Different ERL Applications

CAS
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Kurt Aulenbacher
Johannes Gutenberg-Universität Mainz
1.) Introduction to „different applications“
2.) ERL with fixed target experiments
3.) ERL based Linac-Ring Colliders
4.) Spin-Polarisation for ERLs
1 Introduction

When does it make sense to built a new type of accelerator? ... taking into account risks of new concepts
Introduction

When does it make sense to built a new type of accelerator?

One promise (argument):
If experiments become possible that have not been possible before
Different applications: Scattering experiments for particle physics

Type 1: Fixed target experiment:

Promises:
- Stationary beam conditions even at very low energies due to Pseudo internal target (PIT)
- Reasonable reaction rates even without any target enclosure
- Superior for reactions searching for rare events („Dark particles“)
- All types of reactions investigating low momentum transfer

Planned Experiments: Dark light (JLAB) / MAGIX (MESA)
Different applications: Scattering experiments for particle physics

Type 2: Linac-Ring Collider

Promises: - strong beam beam tuneshift for lepton beam possible
- spin polarization of electron beam easier to manage than in ring/ring designs
- multturn designs feasible (typically 3-6 turns)

Planned set-ups: LHeC (CERN) eRHIC (Brookhaven National Laboratory; BNL)
Conclusion of introduction

Type 1: Fixed target experiment:

- The requirements are somewhat relaxed wrt to radiation generation: in general longer bunches → less coherent radiation problems → less problems with instabilities
- Additional tasks/challenges Type 1
  - Target/Detektor design
  - Halo Control/Collimation

Type 2: Linac-Ring Collider

- Additional tasks/challenges Type 2
  - multiturn desirable (beam dynamics)
  - spin polarisation/spin orientation required
2 ERL with fixed target experiment
2.0 Heinemayers observation

JLAB ERL Laser output: 10kW
Beam Power in Wiggler: ~1MW
R.F power needed: ~100kW

The energy taken away by scattered particles in one passage of the target can be much smaller than the one extracted in the FEL.

Experiments with „Pseudo“ internal targets could be attractive. (Proposed for dark matter search by Heinemayer et al. (2007): arXiv:0705.4056v2)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>IR FEL Upgrade</th>
<th>UV FEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam energy at wiggler</td>
<td>80–210 MeV</td>
<td>200 MeV</td>
</tr>
<tr>
<td>Average beam current</td>
<td>10 mA</td>
<td>5 mA</td>
</tr>
<tr>
<td>Bunch charge</td>
<td>135 pC</td>
<td>135 pC</td>
</tr>
<tr>
<td>Bunch repetition rate</td>
<td>74.85 MHz</td>
<td>74.85 MHz</td>
</tr>
<tr>
<td>Normalized emittance (rms)</td>
<td>13 mm-mrad</td>
<td>5–10 mm-mrad</td>
</tr>
<tr>
<td>Bunch length at wiggler (rms)</td>
<td>200 fs</td>
<td>200 fs</td>
</tr>
<tr>
<td>Peak current</td>
<td>270 A</td>
<td>270 A</td>
</tr>
<tr>
<td>FEL extraction efficiency</td>
<td>1%</td>
<td>0.25%</td>
</tr>
<tr>
<td>( \delta p/p ) before wiggler (rms)</td>
<td>0.5%</td>
<td>0.125%</td>
</tr>
<tr>
<td>( \delta p/p ) after wiggler (full)</td>
<td>10%</td>
<td>5%</td>
</tr>
<tr>
<td>CW FEL power</td>
<td>&gt;10 kW</td>
<td>&gt;1 kW</td>
</tr>
</tbody>
</table>


Replace wiggler by „Pseudo“ internal target
2.1 PIT Primer

Event rate is beam current times target surface density times cross section

\[ R = \frac{I_{beam}}{e} \rho_{\text{target}} d_{\text{target}} \frac{d\sigma}{d\Omega} \]

fixed target luminosity

A measurement of the cross section requires suppression of background reactions

- From target enclosure
- Multiple scattering
- Beam halo and collimation after target:

\[ R_{Koll} = \int_{\text{Acc(ERL)}}^{\text{Acc(Det)}} \left( \frac{d\sigma}{d\Omega} \right)_{\text{all reactions}} d\Phi \]

A windowless gas target eliminates the first aspect. A „thin“ gas target eliminates the second one.

