The MESA Project

Mainz Energy recovering Superconducting Accelerator:
A small superconducting accelerator for particle and nuclear physics

Kurt Aulenbacher
for the MESA-Project-team
• Project objectives
• MESA R&D issues: SRF
• R&D issues: Beamdynamics & Lattice
• Outlook
- No new buildings
- MAMI continues separately for hadron structure exp.
- MESA takes over "low energy" experiments <300MeV
MESA: Concept

**Beam Parameters:**

**1.3 GHz c.w.**
- **EB-mode:** 150 μA, 200 MeV polarized beam (liquid Hydrogen target L≈10^{39})
- **ERL-mode:** 10mA, 100 MeV unpolarized beam (Pseudo-Internal Hydrogen Gas target, PIT L≈10^{35})
Vertical stacking “a la CEBAF” keeps transverse footprint small → compatibility with building.

Ralf Eichhorn
MESA – ”Integration”

V. Bechthold/R. Heine
EB-Experiment: “P2”

150 µA Beamcurrent, 60 cm lq. H2, Beampol: 85%.
10000 h Data-taking (~13-15000 h Runtime)
High accuracy Polarisation measurement (ΔP/P=0.5% !!)
Extremely high demands on control of HC-fluctuations!

→ ~4000h/Year Runtime
→ Accelerator must be optimized for reliability& stability

→ PV is MESA-workhorse experiment
**MESA-Beamparameters in stages 1 (2)**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam Energy ERL/EB [MeV]</td>
<td>105/155 (105/205)</td>
</tr>
<tr>
<td>Operation mode</td>
<td>1300 MHz, c.w.</td>
</tr>
<tr>
<td>Elektron-sources</td>
<td>1.) Polarised : NEA GaAsP/GaAs superlattice, 200keV (?) 2.) unpolarised KCsSb, 200keV</td>
</tr>
<tr>
<td>Bunch Charge EB/ERL [pC]</td>
<td>0.15/0.77 (0.15/7.7)</td>
</tr>
<tr>
<td>7.7pC=10mA@1300MHz</td>
<td></td>
</tr>
<tr>
<td>Norm. Emittance EB/ERL [μm]</td>
<td>0.1/&lt;0.5 (0.1/&lt;1)</td>
</tr>
<tr>
<td>Spin Polarisation (EB-mode only)</td>
<td>&gt; 0.85</td>
</tr>
<tr>
<td>Recirculations</td>
<td>2 (3)</td>
</tr>
<tr>
<td>Beampower at Exp. ERL/EB [kW]</td>
<td>100/22.5 (1050/30)</td>
</tr>
<tr>
<td>R.f.-Power installed [kW]</td>
<td>140 (180)</td>
</tr>
</tbody>
</table>

**Why stages for MESA?**
Constraints by Budget, Space and Schedule: Technology/Physics solutions must be compatible!

Technology:
- Kryogenics
- Kryomodule

Physics:
- Sources/Injector
- BBU Instability
- Rezirculator (Lattice) Design
Challenge: Cryoplant

200 l/h, lq. Helium

Available Power at 2K
100-150 Watt →
\( \Delta E > 50 \text{MeV} \) from Linac would be optimistic
**Motivation for normal Conducting -ILAC:**

- Easy maintenance
- No cryogenic load,
- Established design (MAMI-ILAC, Th. Weis, H. Euteneuer 1984)

Design: See talk bei Robert Heine tomorrow

- Scaled Version of MAMI-ILAC: 2.5GHz → 1.3GHz.
- Phase space shaping by „graded beta“ structure
- 96 KW RF Power (50kW beam loading included)
- $T=5\text{MeV}$, $\Delta\psi_{100\%} < \pm 2.3^\circ$, $\Delta E/E_{\text{rms}} = 0.01\%$ length: 11.5 m
- Graded beta + SRF-Modul: („Hybrid“) similar parameters but length 7.5m and 75kW
Spin rotation and source

\[ \varphi_{\text{Spin}} = \frac{e}{m_e c^2} \frac{1}{\beta^2 \gamma^2} EL \]

100kV \(((\beta \gamma)^2=0.43)\) Filter, L=0.3m operated at 23kV over 2cm gap could probably work at 200keV \(((\beta \gamma)^2=0.94)\)

JLAB development:
A 200keV “inverted” source is nowadays very compact - R. Suleiman et al. Proceedings ERL2011. (200keV source probably capable to reach emittance goal at 7.7pC!)

If 200keV too risky for NEA cathode (field emission!) we may operate at, e.g., 150 + 50keV postacceleration
Spin polarized source layout

- Systematic electron optical helicity reversal! (similar to JLAB/QWEAK)

- Polarized Source & Injector overall length ~15 m
- 7.7 pC operation: Individual High charge source (HCS) with as short connection as possible.
- HCS without chopper?

14.03.2012
PEB workshop Boston
• “ELBE” – Modules are suitable for high gradient c.w. operation.
• Commercially available, no additional R&D
• Costs & Delivery time are (to some extent) predictable
• Limitation in Cryopower requires $Q_0 = 10^{10}$ at $14\text{MeV/m}$ (achieved at DESY/FLASH in operation with TESLA cavity)
Higher order modes (HOMs) with „bands“ of Eigenmodes e.g. TM11-like. → BBU- Instability for beam current $> I_s$
In recirc. Linacs: Feedback-loop!

$$I_s = -\frac{2c^2}{\epsilon \left( R/Q \right)_{HOM} Q_{HOM} \omega_{HOM} } \frac{1}{T_{12} \sin(\omega_{HOM} t_r)}$$

$T_{12} = $ Transformation from angle to position
$t_r = $ Recirculation - time

(simplified formula!)

