The PRISMA⁺ Cluster of Excellence

Hartmut Wittig

PRISMA Cluster of Excellence, Institute for Nuclear Physics and Helmholtz Institute Mainz
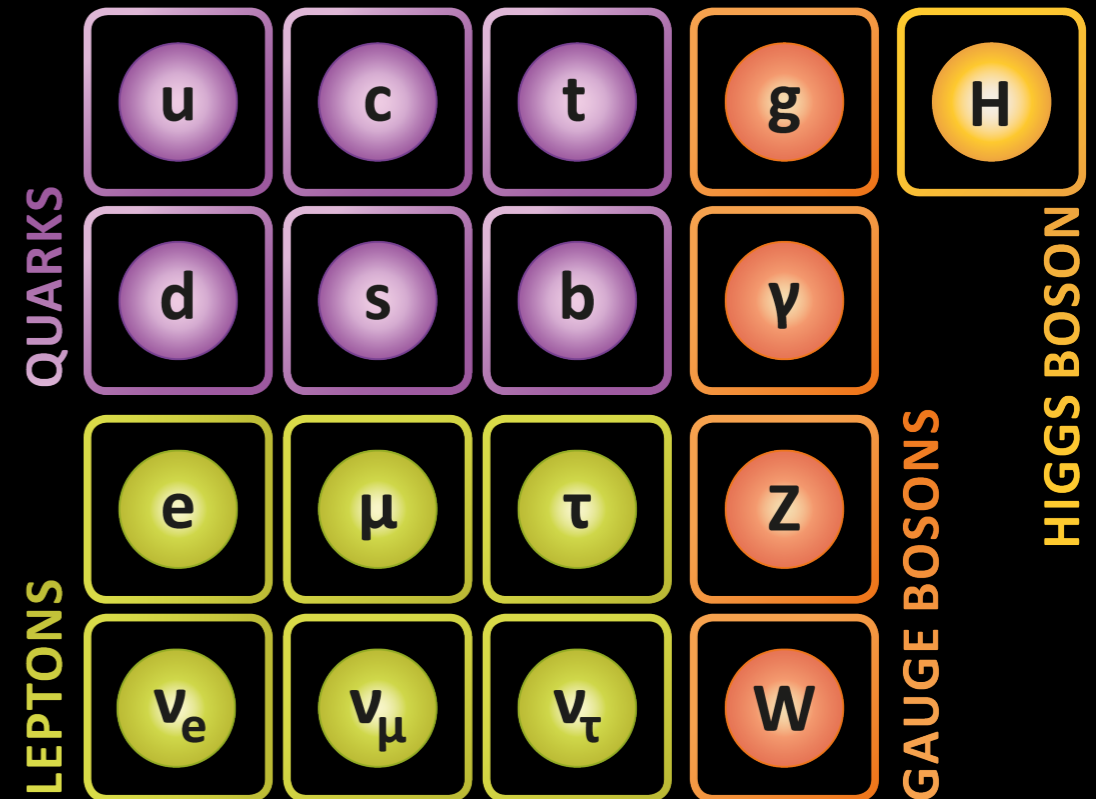
KHuK Jahrestagung 2018
Physikzentrum Bad Honnef
6–7 December 2018

HIM Helmholtz-Institut Mainz

PRISMA⁺

SFB 1044
THE LOW-ENERGY FRONTIER
OF THE STANDARD MODEL

The Quest for New Physics

**Standard Model does not explain**

- Baryon asymmetry
- Mass and scale hierarchies
- Existence of dark matter

Standard Model does not provide a complete description of Nature
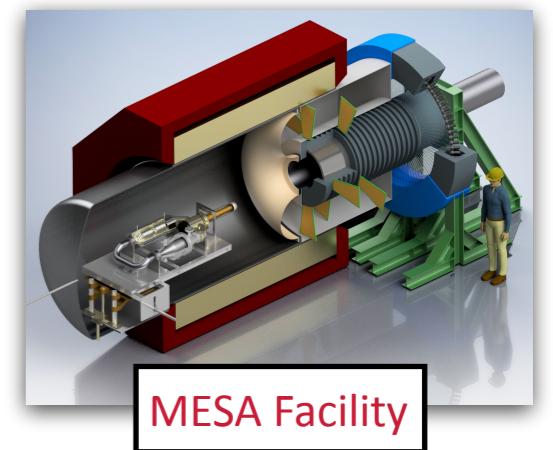
The Quest for New Physics

* Explore the limits of the Standard Model

  - Search for new particles and phenomena at high energies

  - Search for enhancement of rare phenomena

  - Compare precision measurements to SM predictions
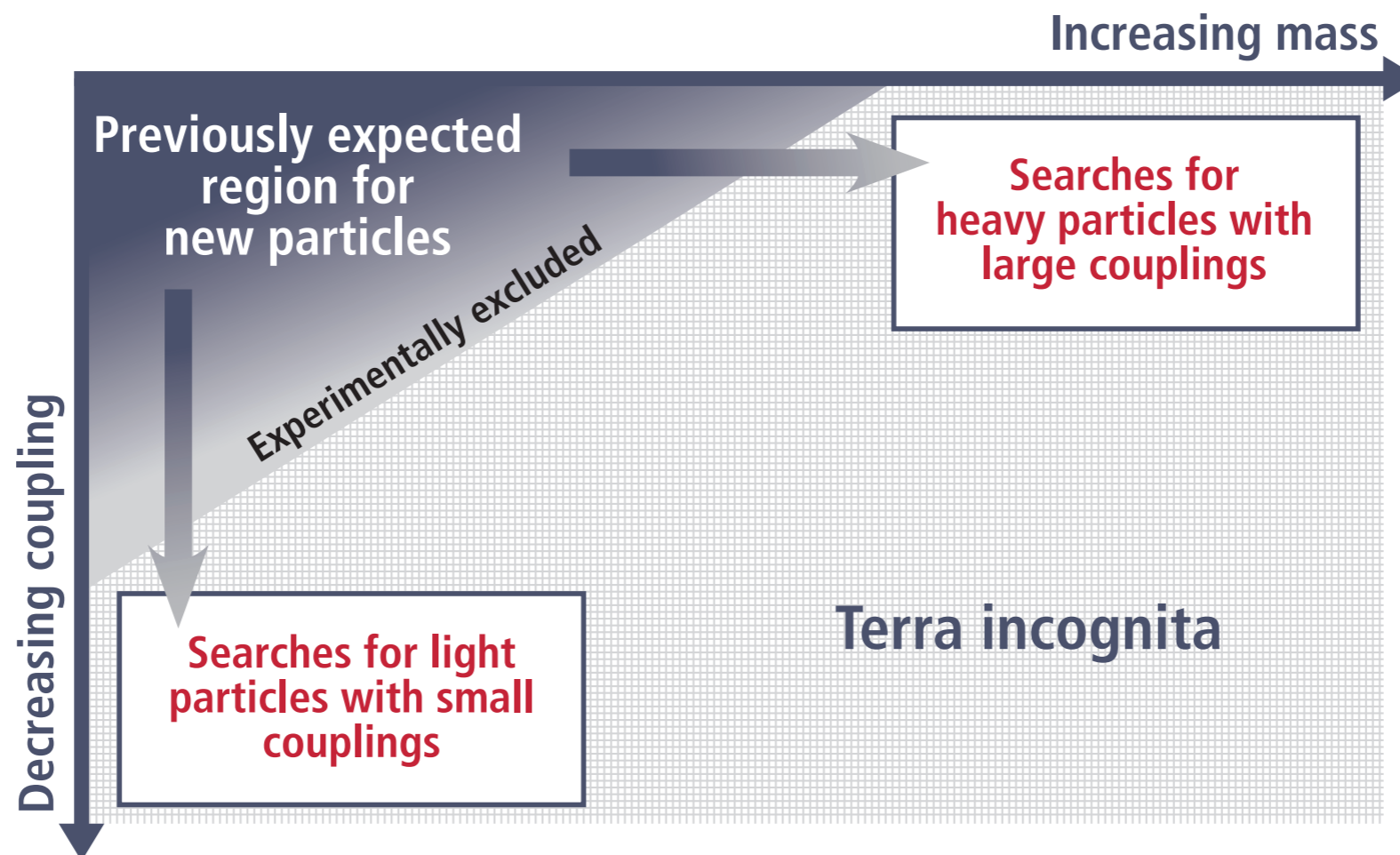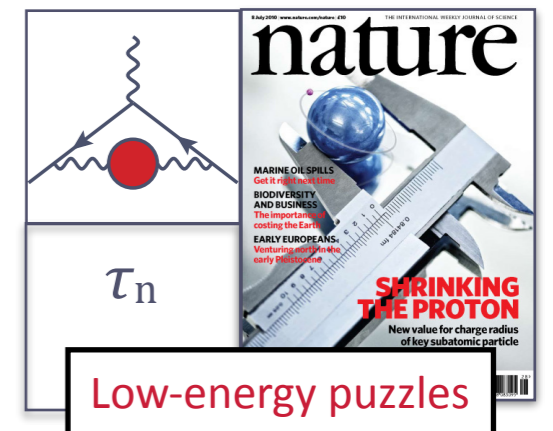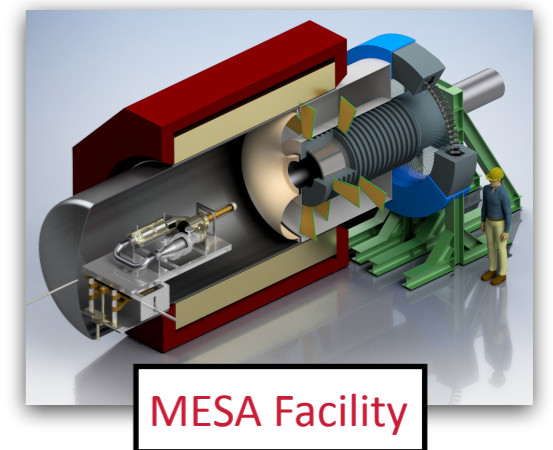
PRISMA⁺ Research Areas

PRISMA⁺ Research Areas

A — Exploring the intensity frontier at MESA

MESA Facility

PRISMA+ Research Areas

A — Exploring the intensity frontier at MESA

MESA Facility

B — Precision physics at the low-energy frontier
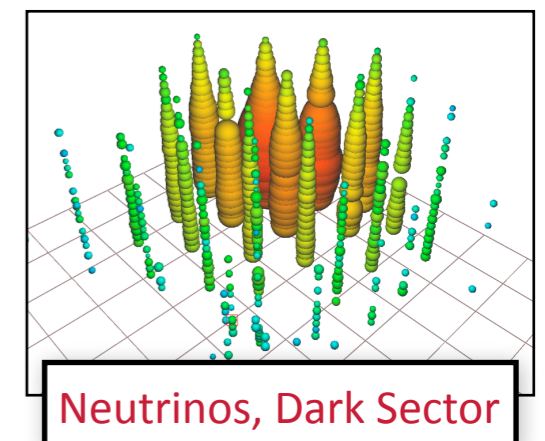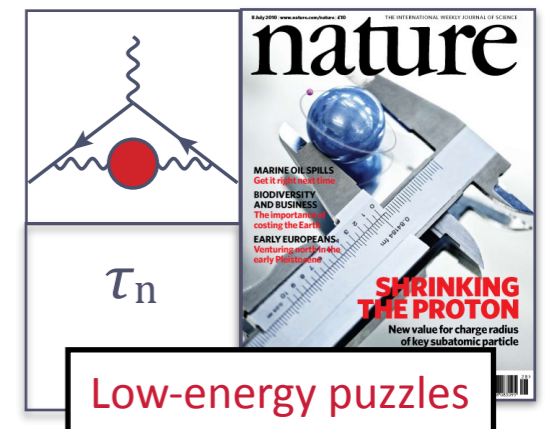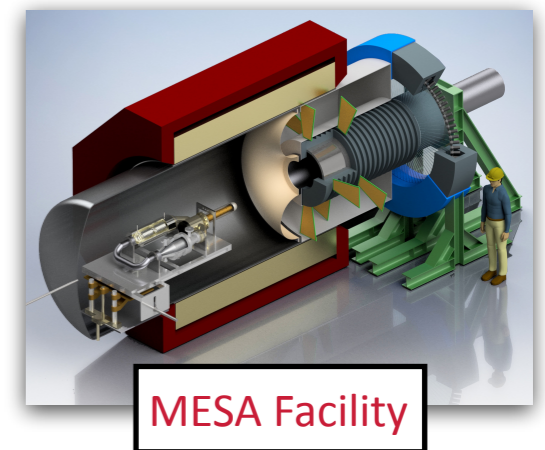