→ In this case the beam current has to be increased correspondingly to keep the rate at the desired level. This motivates the use of ERL’s for low energies
Assume Bunchcharge \( 7.7\text{pC (10mA at 1300 MHz): } \varepsilon_{\text{norm}} \approx 1\mu\text{m} \)

Beam diameter:
\[
r_{\text{beam}}(z) = \varepsilon_{\text{Geo}} \ast \beta(z)
\]

with \( \varepsilon_{\text{Geo}} = \frac{\varepsilon_{\text{Norm}}}{\sqrt{\gamma^2 - 1}} \Rightarrow \varepsilon_{\text{Geo}}(100\text{MeV}) \sim 5\text{nm}. \)

In the region around center of target \( z^* = 0 \)
\[
\beta(z) = \beta(z^*) + \frac{z^2}{\beta(z^*)} = \beta^*(1 + (z / \beta^*)^2) \Rightarrow \beta^* = 1\text{m}
\]

\( \Rightarrow \) Maximum beam diameter (10 sigma) \( \leq 4\text{mm (} z = \pm 1\text{m)} \)
2.1.1 Schematic PIT example

Target-density $N=2\times10^{18}$ atoms/cm$^2$

- $(3.2 \ \mu g/cm^2, 5\times10^{-8} X_0)$
- $I_0=10^{-2}$ A: $L=1.2\times10^{35}$ cm$^{-2}$s$^{-1}$
- (average) Energy loss (Ionisation): $\sim 17$eV
- RMS Scattering angle (multiple scattering): $10\mu$rad
- **Single pass** Beam quality reduction negligible

GEANT-4 Simulation
Histogramm of $10^7$ ref. particles scattered by 1m Hydrogen gas,

$\sigma^*=8\times10^{-6} g/cm^2 (5\times10^{-10} 	ext{nuclei/cm}^2)$

V. Tioukine
### 2.2 Internal targets: state of the art

<table>
<thead>
<tr>
<th>Tube Target</th>
<th>Jet Target</th>
<th>Cluster-Jet Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Molecular Flow inside of a tube</td>
<td>• Gas Jet flows through the Chamber perpendicular to the beam</td>
<td>• Formation of clusters in the Jet</td>
</tr>
</tbody>
</table>

This is needed for POLARIZED Target (a la HERMES at HERA)!

S. Aulenbacher  
https://indico.mitp.uni-mainz.de/event/66/session/5/contribution/48/material/slides/0.pdf
2.2 Internal targets: state of the art

Under development at Uni Münster
For MAGIX at MESA
Design Target density $O(10^{19} \text{ cm}^{-2})$

S. Grieser
https://indico.mitp.uni-mainz.de/event/66/session/5/contribution/27/material/slides/0.pdf
2.3 Example: The „MAGIX“ experiment

Operation of a high-intensity (polarized) ERL beam in conjunction with light internal target
→ a novel technique in nuclear and particle physics
→ measurement of low momenta tracks with high accuracy
→ competitive luminosities
→ Small device if compared to GeV scale spectrometer set ups!

