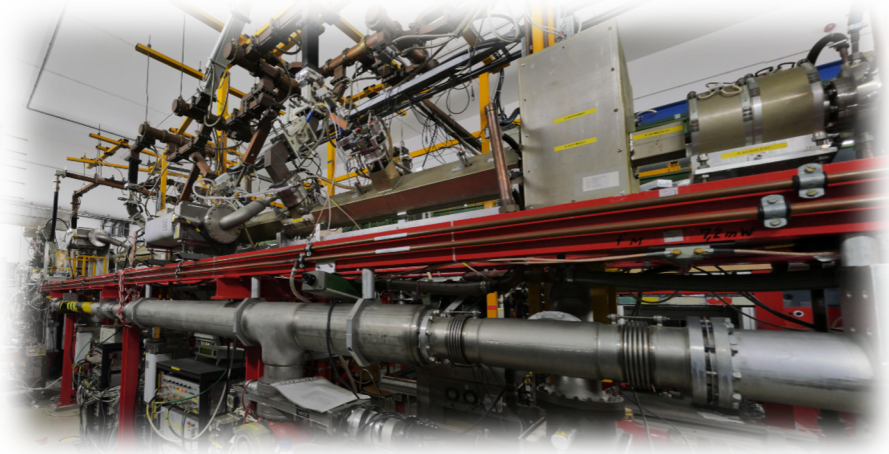
KHUK Annual Meeting
December 10, 2021



Electron Accelerators for Nuclear/Hadron Physics in Germany – quo vadis?

Achim Denig for the ELSA, MAMI, MESA, and S-DALINAC facilities

ELSA

MAMI MAINZER MIKROTRON

MESA

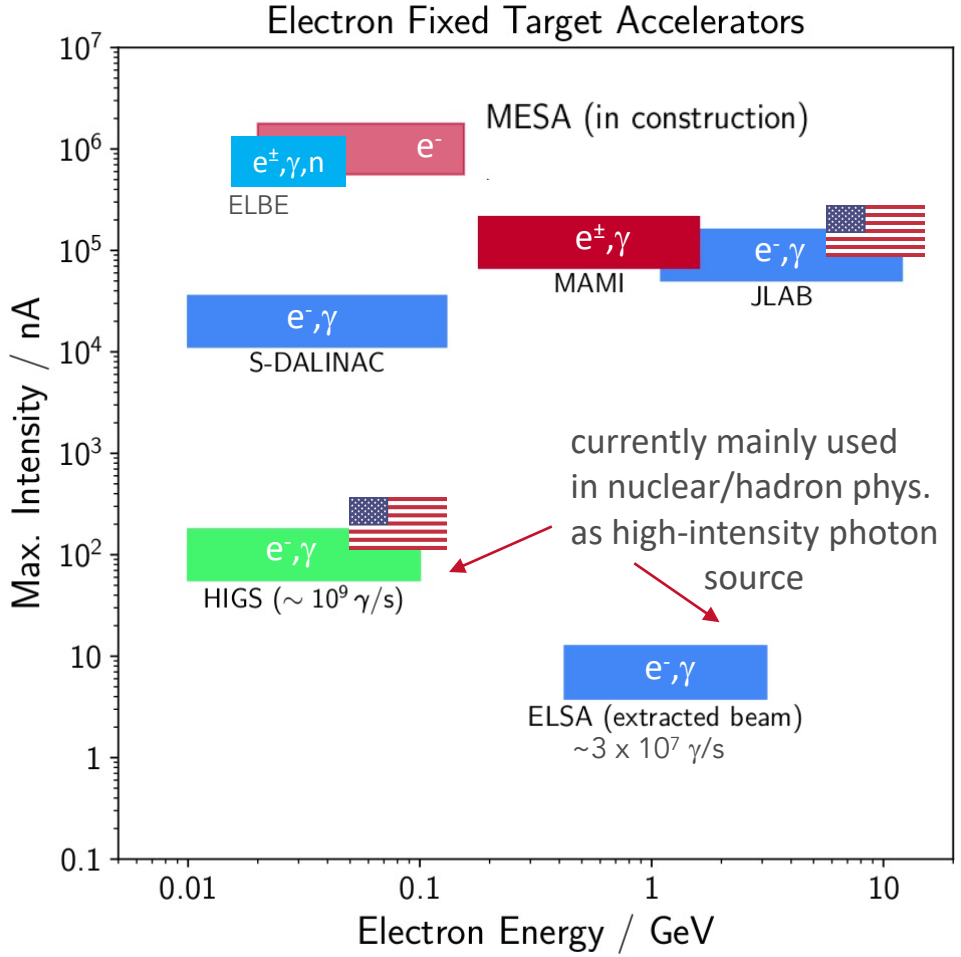
Institut für Kernphysik S-DALINAC Technische Universität Darmstadt

Fixed-Target Electron Accelerators in Germany

U Bonn:
Electron Stretcher Accelerator

U Mainz:
4 stages of Microtrons, CW
2023+ : MESA ERL

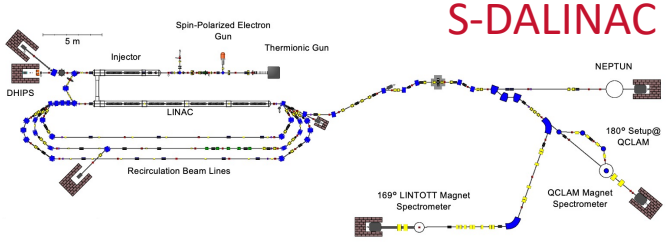
TU Darmstadt:
Recirculating superconducting LINAC (ERL-operation), CW



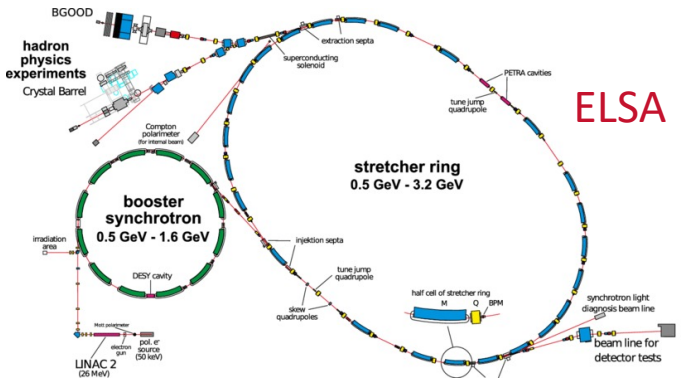
Disclaimer: will not be discussing ELBE, ANKA, DELTA, DORIS,...

