The Light Dark Matter Program at MESA

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Light Dark World 2023, 8th Meeting LDW Int. Fortum
Karlsruhe Institute of Technology

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

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

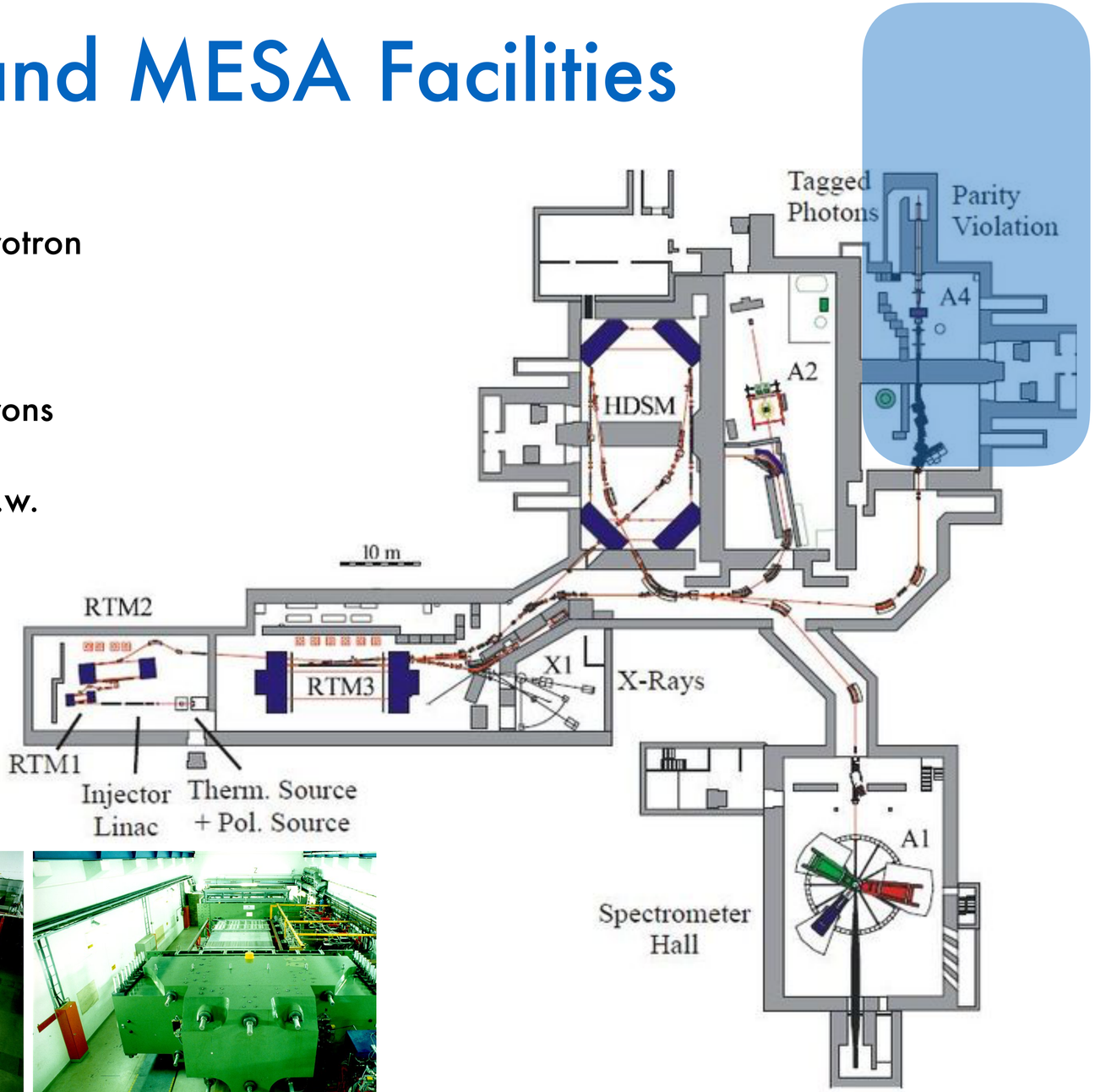
Introduction

- The MESA facility
- Experiments
- The LDM Program

The MAMI and MESA Facilities

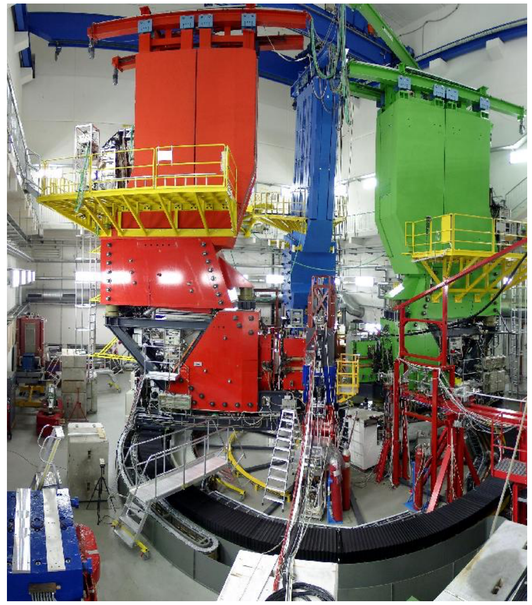
MAMI-C (since 2007)
Harmonic Double-sided Microtron
E= 1.5 GeV

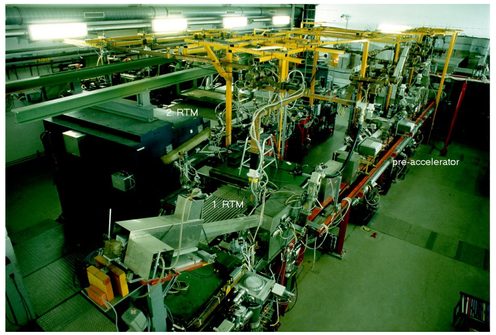
MAMI-B
3 cascaded Racetrak Microtrons
E=180-883 MeV
Max beam current 100 uA c.w.



