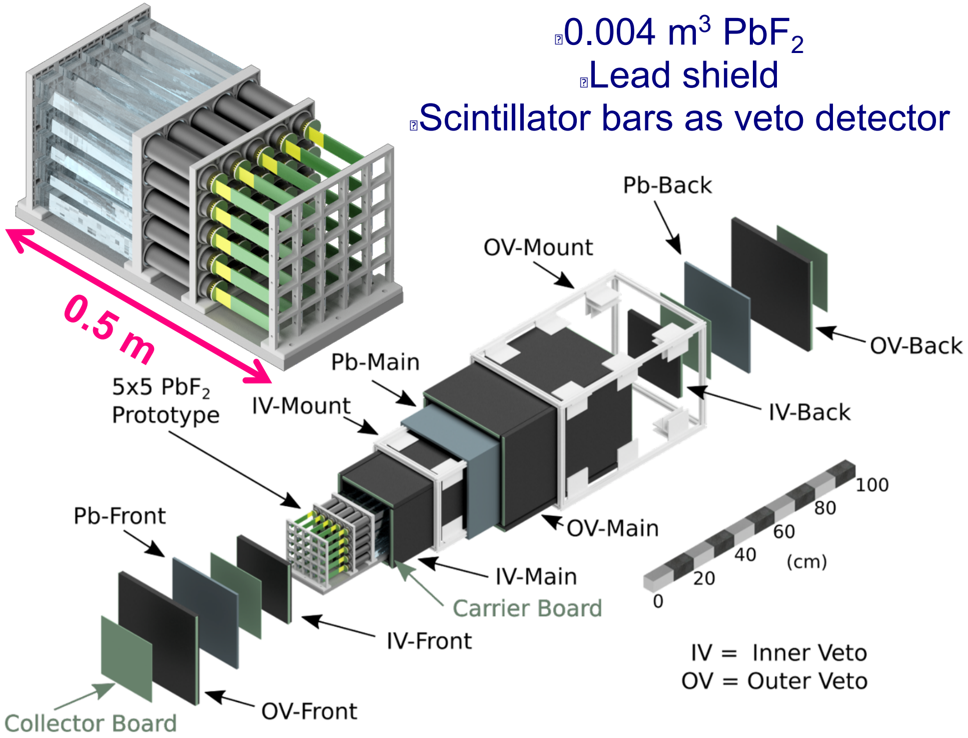


Neutron sensitivity study with an AmBe source

Detector Concept for DarkMESA

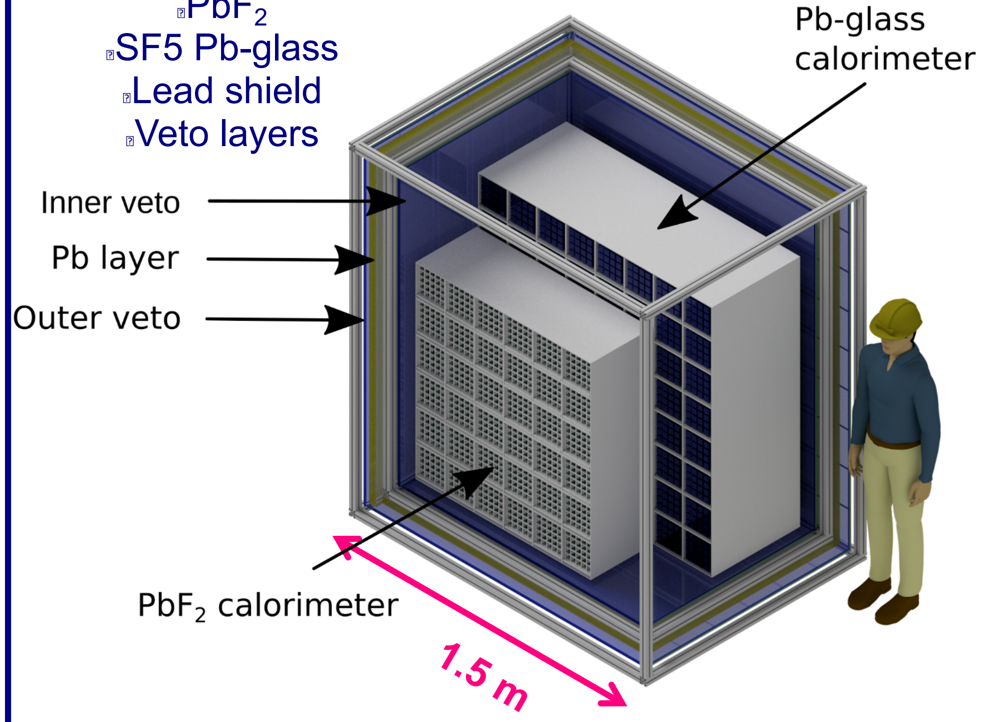
Phase A (prototype)