„University Accelerators“ S-DALINAC, ELSA, MAMI

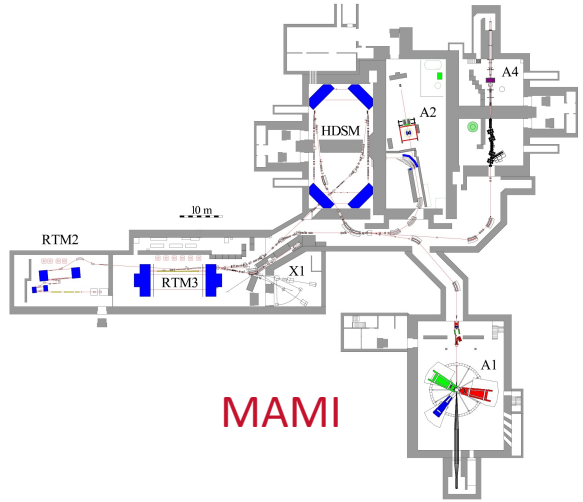
- **Basic funding** provided by **Universities DA, BN, MZ**, and Länder **Hessen, NRW, and RLP**
- **DFG funding** via SFBs, individual proposals, and the **Cluster of Excellence PRISMA⁺** (Mainz)
  → **new funding proposals submitted and/or in preparation**
- **Scientific program evaluated by Program Advisory Committees (PAC)**
- Large number of **international partners** from Europe, America, and Asia
  → **ELSA and MAMI** selected by EU within the **Transnational Access program** (STRONG2020), which provides support to key facilities in hadron physics



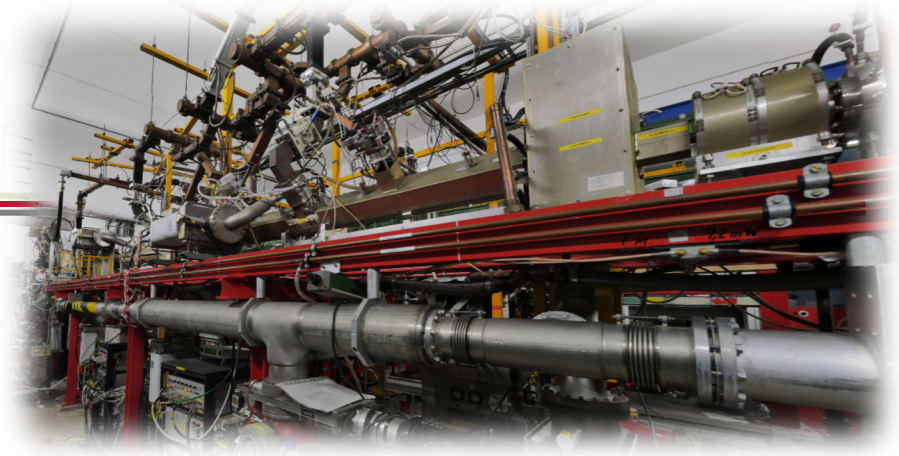
S-DALINAC



ELSA



MAMI



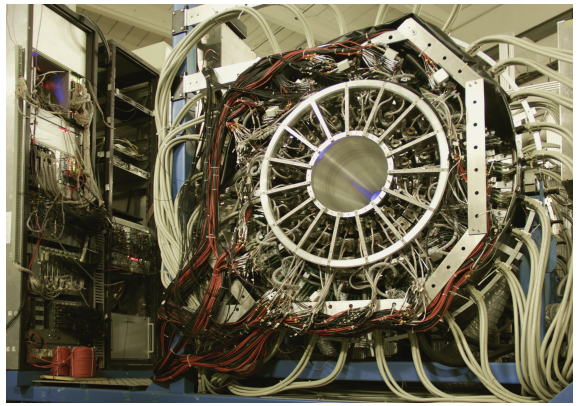
World-class Science at Electron Accelerators

Complementarity to Hadron Machines

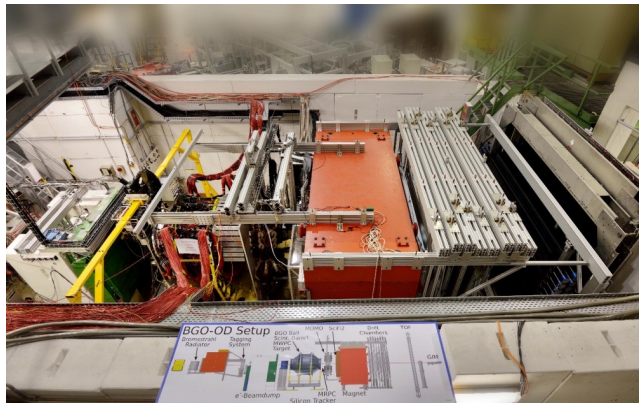
Photon-induced Baryon Physics at ELSA

Photon beam (linear & circular polarization):

- **CB-ELSA** 4π detector **+ TAPS + polarized target**
  - Double polarization experiments: $\vec{\gamma}\vec{p} \rightarrow \pi^0 p, \eta p, \ldots$
  - Full kinem. coverage of asymmetries Σ, E, G, H, …
- **BGOOD** detector (charged final states)
  - BGO 4π calorimeter combined with open dipole setup
  - Photo production strangeness and omega mesons



