PERSPEKTIVES FOR MAMI UND MESA
STATUS AND LONGTERM VISION

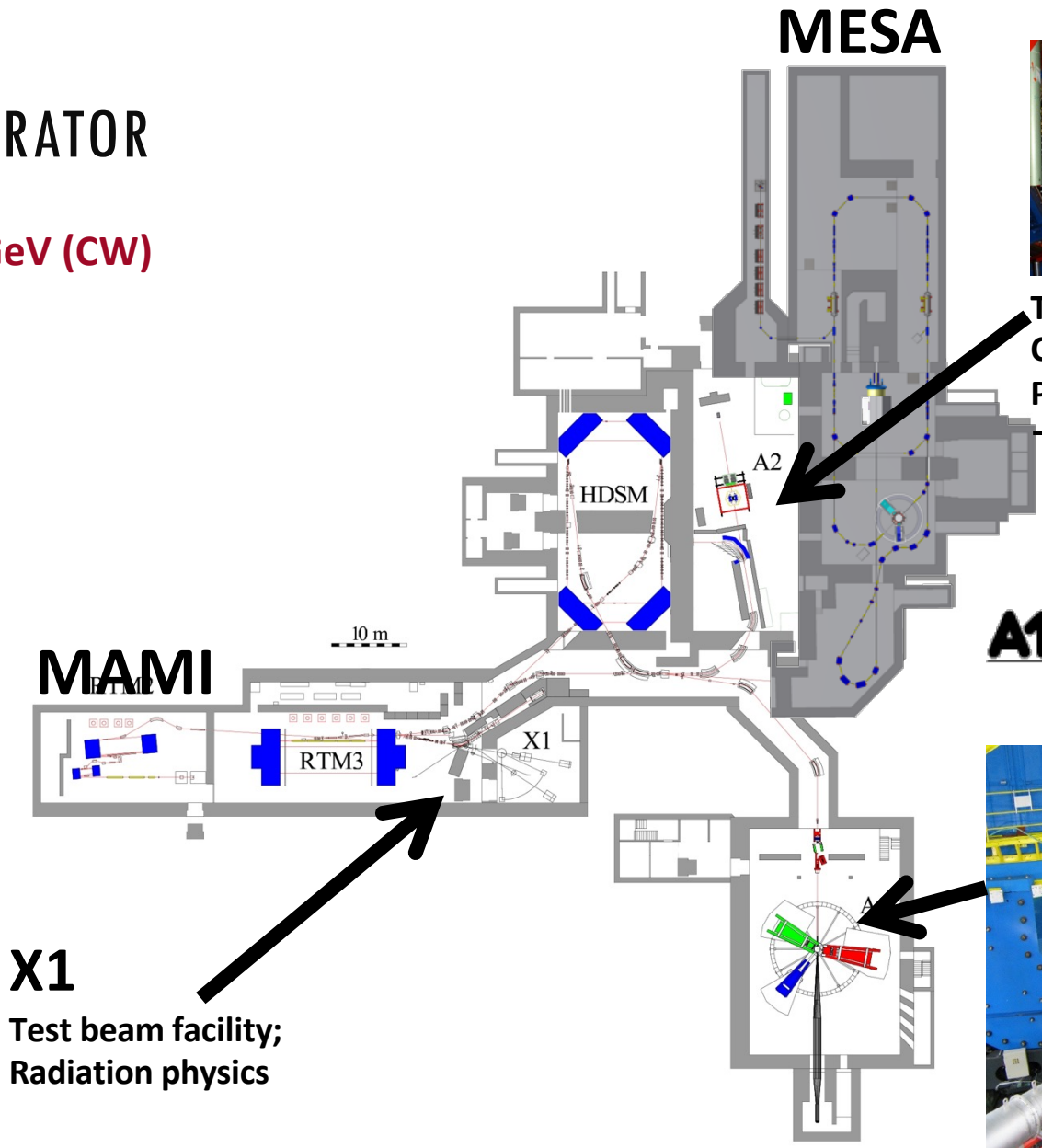
KHUK ANNUAL MEETING (2022)

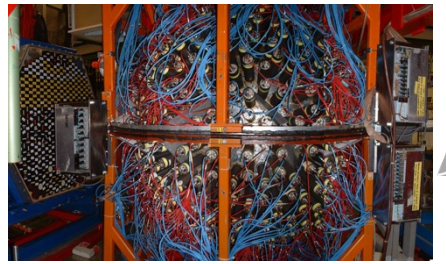
FRANK MAAS, JGU MAINZ, HELMHOLTZ INSTITUT MAINZ, GSI

MAMI ELECTRON ACCELERATOR

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

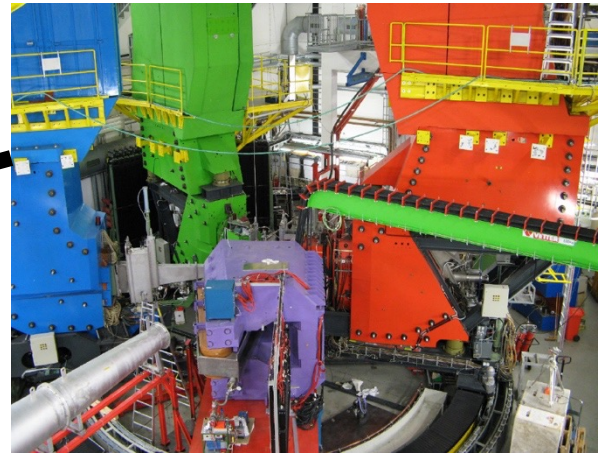
- Intensity max. 100 μA
- Resolution σ_E < 0.100 MeV
- Polarization 85%
- Reliability: up to 7000 h / year





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

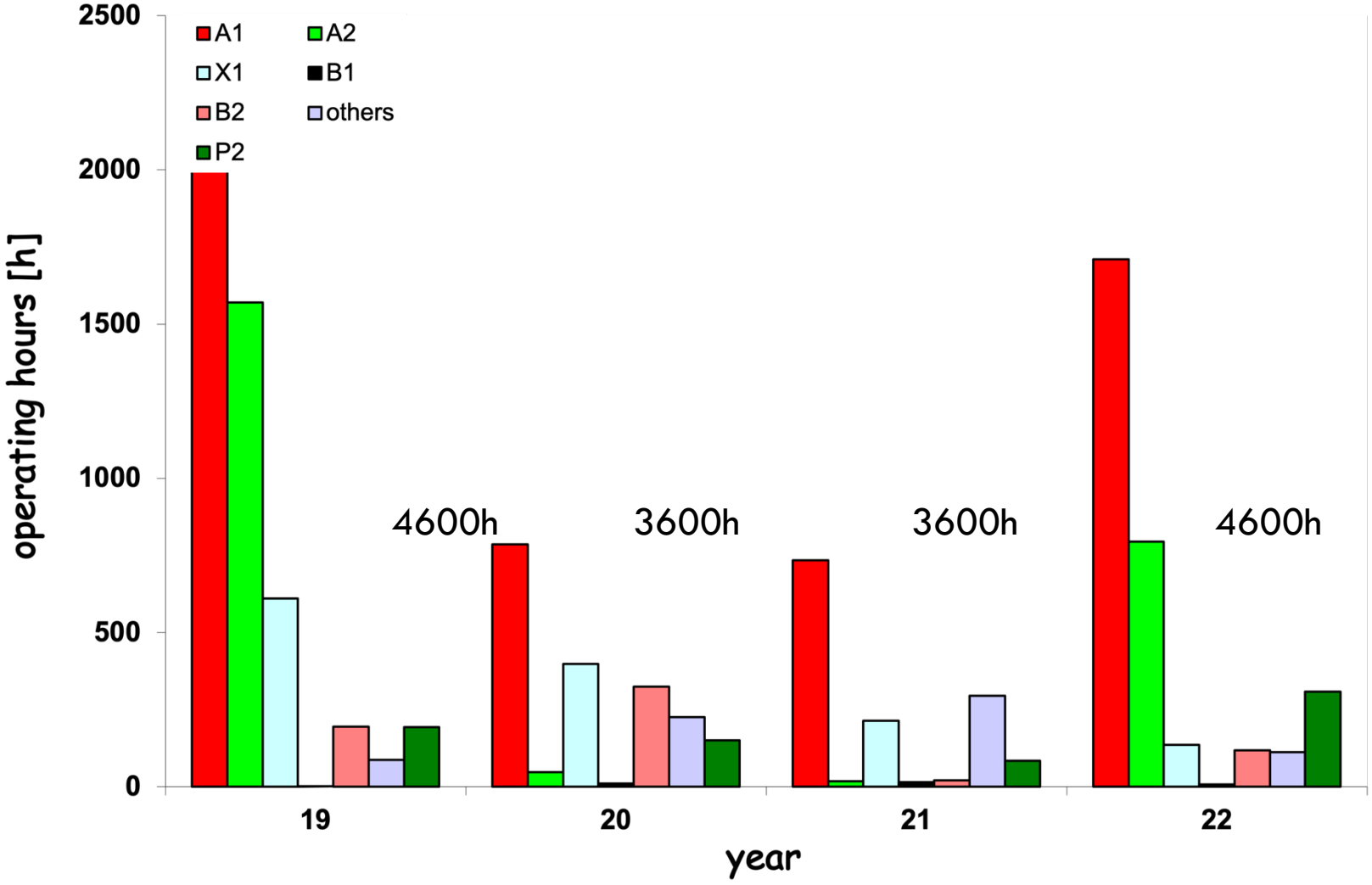
Electron scattering (A1 hall)
High resolution
Magnetic spectrometers