MESA

A1 Collaboration
3-spectrometer setup
Experiments with electrons






M. KORZ
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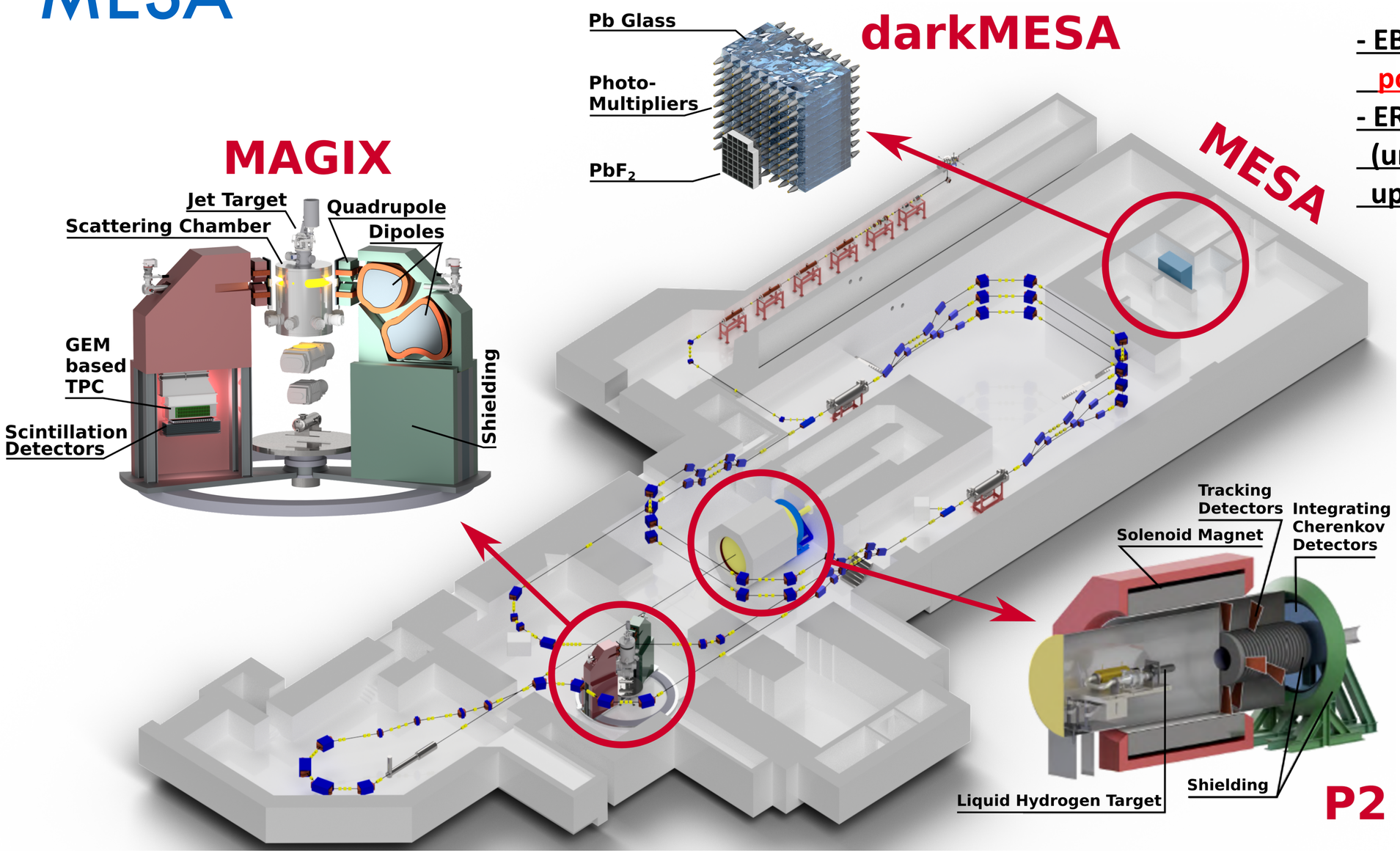
MESA



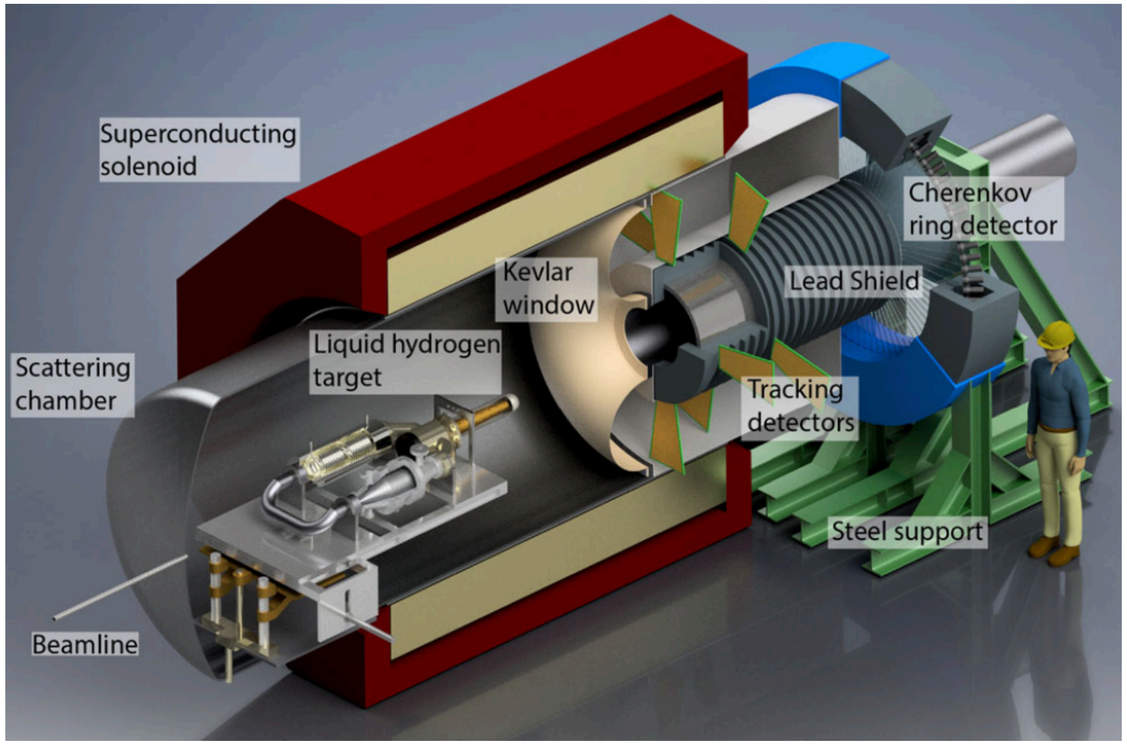
Two modes of operation:

- EB-operation (P2/BDX experiment):
polarized beam, 150 µA @ 155 MeV
- ERL-operation (MAGIX):
(un)polarized beam,
up to 1 (10) mA @ 105 MeV

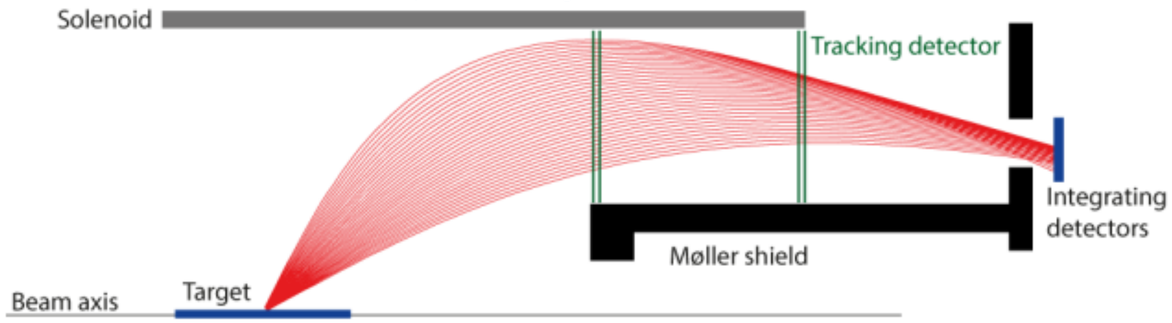
Superconducting Cavities:
9-cell ,1.3 GHz, CW operation
12.5 MeV gain
XFEL-TESLA type
Modified Rossendorf-type Modules

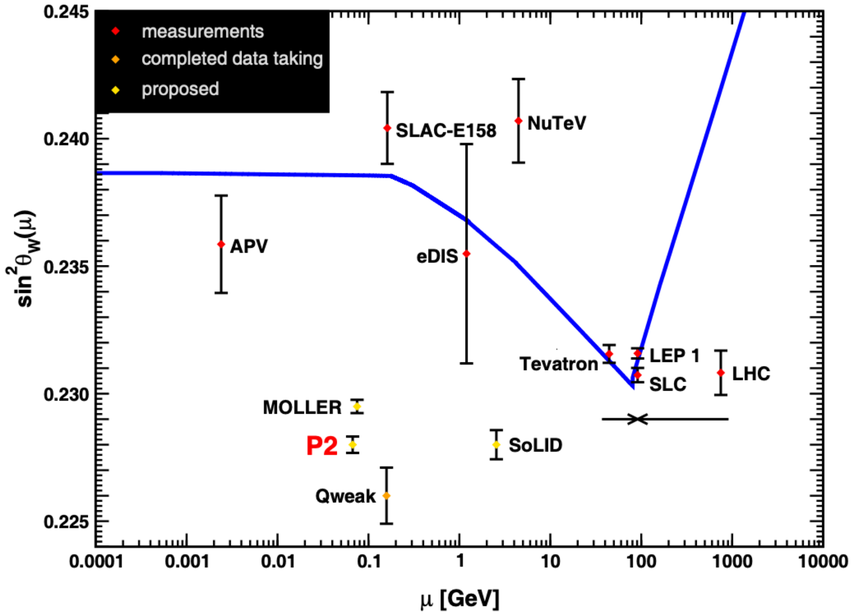
P2

The P2 Experiment



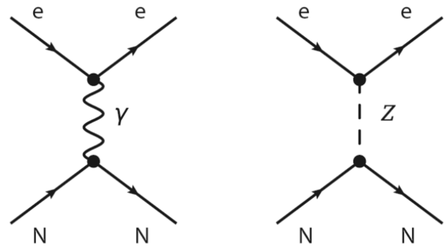
Becker et at, Eur. Phys. J. A (2018) 54: 208





$$A^{\mathrm{PV}} = \frac{-G_{\mathrm{F}}Q^2}{4\pi\alpha_{\mathrm{em}}\sqrt{2}}\left[Q_{\mathrm{W}}(\mathrm{p}) - F(E_{\mathrm{i}}, Q^2)\right]$$

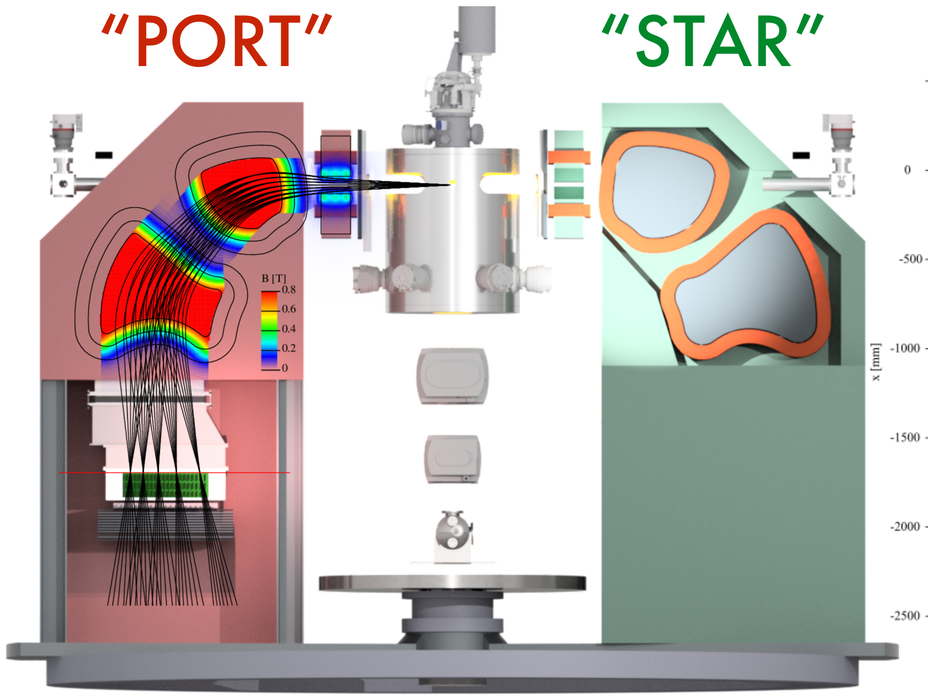
$$Q_{\mathrm{W}}(\mathrm{p}) = 1 - 4\sin^2\theta_{\mathrm{W}}$$

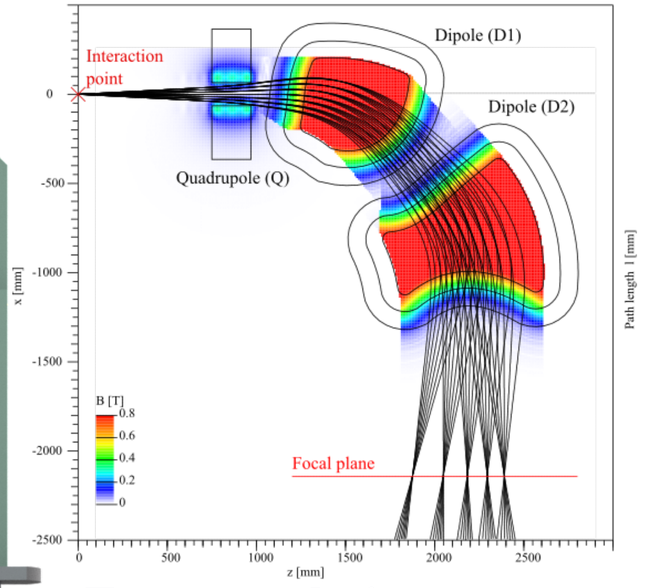


- Precise measurement of the Weinberg angle at low energy
- PV elastic electron scattering
- Polarimetry: Mott+Hydro-Moller
- Feedback beam stabilisation
- High rate: integrating detectors.
- Silicon strip detectors tracking (HV-MAPS)