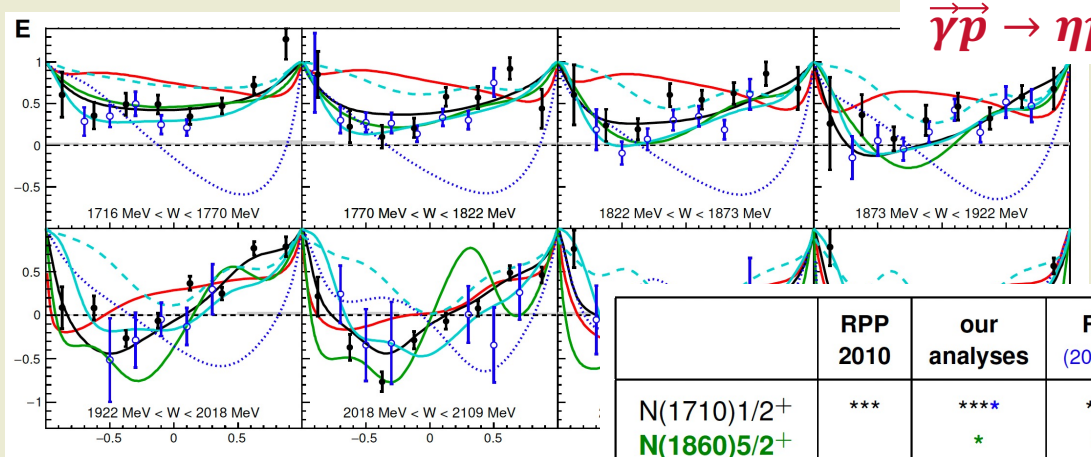
Crystal Barrel/TAPS



BGOOD

Polarization d.o.f.: key to resolve the baryon spectrum

$\vec{\gamma}\vec{p} \rightarrow \eta p$



$$E = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}}$$

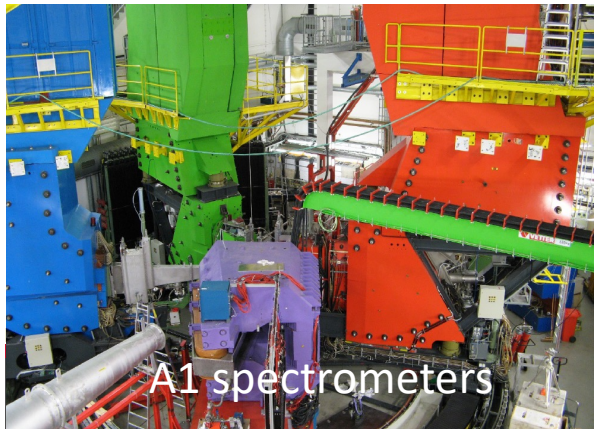
→ huge impact on knowledge of resonances in the second and third resonance region

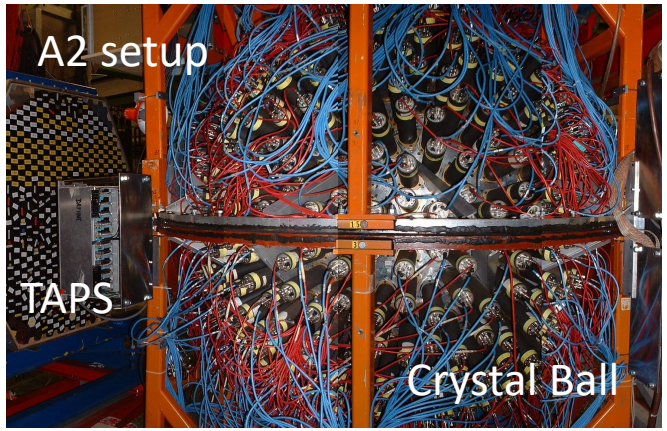
	RPP 2010	our analyses	RPP (2018/20)
N(1710)1/2$^+$	***	****	****
N(1860)5/2$^+$		*	**
N(1875)3/2$^-$		***	***
N(1880)1/2$^+$		***	***
N(1895)1/2$^-$		****	****
N(1900)3/2$^+$	**	****	****
N(1990)7/2$^+$	**	**	**
N(2000)5/2$^+$	**	**	**
N(2060)5/2$^-$		***	***
N(2120)3/2$^-$		***	***
Δ(1900)1/2$^-$	*	***	***
Δ(1920)3/2$^+$	***	***	***
Δ(1940)3/2$^-$	*	**	**
Δ(2200)7/2$^-$	*	***	***

Nucleon Structure and Spectroscopy at MAMI

Electron and Photon beams (linear & circular polar.): ~6000 h/year

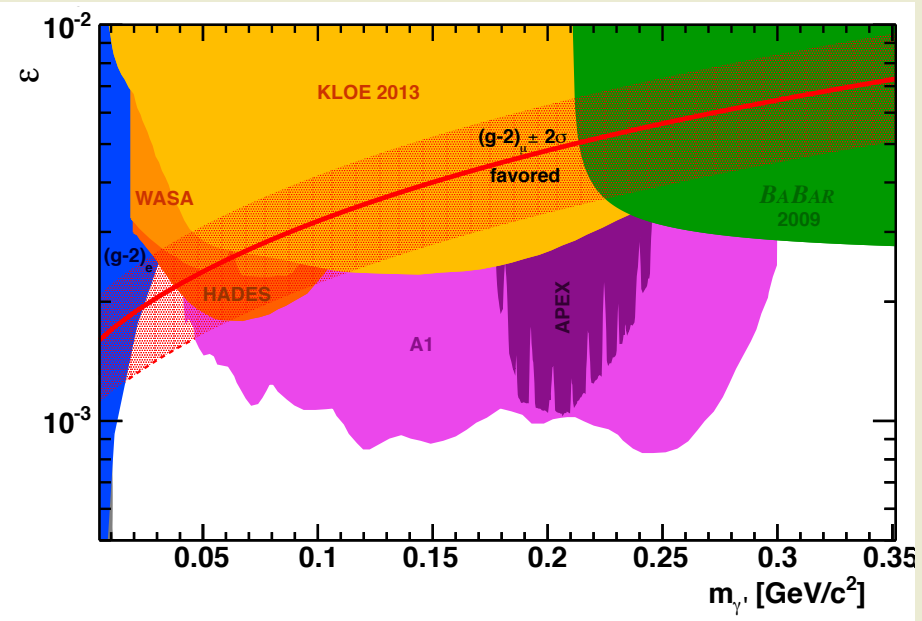
- **A1 high-resolution spectrometer setup (incl. KAOS)**
  - Nucleon electromagnetic Form Factors
  - In-medium properties of nucleons (polarization transfer)
  - Transverse asymmetries as input to neutron skin determination
  - Kaon and hypernuclear physics
  - Generalized polarizabilities of the proton
- **A2: Crystal Ball** 4π detector **+ TAPS + polarized target**
  - Baryon spectrum via double-polarization experiments
  - Proton Polarizabilities via Compton scattering $\vec{\gamma}\vec{p} \rightarrow \gamma' p'$
  - Neutron skin via coherent pion production on nuclei
  - Meson Tranistion Form Factors as input to HLbL $(g-2)_\mu$