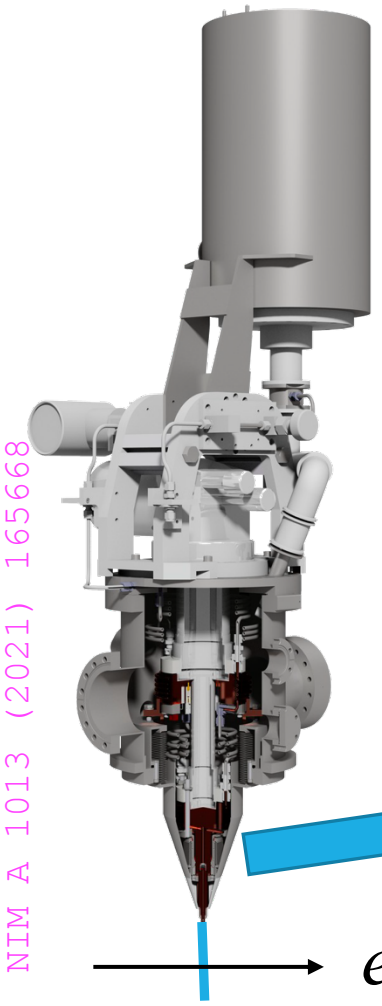
X1
Test beam facility;
Radiation physics

PRISMA+

MAMI OPERATION



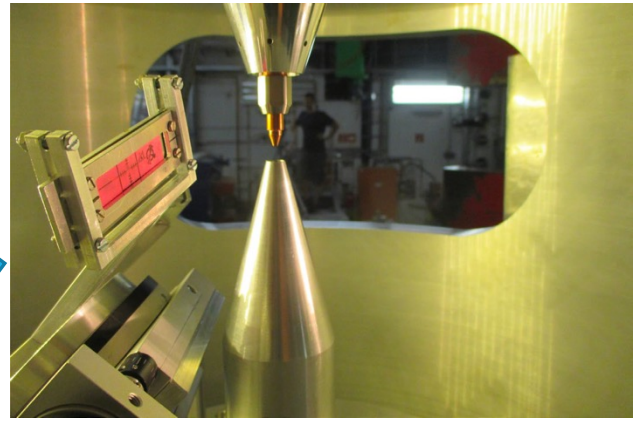
SUPERSONIC GAS-JET TARGET (A1/MAMI, LATER MAGIX/MESA)



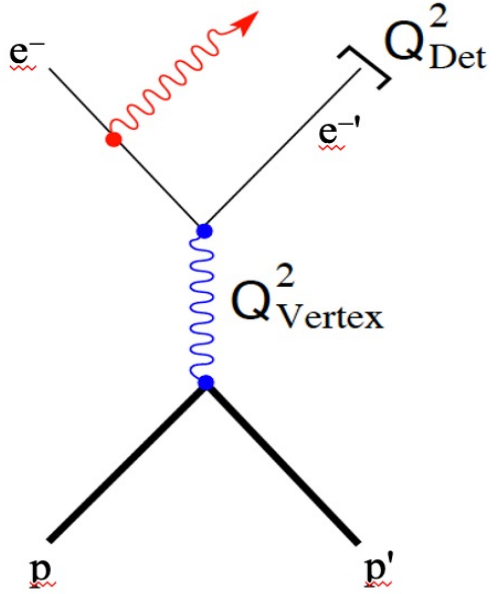
NIM A 1013 (2021) 165668

Construction of a high-density gas jet target in cooperation with University of Münster (A. Khoukaz)

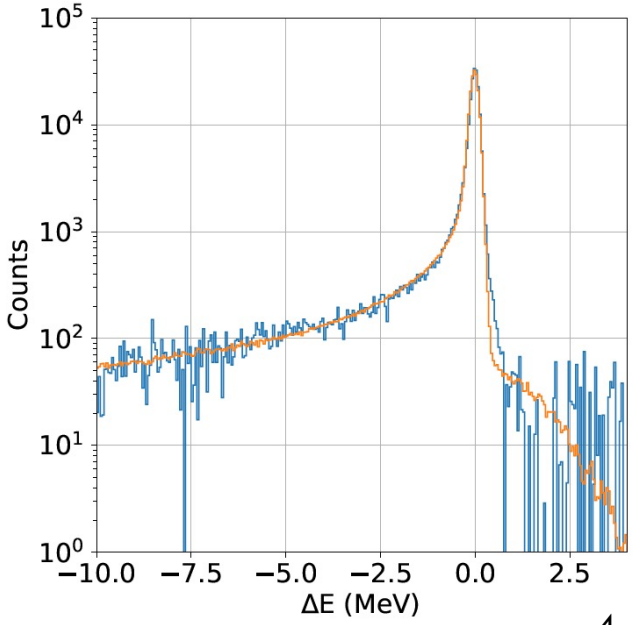
- Future MAGIX experiment at MESA: combination of light gas jet target with ERL electron beam
- Commissioning at A1/MAMI already now
  → Measurement of electron-proton scattering (proton EM factors = flagship project @ Mainz)
  → Most precise determination of proton radius in electron scattering (Bernauer et al. 2010); accuracy limited by scattering of electrons at walls of liquid hydrogen target
- New measurement of G_E with gas jet target via Initial state radiation
  → access low momentum transfer 0.01 GeV^2/c^2



window-less, thin, point-like target !



arXiv:2208.13689

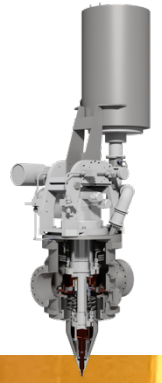


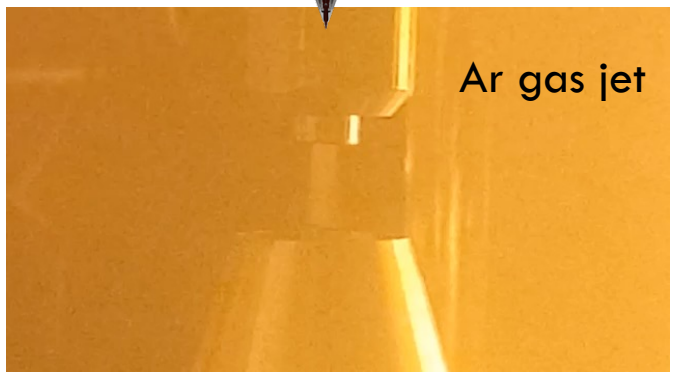
ELECTRONS FOR NEUTRINOS A1

Interpretation of current and future generation of **neutrino experiments** (DUNE,T2K, Hyper-K, Mini-Boone, ...) requires knowledge of **neutrino-nucleus interaction:** **^{12}C, ^{16}O, ^{40}Ar**