High resolution spectrometers MAGIX:
- double arm, compact design
- momentum resolution: $\Delta p/p < 10^{-4}$
- acceptance: $\pm 50$ mrad
- GEM-based focal plane detectors
- Gas Jet or polarized T-shaped target
2.4 Physics with an ERL: Dark matter searches

- Presently, there is no clear evidence if dark matter particles exist
- Searches for WIMPS so far not succesful
- Other possibility: New forces and force carriers: „Dark Photons“ „Dark Z“ „A“
- These are detectable by the so-called kinetic mixing effect

Signal:

QED Untergrund

\[ \sigma(\varepsilon, m_{A'}) \approx 100 \text{pb}(\varepsilon/10^{-4})^2(100\text{MeV}/m_{A'})^2 \]
\[ c\tau = 0.1\text{mm}(10^{-4}/\varepsilon)^2(100\text{MeV}/m_{A'}) \]

\[ \sigma_{\text{QED}} \approx 10^5 \sigma(\varepsilon, m_{A'}) \]
\[ c\tau = 0 \]

A’ Status: Excluded areas in 2013
2.4 Dark matter searches – the \((g-2)_\mu\) temptation

The gyromagnetic anomaly \(a=(g-2)/2\) of the muon has been measured at BNL with extremely high accuracy and disagrees with the standard model prediction by about 3-4 standard deviations.

In 2012 it was claimed that the existence of a dark photon would explain the result. And that the properties of the dark photon would correspond (approximately) to the red line in the figure.
The strong suggestion that it would be possible to discover the particle has meanwhile covered the "red line" (without finding the dark photon...)

2.4 Dark matter searches with MAGIX
2.4 Dark matter searches with MAGIX

- g-2 band could as well be motivated by „invisible“ decay into dark matter...

\[
m'^2_{A'} = (p_e + P_{nucleus} - p_{e'} - P'_{nucleus})^2
\]

By measuring the (very small) recoil of the Nucleus (proton) One reconstruct if particles of the A' type have been Produced – very good conditions for this in the PIT regime
2.5 MAGIX portfolio-II / Form factors & the Proton radius puzzle

MAGIX allows to address much smaller momentum transfer due to very low energy, momentum transfer and minimized material budget...

Simulation:
- Polarized target, $3 \times 10^{15}$ / cm$^2$ (very conservative)
- 80% polarisation
- 1mA beam current, 105 MeV
3 Introduction: ERL’s in the LINAC/RING configuration

Physics motivation is mainly deep inelastic lepton/hadron scattering with the intention to increase knowledge beyond the results obtained at the ring/ring collider HERA.

\[ s \approx 4E_{\text{lepton}}E_{\text{ion}} \approx 10^5 \text{GeV}^2 \]
\[ L \approx 10^{32} \text{ cm}^{-2} \text{ s}^{-1} \]

The objectives are:
• Increase the center of mass energy \( s^{1/2} \) considerably with respect to HERA
• Increase the luminosity in the same way
• Add double polarisation (HERA double polarized only in fixed polarized target mode, with \( s^{1/2} \) very low.

Two approaches:
1.) eRHIC double polarized adding ERL to existing RHIC ring (double polarized, > 10*Hera Luminosity, smaller s.)
2.) LHeC 60 GeV e- beams collides with LHC at 7 TeV \( \rightarrow \) much larger s, >10*L, single polarized,
Physics motivation is mainly deep inelastic lepton/hadron scattering

- Collider mode: Luminosity given by
  \[ L = \int_{Coll} N_{el} N_{ion} \epsilon \beta^* O(1) \]

- The large tune shift for the electrons can be tolerated because of ERL operation!

- Spin polarization is mandatory, at least for the ERL beam, better for both (Double polarized collider)
3 Introduction: Cost issues (Schematic)

Rel. Contribution to facility costs

Minimum of total costs

Conventional recirculator

FFAG recirculator?