Unique possibilities also beyond Hadron Physics, e.g. Dark Photon γ' searches at A1/MAMI

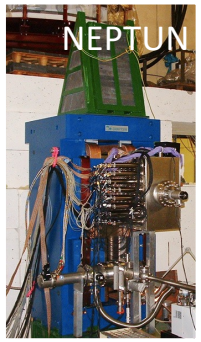
- Force carrier of a dark sector
- Could explain astrophysical anomalies
- Could explain $(g-2)_\mu$ puzzle

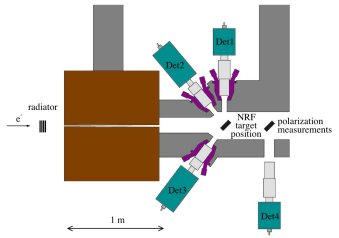


Nuclear (Astro-)Physics at the S-DALINAC

Polarized Electron and Photon beams : ~5000 h/year

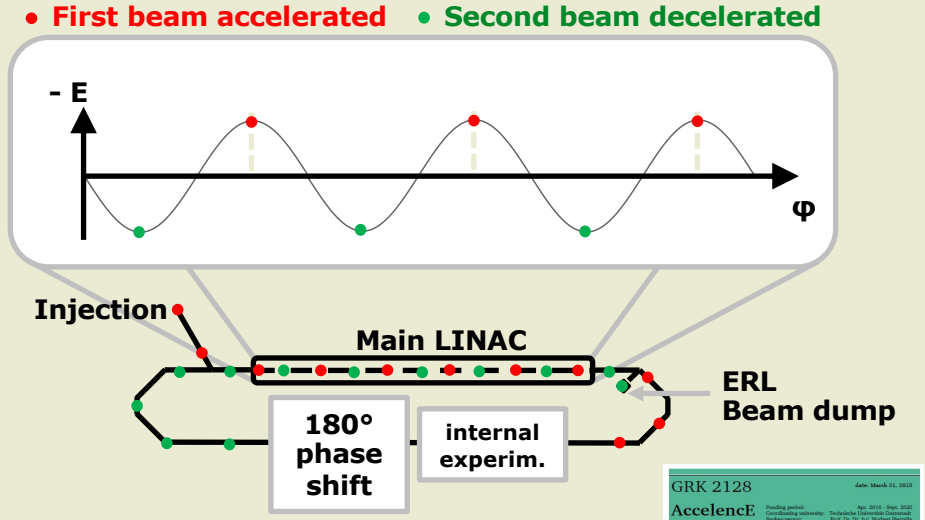
- **Lintott high resolution spectrometer**
  - Measurement of E2 transition strength to 2^+_1 state of ^{12}C
  - First measurem. of collectivity of coexisting shapes based on type II shell evolution: The case of ^{96}Zr
- **QCLAM spectrometer for electron scattering**
  - high acceptance w. possibility to operate under 180°
- **DHIPS low energy, high intensity photon beam**
  - Role of chiral two-body currents in ^{6}Li
- **Neptun tagged photon beam**





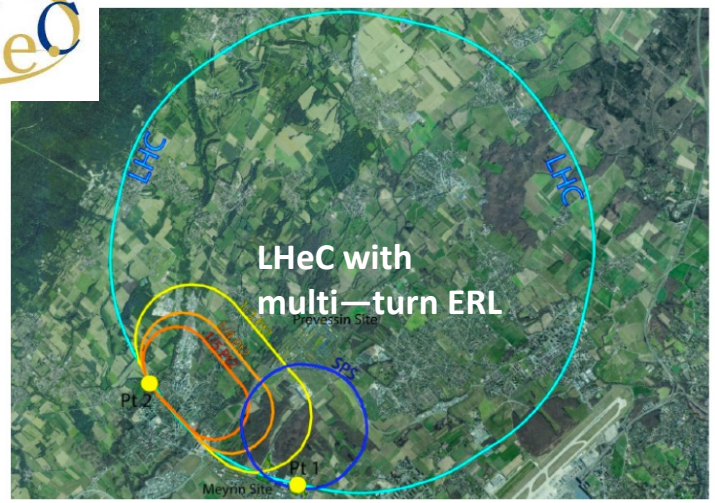
Darmstadt High Intens. Photon Setup (**DHIPS**)

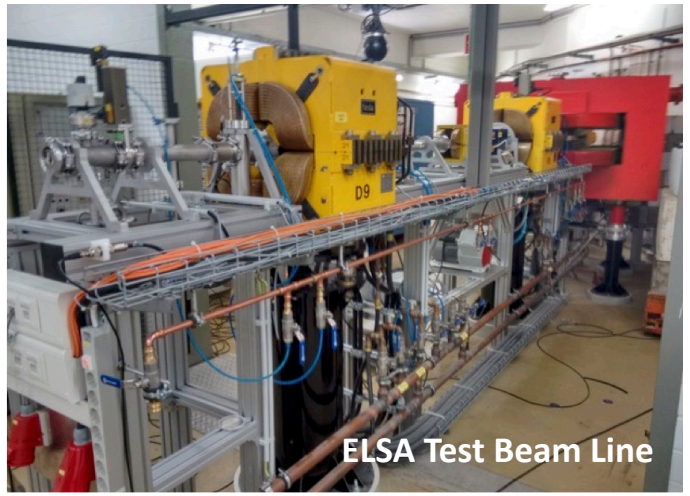
First operation of an Energy-Recovering (ERL) Accelerator in Germany (2017)