General treatment for ERL’s
Cryomodules und BBU

\[ I_T = -\frac{2c^2}{e\left(\frac{R}{Q}\right)_{\text{HOM}} Q_{\text{HOM}} \omega_{\text{HOM}}} \frac{1}{T_{12} \sin(\omega_{\text{HOM}} t_r)} \]

\[ T_{12} = \text{Horizontal Angle} \Rightarrow \text{Position} \]

\[ T_{34} = \text{Vertical}, T_{56} = \text{Longitudinal} \text{ (Energy deviation to phase)} \]

"High current" – Rezirculators call for:
• Strong HOM damping (TESLA-Cavities are not optimized!)
• Flexible Recirculation optics to adjust \( T_{12}, T_{34} \) but probably also \( T_{56} \)

Conclusions:
1. "Non-Tesla Cryomodule" for MESA \( \Rightarrow \) But: compatible with budget & schedule?
2. Second bullet calls for independent orbit recirculation
\( \Rightarrow \) But: Polytronrezirkulator is more compact, inherent stability (at "low" currents)

Reference-Plan: Use TESLA/Rossendorf Module ("Stage-1": limited current)
We investigate alternative (direct stage-2): Rebuilding/designing optimized cavity & cryomodule (e.g. DICC 1300 MHz, LHeC 801.6MHz). Requires collaborative project with "big science" (e.g. CERN)
Beam-dynamics: Recirculator-Lattices

„CEBAF“ inspired

Design: Ralph Eichhorn

Advantage:
• Identical orbits and magnets
• High symmetry

Problem: Vertikal stacking under very constrained long orbit axis
• Large vertical deflection angles
• Small space for compensation quads.
→ Vertical dispersion probably difficult to control

We presently investigate also two types of „flat“ lattices
Horizontal lattices: “Conventional recirculator”

Disadvantages:
• different optics for each orbit
• symmetric set-ups difficult
• Large deflection angle in first orbit

Design: Daniel Simon,
Diploma thesis: Sketch of flat lattice with realistic dipole dimensions

„S-DALINAC“ inspired
Horizontal lattices:
Segment Magnet Recirculator

90 degree Segment

Segment- or „Polytron“- magnet:
Each Orbit enters and exits at THE SAME Pole edge
Orbit is SYMMETRIC around normal to pole edge:
→ Deflection angle $2 \times \text{pol face inclination}$
• Deflection angle is independent of energy
• Very convenient transv. Optics (Apart from fringe fields)
• Dispersion cancels after each two deflections
• Circular orbits achieved after $N \times 2$ Segments
  N=1 Microtron (not suitable for MESA)
  N=2 Double sided Microtron (Two dispersion free sections)
  N=3 Hexatron

„MAMI-C“ inspired

We investigate an Asymmetric Polytron of second order (AP2)
(Not: „single sided DSM“)
Horizontal lattices:
Segment Magnet Recirculator AP2

- Fringe field effect under control (counter field & gradient)
- Phase shift during acceleration under control
- Strong longitudinal focusing (large R56) → good stability and acceptance
- B- Scaling for two orbit operation (ERL) or higher energy
- Disadvantage: not independent orbits → transv. BBU threshold?
- Disadvantage large R56 → long. BBU effects?

First non-dispersive LINAC-straight

2nd non-dispersive straight

B~0.5T Magnet mass ~20to

MAMI-C inspired

Design: K.H. Kaiser
Outlook

- End 2013 Decision Cryomodule
- Spring 2014 Decision Lattice
- Summer 2014 Infrastructure modifications
- End 2014 Start Injector assembly
- 2015/16 Assembly Lattice, Cryoplant ready.
- End 2016 Delivery Cryomodule
- 2017 Commissioning Cryomodule
- End 2017 MESA commissioning
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Ch. Matejcek, U. Ludwig-Mertin, V. Schmitt, D. Simon

Project team is currently expanding rapidly (SRF, Beam-dynamics,...)!

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Thank you
Suche nach dunklen Photonen an MAMI/MESA

“Bump-hunt” Experimente können ($M_A' > 100$MeV) sofort begonnen werden: MAMI/A-1 und JLAB/Aspect

Demonstrationsexperiment an MAMI: 100µA/855MeV auf 0.4% rad. length Tantal (2 Wochen Laufzeit) (H. Merkel et al. PRL 106 251802 (2011))

Region interessant wg. $(g-2)_\mu$ Abweichung
ERL/PIT: Ein neues Regime bei E<1GeV

Target dichte N=2*10^{18} atoms/cm^2 (3.2 μg/cm^2, 5*10^{-8} X_0)
→ I_0=10^{-2} A: L = 1.2*10^{35} cm^2s^{-1}
→ (mittlerer) Energieverlust (Ionisation): ~ 17eV
→ RMS Streuwinkel (Vielfachstreuung): 10μrad
→ Single pass Strahlverschlechterung ist akzeptabel

Bei Bunchladung 7.7pC (10mA): ε_{norm} ≈ 1μm
Strahldurchmesser prop. der strahloptischen Funktion β:
\[ r_{beam}(z) = ε_{Geo} * β(z) \]
mit \[ ε_{Geo} = \frac{ε_{Norm}}{\sqrt{γ^2 - 1}} \] \[ ⇒ ε_{Geo}(100MeV) ~ 5nm. \]

In der feldfreien Region um den Punkt z^* = 0
\[ β(z) = β(z^*) + \frac{z^2}{β(z^*)} = β^*(1 + (z / β^*)^2) \] wähle: \[ β^* = 1m \]
⇒ Maximaler Strahldurchmesser ≤ 0.2mm (z = ± 1m)