- 0.004 m³ PbF_2
- Lead shield
- Scintillator bars as veto detector

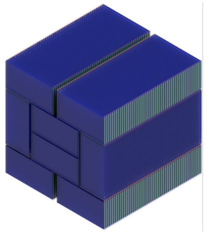


Phase B (increase volume / yield)

- PbF_2
- SF5 Pb-glass
- Lead shield
- Veto layers

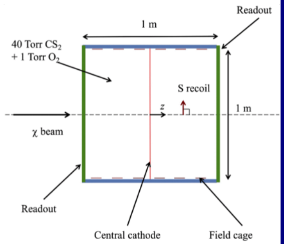


Phase C (range extension)



Radiation protection glas
e.g., SCHOTT-RD30

DRIFT -Time Projection Chamber
CS_2 at 50 mbar ~1 m³ active volume

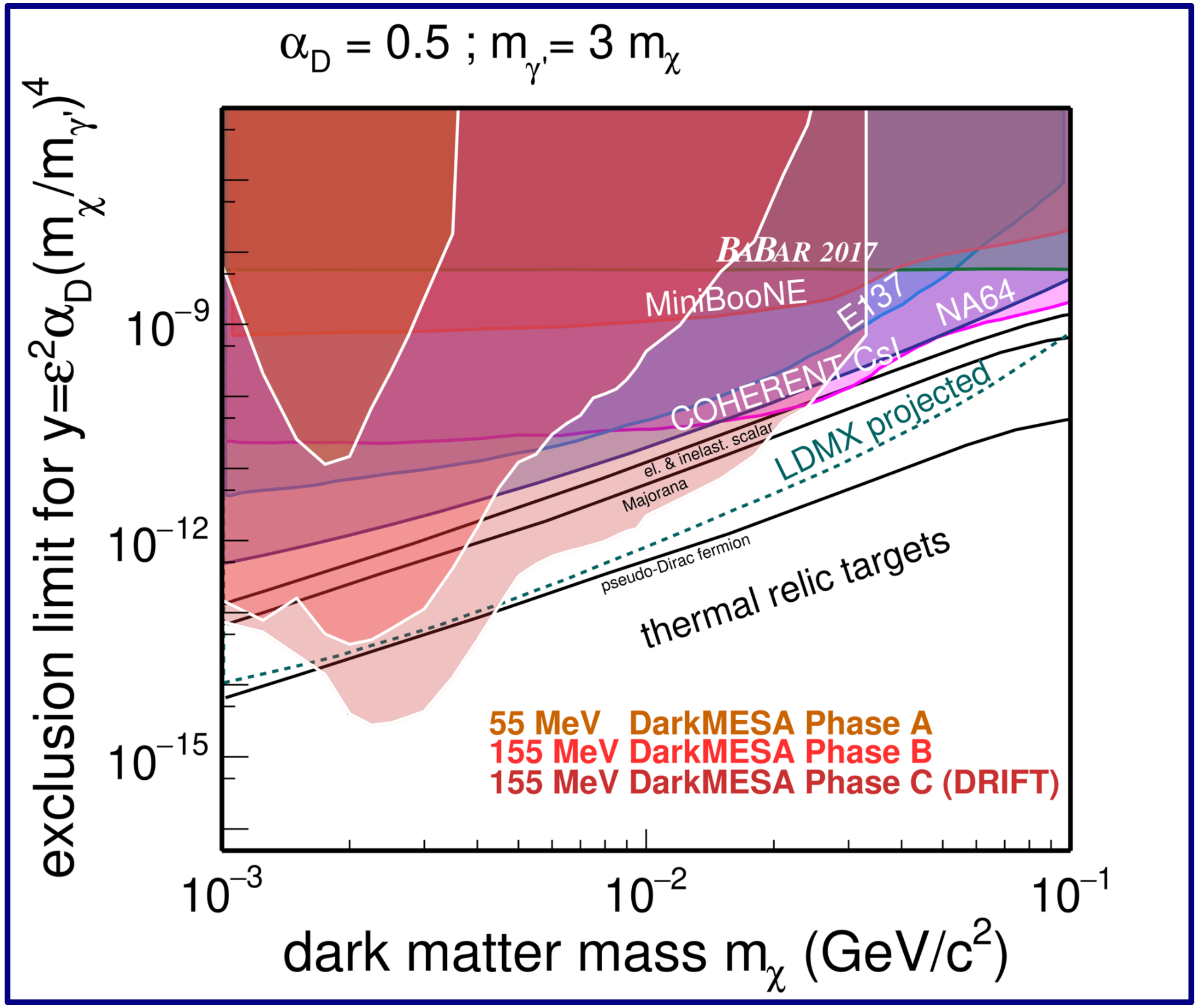


PRD 99 (2019) 061301(R)