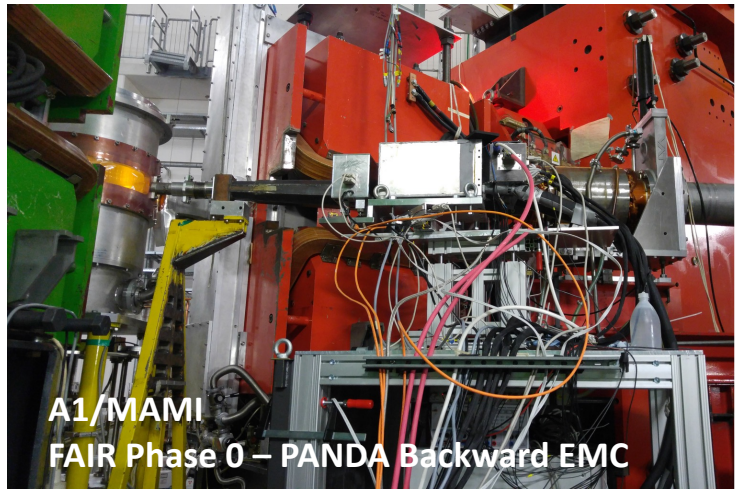


- Required **redesign of lattice**
- **Michaela Arnold** (DPG Nachwuchspreis)
- RTG (Graduiertenkolleg) **Accelence with JGU Mainz** on ERL technology
- Cooperation with TU DA **engineers**

Electron Accelerators for the HuK Community







Future accelerators based on ERL

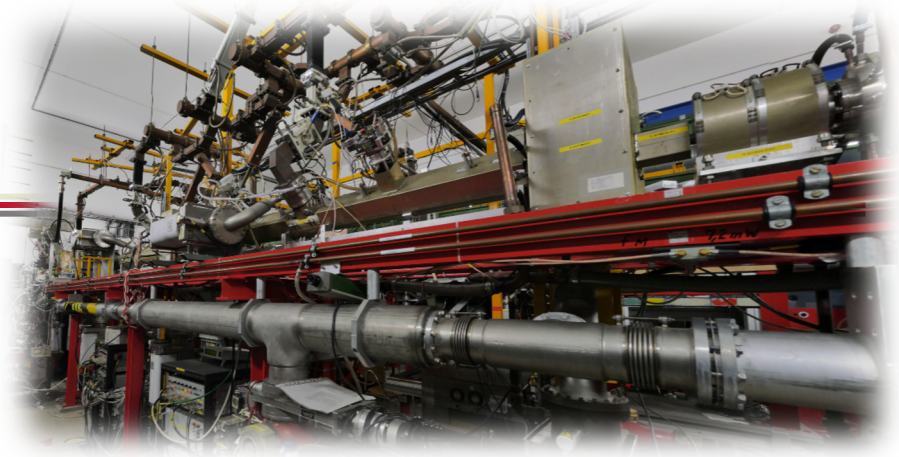
- **LHeC** and **FCC-eh** at CERN
- S-DALINAC and MESA serve as tests for **multi-turn ERL** operation
- Other technologies beyond ERL (e.g. Plasma Wakefield Accel.)

Excellent test beam facilities

- **ELSA test beam facility** < 3.5 GeV
- **X1 area MAMI** <0.855 MeV, highest beam intensity
- **Photon** beam tests behind MAMI **A2 tagger**
- **>>1000 of hours for FAIR detectors**

FAIR-Phase 0 experiment at A1/MAMI

- **Backward EMC of PANDA**
- In operation at **A1/MAMI**
- Goal: low-Q^2 **measurement of π^0 transition form factor**
- Motivated by hadronic Light-by-Light contribution to muon g-2



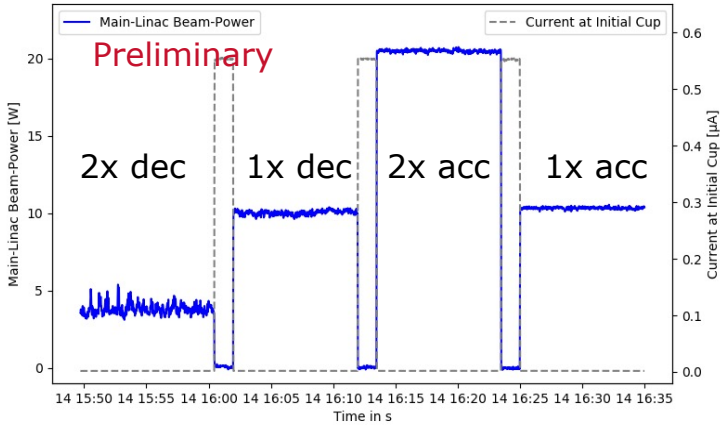
Future Perspectives

Future Directions S-DALINAC @ Darmstadt

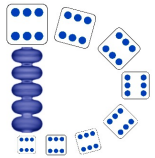
Future continuation of operation of S-DALINAC with typical yearly operation hours of 4000 – 6000 h/y

Further development of ERL operation

- **August 2021: multi-turn operation in ERL-mode**

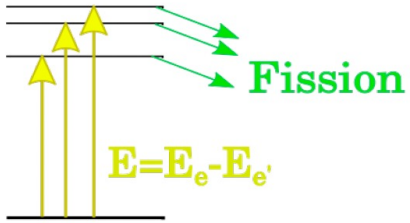


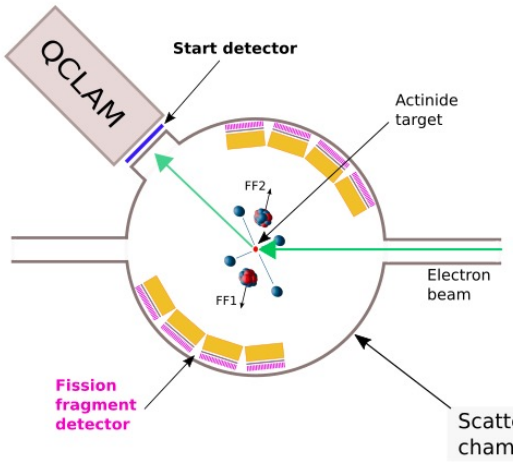
- **Possible future: DICE (Darmstadt Individually-Circulating Compact ERL)**
  - complementary to MESA
  - further requirements of community

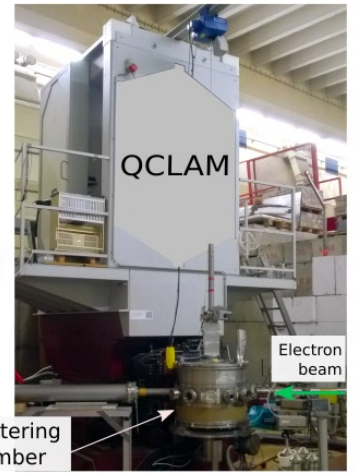


New electrofission setup for the S-DALINAC

→ **new information on neutron-capture rate and on properties of transruranium actinides that provide constraints for the fission cycle of the r-process of nucleosynthesis in neutron star mergers**