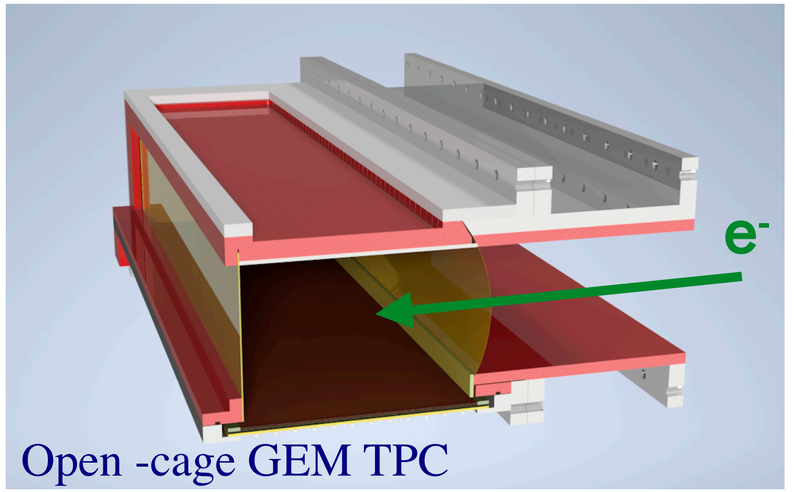
MAGIX

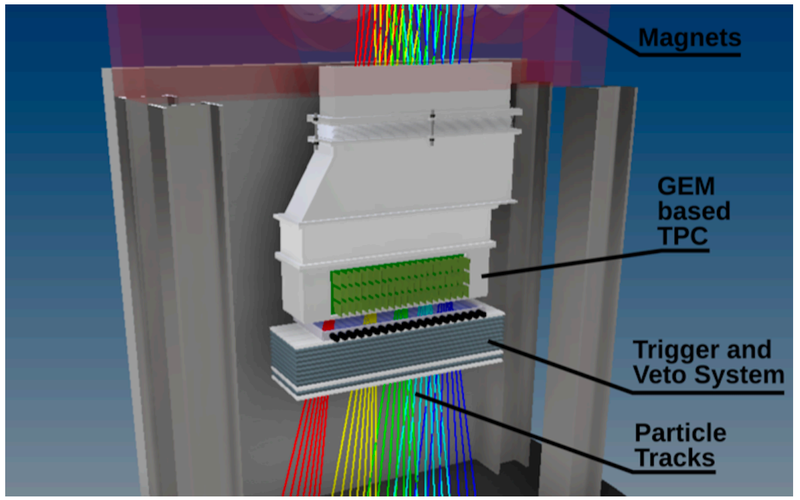
MAGIX





Rotation: 15°-165°





Timing

- TPC trigger: ~ 1 ns
- coincidence time STAR↔PORT: ~100 ps

Focal Plane resolutions (*p*-dependent etc)

- positions: ~ 100 µm angles: ~ 3.5 mrad

Target resolutions

- dp/p: 6×10^{-5}
- in-plane angle ϕ_0: 6.5 mrad
- oop angle θ_0: 1.6 mrad vertex y_0: 60 µm

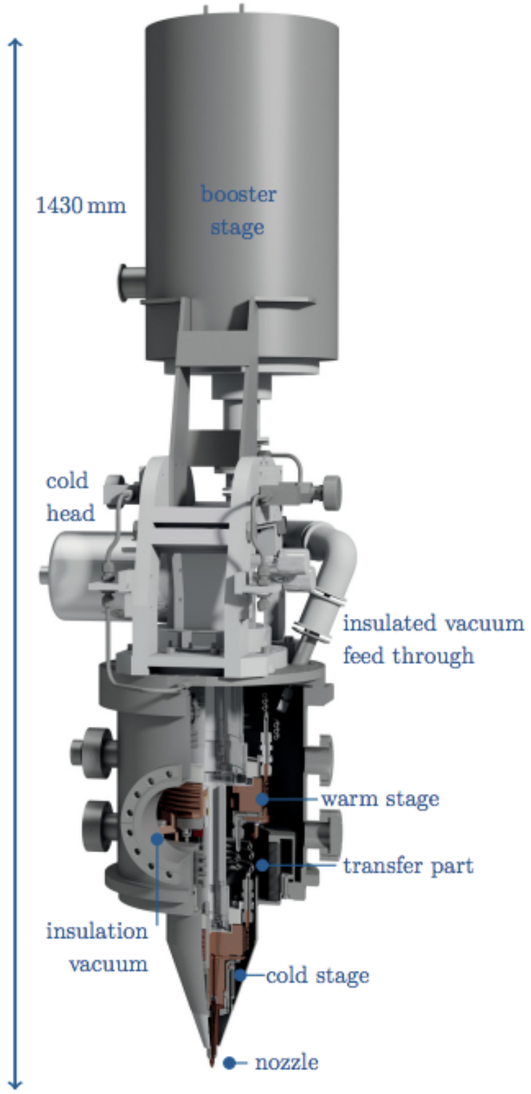
Acceptances

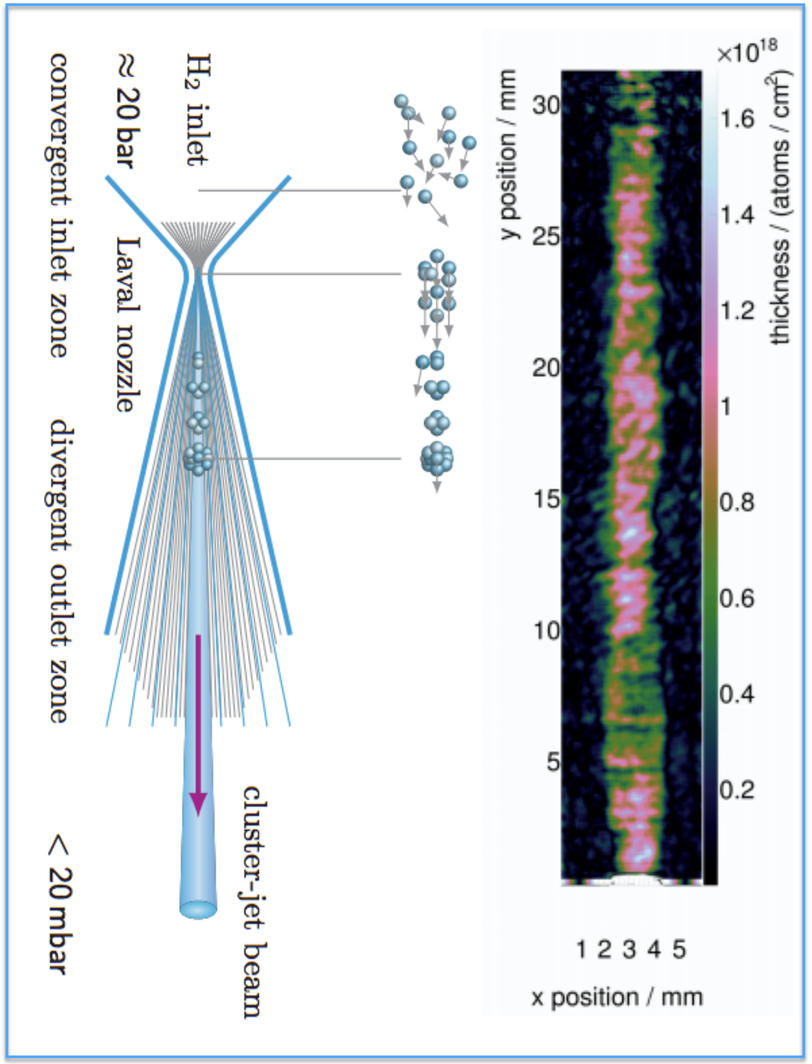
- momentum acceptance: ± 15 %
- solid angle: 18 msr

Focal Plane Dectectors

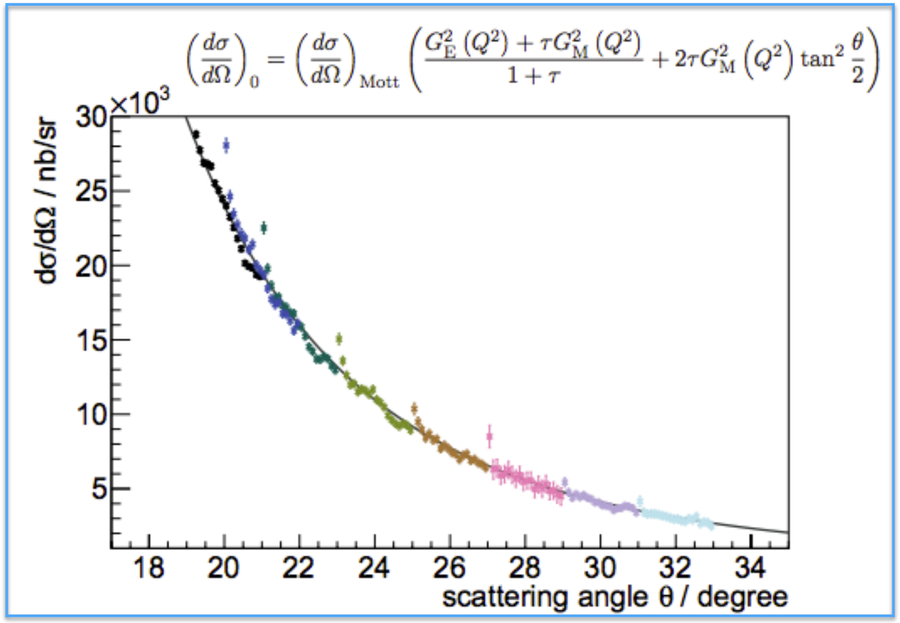
- Low-material open-cage GEM TPC
- Scintillator stack

The gas-jet Target





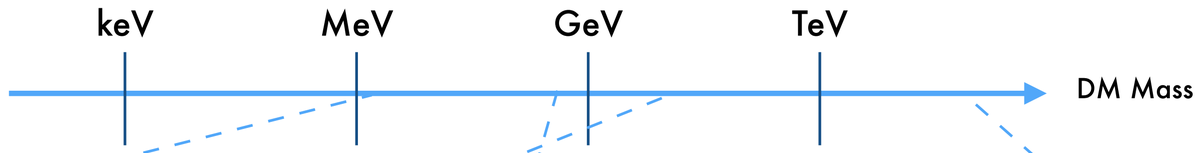
- Supersonic gas flow from Laval nozzle
- Supersonic shockwaves and clustering at cryogenic temperatures limit gas diffusion
- mm-wide collimated gas stream



B.S. Schlimme et al., NIM A, 1013, 11, 165668 (2021)