τ_n
Low-energy puzzles

PRISMA⁺ Research Areas

A — Exploring the intensity frontier at MESA

B — Precision physics at the low-energy frontier

C — Exploring the weakly interacting universe

MESA Facility

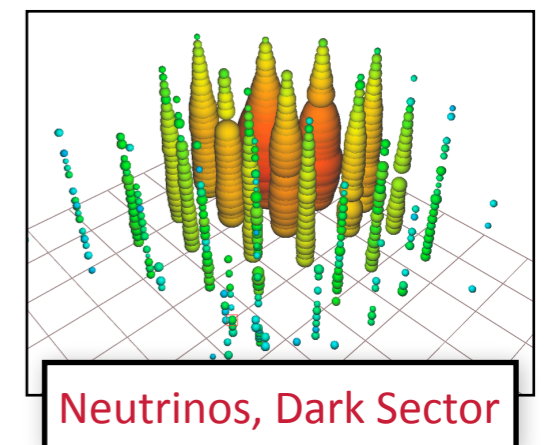Low-energy puzzles

Neutrinos, Dark Sector

PRISMA⁺ Research Areas

A — Exploring the intensity frontier at MESA

B — Precision physics at the low-energy frontier
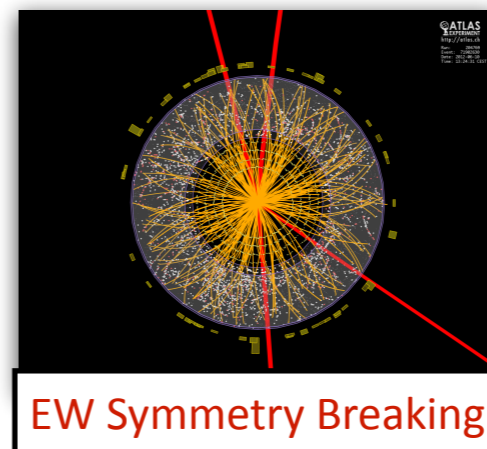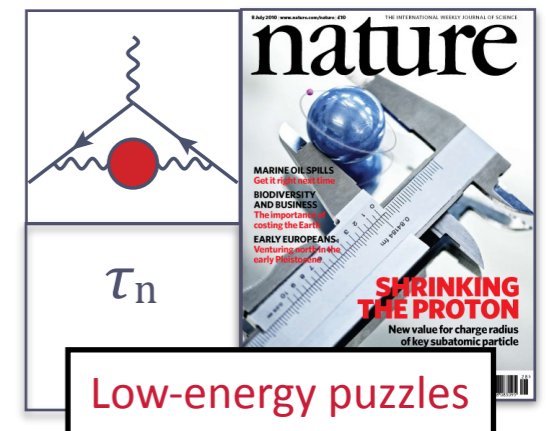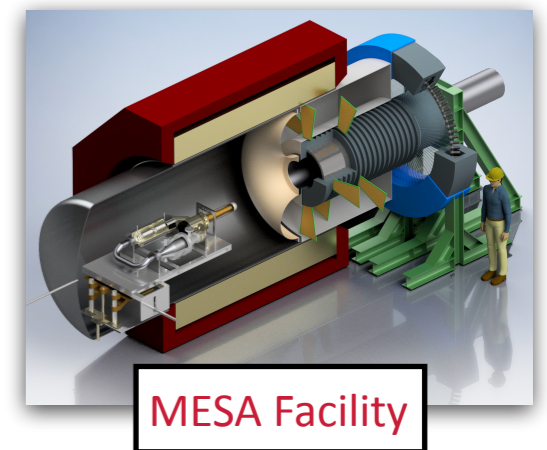
C — Exploring the weakly interacting universe

D — Physics at high-energy accelerators

MESA Facility

τ_n

Low-energy puzzles

EW Symmetry Breaking

Neutrinos, Dark Sector
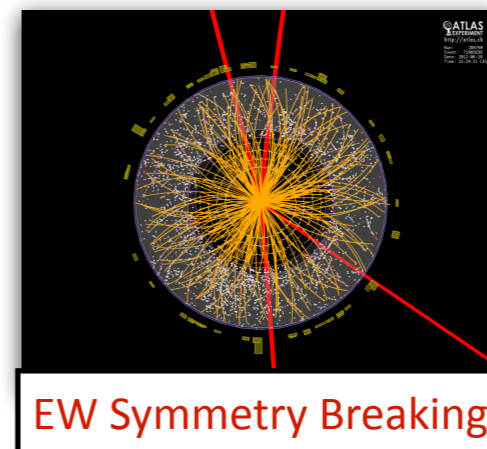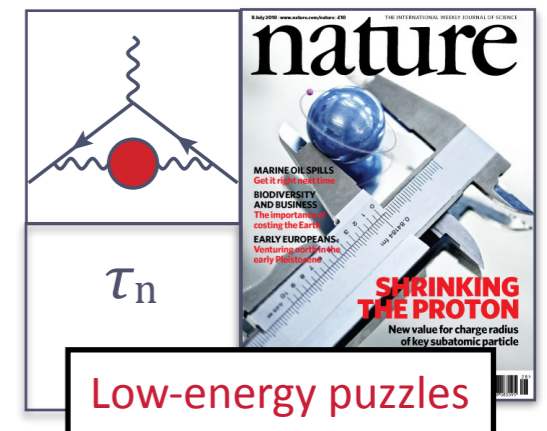
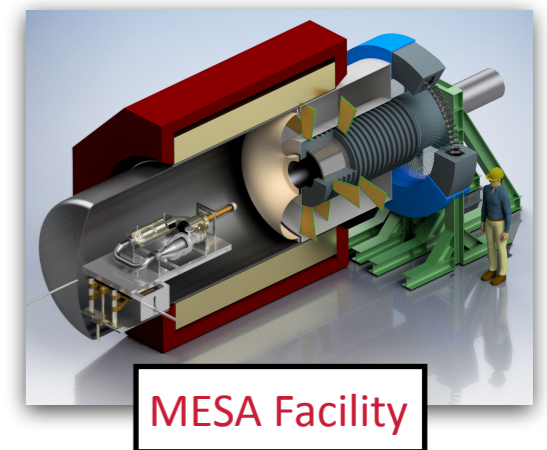# PRISMA⁺ Research Areas

A — **Exploring the intensity frontier at MESA**

B — **Precision physics at the low-energy frontier**

C — **Exploring the weakly interacting universe**

D — **Physics at high-energy accelerators**

E — **Theory and phenomenology of fundamental interactions**

MESA Facility

τ_n
Low-energy puzzles

EW Symmetry Breaking

Neutrinos, Dark Sector
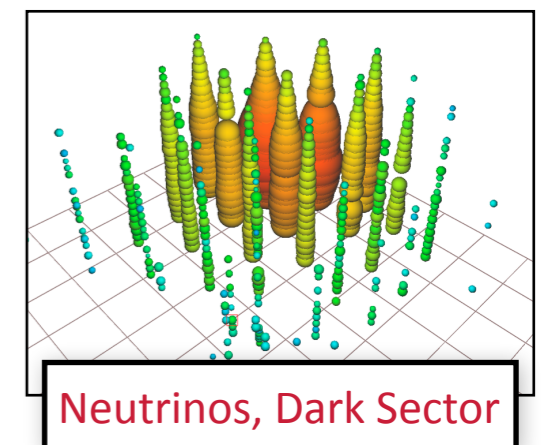
Key Scientific Objectives

Weak mixing angle at low energy	High-energy precision tests
Muon anomalous magnetic moment	Key neutrino parameters
Lifetime of the neutron	Searches for dark matter
Proton radius puzzle	Novel probes of light dark sectors

PRISMA⁺ Scientists

Areas of expertise

- Particle and Astroparticle Physics
- Hadron and Nuclear Physics
- Laser Spectroscopy, Magnetometry
- Accelerator Physics
- Theory and Computing
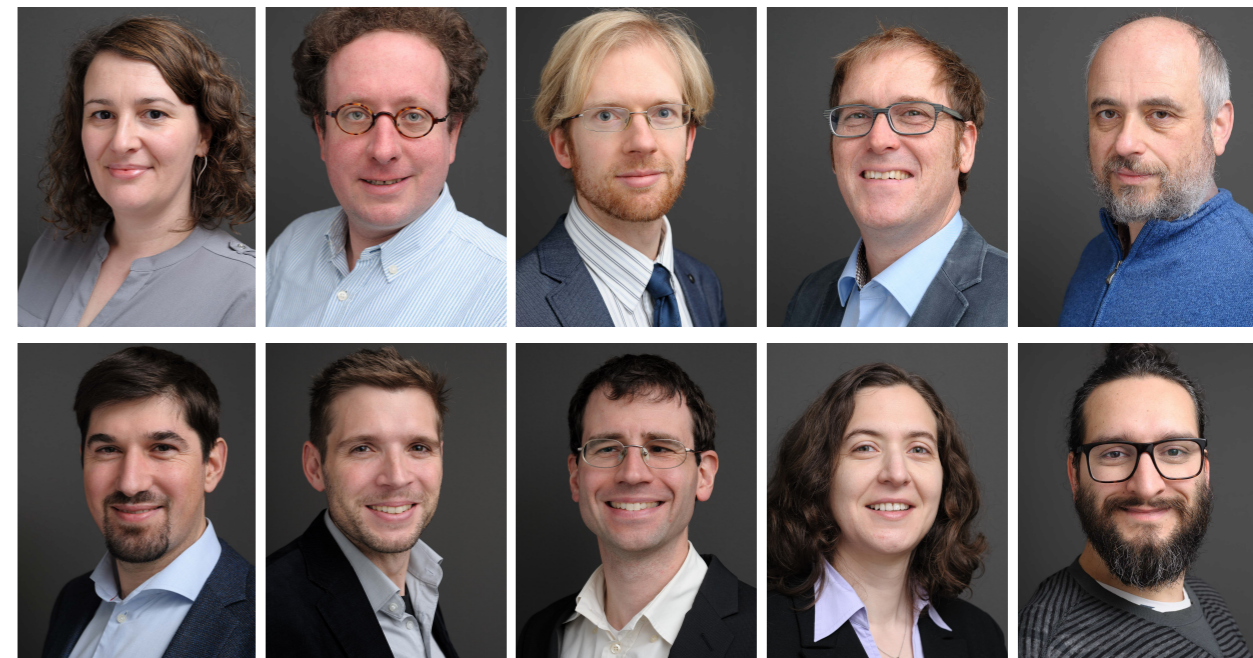
Appointments since 2013

- Hadron and Nuclear Theory
- Particle and Hadron Physics (Exp)
- Lattice Gauge Theory
- Laser Spectroscopy
- Neutrino Physics
- Axions and Dark Matter