- use of electrons to **excite the nucleus**
- excited states **decay directly via fission**
- **Coincidence** of scattered electrons and fission fragments
- new start detector and fission fragment detectors (Si, MCP)

Future Directions ELSA @ Bonn

ELSA mid-term future (2022 - 2025): ~2000 beam hours/year

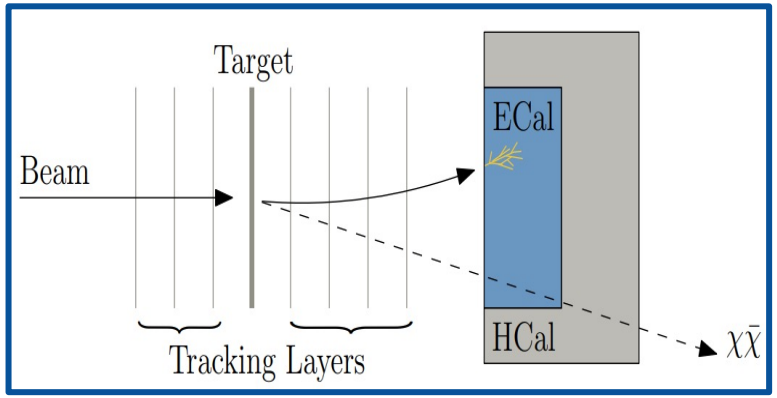
- Major **upgrade of readout electronics** for Crystal Barrel completed (x4!)
- **Data taking for hadron physics experiments**
  - Double polarization program on the **neutron @ Crystal Barrel**
  - **BGOOD**: photo production $K^+\Lambda(1405), K^0\Sigma^0$ → **multiquark structure**

ELSA as a key facility of the FTD (Forschungsbau und Technologie-zentrum Detektorbau) at University of Bonn

Long-term perspectives after shutdown (2025/26)

- **LOHENGRIN proposal: Search for Light Dark Matter** via dark bremsstrahlung – need 10^{15} Electrons on Target via ELSA slow extraction @ 500 MHz → **GHz tracker based on CMOS technology**
- **Possible replacement of injectors by PWA** (plasma wakefield acceleration) in cooperation with DESY

LOHENGRIN concept inspired by LDMX/SLAC



Future Directions MAMI @ Mainz

Continuation of operation of A1 and A2 setup

- **A1 high-resolution spectrometer setup**
  - Operation of supersonic **gas jet target** constructed with U Münster (A. Khoukaz)
  - Improved **MAMI energy measurement**
- **A2 Crystal Ball/TAPS setup**
  - **Neutron polarizability** program
  - Searches for **hexaquark d*(2380)**
  - **Meson TFF** program motivated by $(g\text{-}2)_\mu$

PRES: Innovative proton form factor measurement

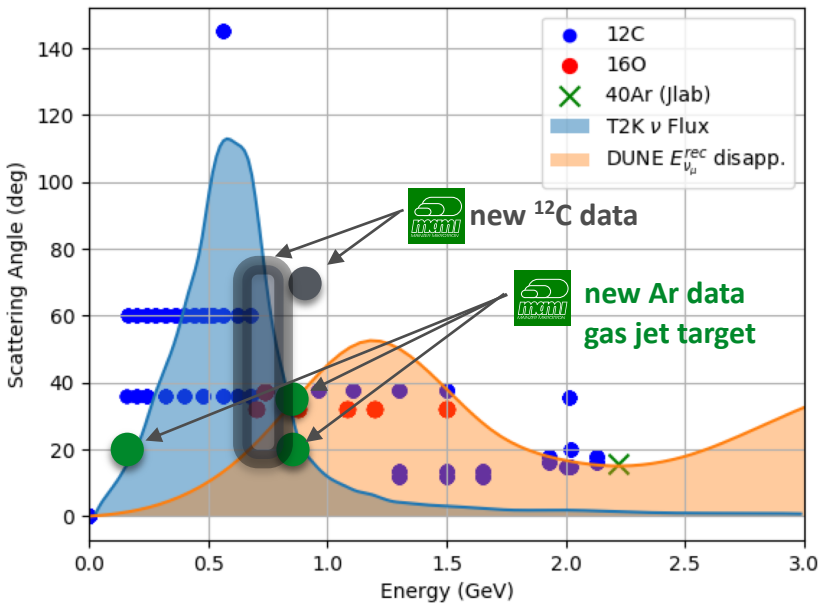
→ **clarify situation regarding proton FF**

- High pressure **active TPC** (1 m^3, 20 bar)
- Q^2 determ. via **proton recoil measur.**
- **Absolute determination** of cross section with reduced uncertainty from rad. correct.
- Coop. with PNPI **St. Petersburg**

Electrons for Neutrinos (A1 experiment)

Interpretation 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-programs** via dedicated program of **electron-nucleus measurements**