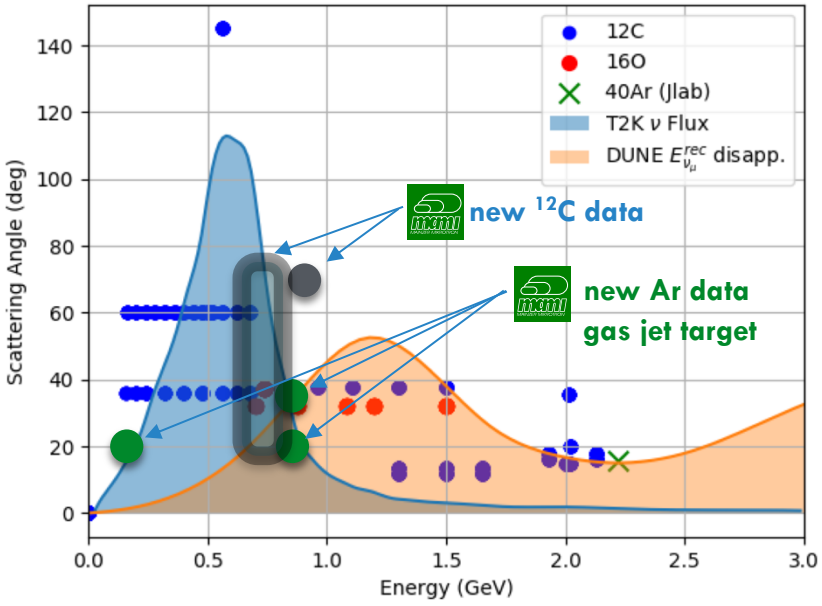
→ **Check and calibrate MC-generators** via dedicated program of **electron-nucleus measurements**

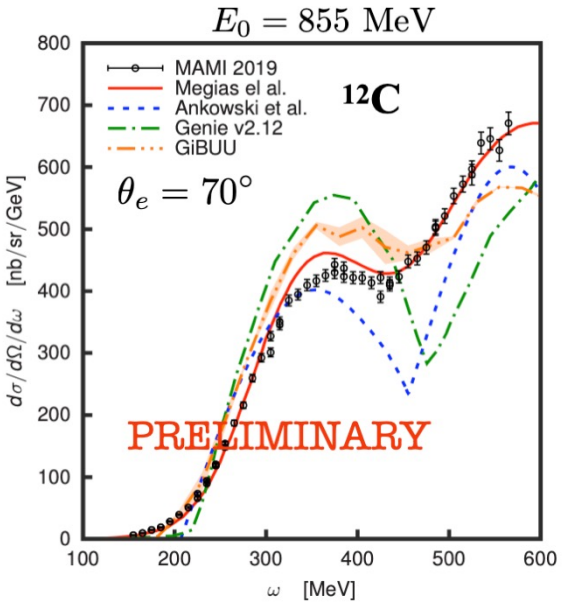
→ **MAMI energy range complementary to program at JLAB**

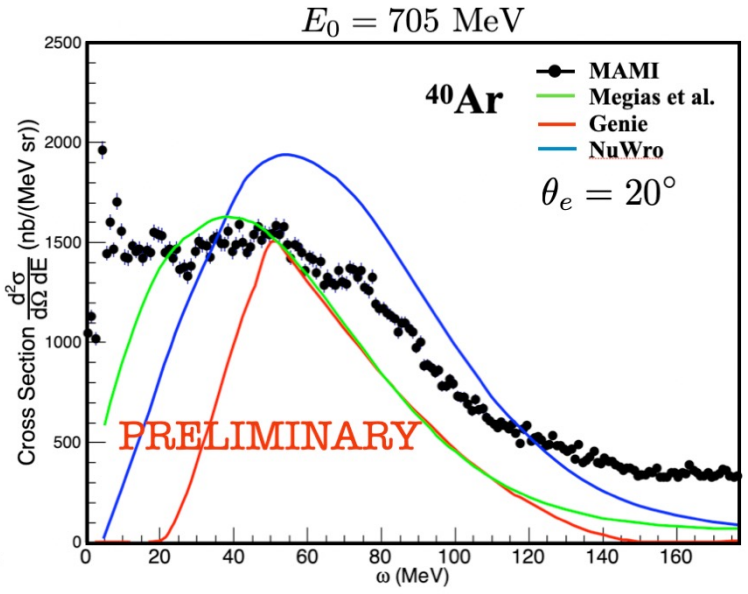




courtesy Sören Schlimme







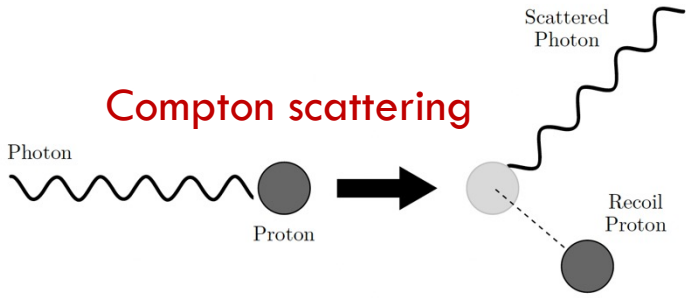
PROTON POLARIZABILITIES @ A2/MAMI

Reaction of nucleon under influence of an EM field provides fundamental information of the nucleon; very sensitive test of theories (H/BχPT, Disp. Rel.).

- Electric Polarizability: α_{E1}
- Magnetic Polarizability: β_{M1}

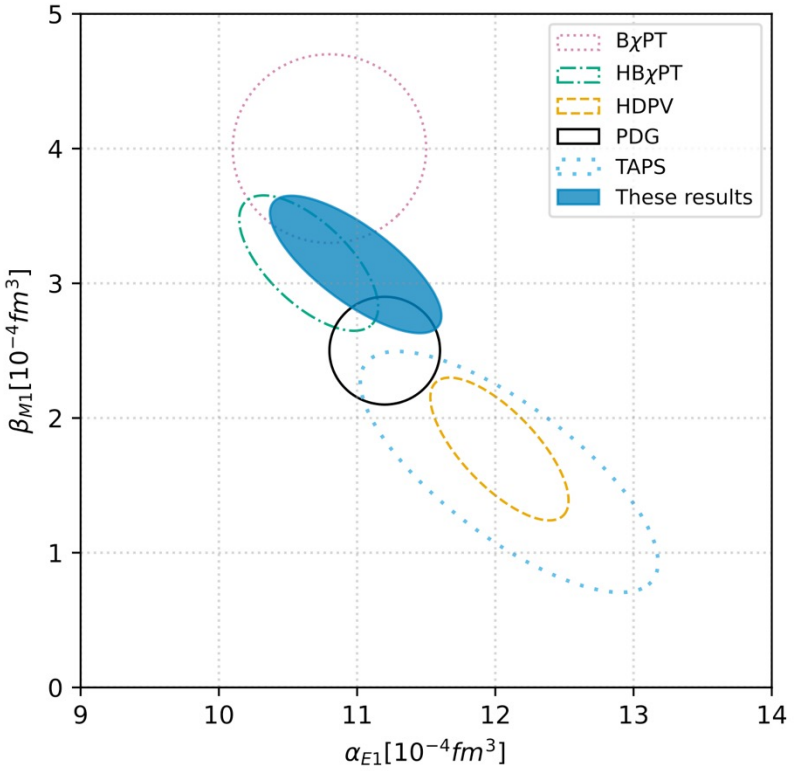
$$H_{\text{eff}}^{(2)} = -4\pi\left[\frac{1}{2}\alpha_{E1}\vec{E}^2 + \frac{1}{2}\beta_{M1}\vec{H}^2\right]$$