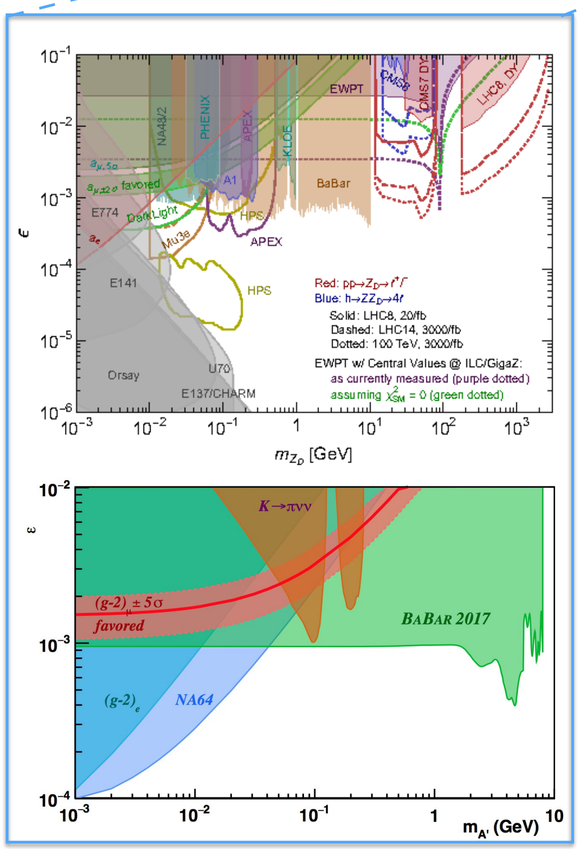
LDM with MAGIX

Light Dark Matter

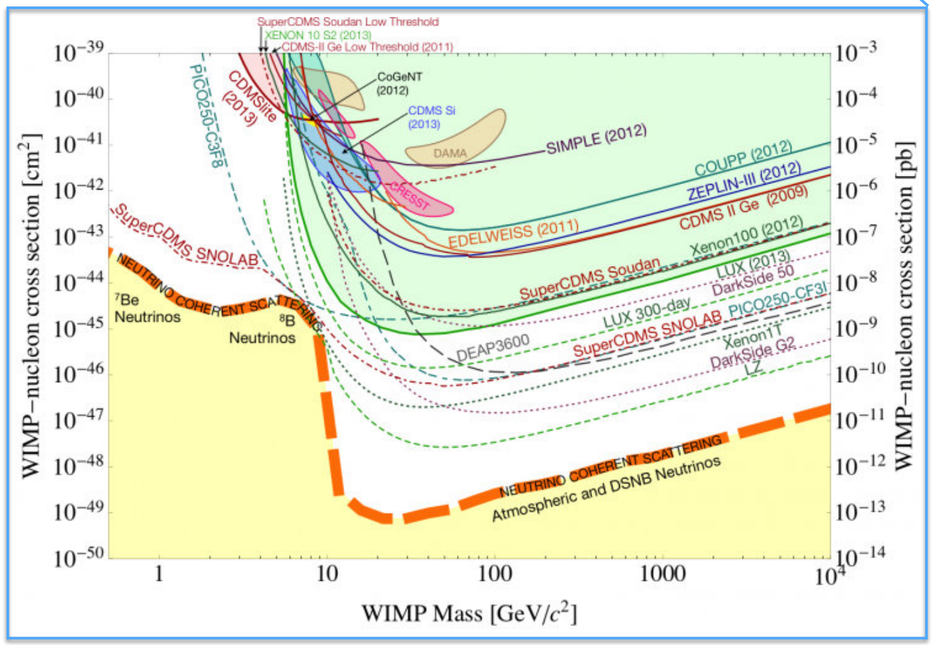


m_p

LDM

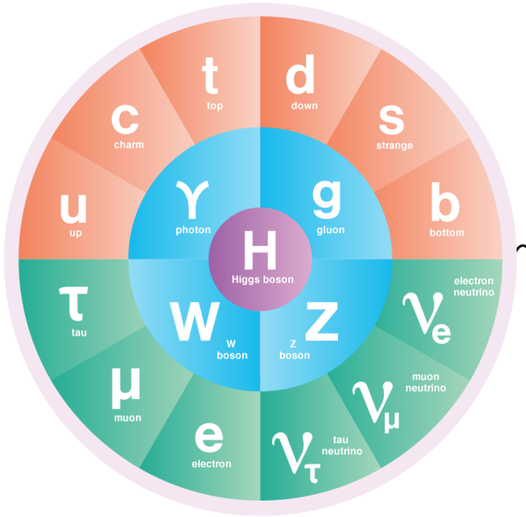


WIMPs

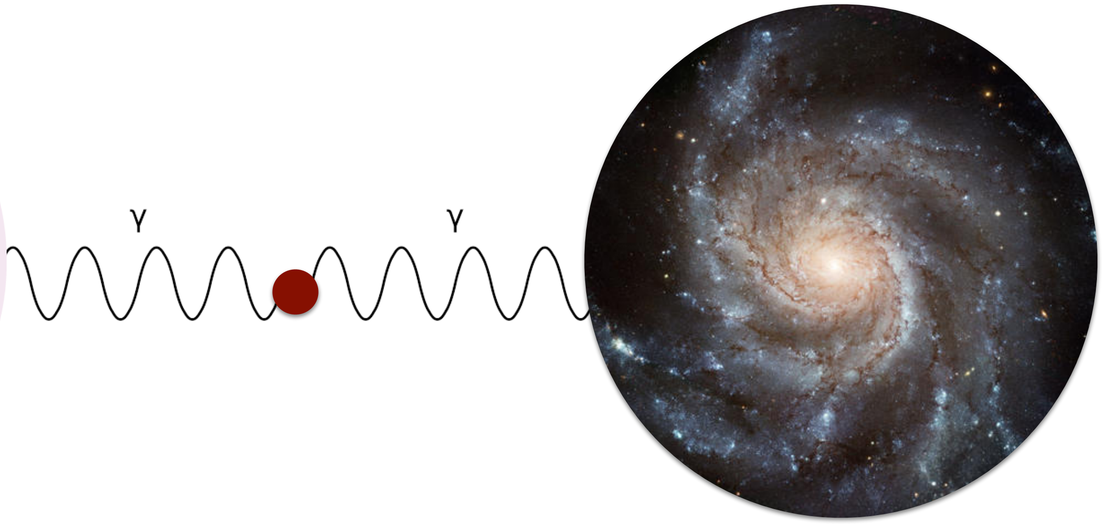


Dark Photon Models

Standard Model



Dark Sector



"Portals"

Vector Portal	$\frac{1}{2}\epsilon_Y F_{\mu\nu} F^{'\mu\nu}$
Higgs Portal	$\epsilon_h \lvert h\rvert^2 \lvert\phi\rvert^2$
Neutrino Portal	$\epsilon_\nu h L \psi$
Axion Portal	$\frac{G_{a\gamma\gamma}}{4} a F_{\mu\nu} \tilde{F}^{\mu\nu}$

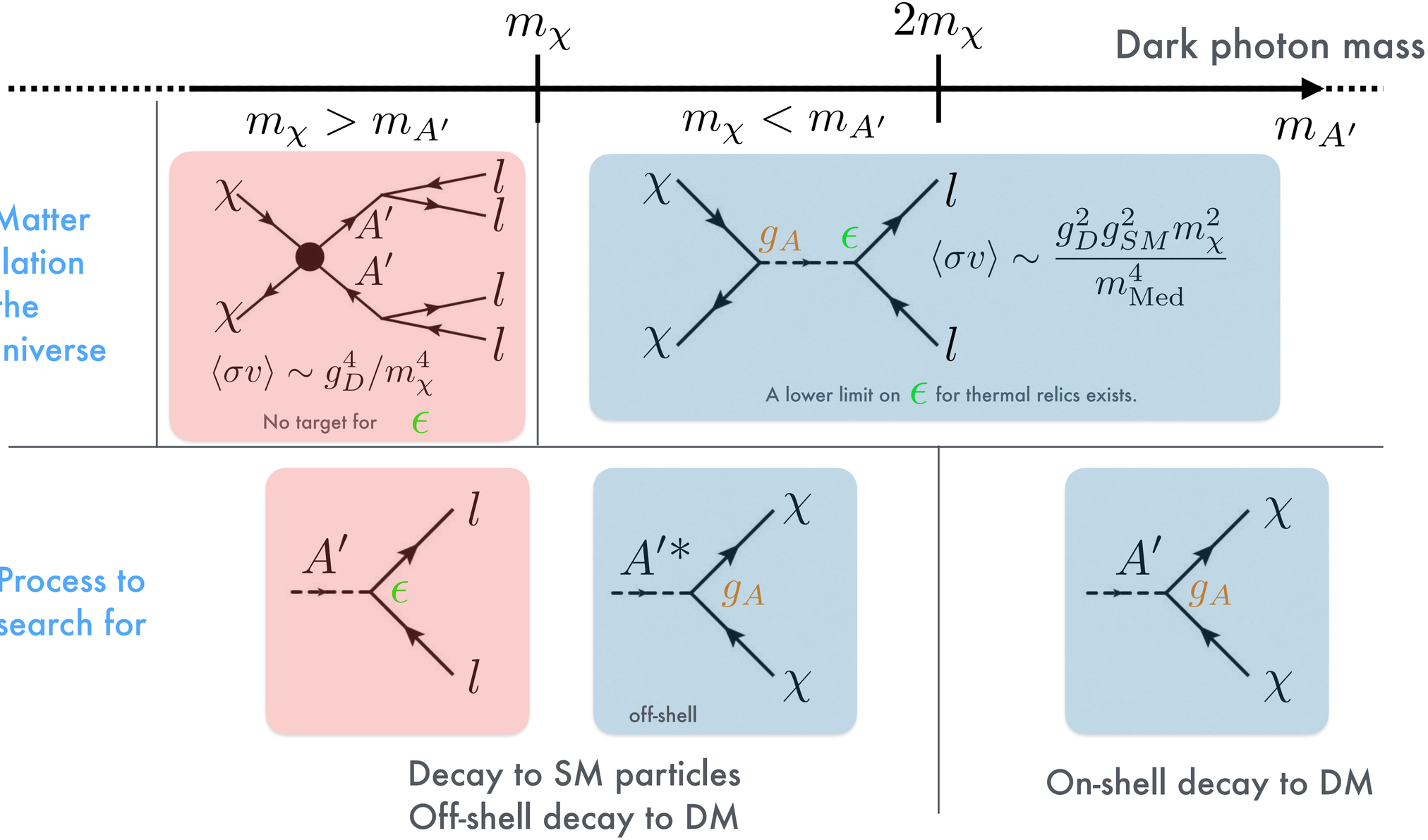
Minimal Dark Photon Model

$$\mathcal{L} \sim \bar{\chi}(i\not{D} - m_\chi)\chi + \frac{1}{2}\epsilon_Y F^{'}_{\mu\nu} B_{\mu\nu} + \frac{1}{2} m^2_{A'} A^{'}_\mu A^{'\mu}$$