N=0  N=1  N=2  N=3  N=many

# of recirculations
3 ERL’s in the L/R configuration: eRHIC

• 16 recirculations in two beamlines!
• Only on 1,3 GeV Linac required
• FFAG test set up presently being designed at Cornell University

Table 1: BNL eRHIC Beam Parameters and Luminosities

<table>
<thead>
<tr>
<th></th>
<th>e</th>
<th>P</th>
<th>$^3$He$^{2+}$</th>
<th>$^{197}$Au$^{72+}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (GeV)</td>
<td>15.9</td>
<td>250</td>
<td>167</td>
<td>100</td>
</tr>
<tr>
<td>CM energy (GeV)</td>
<td>122.5</td>
<td>81.7</td>
<td>63.2</td>
<td></td>
</tr>
<tr>
<td>Bunch freq. (MHz)</td>
<td>9.4</td>
<td>9.4</td>
<td>9.4</td>
<td>9.4</td>
</tr>
<tr>
<td>Bunch Int. (nucl.), 10$^{11}$</td>
<td>0.33</td>
<td>0.3</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Bunch charge (nC)</td>
<td>5.3</td>
<td>4.8</td>
<td>6.4</td>
<td>3.9</td>
</tr>
<tr>
<td>Beam current, mA</td>
<td>50</td>
<td>42</td>
<td>55</td>
<td>33</td>
</tr>
<tr>
<td>Hadron rms $s_N$ ($\mu$m)</td>
<td>0.27</td>
<td>0.20</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>Electron rms $s_N$ ($\mu$m)</td>
<td>31.6</td>
<td>34.7</td>
<td>57.9</td>
<td></td>
</tr>
<tr>
<td>$\beta^*$ (cm) (both planes)</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Hadron beam-beam $\varsigma$</td>
<td>0.015</td>
<td>0.014</td>
<td>0.008</td>
<td></td>
</tr>
<tr>
<td>Elect. Beam disruption</td>
<td>2.8</td>
<td>5.2</td>
<td>1.9</td>
<td></td>
</tr>
<tr>
<td>Space charge par. $\zeta$</td>
<td>0.006</td>
<td>0.016</td>
<td>0.016</td>
<td></td>
</tr>
<tr>
<td>rms bunch length, cm</td>
<td>0.4</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Polarization, %</td>
<td>80</td>
<td>70</td>
<td>70</td>
<td>none</td>
</tr>
<tr>
<td>Peak $\beta$, 10$^{22}$ cm$^2$s$^{-1}$</td>
<td>1.5</td>
<td>2.8</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td>Improve $\beta$, 10$^{24}$ cm$^2$s$^{-1}$</td>
<td>1.5</td>
<td>2.8</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td>Ultimate $\beta$, 10$^{26}$ cm$^2$s$^{-1}$</td>
<td>1.5</td>
<td>2.8</td>
<td>1.7</td>
<td></td>
</tr>
</tbody>
</table>

V. Litvinenko et al.
TUPTY047 Proceedings of IPAC2015, Richmond, VA, USA
3 ERL’s in the L/R configuration:eRHIC

LHeC Linac-Ring ERL layout

- Two 10-GeV SC linacs, 3-pass up, 3-pass down; 6.4 mA, 60 GeV e⁻'s collide w. LHC protons/ions
- "Single" polarised collider
- Higher CM energy than eRHIC
- Luminosity ~10^33
- Separate recirculation orbits

(C=1/3 LHC allows for ion clearing gaps)

A. Bogacz, O. Brüning, M. Klein, D. Schulte, F. Zimmermann, et al
Electron Spin-Polarisation for L/R colliders
ERL based L/R colliders require to improve the „lifetime parameters“ of polarized sources since the average beam currents are about 1-2 orders of magnitude higher than presently practical.

→ Physics of polarized electron sources
4.1 Basics of photoemission
4.1.1 Basics of Photoemission

- **Remember**: A laser of 1 Watt power with 1 eV photon energy (1240nm wavelength) carries $6 \times 10^{18}$ photons per second.

$$1 \text{ Watt} = P = n\hbar\omega \Rightarrow n = \frac{1/e}{s^{-1}}$$

- If each Photon is converted into one electron by the photoelectric effect the current is $n * e = 1\text{Ampere}$,

- The **quantum efficiency** is the fraction of Photons that are converted into electrons for a given photocathode