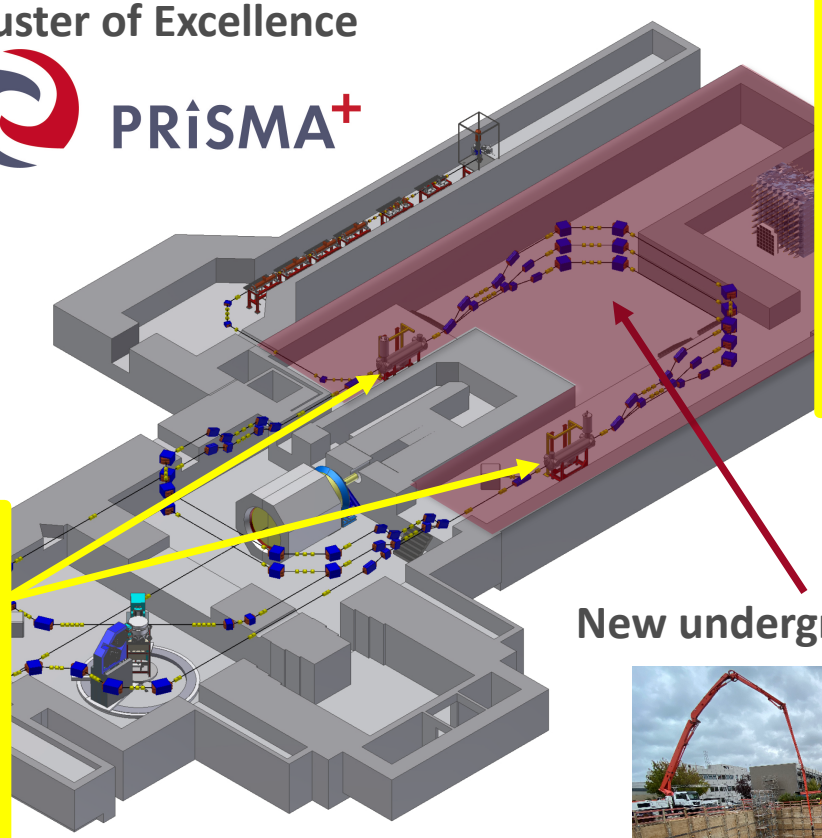


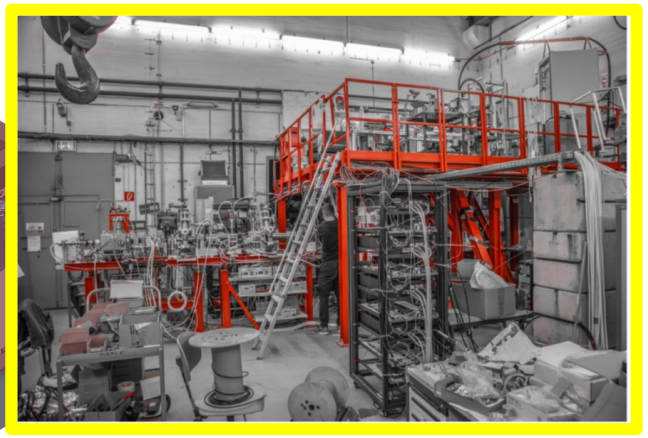
MESA: Mainz Energy Recovering Superconducting Accelerator

Key parameters MESA:

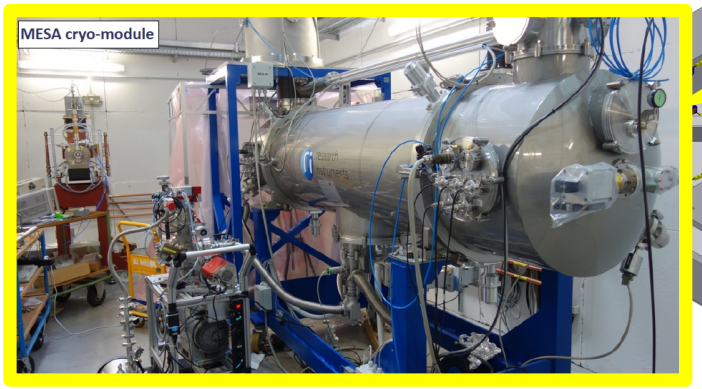
- Max. beam energy 155 MeV
- Beam current >1 mA (ERL mode)
- Superconducting cavities
- Start commissioning 2023
- New research building (par. 91b GG)
- Can run in parallel to MAMI

Cluster of Excellence PRISMA+





Polarized Source Test Setup



Cryomodules successfully tested

New underground experimental hall (par. 91b GG)

MESA Experiments

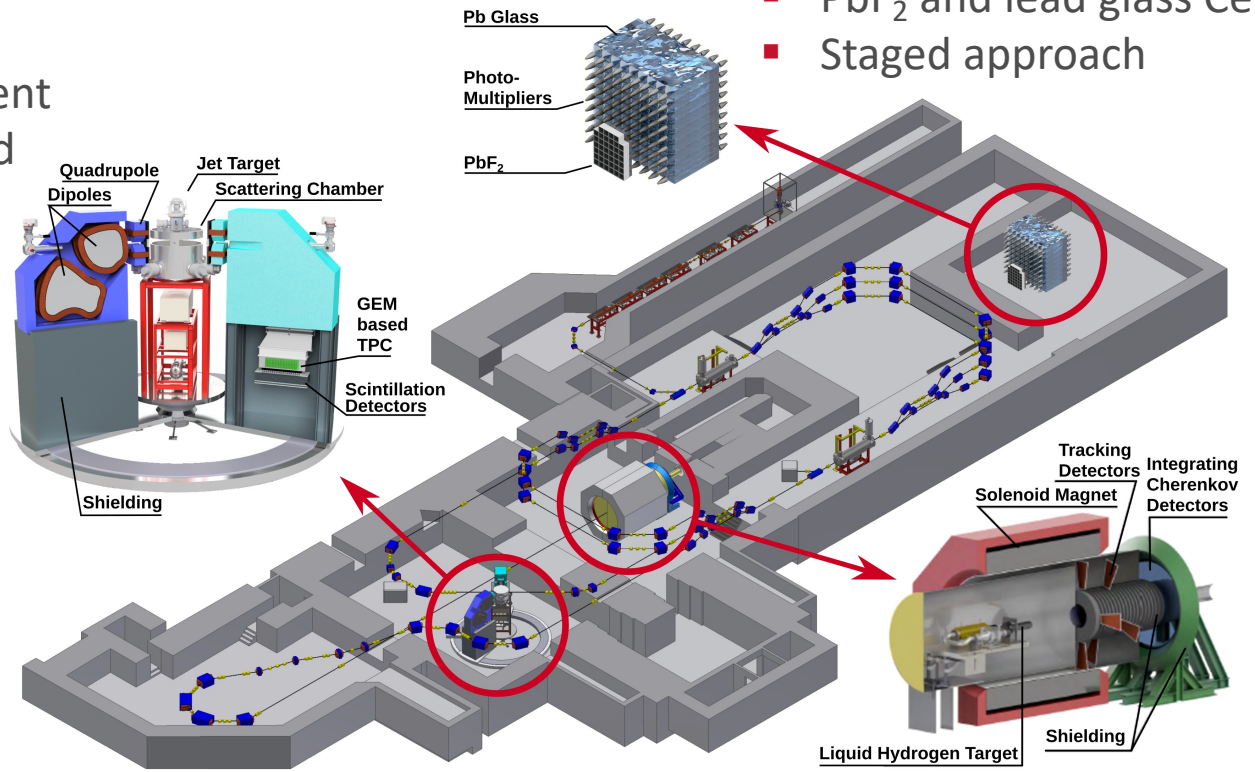
Cluster of Excellence PRISMA+

MAGIX experiment

- Operated in ERL mode of MESA
- Double-arm spectrometers
- Internal gas target experiment
- Gas jet target commissioned in 2017/18
- From **nuclear astrophysics** to **Dark Sector**