New U(1) massive gauge boson

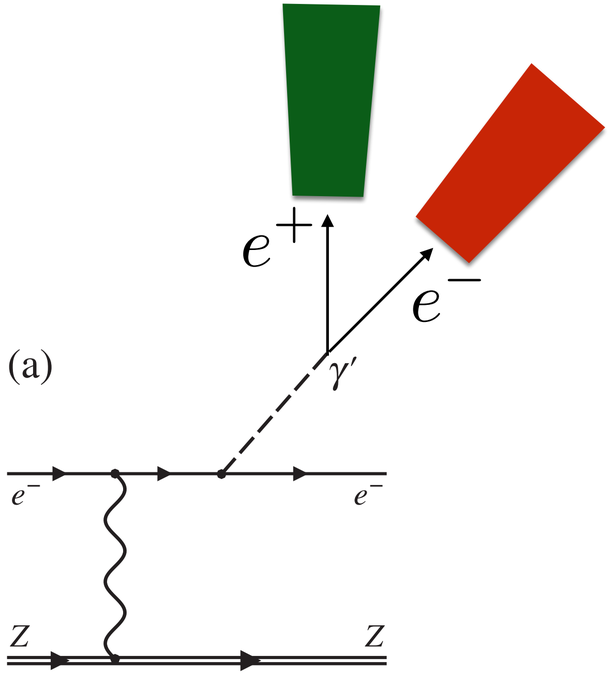
4 parameters: $m_{A'}$ m_χ $\alpha_D = \frac{g_D^2}{4\pi}$ ϵ_Y

Dark Photon Models



Visible Dark Photon Decays

Visible decays

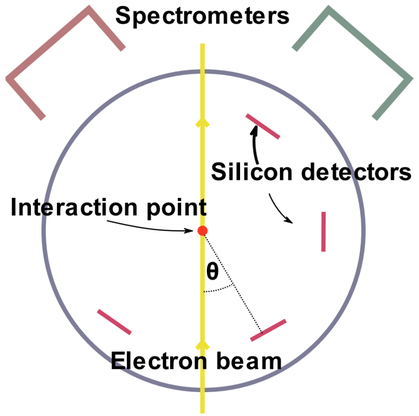


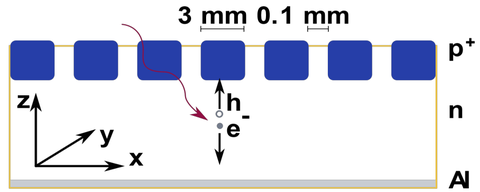
Coincidence detection of decay products
Production on heavy nucleus (Ar, Xe, ..)
Technique proved at A1

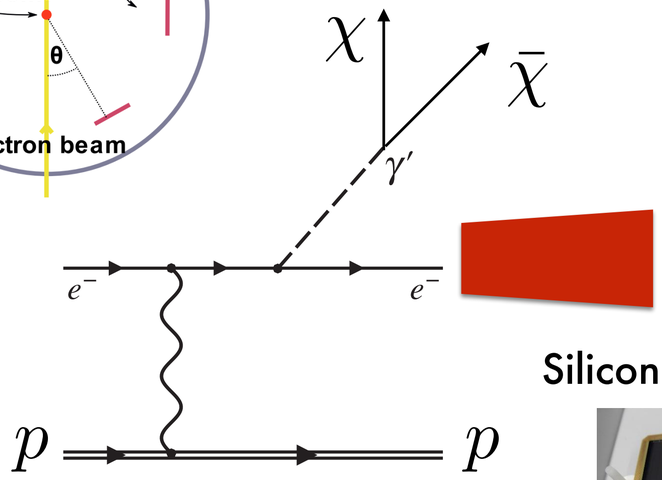
H Merkel et al. Phys. Rev. Lett. 106 (25), 251802 (2011)

H Merkel et al., Phys. Rev. Lett. 112 (22), 221802 (2014)

Invisible decays



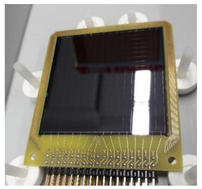




Detect:
- Scattered electron
- Recoil proton

<u>Search on missing mass spectrum</u>

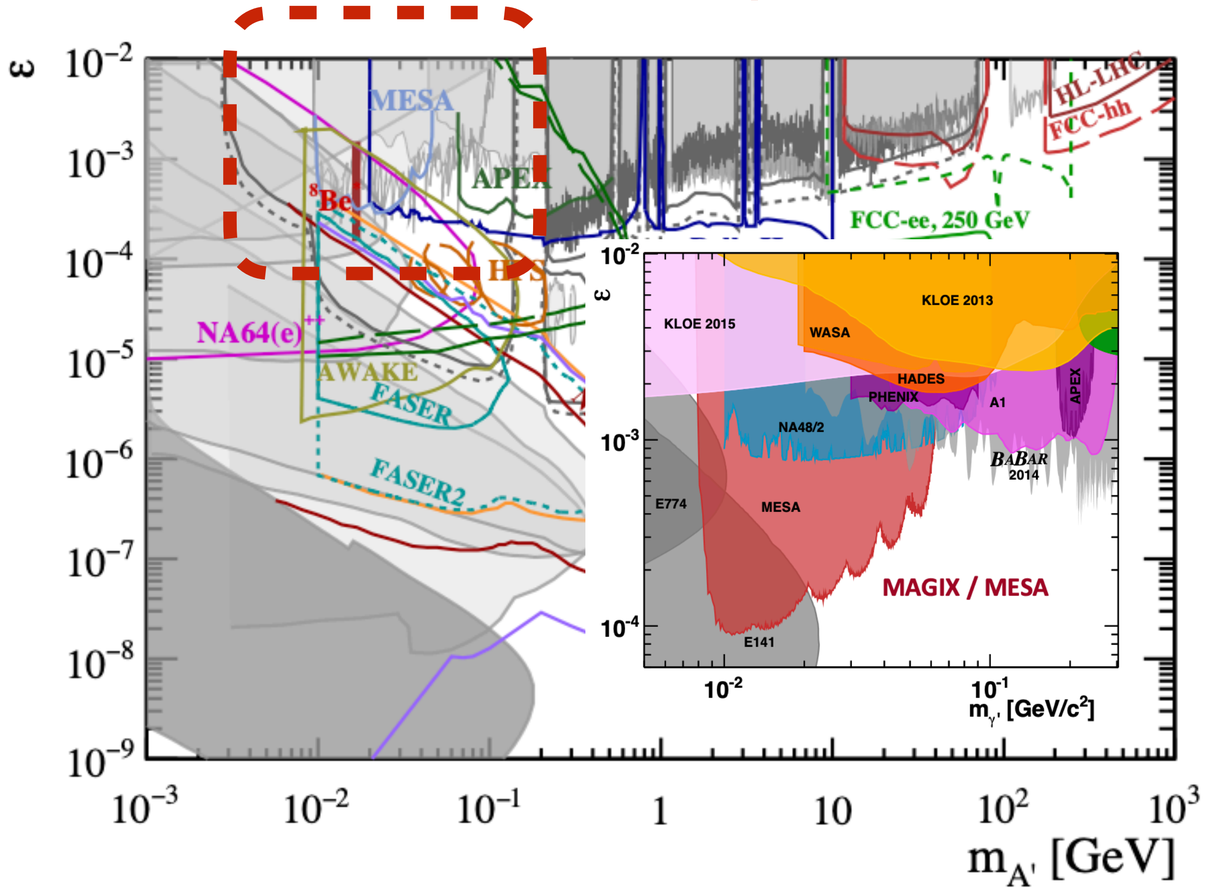
Silicon Detectors



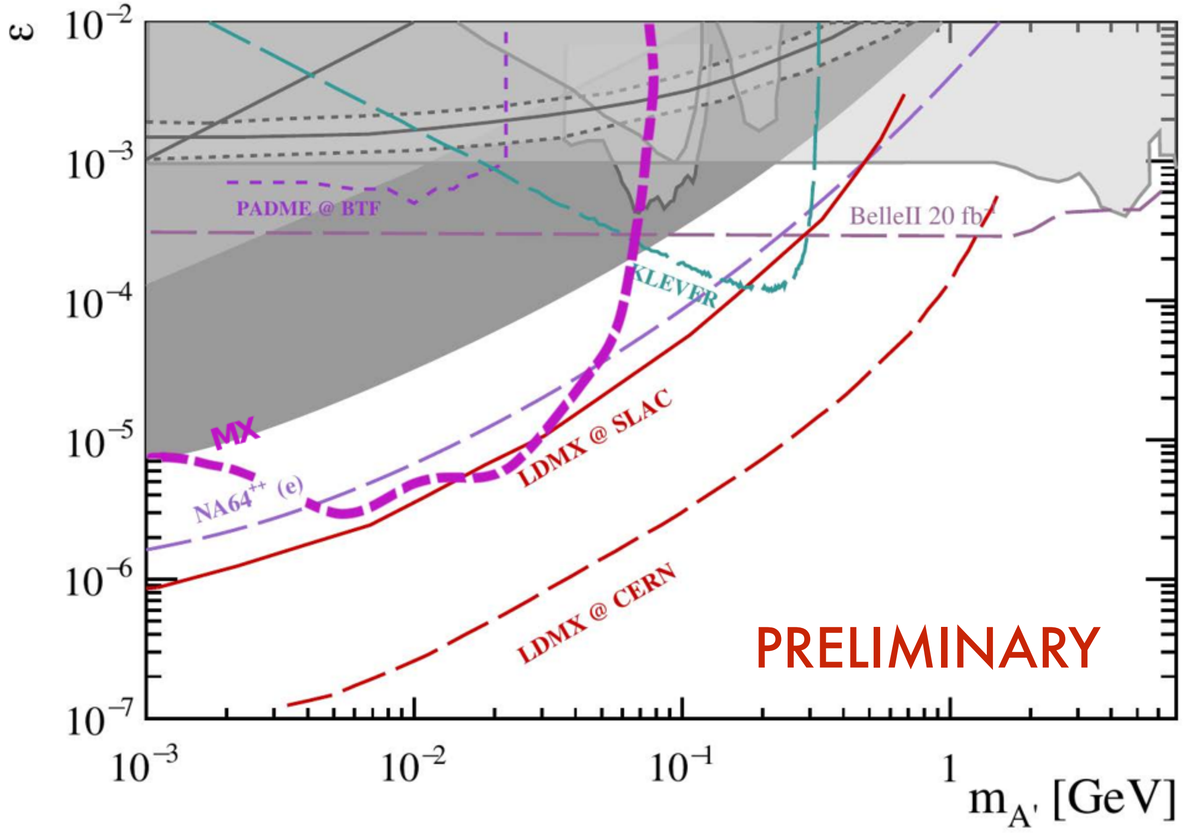
Dimension substrate	50 x 50 mm^2
Thickness substrate	995 µm
p-doped strips	16
Strip width	3 mm
Bias voltage	140 V

