MESA - an ERL project for particle physics experiments

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on behalf of MESA accelerator and experiment groups

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DFG through the research training group “AccelencE” RTG 2128

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• MESA Building Overview and Accelerator Layout

• MESA Accelerator Components
  • Injector
  • Cryomodules
  • Recirculation Arcs

• Experiments
  • with External Beam: P2 and BDX
  • with ERL beam: MAGIX

• Summary & Outlook
• MAMI is operating since >25 years at KPH

• In 2012 funding of PRISMA cluster of excellence has been granted including a new accelerator project: Mainz Energy Recovery Superconducting Accelerator (MESA) to be built in the existing facility

• In June 2015 DFG granted a research building to JGU „Center for Fundamental Physics (CFP)“ including an extension for MESA halls
- Extension of the halls provides advantages to experiments and accelerator layout
- Additional space for future experiments available
- BDX possible

Trade off: some project delay due to civil construction time
Double sided recirculation design with normalconducting injector and superconducting main linac

Two different modes of operation:

- EB-operation (P2/BDX experiment): polarized beam, up to 150 µA @ 155 MeV
- ERL-operation (MAGIX experiment): (un)polarized beam, up to 1 (10) mA @ 105 MeV
First construction works (workshop and storage buildings) are expected to be finished in **end 2018**

→ afterwards: workshop moves into new building. Existing workshop building can be removed

- Ground breaking for new underground hall in **spring 2019**

- Construction on existing halls will start in **2019**

- Handover of the buildings will be not before **end 2020**

→ Huge impact on MESA construction timeline

→ Existing halls still usable for some time for tests
MESA Injector Test Setup until 2019

Picture: S. Friederich
MELBA will prepare the beam for further acceleration

- Spin rotation in EB mode
- Low energy beam transport
- Beam diagnostics

- Longitudinal and transverse matching to the MAMBO injector

Picture: C. Matejcek
• Design inspired by the MAMI injector LINAC
• 4 room temperature RF bi-periodic pi/2 standing wave structures @ 1.3 GHz
• 1 graded-β, 3 const. β sections; Energy gain ΔE=1.25 MeV/section
• RF-Amplifiers: SSA with ~90 kW (graded β) and 3 x ~60 kW (fixed β)
→ Status: design completed, test cavity and 15 kW SSA-prototype under test

Pictures: R. Heine
15 kW SSA-prototype

Test results

→ SSA will be used for SC cavity tests at HIM

R. Heine, F. Fichtner, IPAC 2018
• testing rf-properties of couplers and tuners
• multipacting studies
• First test of PLL for SRF cavity tests (MSc thesis S. Thomas)

Pictures: R. Heine
Cryomodules of the 'Rossendorf'-type (2 x 9-cell TESLA/XFEL cavities), which are in use at ELBE (and have been at ALICE) will be used for MESA

→ we applied some adaptations in order to allow 1 mA ERL operation:
  - added tuners with piezo elements (XFEL/Saclay-type)
  - used sapphire windows at HOM feedthroughs

→ beam current of 10 mA will not be achievable with that type of cryomodule
Thermal calculations at HOM antenna ongoing (T. Stengler):

→ Provide optimised thermal connection design
→ Limitation by heat input from cable, need for heat sink

Status: striplines constructed and integrated for better thermal connection

Pictures: T. Stengler
→ all resonators within specs. One with lower quench field of ~16.5 MV/m (breakdown)
Completely connected
Warm leak tests successful
⇒ Ready for first cooldown

Cryomodule Integration into Test Bunker
Normalconducting Injector MAMBO:

- Design inspired by the MAMI injector LINAC
- 4 room temperature RF bi-periodic pi/2 standing wave structures @ 1.3 GHz
- 1 graded-β, 3 const. β sections
- Energy gain ΔE=1.25 MeV/section
- RF-Amplifiers: SSA with ~90 kW (graded β) and 3 x ~60 kW (fixed β)
Optics symmetric with respect to the middle of the long straight section. \( \alpha = 0 \) in the middle of each return arc

Return arc is free of transverse and vertical dispersion

Longitudinal dispersion \( r_{56} \) can be adjusted by changing the gradients of the middle quadrupoles in the 45° sections

Total length of 1\(^{st}\) return arc: \(~45\text{m}\)

difference in time-of-flight for beams of 15 MeV and 30 MeV: \( \Delta t = 60.5 \text{ ps} \rightarrow 2.83^\circ \) in RF @ 1.3 GHz

Path length adjustment needed (2 cm minimum) for complete flexibility in beam energy (chicane or moveable magnets)
Complete 1st recirculation arc lattice

Simulation by D. Simon
Complete 1st recirculation arc lattice

Simulation by D. Simon
P2 experiment @ MESA:

• Main Goal: precision measurement of electroweak mixing angle $\theta_W$ 
  \[ \rightarrow \text{measure } \sin^2 \theta_W \text{ to a precision of } 0.13\% \]