Compton scattering

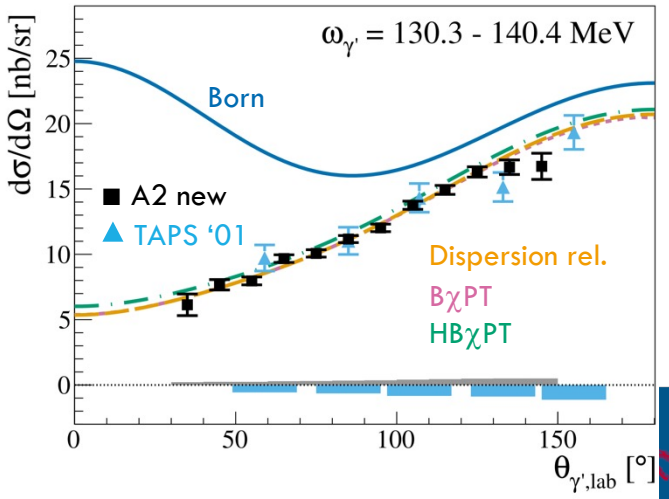


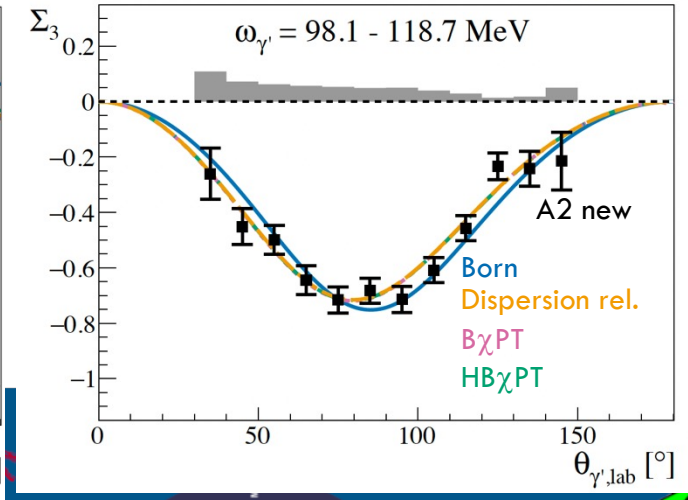
- in addition 4 Spin Polarizabilities

PRL 128 (2022) 132503



Exploit linear beam polarization to measure asymmetry $\Sigma_3 \equiv \frac{d\sigma^{\perp} - d\sigma^{\parallel}}{d\sigma^{\perp} + d\sigma^{\parallel}}$

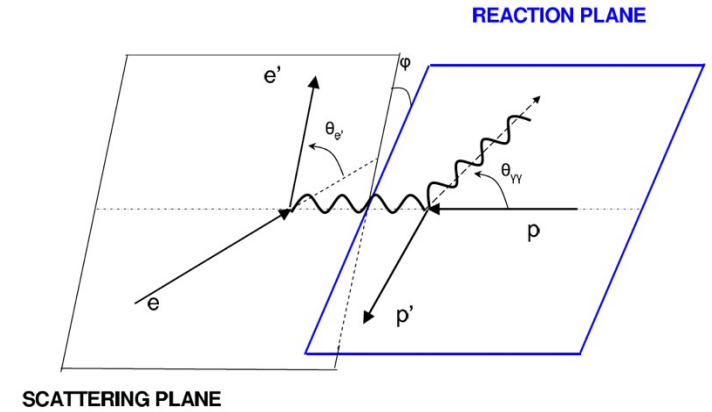




	stat	syst.	spin polar.	model dep.
$\alpha_{E1} = 10.99 \pm 0.16 \pm 0.47 \pm 0.17 \pm 0.34$				
$\beta_{M1} = 3.14 \pm 0.21 \pm 0.24 \pm 0.20 \pm 0.35$				

PRL 129 (2022) 102501

PROTON GENERALIZED POLARIZABILITIES @ A1/MAMI



Accessible via Virtual Compton Scattering:

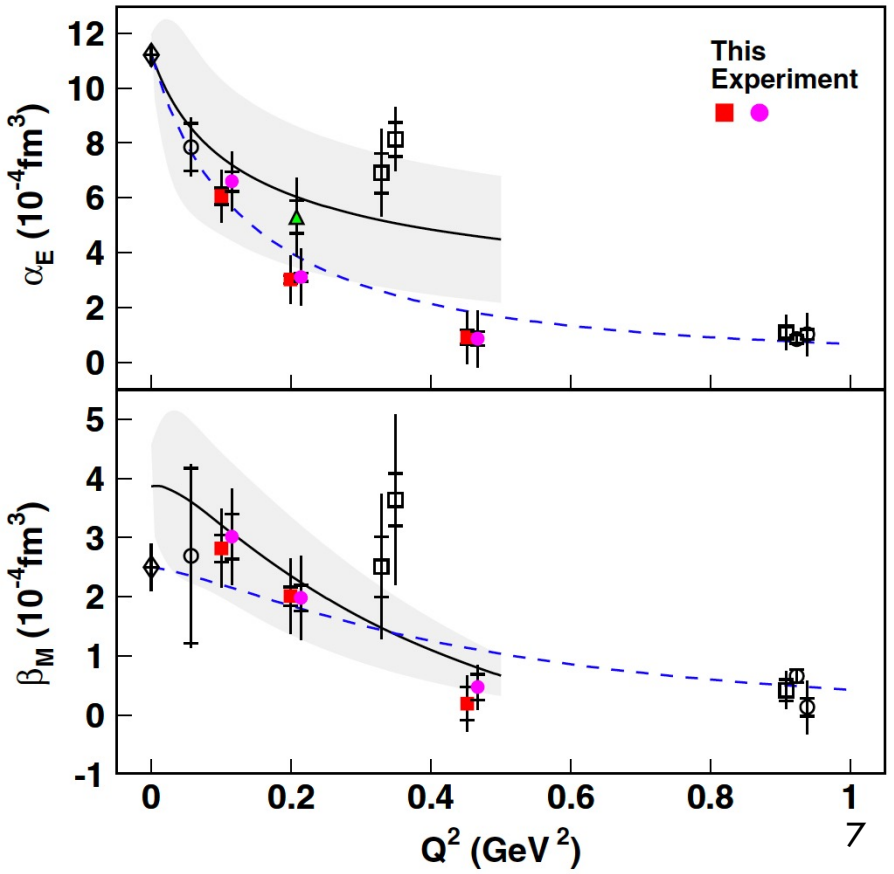
Virtuality of photon gives access to Generalized Polaribilitiess :

$\alpha_E(Q^2)$; $\beta_M(Q^2)$ (+ 4 spin GPs)

→ mapping out the spatial distribution of the polarization densities

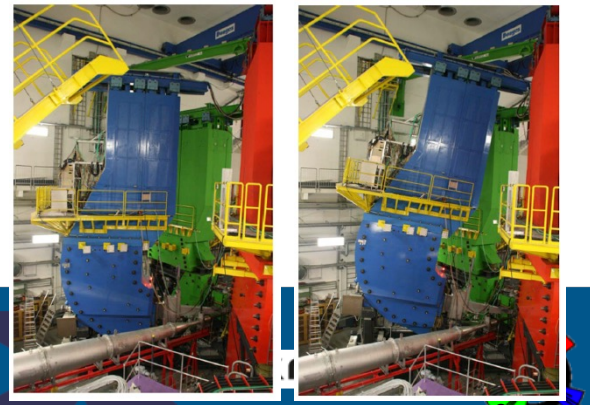
→ Fourier transform of densities of electric charges and magnetization of a nucleon deformed by an applied EM field

PRL123 (2019) 192302



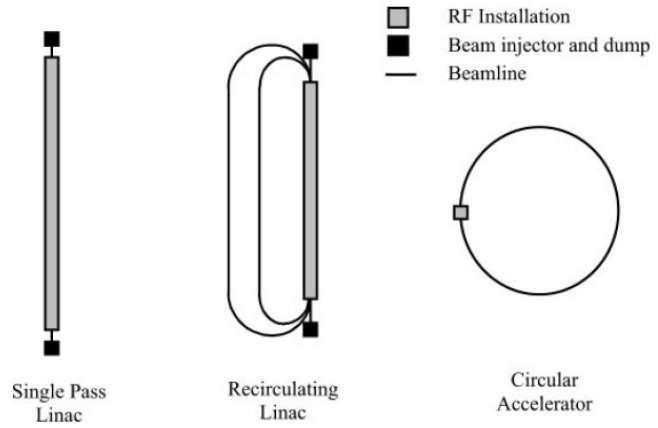
New MAMI data in two measurement campaigns:

- Detailed understanding of systematics (4 PhD students)
- Out of plane (oop) measurement to access kinematic range, in which higher order terms small and extraction possible
- Final extraction according to LEX (low energy expansion) and DR
- First extration of N-Δ transition FF via gamma channel