- More practical: Photosensitivity $S$

$$S[A/\text{Watt}] = QE \cdot \frac{\lambda[\mu\text{m}]}{1.24}$$

- 1% at 800 nm wavelength is therefore $\sim 6\text{mA/Watt}$

- Many Watts Laser power available even under ERL conditions (ps pulses, high rep rate...)
4.1.1 Basics of Photoemission

• „Direct“ Semiconductors offer the following effects/options:
  - Strong photoabsorption
  - Long lifetime of electrons in conduction band
  - Nanostructuring developed for semiconductor lasers allows „band structure design“

→ Create an artificial crystal optimized for spin transfer from photons to electrons
4.1.2 Band structure design

Importance of symmetry breaking

\[ a_s < a < c \]

GaAs

s-GaAs

\[ a_s < a < c \]
4.1.2 Band structure design

\[
\begin{array}{c}
\text{Undeformiert} \\
\end{array}
\]

\[
\begin{array}{c}
\Gamma^6 \\
E_G \\
\Gamma^8 \\
\end{array}
\]

\[
\begin{array}{c}
\Gamma^7 \\
E_{G+\Delta} \\
\end{array}
\]

\[
\begin{array}{c}
K\text{-Vektor} \\
\end{array}
\]

\[
\begin{array}{c}
\text{Deformiert} \\
\end{array}
\]

\[
\begin{array}{c}
\Gamma^6 \\
E_{G}^{\text{DEF}} \\
\Gamma^8 \\
\end{array}
\]

\[
\begin{array}{c}
\Gamma^7 \\
E_{G}^{\text{DEF}} + \Delta E_{\text{Str.}} \\
\end{array}
\]

\[
\begin{array}{c}
K\text{-Vektor} \\
\end{array}
\]
4.1.2 Band structure design

Idea: Use spin orbit coupling together with symmetry breaking

\[
\begin{align*}
&\text{E} \\
&\uparrow \\
&S_{1/2} \\
&P_{3/2} \\
&M_j = -3/2, -1/2, +1/2, +3/2 \\
&\Delta E_{\text{strain}} \\
&\text{Leitungsband} \\
&\text{Valenzband}
\end{align*}
\]
4.1.3 Advanced Band structure design: Superlattices

Maruyama et al, Nakanishi et al., Mamaev et al (SLAC/Nagoya/St. Petersburg)

„Hot rod“ photocathode: with built in Bragg reflector for optimized thermal conditions and high QE! (Mamaev et al. 2007)
4.1.3 Band structure design: Achievable performance

Y. Mamaev et al.
4.1.3 Band structure design: Achievable performance

Photocathode active layer thickness \( D = 100 \text{nm} \)
\( D^2 \) scaling of response time reduces pulse response with respect to normal "bulk" GaAs. Note tail at ~1% intensity

E. Riehn et al
4.2 Beam brightness

For given source field parameters, the maximum brightness is given by the transverse temperature of the emitted Ensemble.

This is optimal in spin polarized Photemission!

\[ B = \frac{I}{\varepsilon_{r,n}^2} \]

\[ \varepsilon_n = \sigma_0 \sqrt{kT_\perp / mc^2} \]

\( \sigma_0 \) = beam radius at cath.

I Bazarov et al.
Proceedings of PAC07, Albuquerque, New Mexico, USA TUPMS020
Exploiting the properties of near band gap photoemission for spin polarized, highly efficient, high brightness beams.

Requires maintaining the state of „Negative Electron Affinity“ (NEA).

**Definition of Electron Affinity**

\[
EA = E_{VAK} - E_{CB}
\]

\(E_{VAK}, E_{CB}\)  Energy of Electron in Vacuum and in Conduction band minimum respectively.