• Experimental Method: Measurement of parity violation asymmetry in elastic electron proton scattering at low momentum transfer $Q^2$

\[ \frac{N_- - N_+}{N_- + N_+} = \frac{G_F Q^2}{4 \sqrt{2} \pi \alpha} (Q_w - F(Q^2)) \]

\[ Q_w = 1 - 4 \cdot \sin^2(\theta_W) \]

• The expected asymmetry is very small $\sim 30 \text{ ppb}$

\[ \rightarrow \text{High demands on beam quality: We need a polarized beam of } \]
\[ 150 \mu\text{A} \text{ @ } 155 \text{ MeV with high polarization and high stability in energy, energy spread, position and angle for a very long time (} \sim 10.000 \text{ h} \) \]
Experiments with External Beam: P2

Experimental setup of P2:

- 60 cm Liquid Hydrogen target, beam deposition 2.8 kW @ 15 K
- 0.6 T superconducting FOPI Solenoid, outer coil diameter 3.8 m
- 2 \( \pi \) symmetric detector plane with Cherenkov detectors, additional tracking detectors

I. Sorokin
Idea of BDX experiment @ MESA:

- Dumped beam from P2 might produce a Dark Matter beam via pair production:

- This beam can be very penetrating → let it pass some shielding and set up a simple detector (e.g. a scintillator)

- Measure whenever P2 is running

FLUKA simulation of MESA beam dump:
MAGIX experiment @ MESA:

Main Goals:

- Search for dark photons
- Precision measurement of magnetic proton radius
- Determination of Astrophysical S-Factors
- ...

➔ Make best use of the ERL-beam with high intensity 1 (10) mA and beam quality
MAGIX experiment @ MESA:

Picture: MAGIX group, S. Aulenbacher
(Pseudo) Internal Targets @ MAGIX:

**Tube target:**
- Gas polarization possible
- Scattered particles pass tube material
- Focused Beam has to pass thin structures

Luminosities:
\[ \sim 10^{36} \text{ cm}^{-2}\text{s}^{-1} \quad \sim 10^{31} \text{ cm}^{-2}\text{s}^{-1} \text{ (pol.)} \]

**Jet target:**
- No gas polarization possible
- Complete windowless

Luminosity:
\[ \sim 10^{36} \text{ cm}^{-2}\text{s}^{-1} \]
Experiments with ERL Beam: MAGIX

Challenges on ERL operation using Internal Targets @ MAGIX:

- Using the tube target the beam needs to pass a 2m long tube without hitting any structure
- Scattered electrons with small scattering angles can produce beam halo
- Halo particles can get dangerous when hitting the SRF cavities

Pictures: K. Aulenbacher
• MESA will be a superconducting, recirculating linac for **particle and nuclear** physics experiments

• Two operation modes will be used
  - polarized external beam with up to 150 µA @ 155 MeV
  - unpolarized or polarized ERL beam with up to 1 mA (later 10 mA) @ 105 MeV

• P2 experiment measures parity violation asymmetry and. Main task is the measurement of with high accuracy. Later research on e.g. neutron skins
  (P2 Design report published: D. Becker et al., arXiv:1802.04759 [nucl-ex])

• MAGIX is a double arm electron spectrometer and can be used for many purpose. Two main goals are the search for dark photons and the measurement of magnetic proton radius
bERLinPro = Berlin Energy Recovery Linac Project
100 mA / low emittance technology demonstrator (covering key aspects of large scale ERL) test and diagnostic line
(5mA@10MeV dump, energy & slice diag.)

- **srf-gun**: 1.4 cell srf cavities
- **1.5-2.3 MeV, single solenoid,**
- **modified Cornell booster**: 3 x 2 cell srf cavities
- **4.5 MeV**
- **liner module**: 3 x 7 cell srf cavities
- **44 MeV**
- **merger dogleg**
- **beam dump**
  - 6.5 MeV, 100 mA
  - = 650 kW

**bERLinPro**
Helmholtz-Zentrum Berlin

- **max. beam energy**: 50 MeV
- **max. current**: 100 mA (77 pC/bunch)
- **normalized emittance**: 1 μm (0.5 μm)
- **bunch length (straight)**: 2 ps or smaller (100 fs)
- **rep. rate**: 1.3 GHz
- **losses**: < 10^{-5}

**project started 2011, fully funded**
**building ready 2017**
**first electrons 2018**
**recirculation 2019/2020**

28.6.2018 F.Hug: MESA - an ERL project for particle physics experiments
bERLinPro: existing hall, injector and recirculation but no linac cryomodule

MESA: existing cryomodule but no hall, recirculation, ...

→ collaborate! (integrate MESA module at HZB)
• Construction of the extended MESA hall will delay the construction start of the accelerator to at least **2020**. Commissioning is planned in **2021**

• But many accelerator parts have been ordered or even built already

• We will test the injector in a test setup in Hall 3 (old part of the building) until civil construction progress requires to empty the underground halls (expected **spring/summer 2019**)

• Cryomodule tests started at HIM **in June 2018**

• Kick-Off Meeting MESA @ bERLinPro took place at Mainz **in April 2018**
  MESA modules can stay at Berlin from **2019 to end 2020**

• Parts of experimental setups, detectors etc. are tested at MAMI as well
Thank you for your attention!