Total number of scientists: 385

Faculty: 43
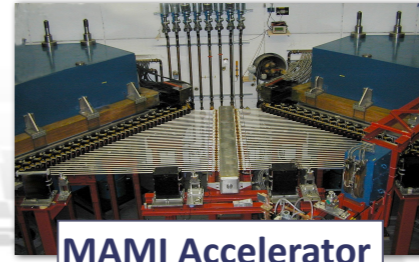Postdoctoral researchers: 121
PhD Students: 221
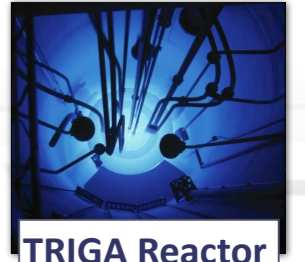
Research infrastructure at Mainz
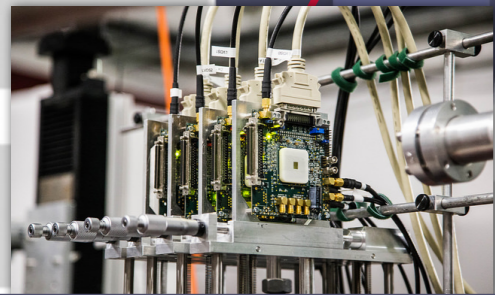

Mainz Institute for Theoretical Physics

Detector Laboratory

Helmholtz Institute Mainz
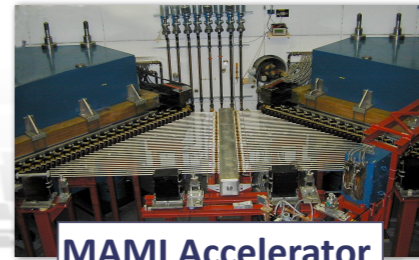
MAMI Accelerator

TRIGA Reactor

Research infrastructure at Mainz

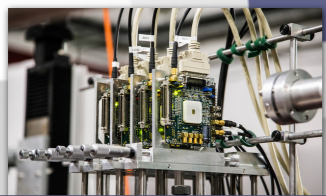Mainz Institute for Theoretical Physics

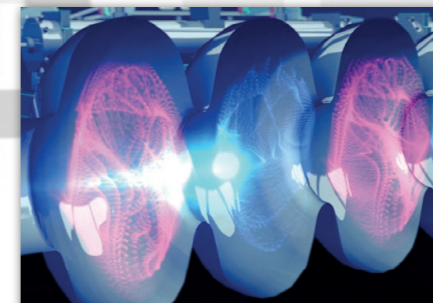Helmholtz Institute Mainz

MAMI Accelerator

TRIGA Reactor

Center for Fundamental Physics

- Office and Laboratory Building
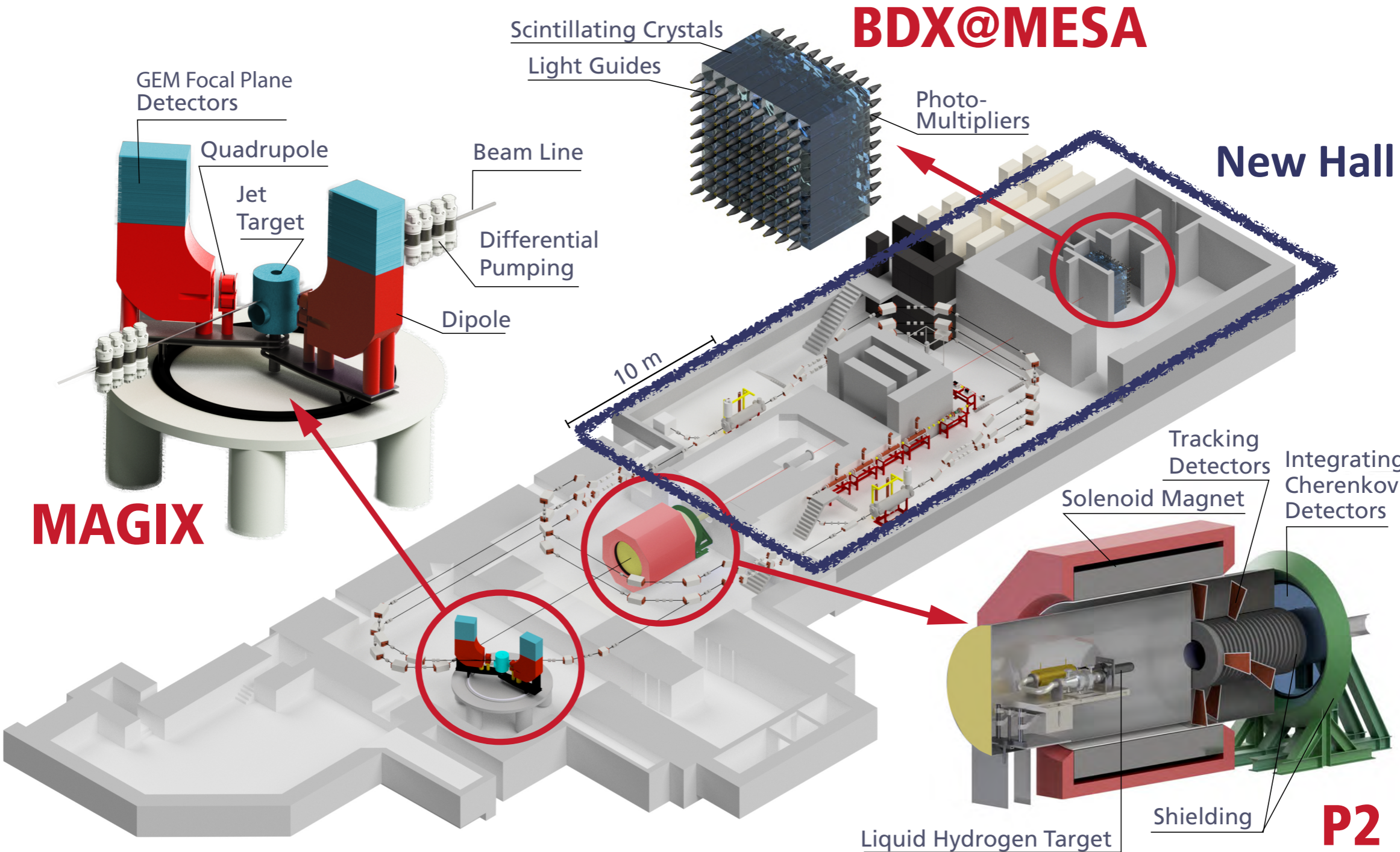- Underground Experimental Hall
- Completion in 2020

Detector Laboratory

MESA Accelerator

The MESA Facility

BDX@MESA

Scintillating Crystals
Light Guides
Photo-Multipliers

New Hall

GEM Focal Plane Detectors
Quadrupole
Beam Line
Jet Target
Differential Pumping
Dipole

10 m

MAGIX

Tracking Detectors
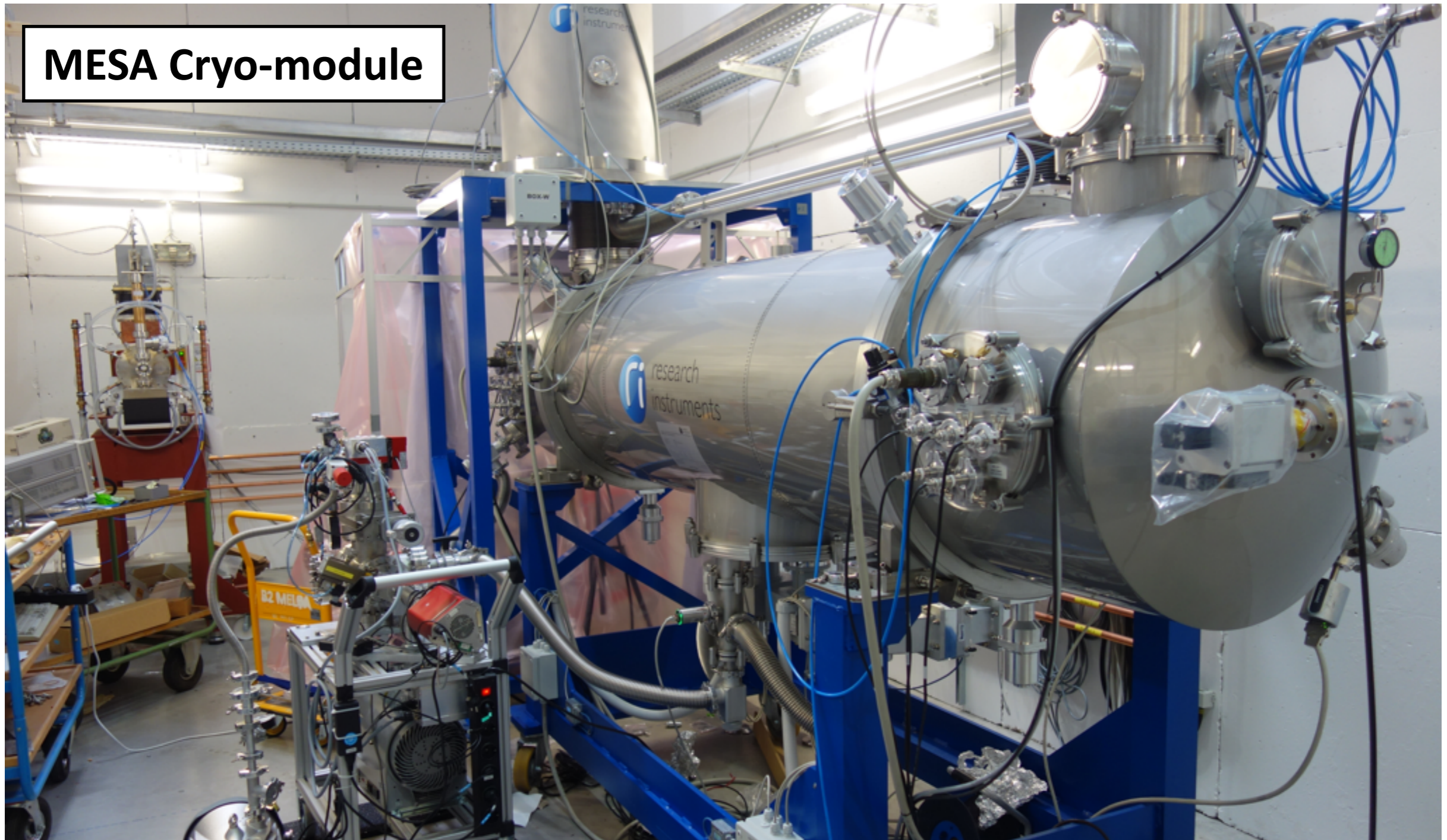Integrating Cherenkov Detectors
Solenoid Magnet

Liquid Hydrogen Target
Shielding
P2

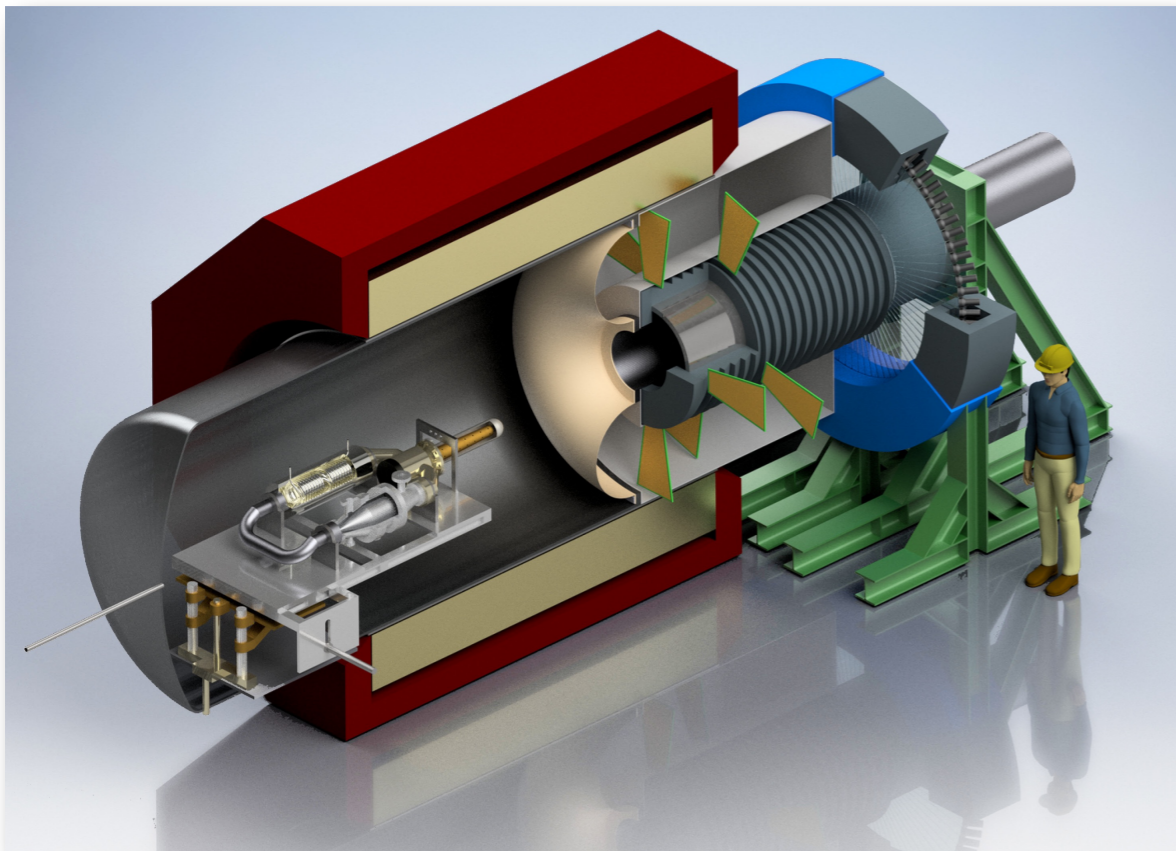# Mainz Energy-recovery Superconducting Accelerator