Negative Electron affinity means that electrons can escape from the crystal once they reach the surface. Natural NEA is possible in wide band gap crystals such as diamond. Its employment for low band gap material requires „work function lowering“ by monoatomic layers of Cesium.
7.1.3. Modell der Photoemission aus Halbleitern
Dreistufenmodell: Emission und Zweifel an der Polarisationserhaltung

Dreistufenmodell:

1. Halbleiter/Vacuum Grenzschicht (10nm)
   Raumladungszone, komplizierte Streuprozesse
2. Schneller Zerfall der Polarisation in weniger als 100ps!
   $P(t) = \frac{P(0)}{1 + \frac{t}{\tau_{\text{spin}}}}$
3. Eventuell nicht vollständige Polarisation nach der Absorption

Extraktion inelastische und elastische Streuprozesse mit depolarisierender Wirkung vorstellbar

---

*Diagrammes und Formeln sind mit Text ergänzt.*
4.3 Lifetime issues - temperature

Lifetime is temperature dependent!
Relatively low quantum efficiency req
4.3. 1 Lifetime - more effects

\[ Qe(t) = Qe_0 \exp(-t / \tau) \]

Parallel acting processes:

\[ \frac{1}{\tau} = \sum_i \frac{1}{\tau_i} \]

z.B. Restgasspezies H₂O:

\[ \tau_{H₂O} = \frac{k}{p} \]

\( \tau_{H₂O} = 20 \text{days} \rightarrow p = 4.2 \times 10^{-13} \text{mbar} \)

Many other processes: transmission loss, heat, ion backbombardment
4.3. 3 Fluence Lifetime

exp. decay at zero current
$\tau_{\text{obs}} = 850\,\text{h}$

exp. decay at 10, 30, and 200 $\mu$A:
$\tau_{\text{obs}} = 720, 516, 220\,\text{h}$
4.3.3 Fluence Lifetime

- Excentrically started electron beam
- Backward travelling, positive Ions

QE-distribution
Before/after

→ FLUENCE lifetime $\sim 10^3 \text{ C/cm}^2$
→ 50mA is 180 C/hour ???

K. Aulenbacher SLAC report, 1993
4.4 Possible Lifetime Improvements

- Multiple cathodes in time sharing system: BNL „gatling gun“
- Improve vacuum conditions, reduce backbombabardment: SRF gun (ELBE, BNL, )
The End & thank you for your attention
Spares
Electron beam polarimetry at ERL's

ERL workshop, Novosibirsk
15. 03. 2013
Kurt Aulenbacher for the P2 collaboration at IKP Mainz
Spin polarized beams give access to mainly two fundamental questions:
- Spin structure of strongly interacting particles
- Parity violating processes

Observables: Scattering Asymmetries $A_{\text{exp}} = P_{\text{beam}} S$

1.) The interesting quantity is $S$
   (the „analyzing power“ of the scattering process)
2.) Beams are always partially polarized; an error of the polarization measurement may limit the accuracy for $S$!
3.) A „polarimeter“ uses a process for which $S$ is well known and measures $A_{\text{exp}} / S = P_{\text{beam}}$
Introductionary remarks-2

• Spin-Polarized beams at ERL: LHeC. eRHIC, MESA....
• ‘Polarimetry’ must be minimal invasive if installed upstream of the experiment
• Consequence: Online Operation!
• Polarimetry may also be done in invasive fashion in the beam dump
• Contrary to synchrotrons, depolarization (and self-polarization) should be strongly suppressed
Example: Polarimeter-chain for MESA

MESA: so far, Polarimetry is foreseen only in EB mode!