Dark Photons at MAGIX: Projections

Visible decays



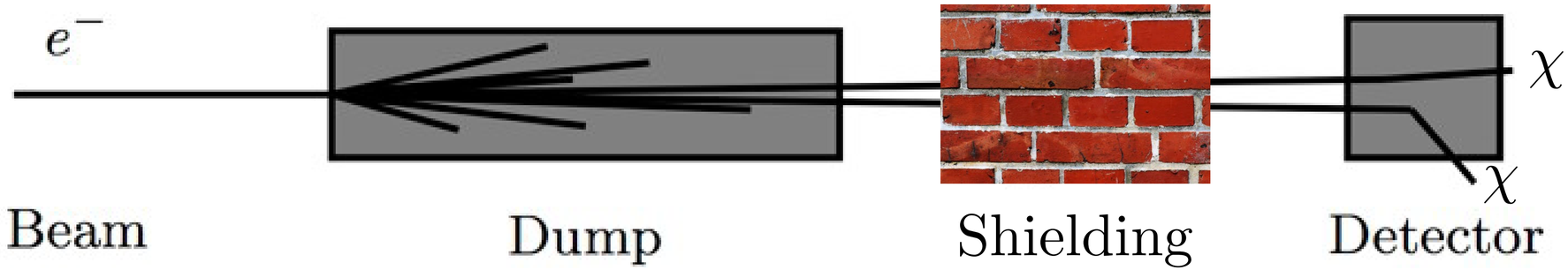
Invisible decays



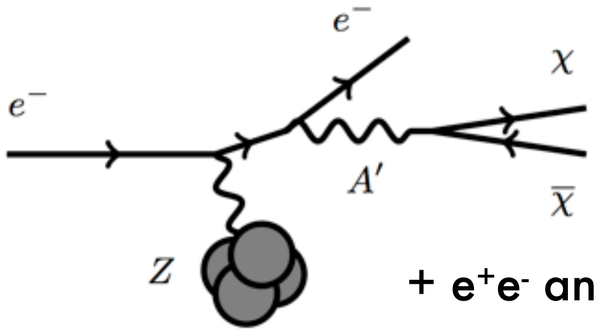
LDM with DarkMESA

DarkMESA

Bjorken et al., Phys. Rev. D80, 075018 (2009)



Production

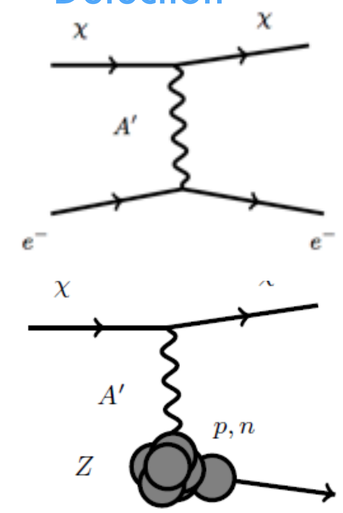


+ e^+e^- annihil.

$$\theta_{A'\,\max} \sim \max\left(\frac{\sqrt{m_{A'} m_e}}{E_0}, \frac{m_{A'}^{3/2}}{E_0^{3/2}}\right)$$

$$\frac{d\sigma}{dx} \approx \frac{8Z^2\alpha^3\epsilon^2 x}{m_{A'}^2}\left(1 + \frac{x^2}{3(1-x)}\right)\mathcal{L}og$$

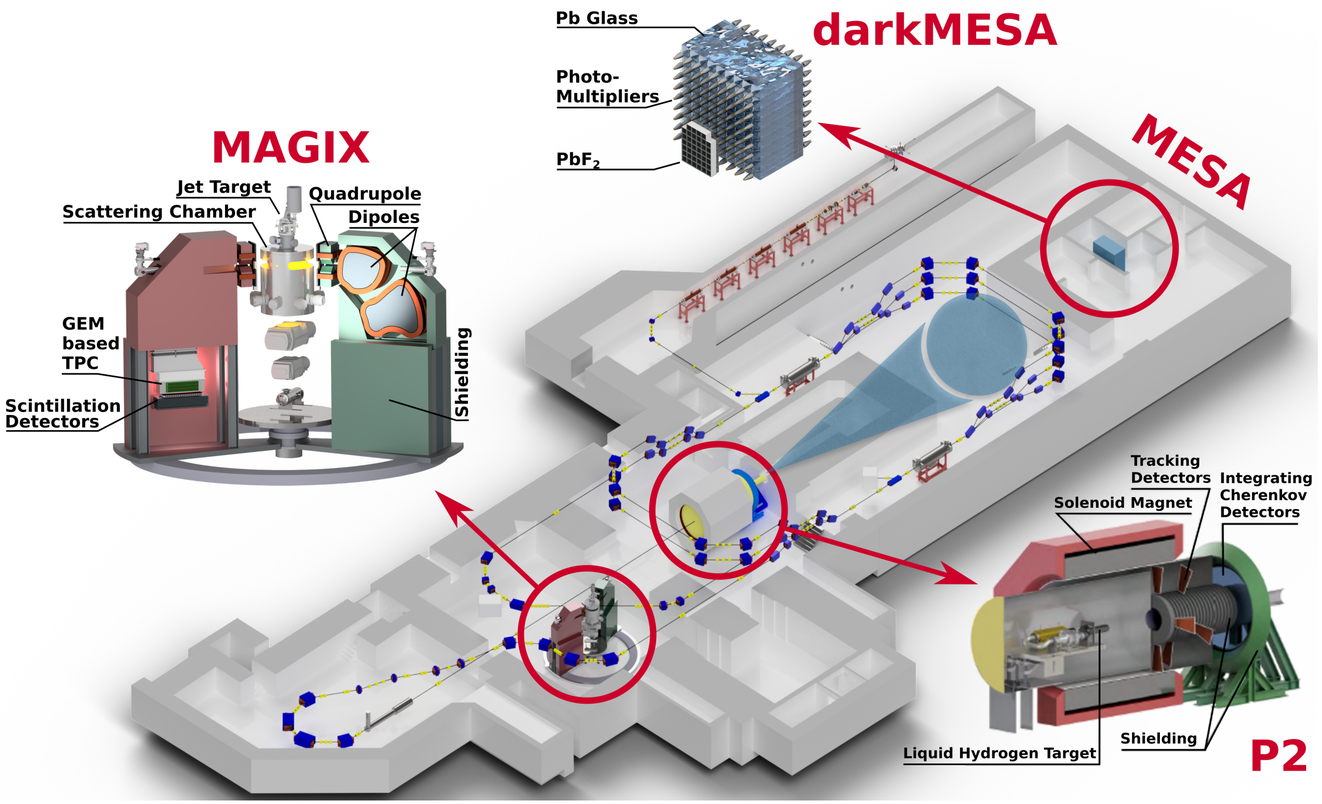
Detection



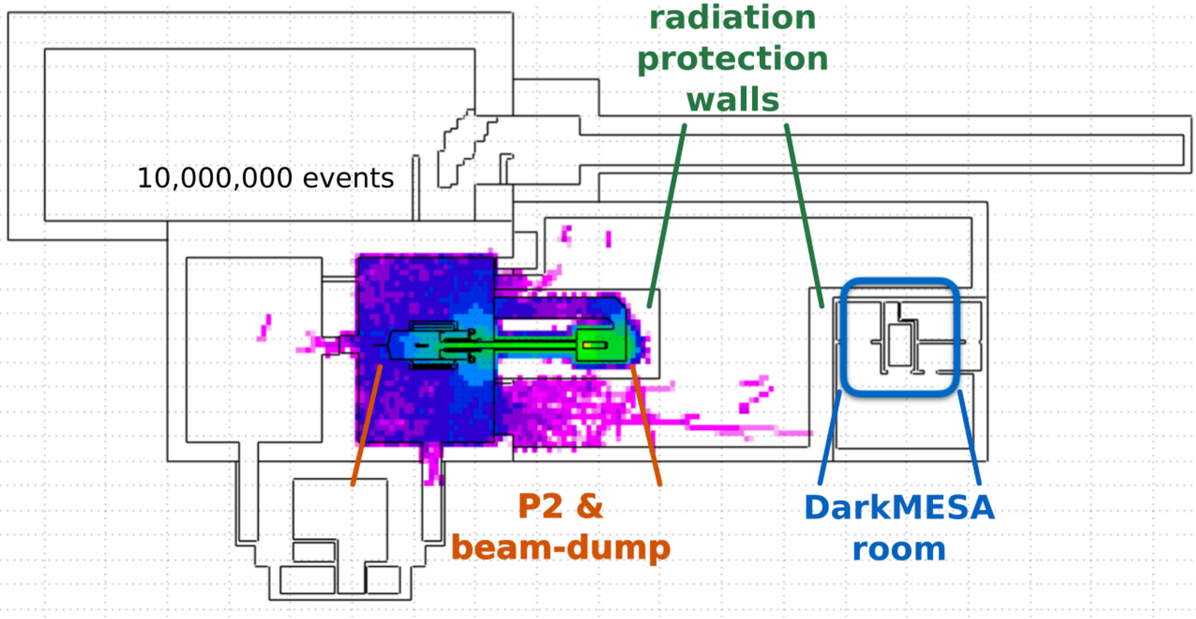
Total Yield

$Y_{Prod} \sim \epsilon^2/m_A^2$ → $Y_{TOT} \sim \epsilon^4\alpha_D/m_A^4$ ← $Y_{Det} \sim \epsilon^2\alpha_D/m_A^2$