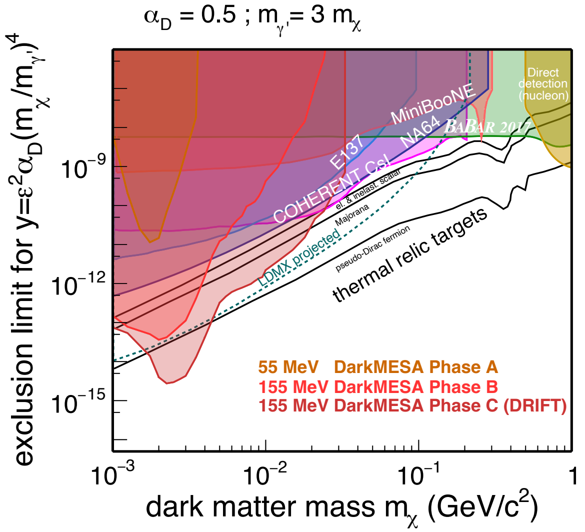
DarkMESA Physics Reach

Run plan for DarkMESA

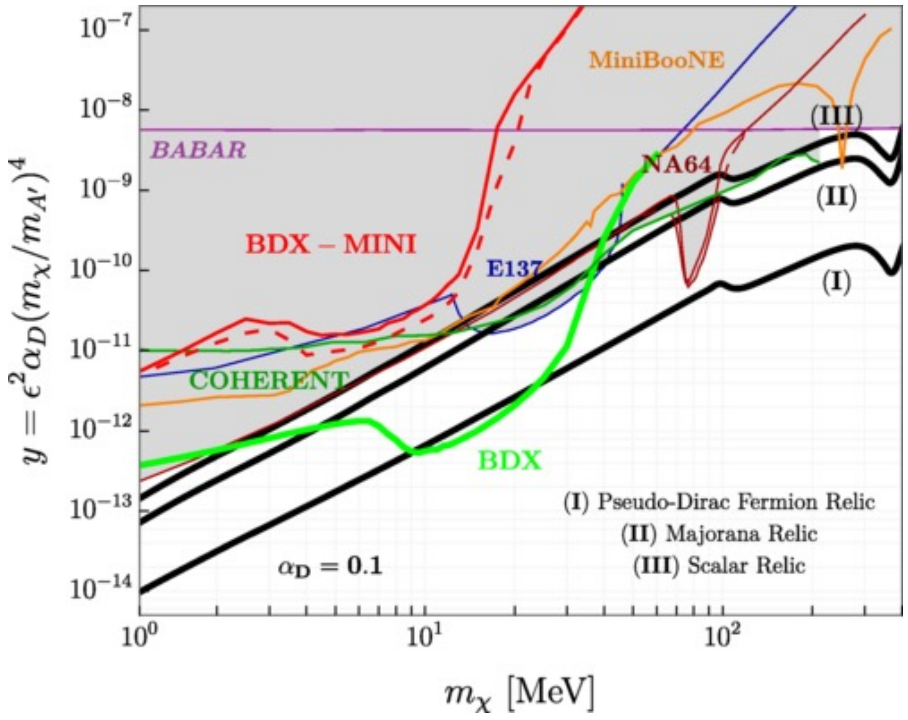
Phase	Detector	Period	Time	EOT
A	Prototype	1.-4. year	2,200 h	$7.42 \cdot 10^{21}$
B	PbF_2, SF5	4.-6. year	6,600 h	$2.22 \cdot 10^{22}$
C	+TPC	7.-12. year	13,200 h	$4.45 \cdot 10^{22}$