MESA Cryo-module

P2 — Parity violation at low energies

* Left-right asymmetry in polarised *ep*-scattering:

$$A_{LR} \equiv \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = -\frac{G_{\mathrm{F}}\, Q^2}{4\sqrt{2}\pi\alpha}\,(Q_W^p + F^p)$$

* Weak charge of the proton: $Q_W^p = 1 - 4\sin^2\theta_W$ (tree level)

Magnetic spectrometer

Liquid hydrogen target

Expected precision:

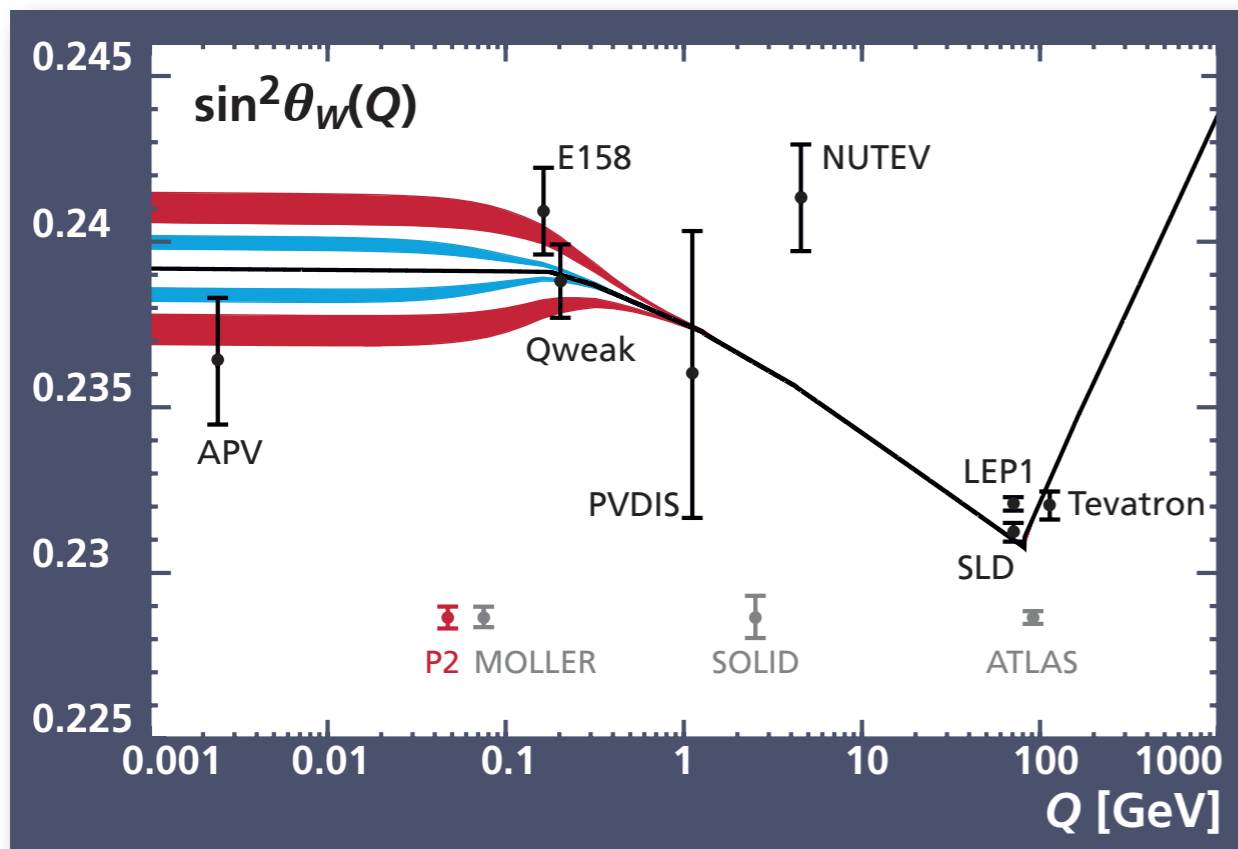$$\frac{\delta(\sin^2\theta_W)}{\sin^2\theta_W} = 0.15\%$$

[Becker et al., arXiv:1802.04759]

P2 — Parity violation at low energies

* Left-right asymmetry in polarised *ep*-scattering:

$$A_{LR} \equiv \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = -\frac{G_F\, Q^2}{4\sqrt{2}\pi\alpha}\left(Q_W^p + F^p\right)$$

* Weak charge of the proton: $\qquad Q_W^p = 1 - 4\sin^2\theta_W \qquad$ (tree level)

Magnetic spectrometer

Liquid hydrogen target

Expected precision:

$$\frac{\delta(\sin^2\theta_W)}{\sin^2\theta_W} = 0.15\%$$

[Becker et al., arXiv:1802.04759]

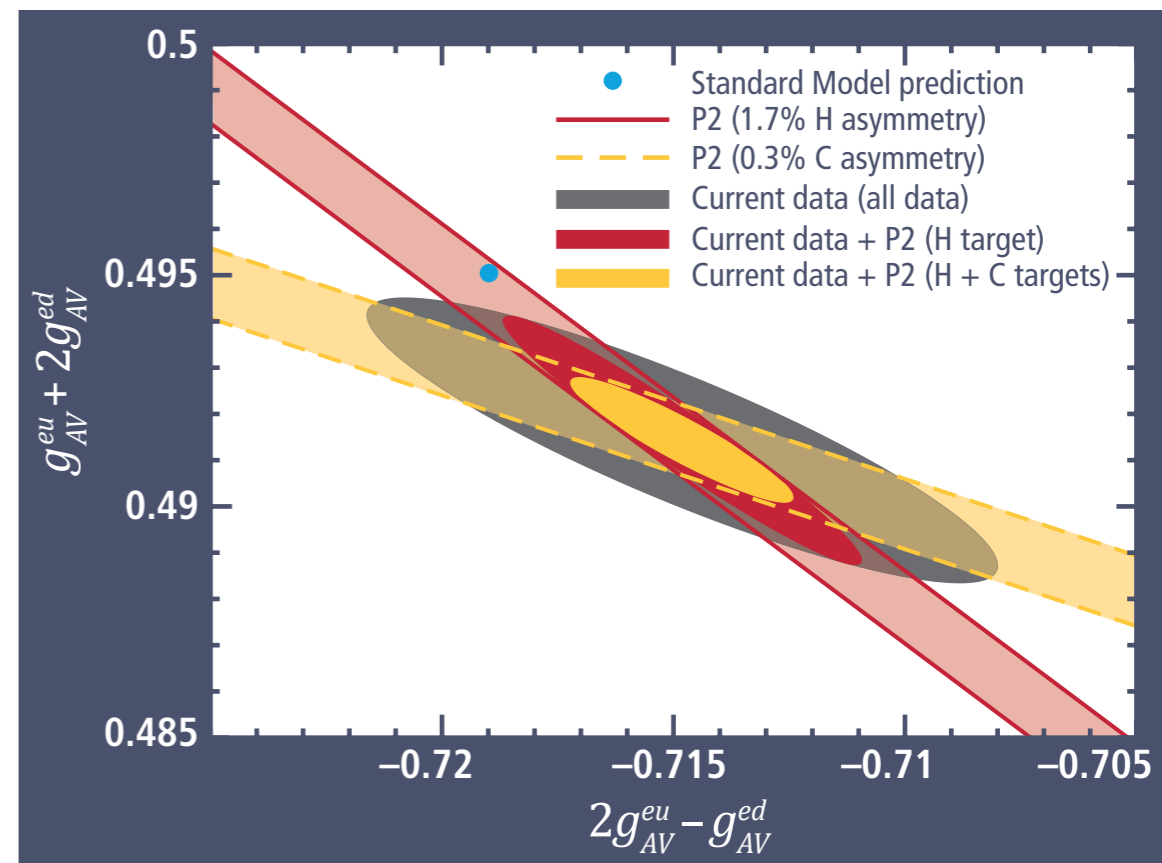# P2 — Parity violation at low energies

* Left-right asymmetry in polarised *ep*-scattering:

$$A_{LR} \equiv \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = -\frac{G_F\, Q^2}{4\sqrt{2}\pi\alpha}\,(Q_W^p + F^p)$$

* Weak charge of the proton: $Q_W^p = 1 - 4\sin^2\theta_W$ (tree level)