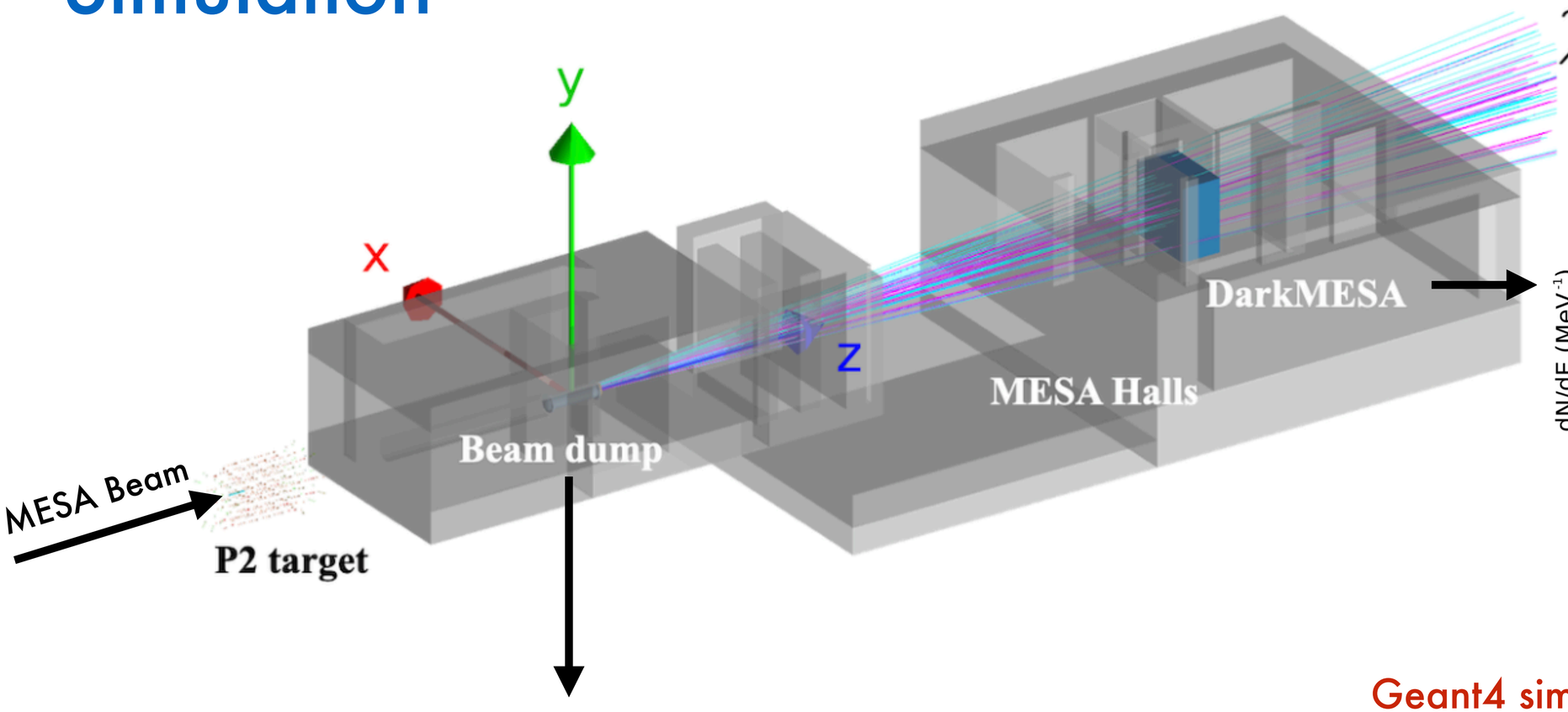
DarkMESA

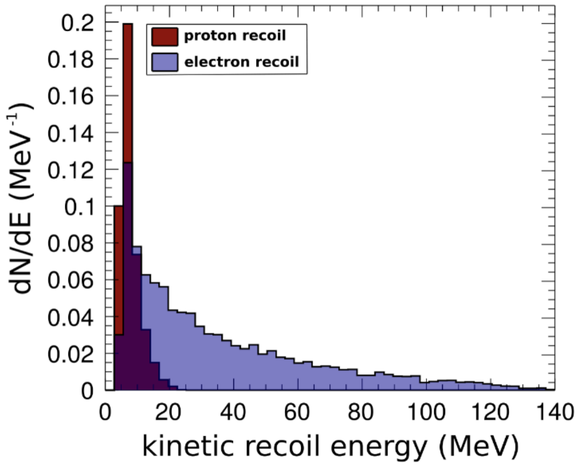


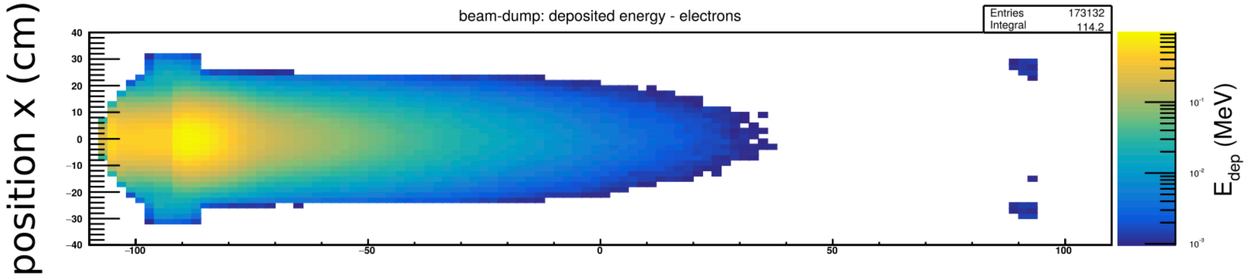
FLUKA Simulation (neutrons)



Simulation



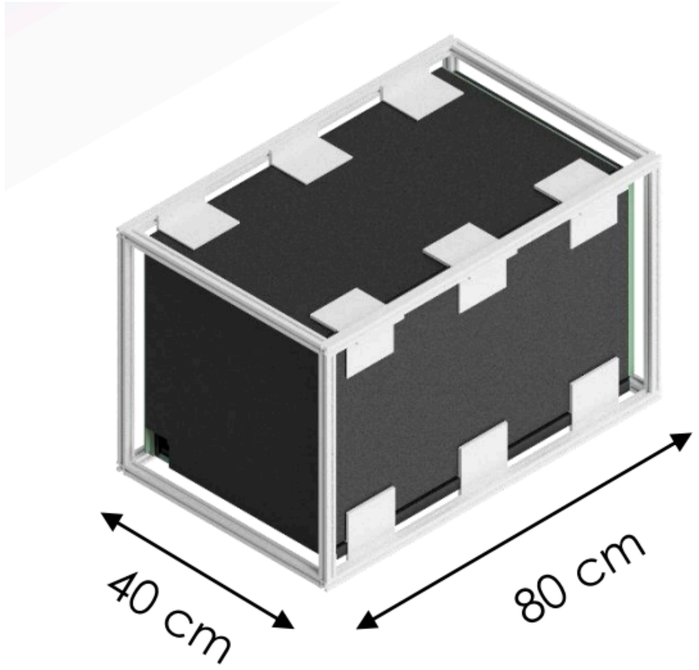


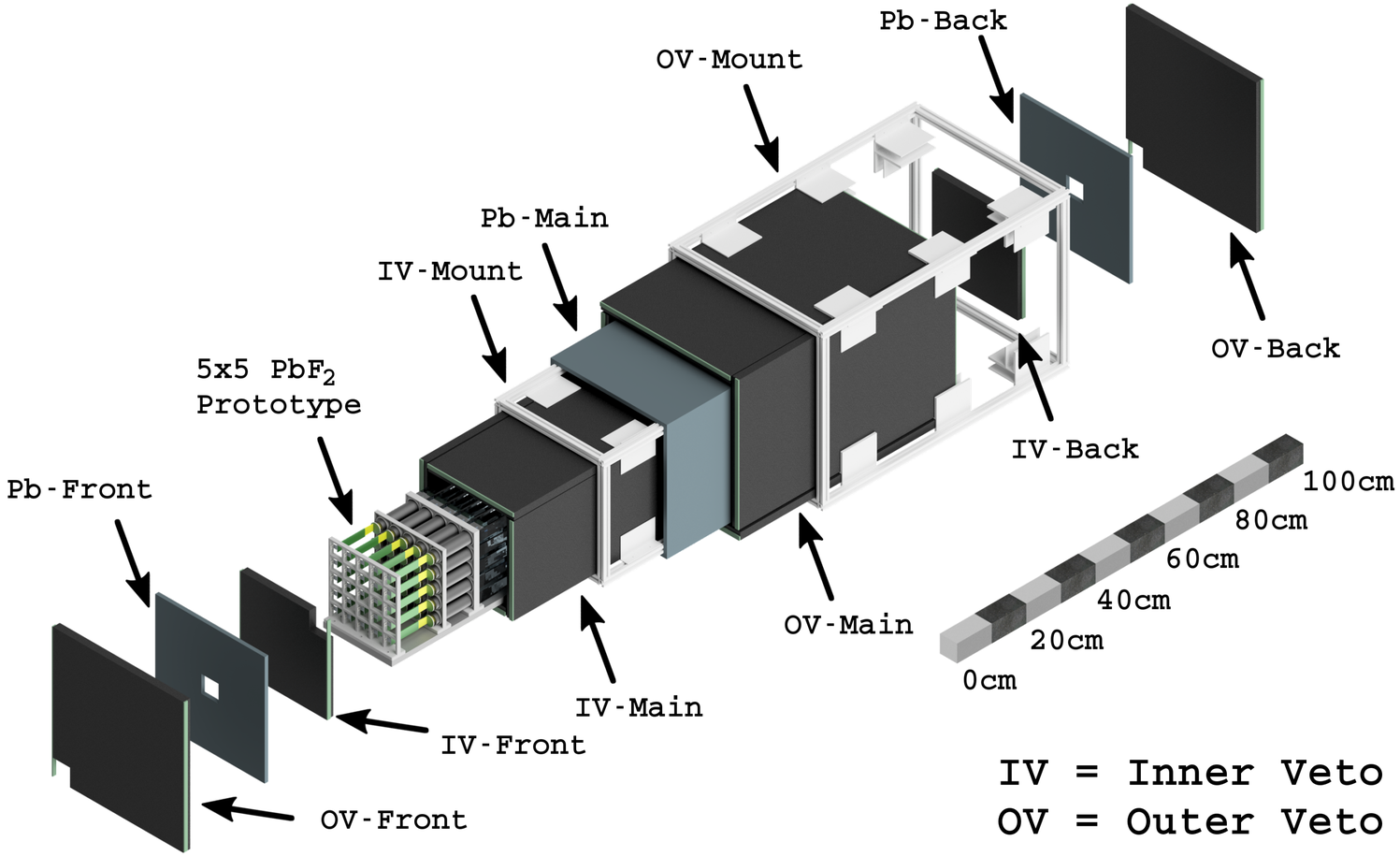


Geant4 simulation:

- LDM production with MADGRAPH
- Experimental halls
- P2 target and magnetic field
- Beam dump (particle distributions)
- Cosmics (CRY package)