DarkMESA

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



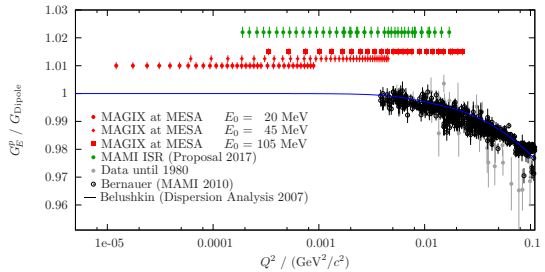
P2

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

MESA Physics Program

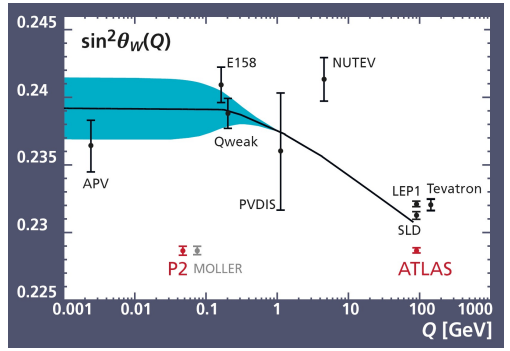
Cluster of Excellence PRISMA+

From Nuclear Physics to Hadron and Particle Physics



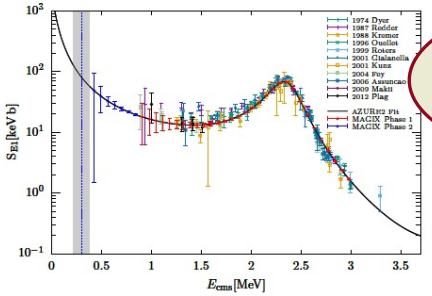
Low Q^2 EM Form Factor p,n (MAGIX)

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



Neutron Skin Pb (P2-MREX)

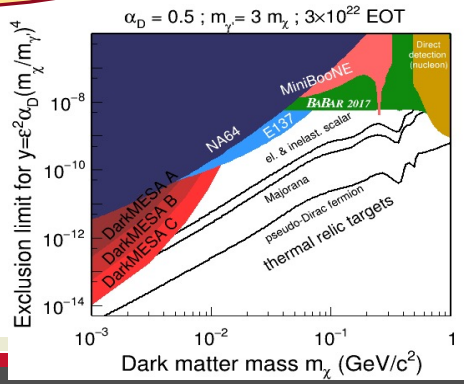
Search for Dark Photon and Axions (MAGIX)

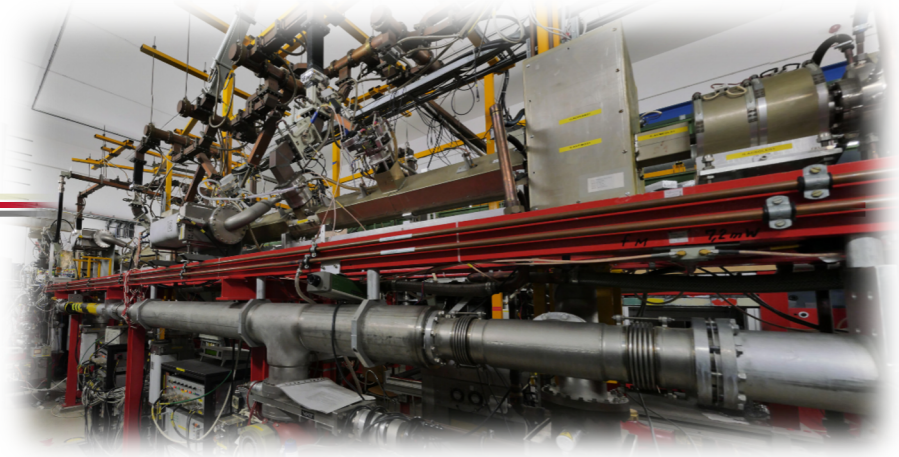


$^{12}C\ (\alpha,\gamma)\ ^{16}O$ (MAGIX)

Few Body Physics (MAGIX)

Light Dark Matter direct detection (DarkMESA)

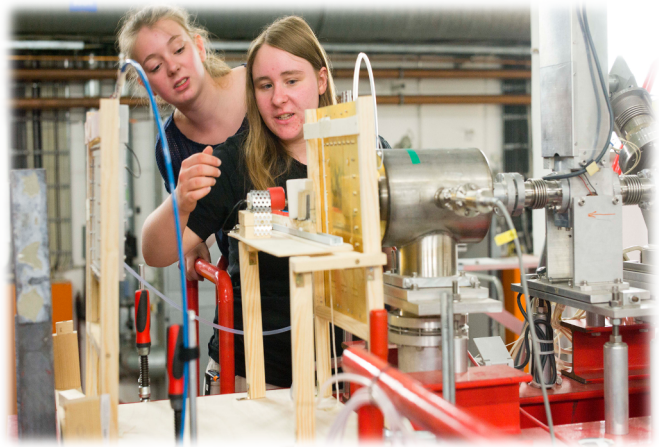




Conclusions

German Electron Accelerators - Conclusions

- **Complementary program to FAIR / Hadron and High-Energy Accelerators**
  low momentum transfer – intensity frontier experiments!
- **Highly-active research field** (in hadron physics ~40% of talks at DPG meetings)
  → ranges from **nuclear fission** to **baryon spectrum** and **precision SM tests**!
- **Important for FAIR experiments**, e.g. for detector tests
- University environment provides excellent opportunity for **education of future generation of accelerator physicists** (important service to society!)
- Operation of large-scale facilities on campus of Universities provides unique opportunities to **research-oriented educatio**n of physics students



→ **Upgrades and new technologies of accelerators, new experiments, new MESA facility**

German Electron Accelerators - Conclusions

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Many thanks to the Länder of Nordrhein-Westfalen, Hessen, Rheinland-Pfalz, the Universities of Bonn, Darmstadt, Mainz, as well as to DFG for long-standing support !