Other Topics

* Neutron skin measurement of ^{208}Pb
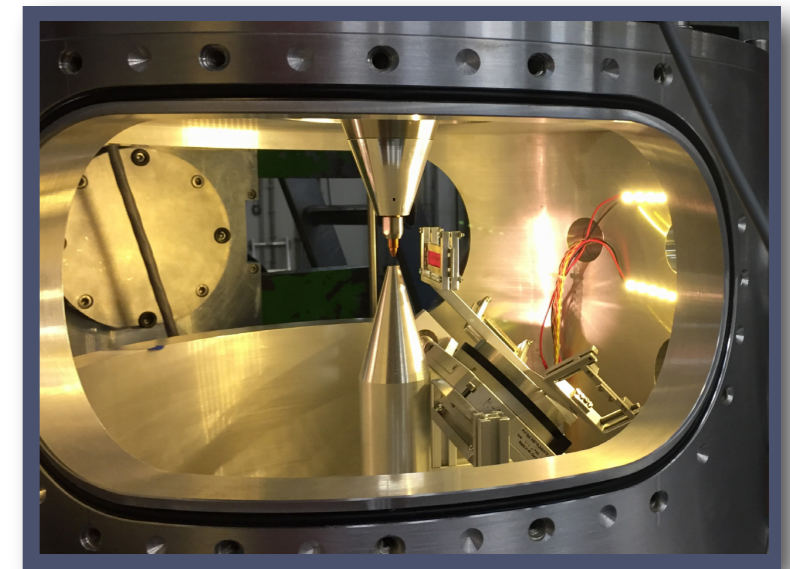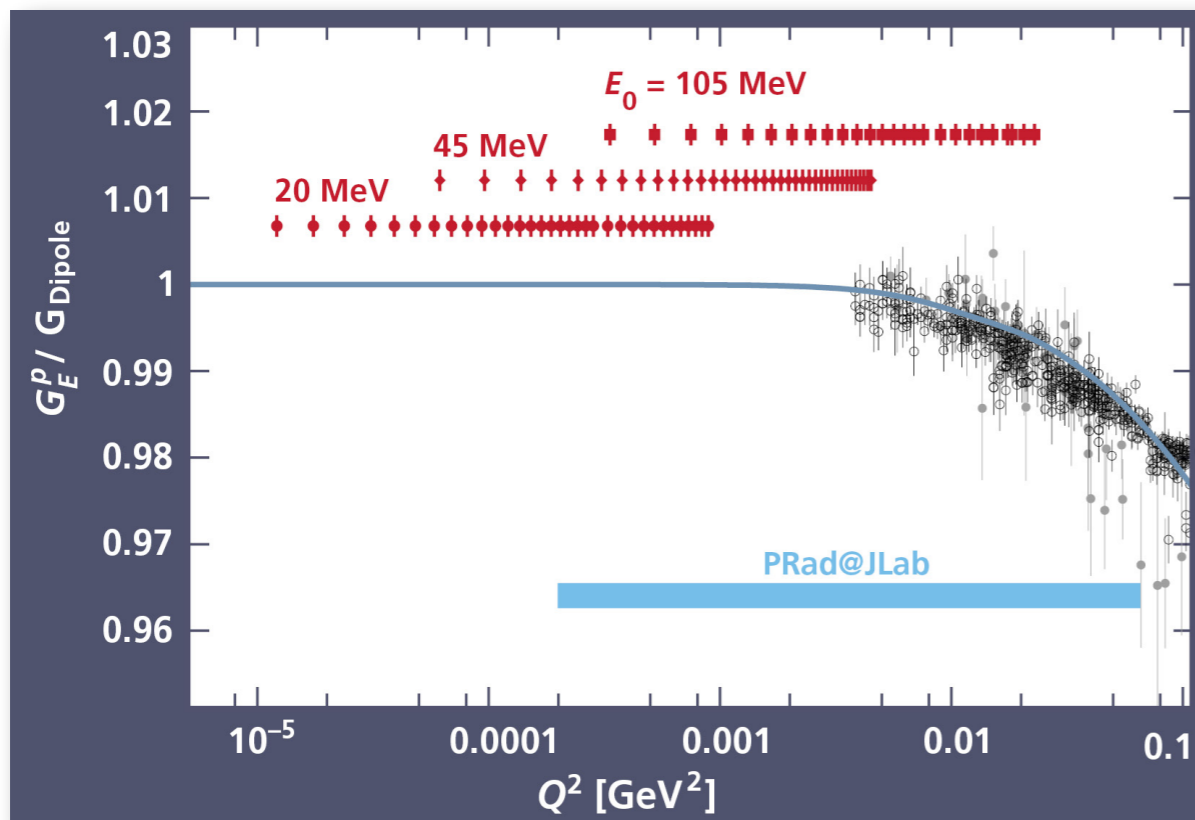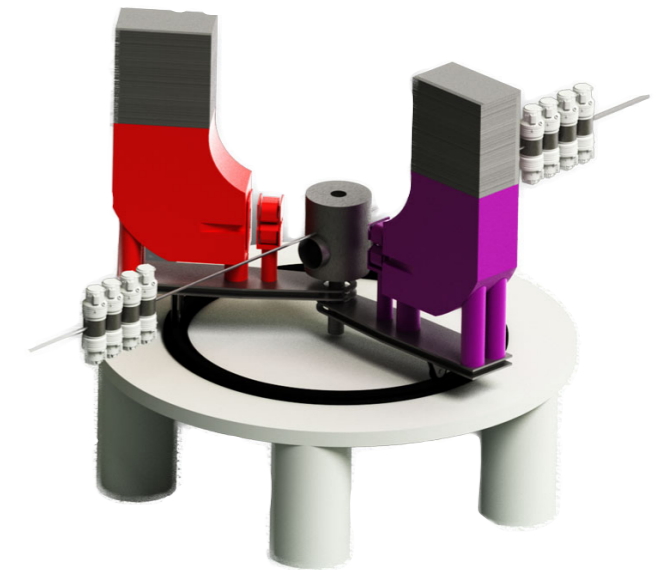
* Parity violation in ^{12}C

The MAGIX spectrometer

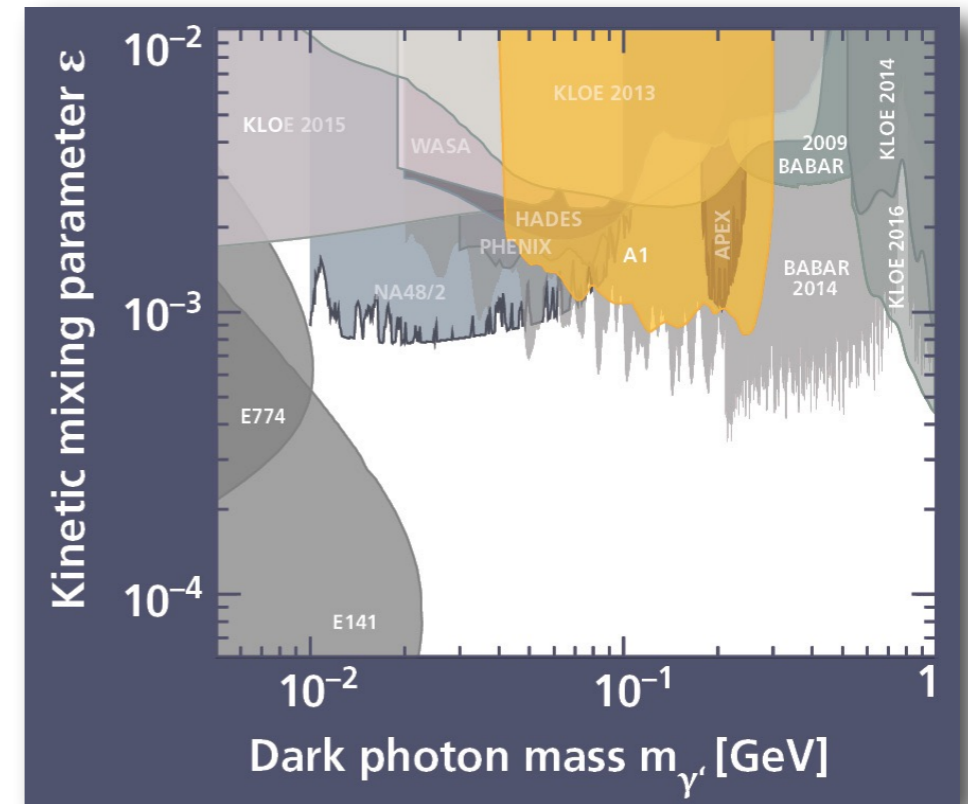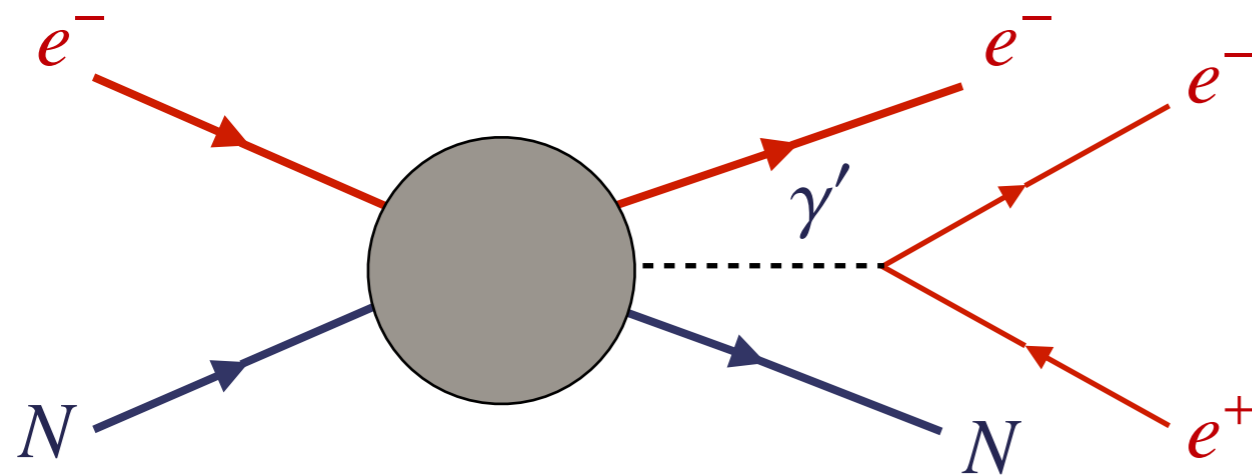**Double arm spectrometer**

Internal gas target

Momentum resolution: $\Delta p/p < 10^{-4}$

$\Rightarrow$ Proton radius puzzle: form factor measurements for $Q^2 \gtrsim 10^{-5}\,\mathrm{GeV}^2$

Dark Matter @ MESA

* Dark photon production in *ep* scattering:

Dark Matter @ MESA

* Dark photon production in *ep* scattering:
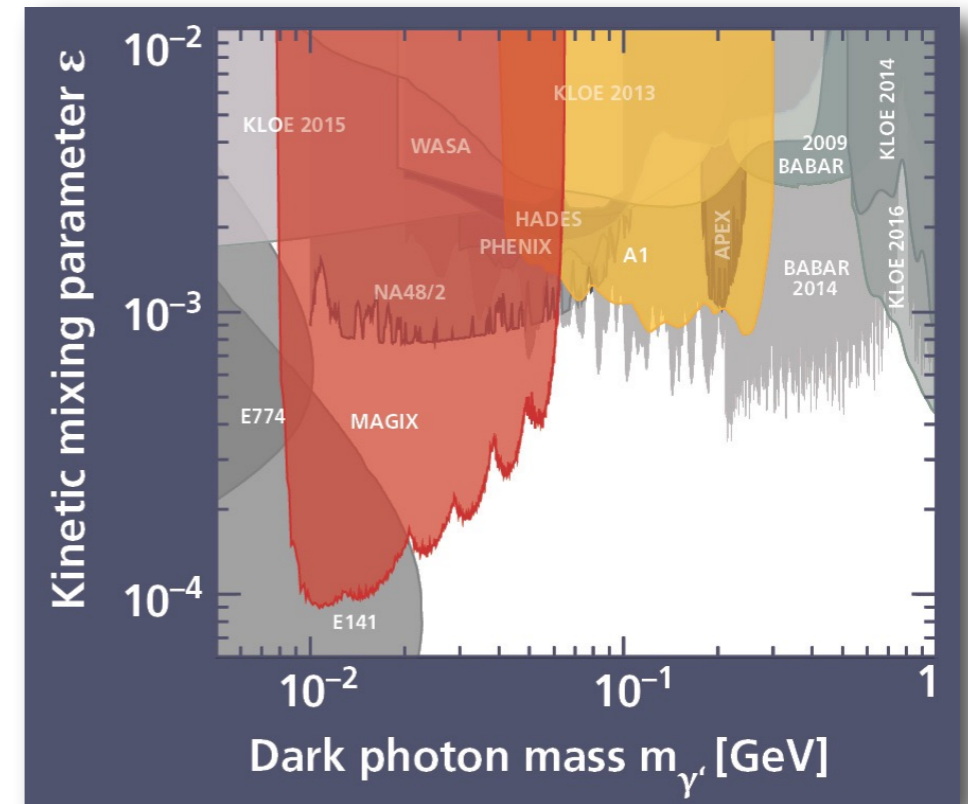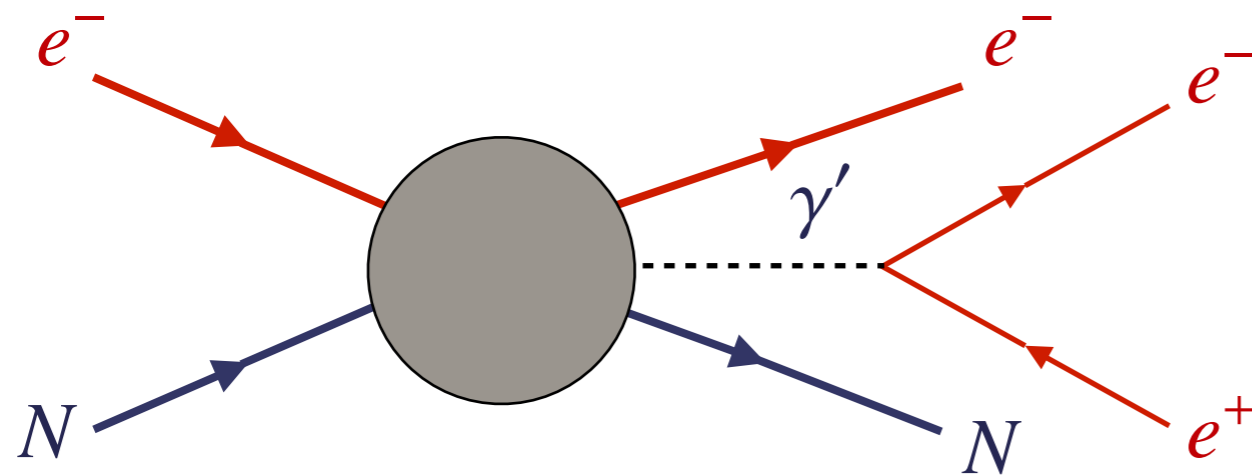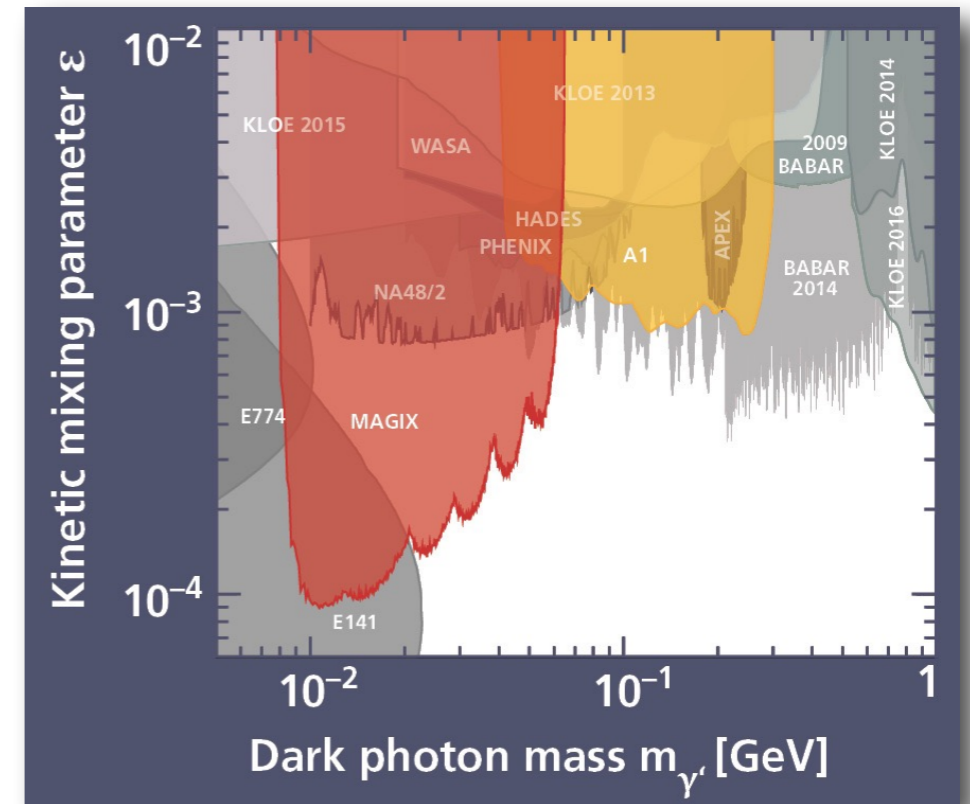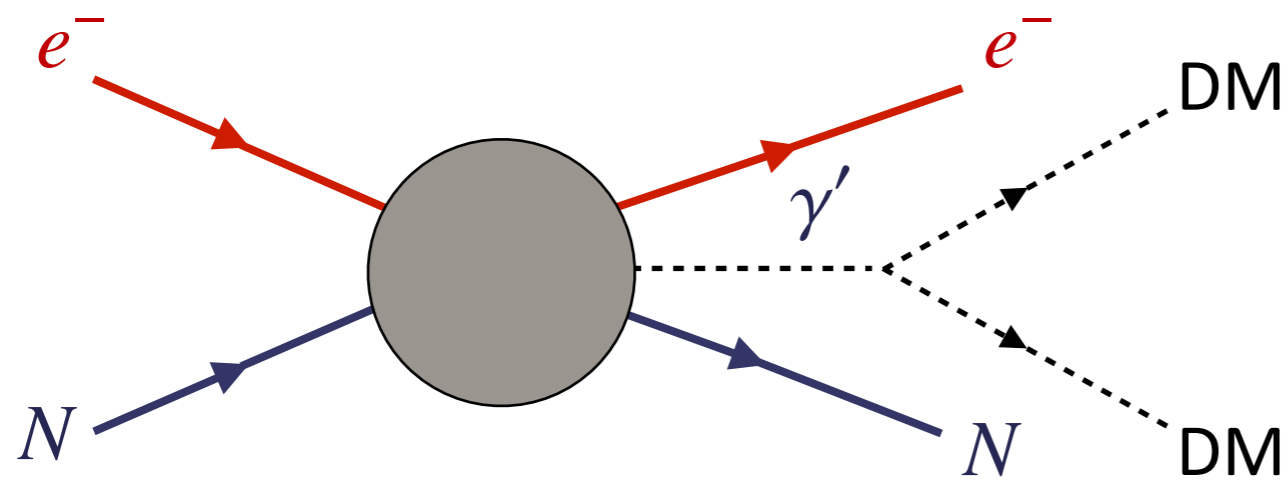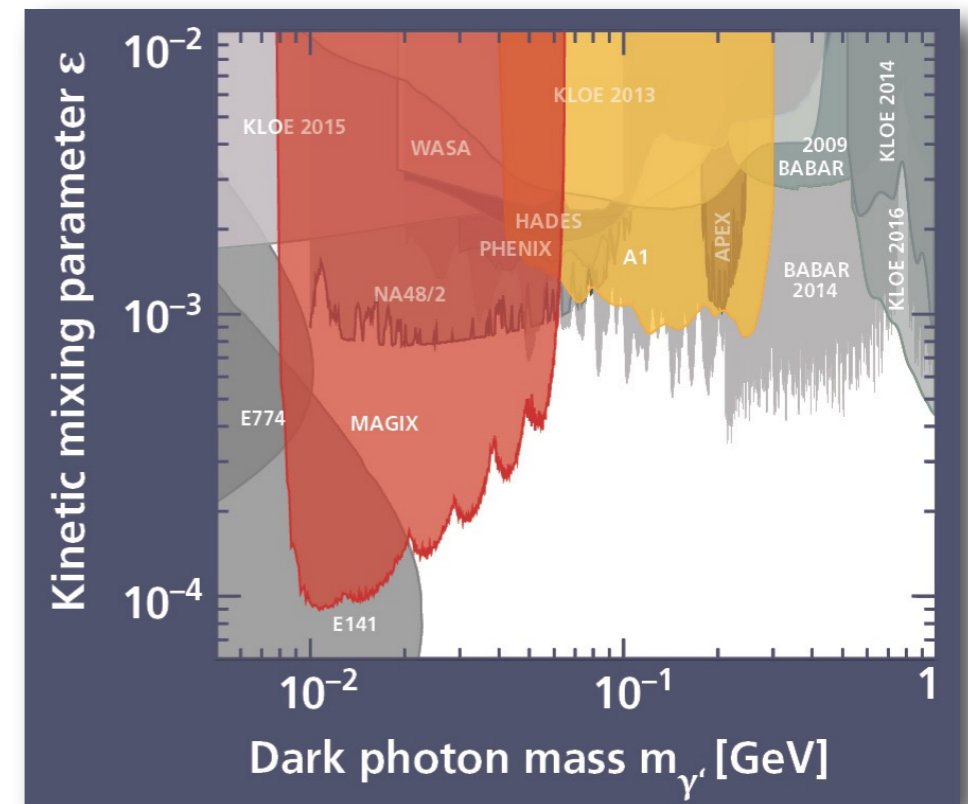
Dark Matter @ MESA

* Dark photon production in *ep* scattering:

Dark Matter @ MESA

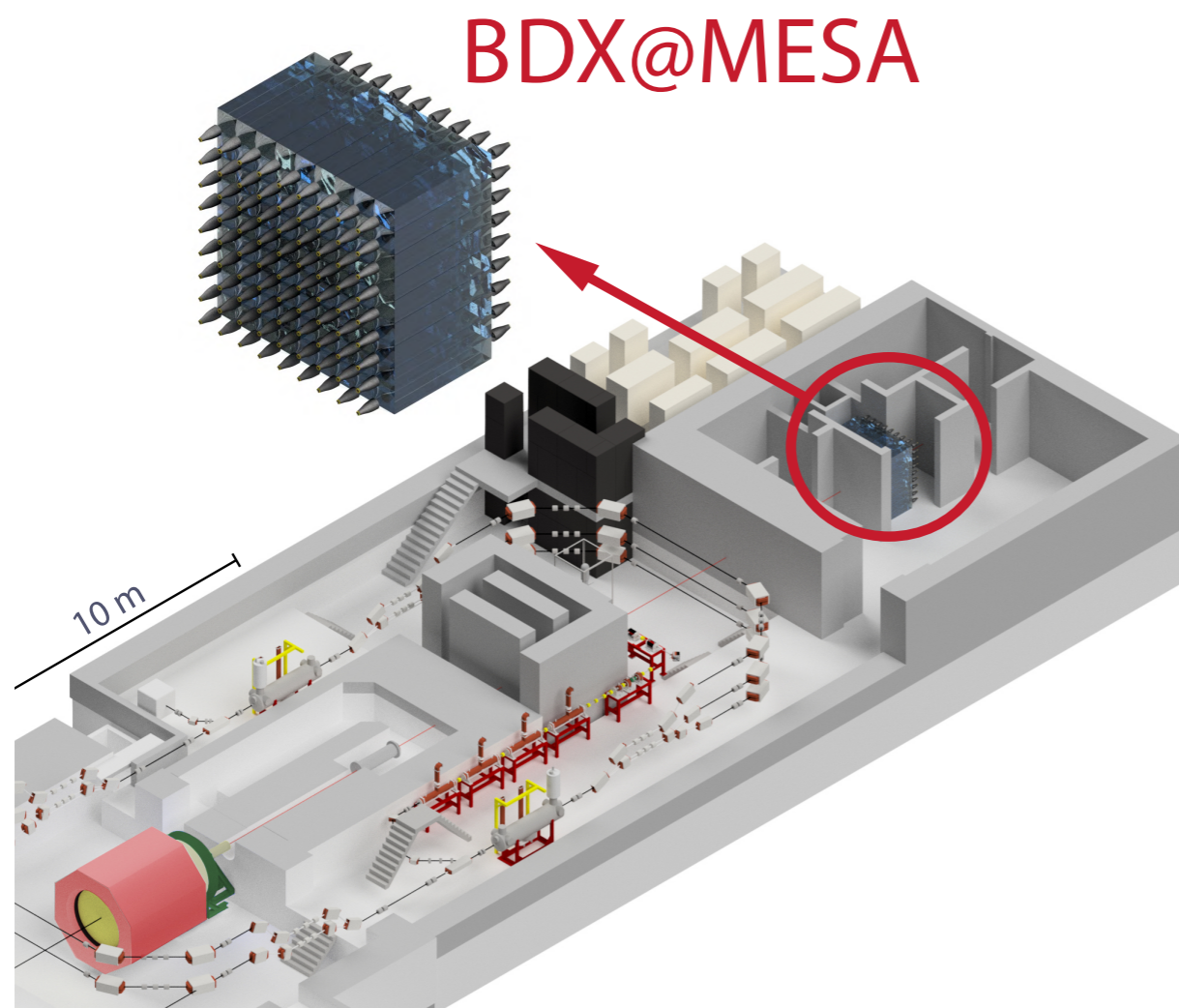* Dark photon production in *ep* scattering:

BDX@MESA

* **B**eam-**D**ump e**X**periment: BDX @ MESA

* **P2** dumps 10^{22} electrons/ year

The proton radius puzzle

* High-precision **laser spectroscopy** on muonic atoms (He, Li, Be, B)

* **Electron scattering** at **MAGIX** at very low momentum transfers

* **Nuclear charge radii** from scattering off D, He

* Nuclear **polarisabilities** via nuclear EFT and dispersion theory

* **Lattice QCD** calculations of nucleon form factors
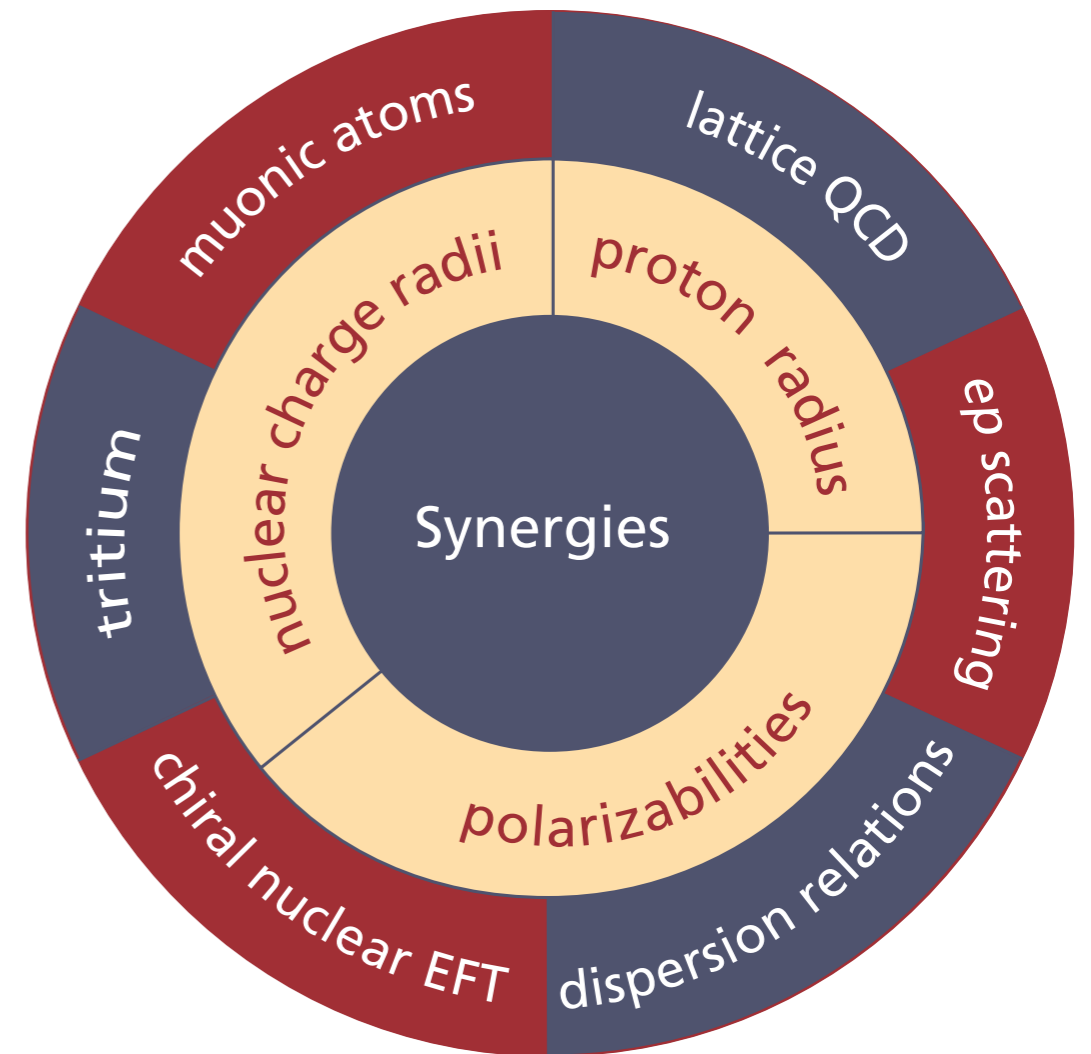
Neutrino Physics

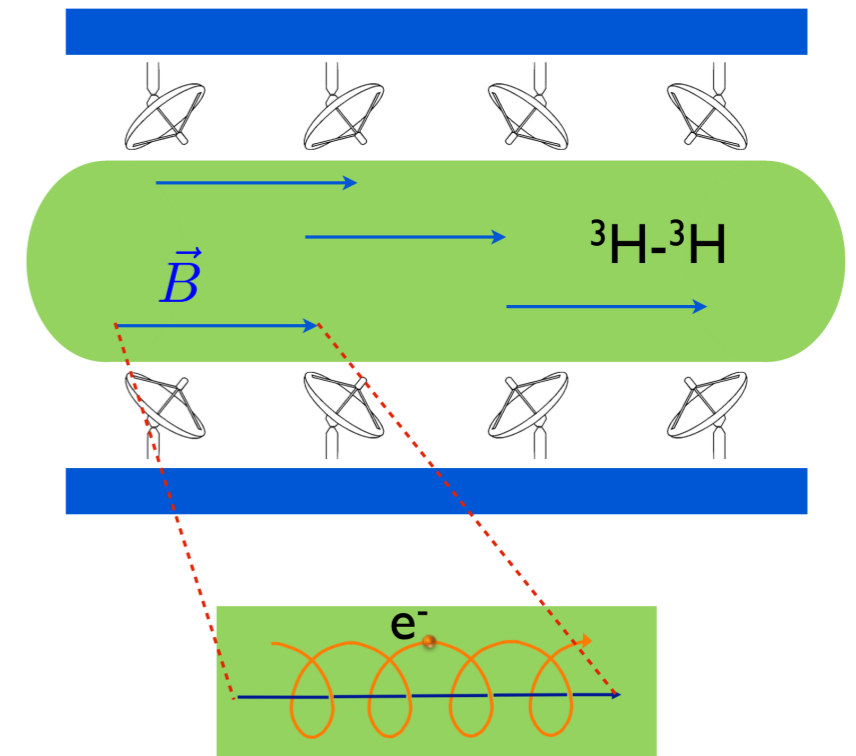* **Project 8** — absolute neutrino mass measurement

* Measure cyclotron radiation of electrons in Tritium decay

$\Rightarrow$ Tritium end-point spectroscopy
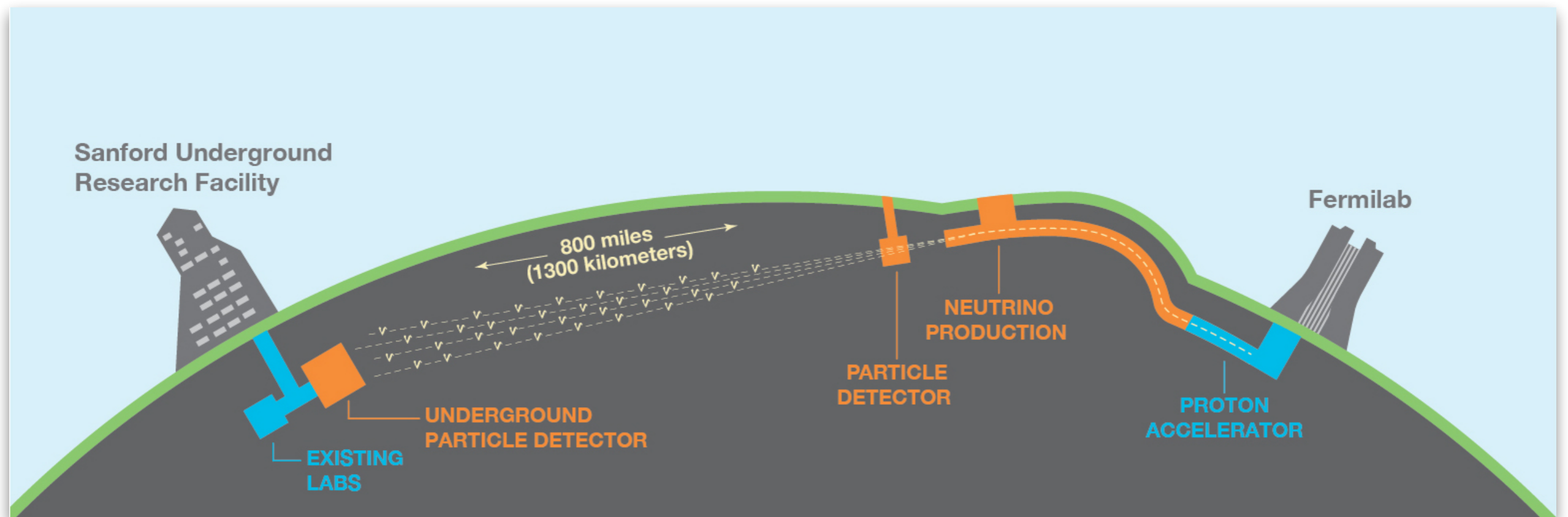
Sensitivity goal: $m_\beta > 0.04$ eV

Mainz/PRISMA+ contribution:

* Real-time interferometric readout system

* Atomic Tritium source
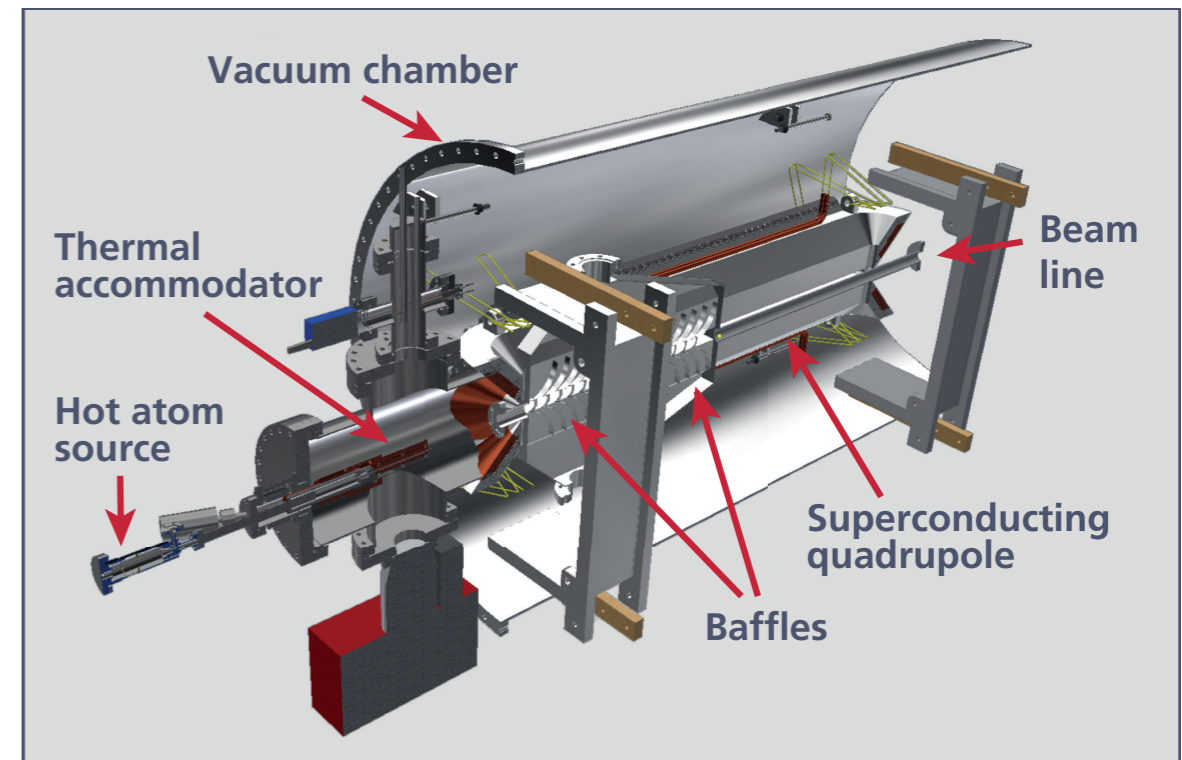
Neutrino Physics