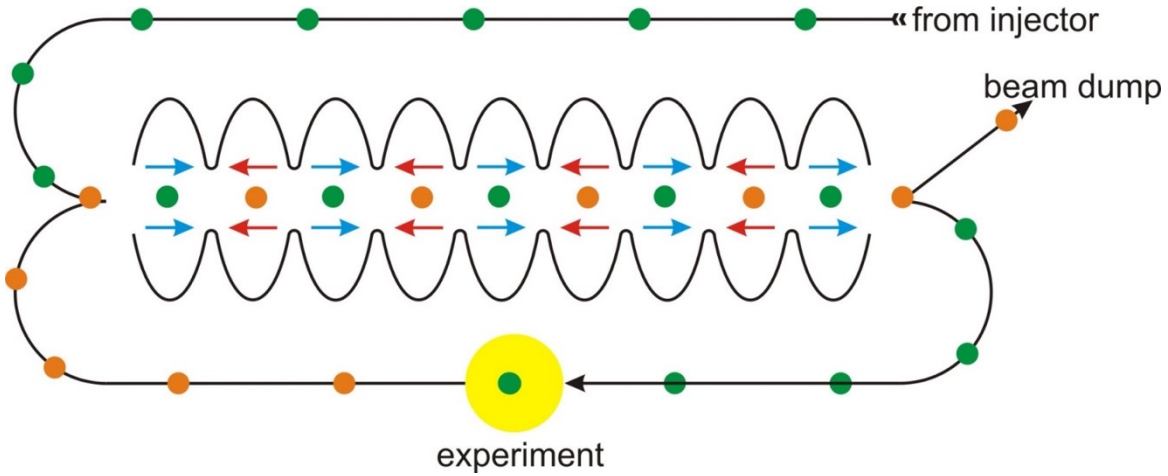


in plane oop (8.5°)

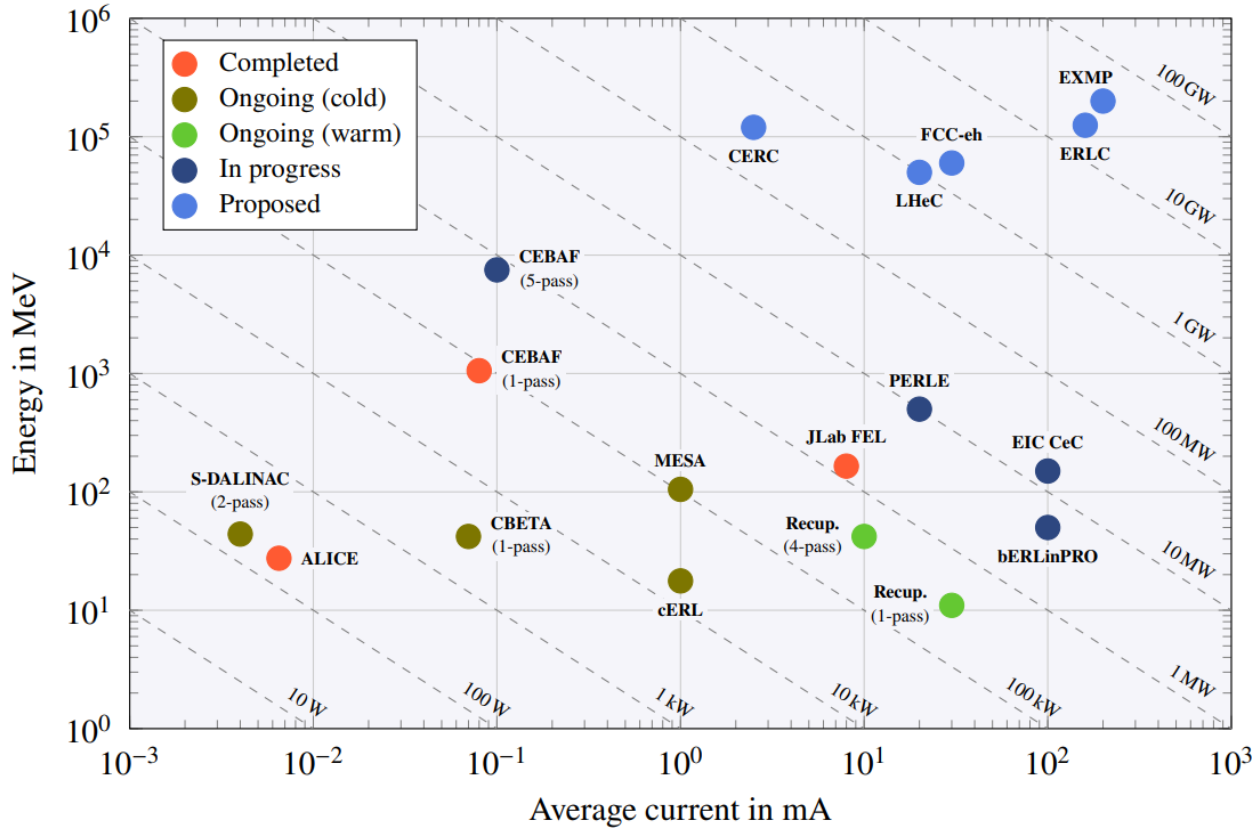
MESA ACCELERATOR



Energy Recovering LINAC



ERLs world-wide (status fall 2022)



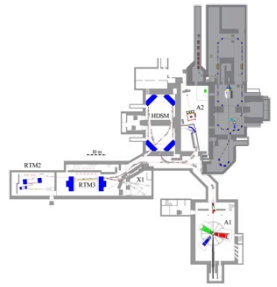
→ MESA is one of 3-4 ongoing ERL activities
→ The **only** facility which will be used for physics experiments

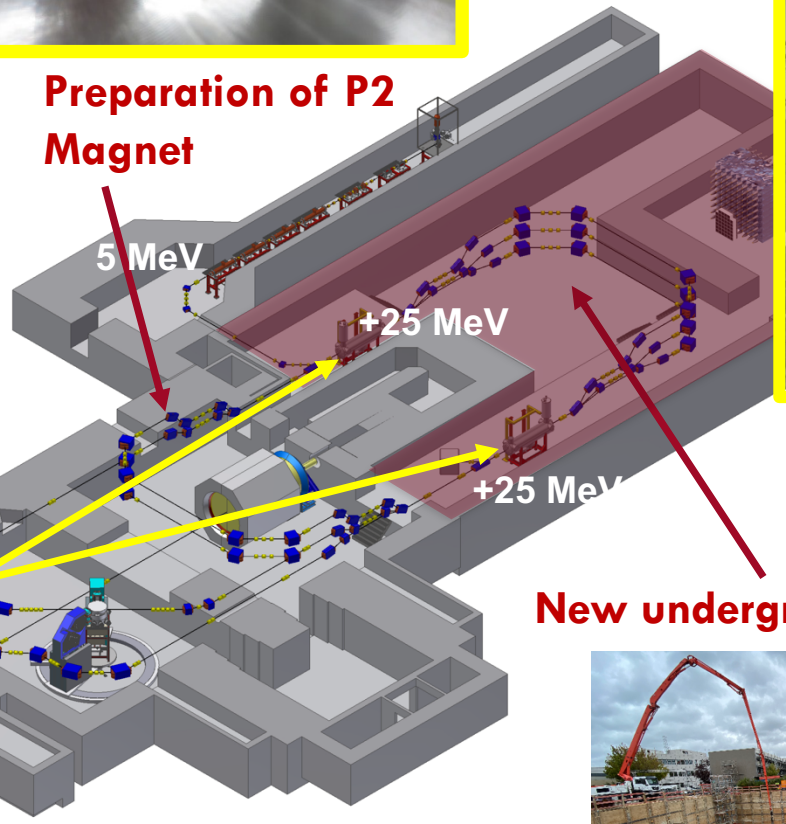
MESA ACCELERATOR

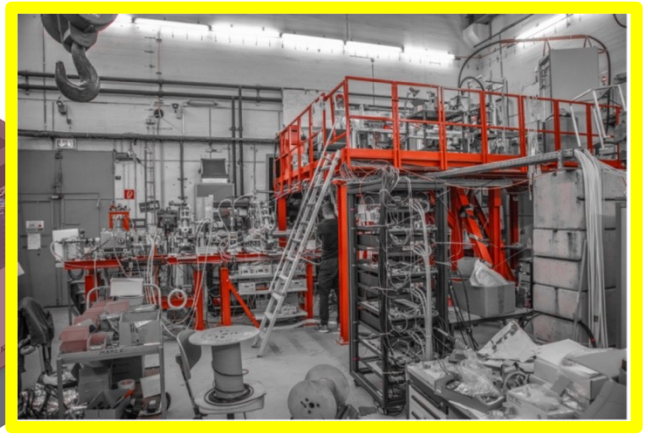
Key parameters MESA:

- Two operation modes: extracted beam (EB) or energy recovering (ERL)
- Max. beam energy 155 MeV (EB), 105 MeV (ERL)
- Beam current 150 µA (EB), 1 mA (ERL)
- Superconducting cavities
- Start commissioning 2024
- New research building (par. 91b GG)
- Can run in parallel to MAMI

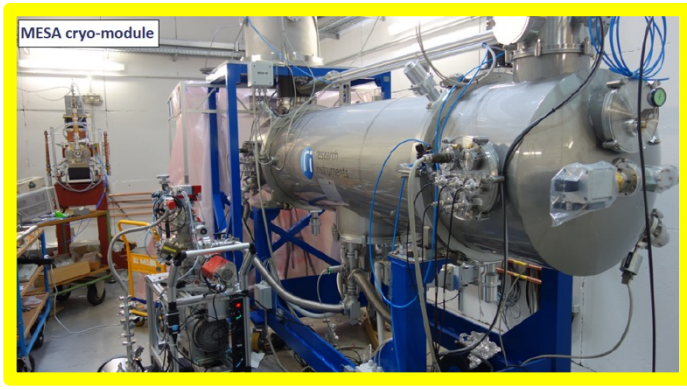
Preparation of P2 Magnet







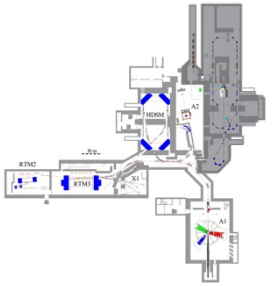
Polarized Source Test Setup



Cryomodules successfully tested

New underground experimental hall (par. 91b GG)

MESA EXPERIMENTS



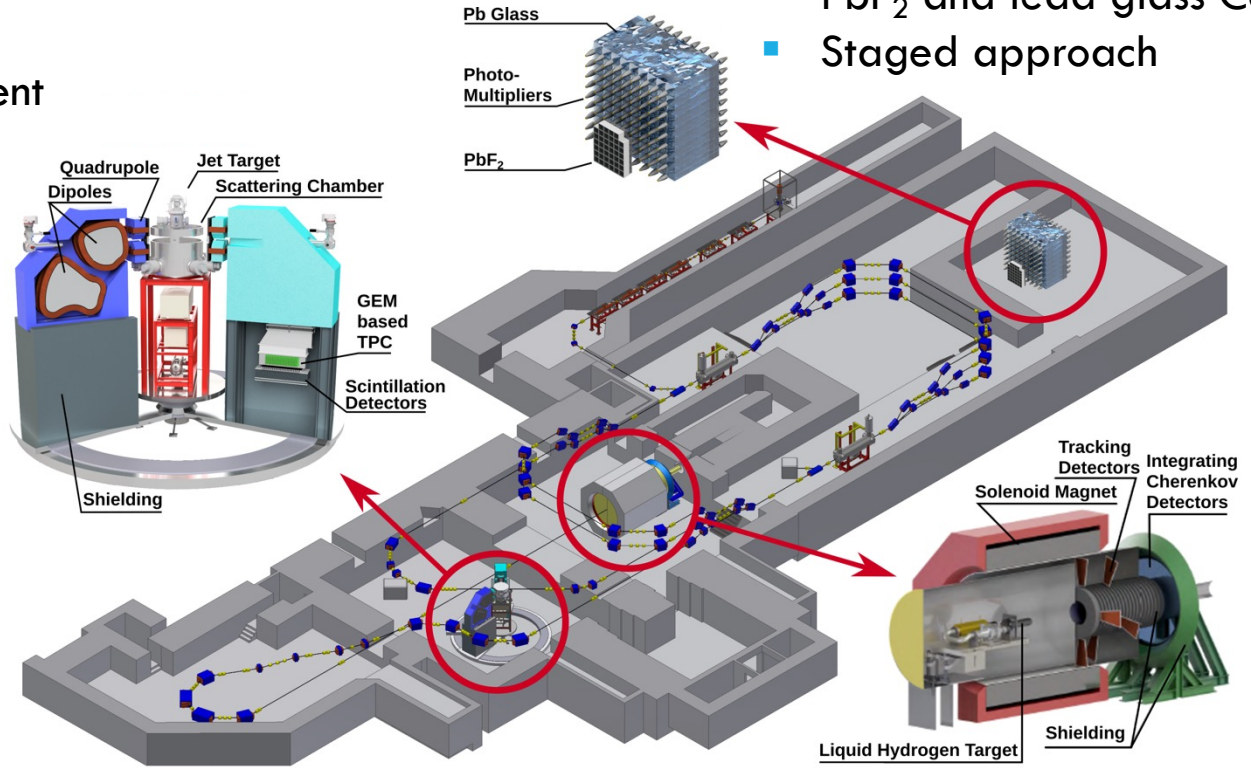
MAGIX experiment

- Operated in ERL mode of MESA
- Double-arm spectrometers
- Internal gas target experiment
- Gas jet target commissioned at A1/MAMI already

Main components of MAGIX and P2 presently constructed in industry and assembled in house (funding via major research instrumentation program of federal government)
Phase 1 detecctor for DarkMESA almost ready.

DarkMESA

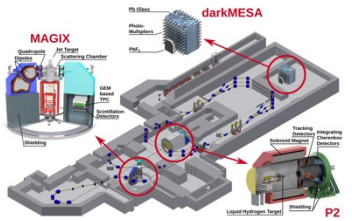
- Beam dump experiment
- Direct detection of light dark matter
- PbF_2 and lead glass Cerenkov calorimeter
- Staged approach