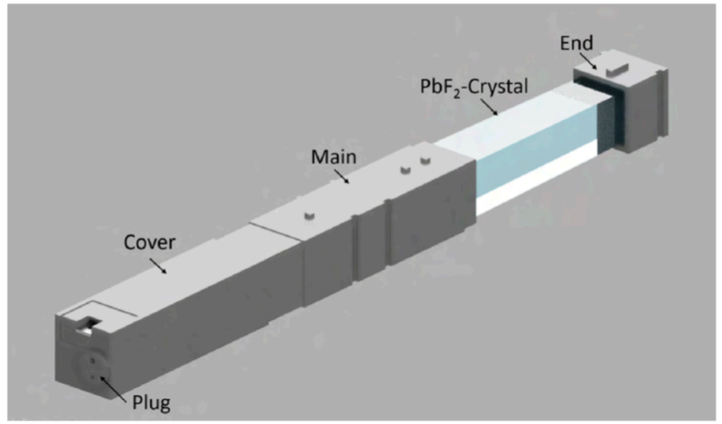
DarkMESA prototype



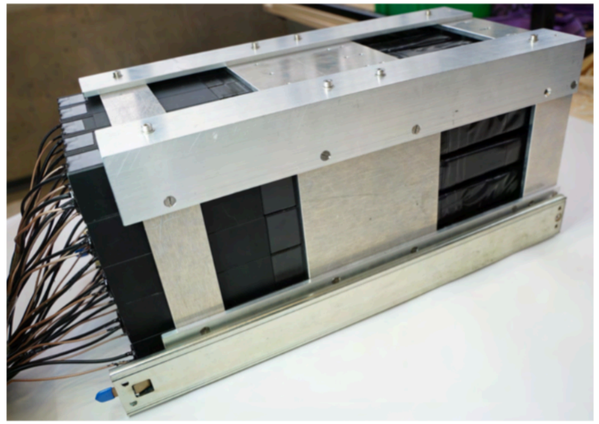


DarkMESA prototype

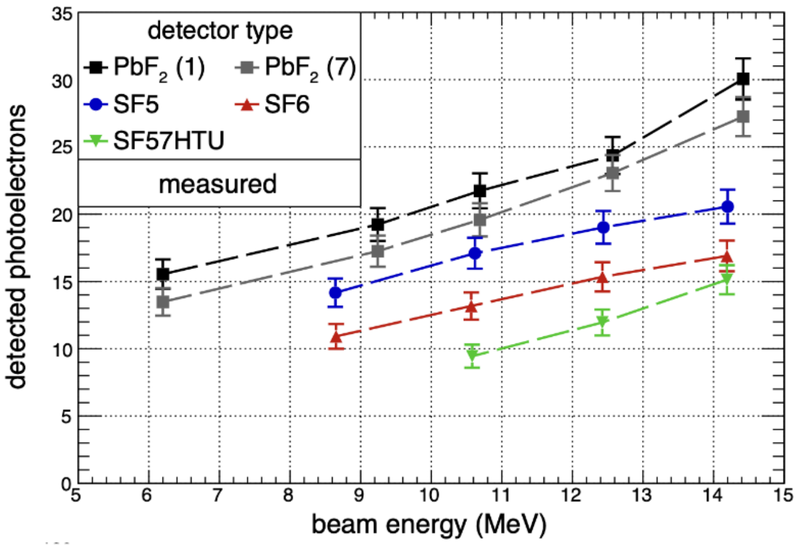
3D-printed crystal casings



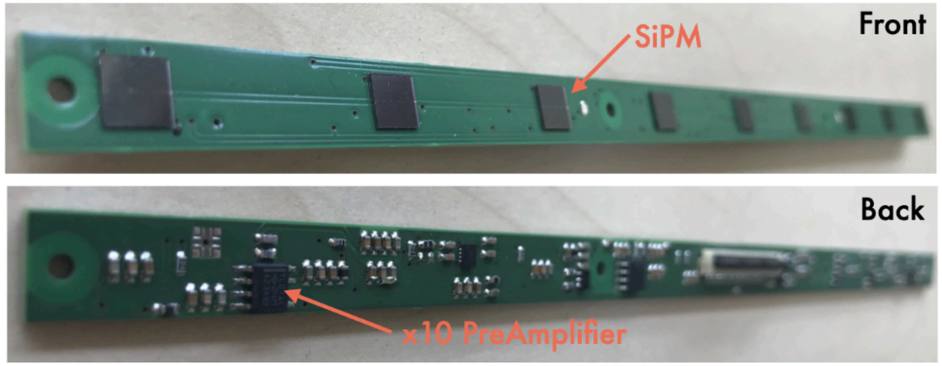
Assembled prototype



MAMI 14 MeV beam test



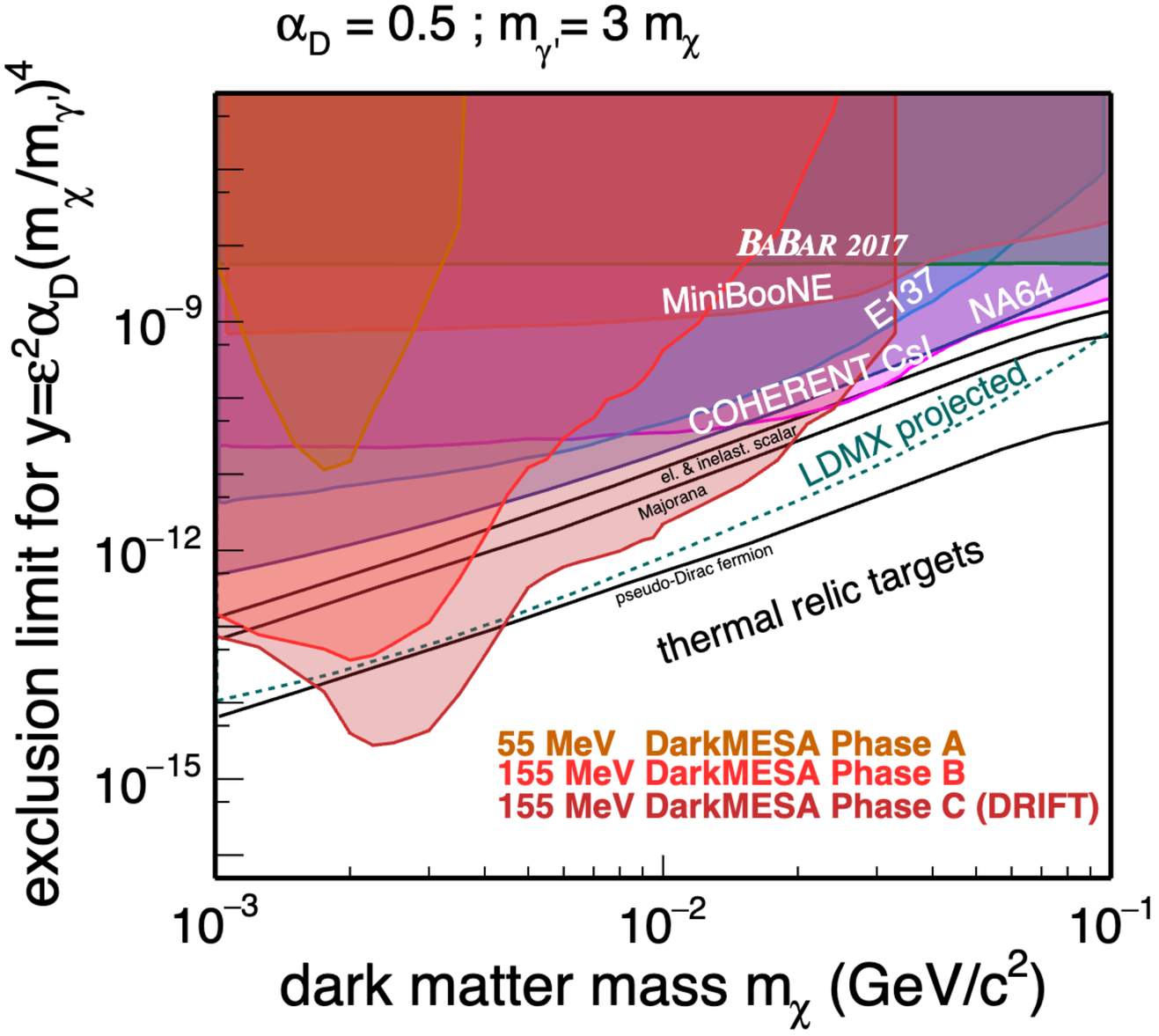
SiPM board for scintillator readout



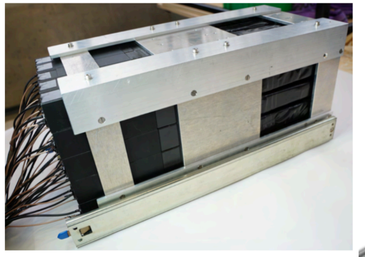
Prototype ready for testing:

- Electronics/DAQ
- comics veto efficiency
- optimization
- measurements above/below ground

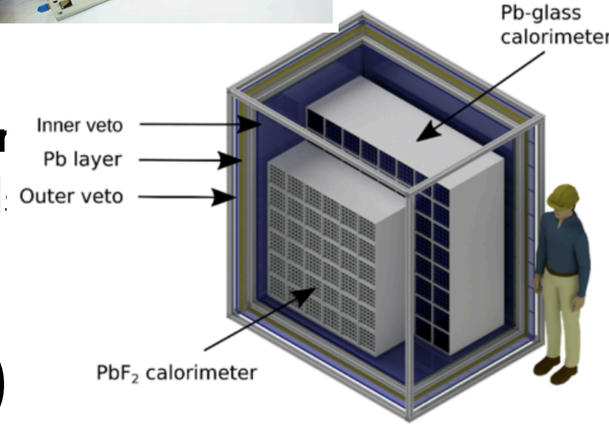
Dark Photons at DarkMESA: Projections



Phase A: Prototype
5x5 PbF2 crystals
0.04 m^3 volume



Phase B:
PbF2 + SF5 calorimeter
~1000 + ~1000 crystals
>1 m^3 volume



Phase C: TBD..(DRIFT?)

Summary

* MESA: Superconducting energy recovery electron accelerator
  - High current CW operation
  - 3 Experiments
* MAGIX:
  - Very flexible setup
  - Rich experimental program (LDM, Hadron/Nuclear/Astrophys.)
  - Unique: high current + jet target

* DarkMESA: opportunity detector for LDM, parasitic operation with P2.

Thank you!