* **DUNE/SURF:** Long-baseline neutrino facility

* Goal: Detect CP-violating phase in neutrino sector

Neutrino Physics

* **DUNE/SURF:** Long-baseline neutrino facility

* Goal: Detect CP-violating phase in neutrino sector

Mainz/PRISMA+ contribution:

* ECAL for near detector

* THEIA detector
  (liquid scintillator)
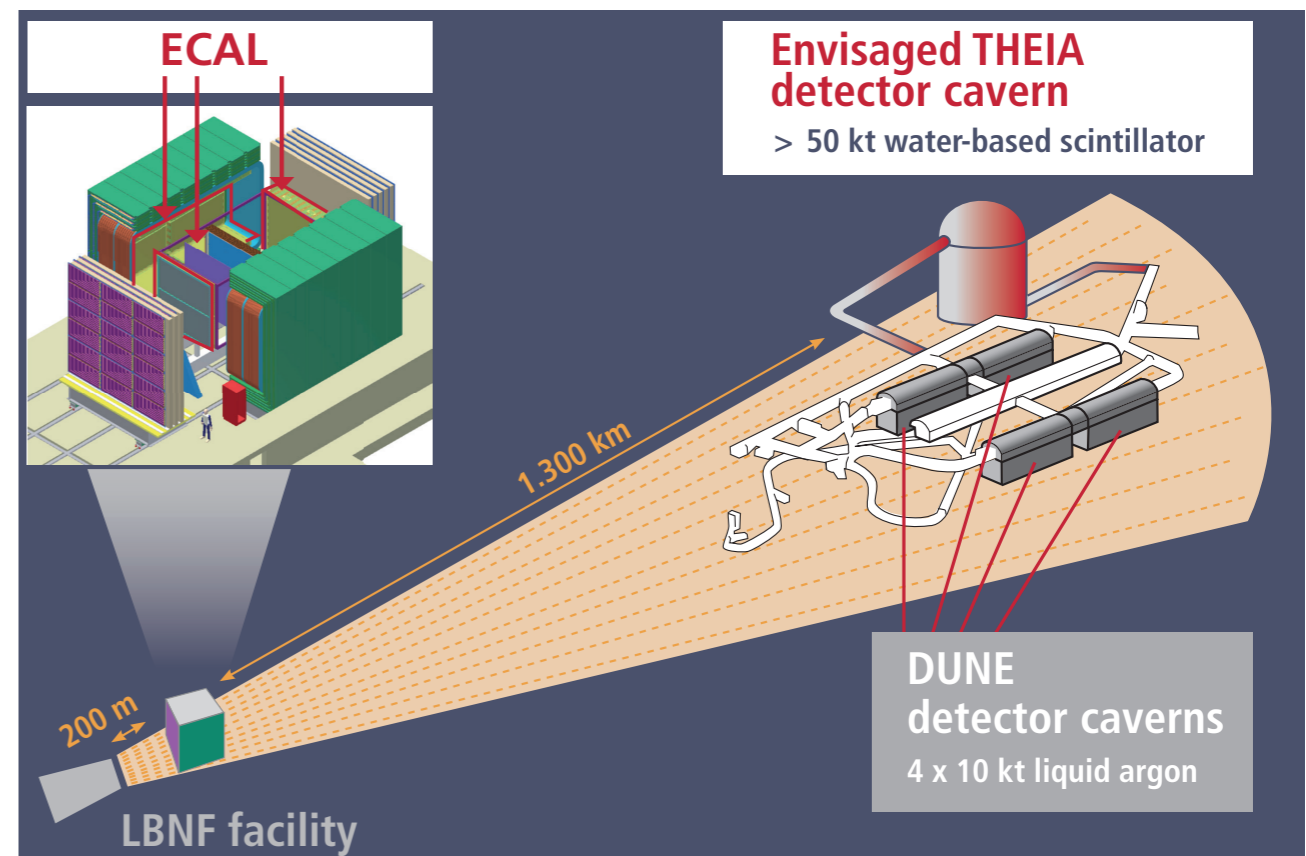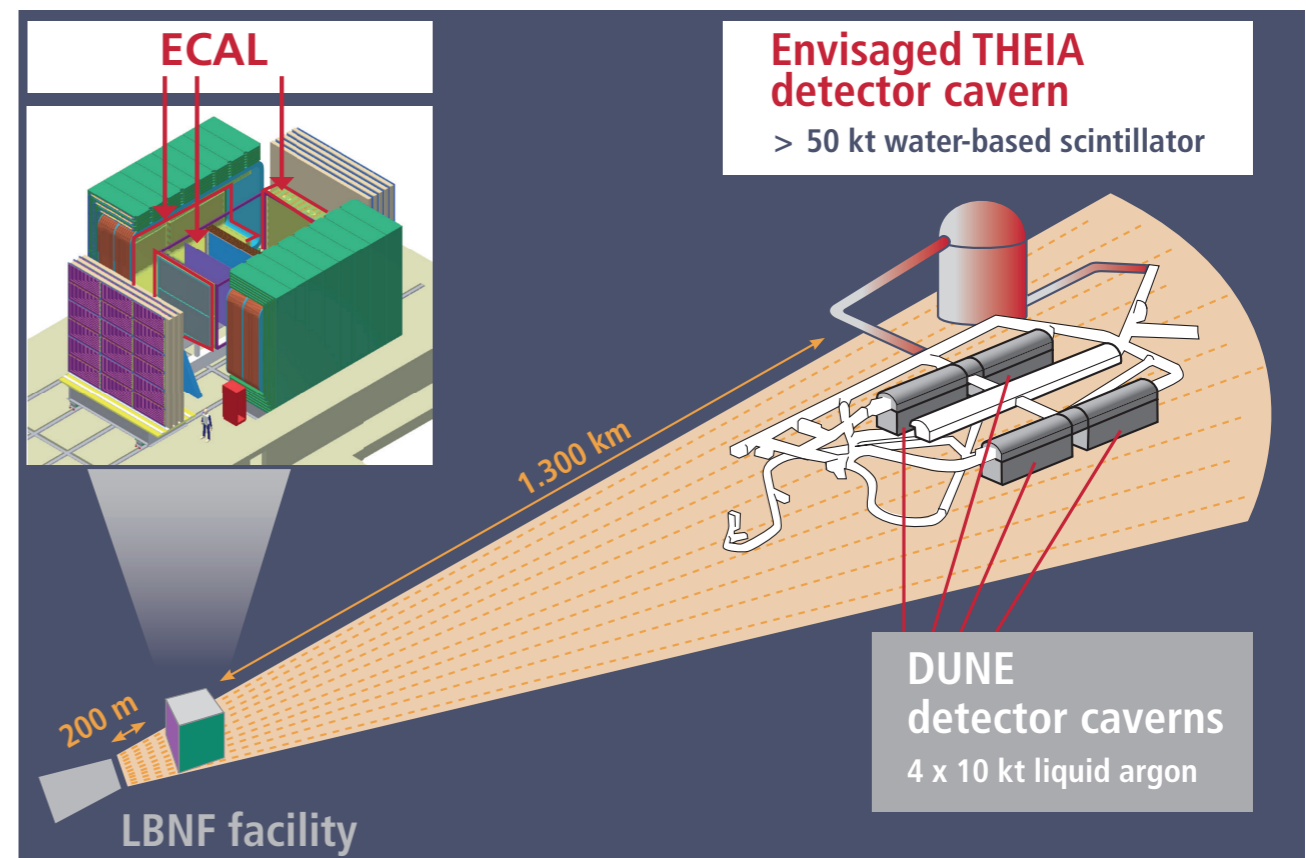
* Nucleon axial form factors
  $G_A(Q^2),\ G_P(Q^2)$

Neutrino Physics

* **DUNE/SURF:** Long-baseline neutrino facility

* Goal: Detect CP-violating phase in neutrino sector

Mainz/PRISMA+ contribution:

* ECAL for near detector

* THEIA detector
  (liquid scintillator)
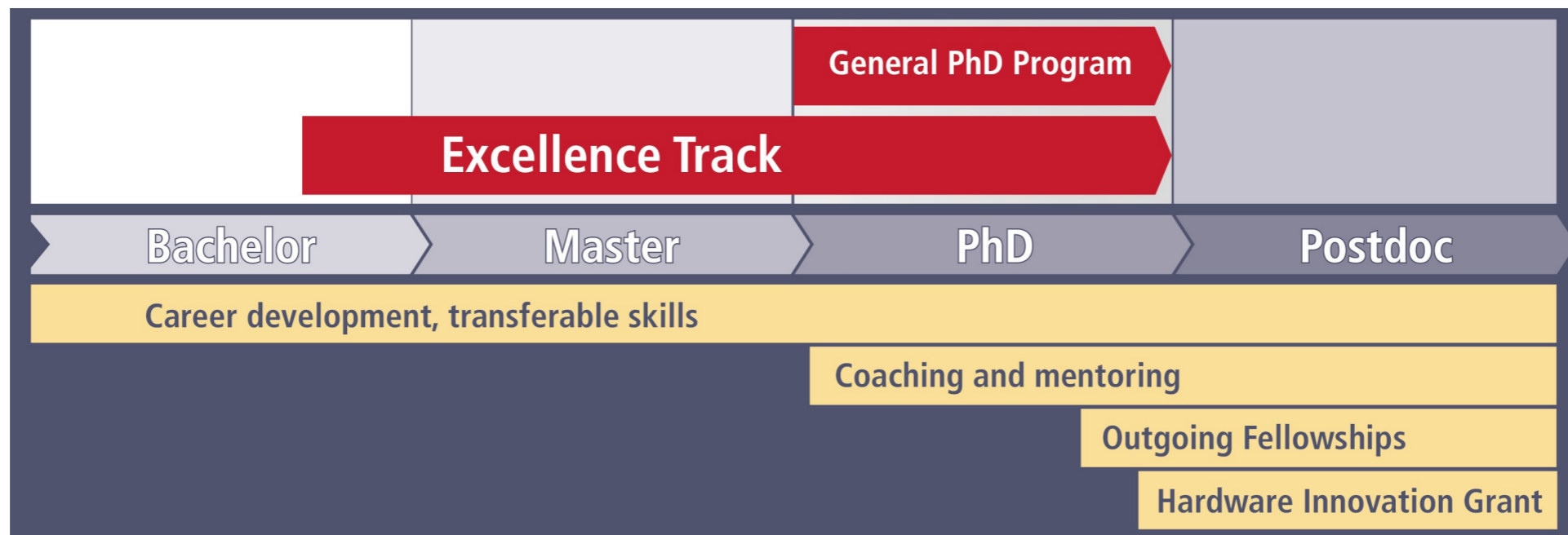
* Nucleon axial form factors
  $G_A(Q^2)$, $G_P(Q^2)$

New research group — joint appointment with Fermilab

Structural Goals

* Research-oriented training environment and early-career support

Mainz Physics Academy

Outreach Activities

* Public Lecture series
  "Physik im Theater"

* Exhibitions

* Training opportunities
  for high-school students

Public lecture series: "Physics in the Theatre"

Teilchen-Akademie — High-school students

Outlook — Timeline

✱ Construction of MESA Hall completed by end of 2020

⇒ Construction of MESA accelerator: 2021–22

⇒ MESA experiments MAGIX, P2: 2023—

Outlook — Timeline

✳ Construction of MESA Hall completed by end of 2020

⇒ Construction of MESA accelerator: 2021–22

⇒ MESA experiments MAGIX, P2: 2023—

Challenge

✳ **Budget cuts of 25% imposed on all clusters**