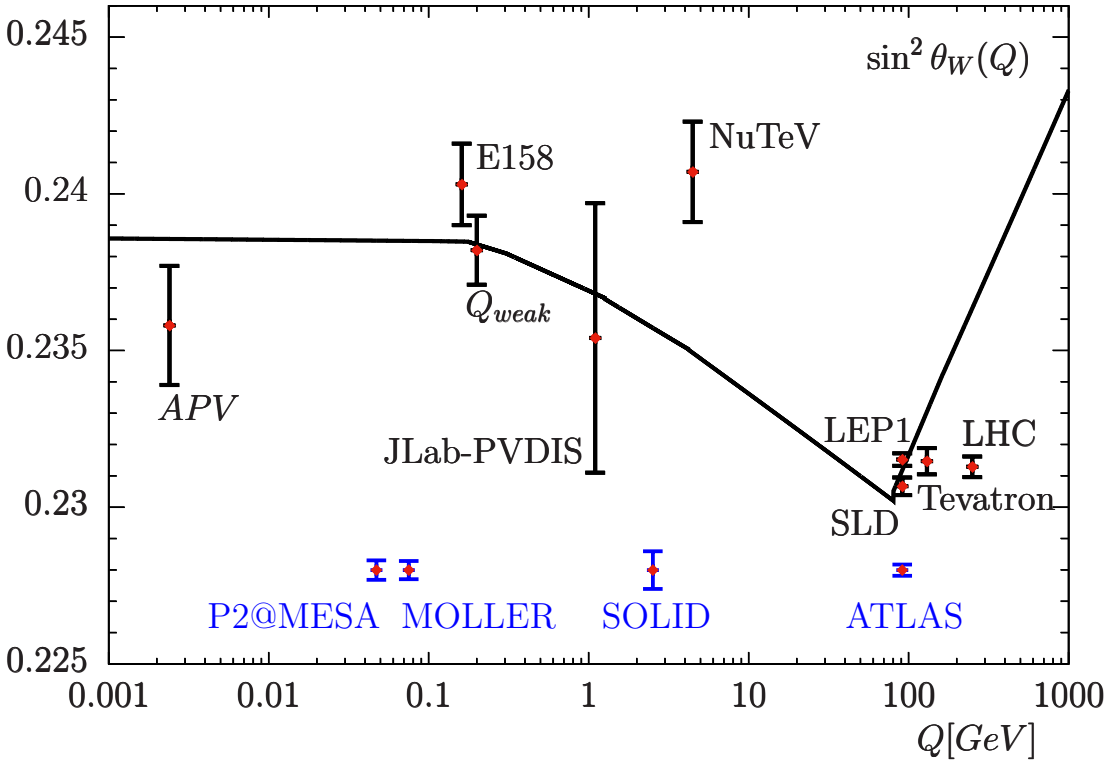


P2

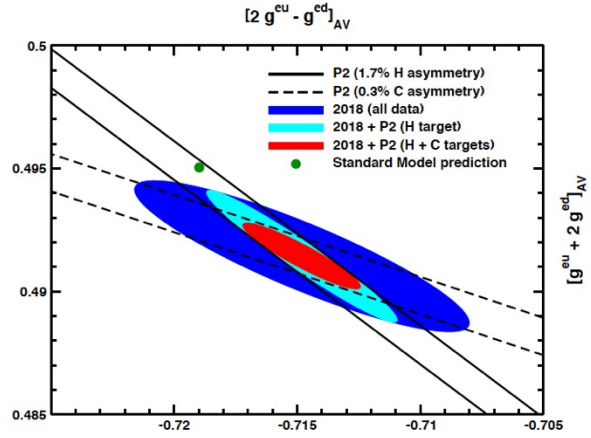
- Extracted beam mode
- Parity violation experiment
- 10^{22} Electrons / a
- $\sin^2\theta_W$ and neutron skin

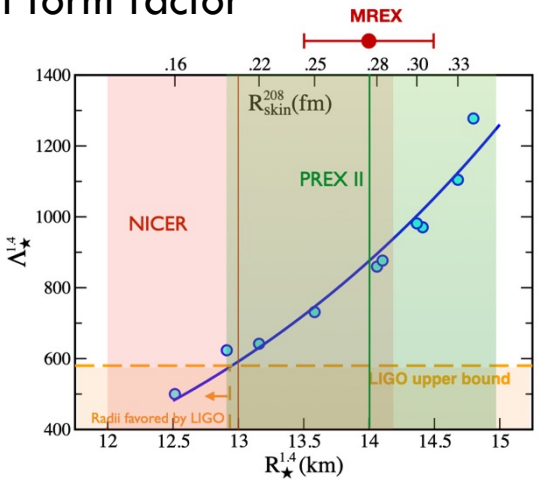
P2: HIGH PRECISION DETERMINATION OF THE WEAK MIXING ANGLE

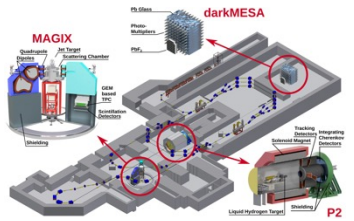




- Parity violating asymmetry in elastic electron scattering
- 25 times smaller asymmetry, 5 times smaller relative error
- Low energy test of the standard model
- PV brother of the dark photon: down to 70 MeV
- Proton: weak mixing angle, test of new physics up to 49 TeV
- Carbon: weak mixing angle, test of new physics up to 49 TeV
- Lead: neutron skin of nuclei: infer the radius of neutron stars.
- Transverse asymmetries: nuclear phjysics
- Precise measurement of axial form factor



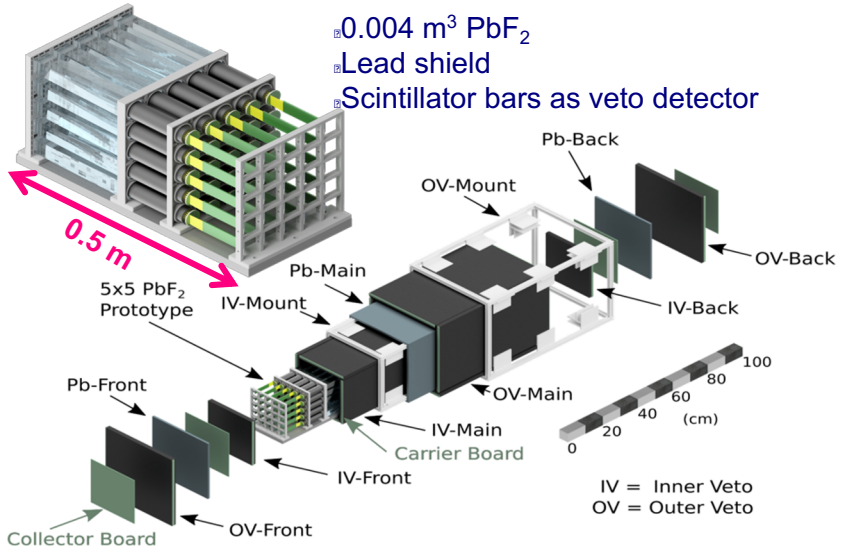




DARKMESA: BEAM DUMP EXPERIMENT, SEARCH FOR DARK PHOTON

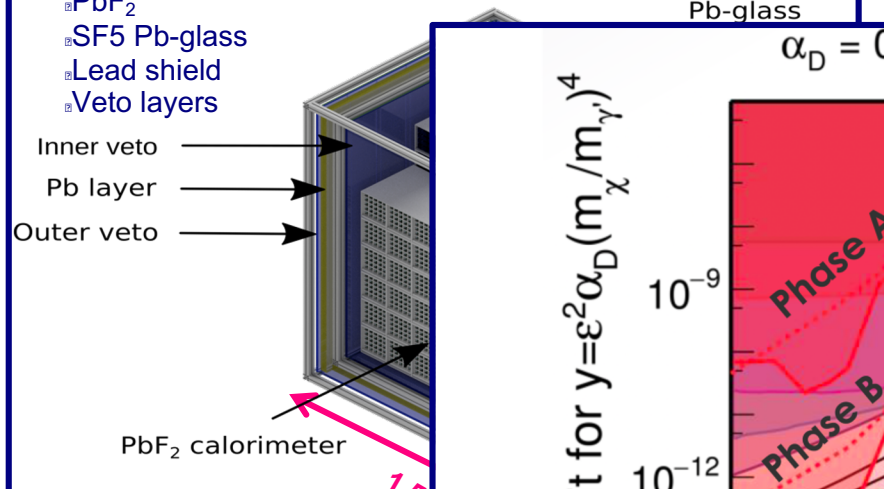
Phase A (prototype)

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

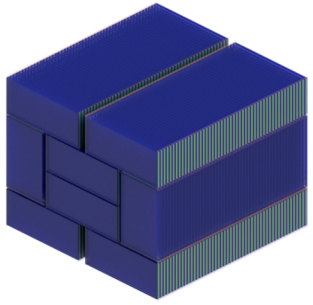


Phase B

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



Phase C (range extension)



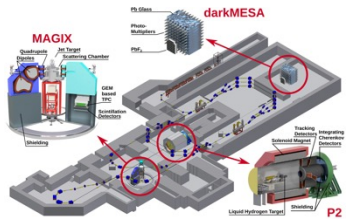
options

Radiation protection glas
e.g., SCHOTT-RD30
Moderate cost: 137 k€ / m³
High density: 3.13 g / cm³

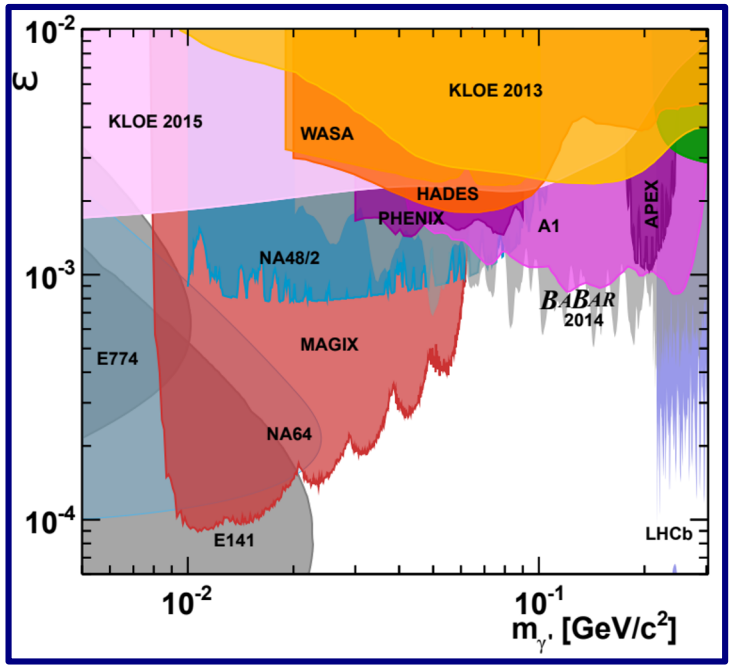
DRIFT -Time Projection Chamber
CS_2 at 50 mbar
~1 m³ active volume
Nuclear recoil threshold: 20 keV