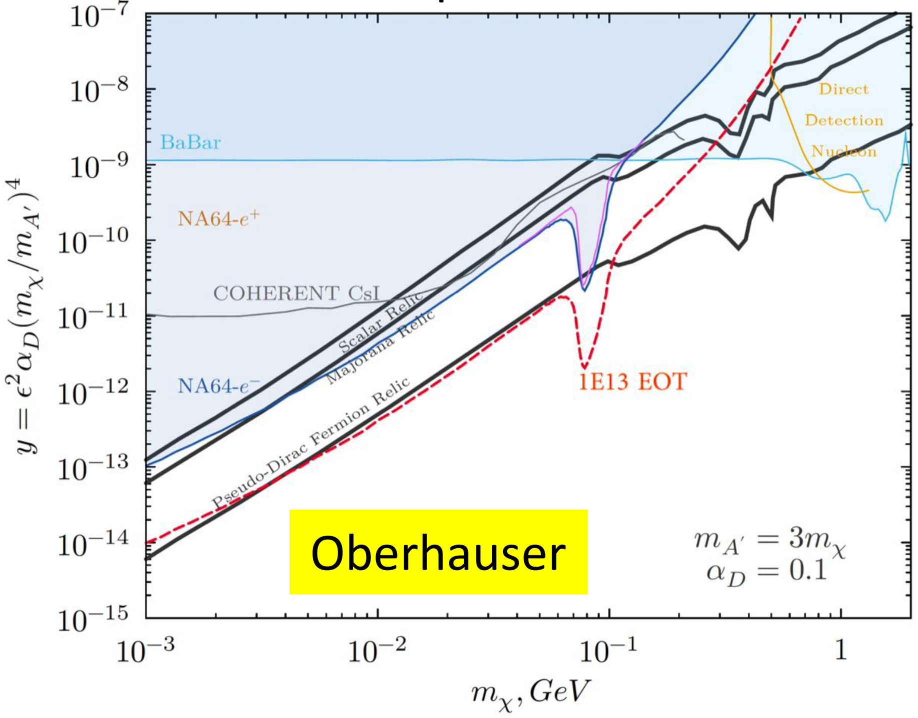
Competitors to DarkMESA



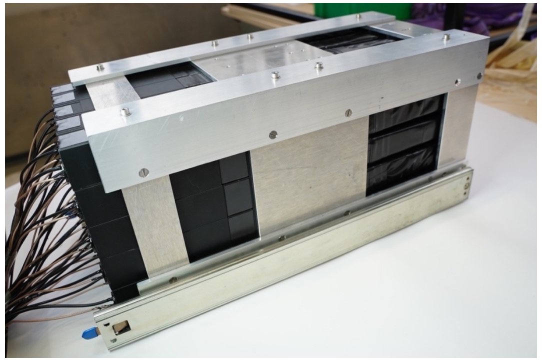
complementarity to BDX@JLAB



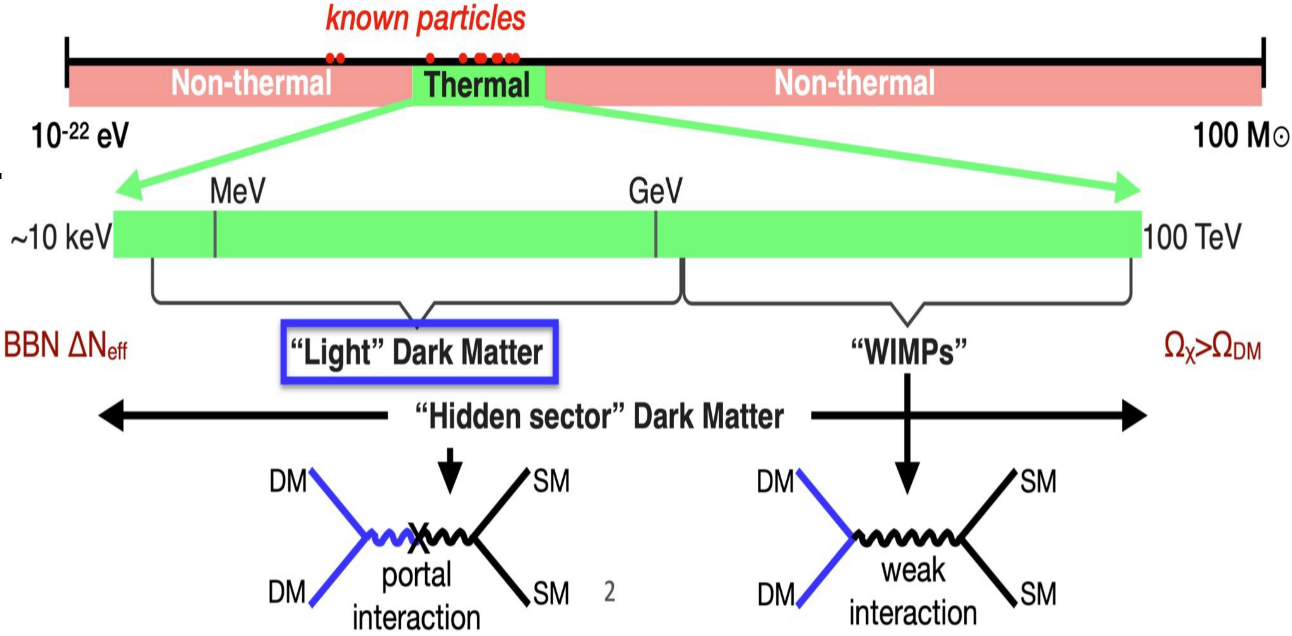
strong competition from NA64
LHC-Run3 expectation



Conclusions



Phase A
DarkMESA detector



- DarkMESA allows to test parameter space in well-motivated thermal DarkMatter model (complentary to WIMP model, for which room for discovery is narrowing)
- Based on rather conservative calorimeter design
  Phase C might need more inovative detector aspects
- Strong competition world-wide, however complementarity (direct vs. indirect searches, different probes)

Potential to make a very fundamental discovery in physics !

DARK MESA