⇒ Extended parameter space

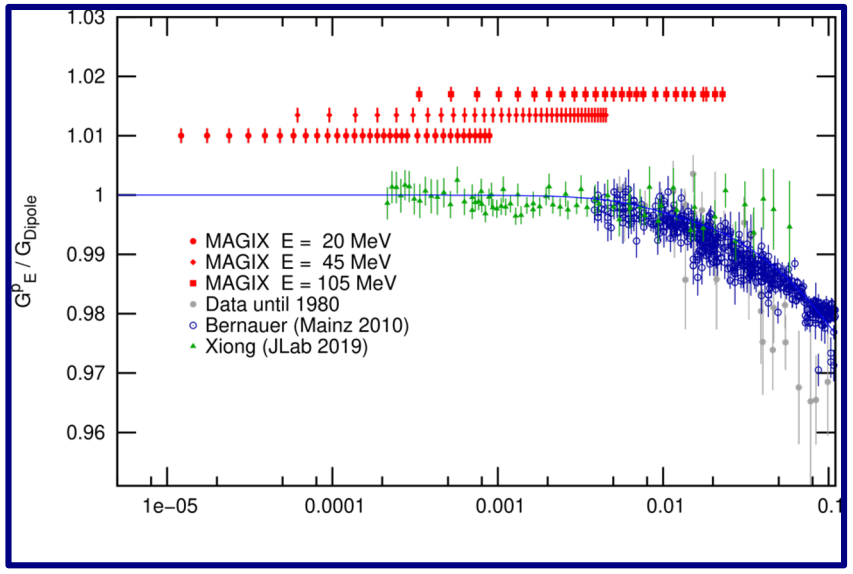
MAGIX: MAGNETIC SPECTROMETER AND CLUSTER JET TARGET (SELECTION OF TOPICS)



Dark Matter search with MAGIX

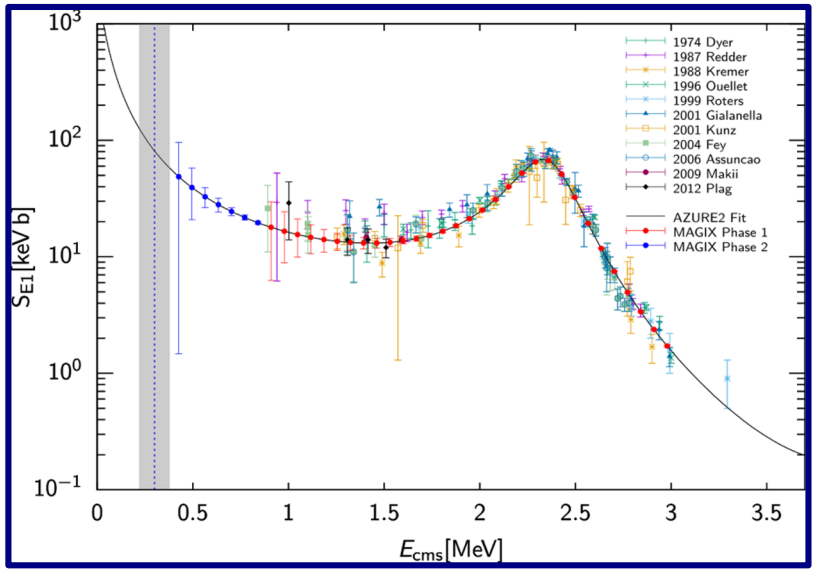


G_E and Proton Radius, projected stat. errors



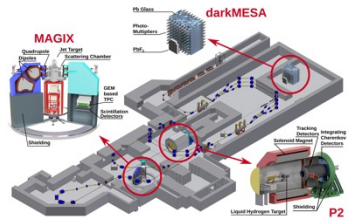
- Coverage from Q2 = 1·10-5 to 0.03 GeV² ⇒ proton radius!
- Dominated by systematic error
- Windowless target, negligible background, high resolution, high efficiency, ...

Nuclear Astrophysics, S-Factor measurement

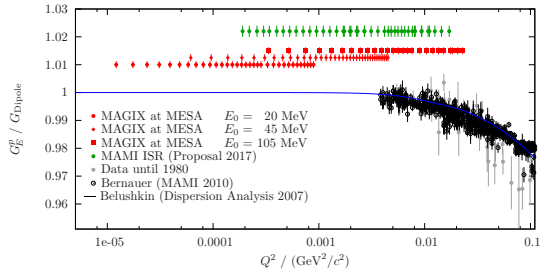


- **$^{12}C + \alpha \rightarrow {}^{16}O + \gamma$:**
  one of most important reactions to describe nucleosynthesis in burning of a star:

MESA PHYSICS PROGRAM

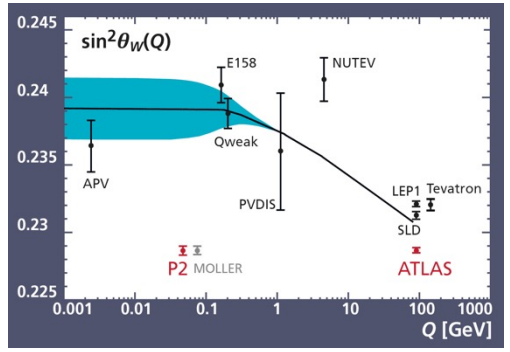


From Nuclear Physics to Hadron and Particle Physics



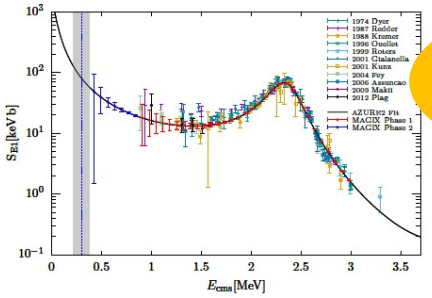
Low Q^2 EM Form Factor p,n (MAGIX)

Precision Measurement of $\sin^2\theta_W$ via p,^{12}C (P2)



Neutron Skin Pb (P2-MREX)

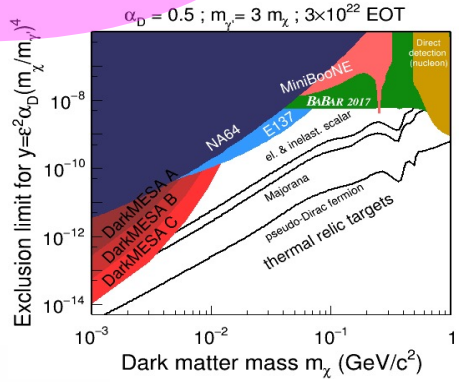
Search for Dark Photon and Axions (MAGIX)



$^{12}C\ (\alpha,\gamma)\ ^{16}O$ (MAGIX)

Few Body Physics (MAGIX)

Light Dark Matter direct detection (DarkMESA)



SUMMARY AND OUTLOOK

- Despitge the pandemics: MAMI beam and experiment operation under severe restrictions
- Diverse past and future program at MAMI with results at A1, A2, X1
  (only small fraction in this talk, Hypernuclei, Pion transition FF in virtual Primakoff kinematics,…)
- Test beam at MAMI for MESA detectors and accelerator components instrumental
- Impact on future MAMI physics program; collaboration with russian institutes: Polarized frozen-spin target and Hydrogen TPC
- Construction of MESA accelerator and MESA experiments MAGIX, P2, DarkMESA continuing successfully
- Exciting experimental program at MESA in nuclear, hadron and particle physics
- Staged approach for construction, commissioning and first measurements with MESA experiments
- Very rich results expected from all MESA experiments
- First experiments Q1/2025