„Mott-polarimeter“ (5 MeV) ILAC Polarized source

Hydro-Möller Polarimeter (150-200 MeV)

EB-experiment (polarized)

ERL-experiment (polarized)
Scenario: Polarimetry in ERL-mode

„Mott-polarimeter“ (5 MeV)  ILAC  Polarized source  Hydro-Möller Polarimeter (150-200 MeV)

EB-experiment (polarized)  ERL-experiment (polarized)
### Existing Electron-Polarimeter chain at MAMI

<table>
<thead>
<tr>
<th>Polarimeter</th>
<th>∆P/P present (Potential)</th>
<th>Main uncertainty</th>
<th>Measurement Time @1% stat</th>
<th>Operating current</th>
<th>Energy range [MeV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mott</td>
<td>0.05 (0.01)</td>
<td>Background</td>
<td>3s-1h</td>
<td>5nA - 100μA</td>
<td>1-4</td>
</tr>
<tr>
<td>Möller</td>
<td>0.02 (0.01)</td>
<td>Target pol.</td>
<td>30min</td>
<td>50nA</td>
<td>300-1500</td>
</tr>
<tr>
<td>Laser-Compton</td>
<td>0.02 (0.01)</td>
<td>Calibration,</td>
<td>12 h</td>
<td>20μA</td>
<td>850-1500</td>
</tr>
</tbody>
</table>

Details: see talk by Valeri Tioukine!

A new concept is needed for demanding Experiments planned at MESA!
“Unimpeachable” polarization measurement: two independent polarimeters with $\Delta P/P < 0.5\%$ each. : “Double-Scatter-Polarimeter” +”Hydro Möller,”
Cross checks and intensity-linking by multi MeV Mott
Some remarks

low energy operation of Mott scattering
probably no cause for additional systematics at MESA
(→ exact spin tracking possible, no resonances)
LCP not possible at MESA due to small energy, Hydro-Möller could work

Different concepts (‘paradigms’) of measurements:
- Hydro Möller ‘double-polarization’
- Double-scattering Polarimeter ‘double scattering’
Different ERL Applications


Hydro-Möller

Details: see talk by Patricia Bartholomae

„Prototype“ of atomic trap was donated by UVA/Don Crabb

→ Template for cryostate development

→ Solenoid may be usable

Johannes Gutenberg-Universität Mainz

12.09.2013

ERL workshop, Budker Institute, Novosibirsk
The Hydro-Möller follows a 'paradigma':

"accurate determination of effective analyzing power is achieved by factorization of theoretical and several experimental effects and accurate determination of all of them"

\[ A_{\text{exp}} = P_{\text{beam}} \underbrace{\text{Corr} P_T S_{0}}_{S_{\text{eff}}} \]

Corr = i.e dilution by background

- Apparent attractiveness of standard (single-spin) Mott-scattering:

\[ A_{\text{exp}} = P_{\text{beam}} \underbrace{\text{Corr} S^y_{0}}_{S_{\text{eff}}} \Rightarrow \text{No } P_T ! \]

(but no change of Paradigma)
A very old idea

In **double** elastic scattering $S_{\text{eff}}$ can be **measured**! (...another paradigm...) After scattering of **unpolarized** beam:

$$P_{\text{sc}} = S_{\text{eff}}$$

(Equality of polarizing and Analyzing Power :)

After second "identical" scattering process

$$A_{\text{exp}} = S^2_{\text{eff}}$$

with great effort to eliminate apparative asymmetries and to provide 'identical' scattering)

the claimed accuracy in $S_{\text{eff}}$ is $< 0.3\%$

- The apparatus of Gellrich & Kessler is in our possesion
- Goal:-1 Reproduction of Kesslers claims using test source
- Electronics has been upgraded , measurements will start in 2013 (PhD thesis M. Molitor)
- Then installation at MESA
More remarks

DSP works at ~100keV; ideal for 1mA-MESA-stage-1
Targets **not** extremely thin (~100nm)
Elimination of apparatus asymmetry depends critically on geometrical arrangement of normalization counters
Apparatus calibrates $S_{\text{eff}}$, but does not allow to measure $S_0$
Claim: Inelastic contributions do not jeopardize the accuracy!

potential issues

→ how to use with polarized beam?
→ What if the two targets are NOT identical?

Hopster&Abraham (1989):
No problem, If a switchable polarized beam is available ($|P+|=|P-|$), the first target may then be treated as an **auxiliary target** which may be exploited for **systematic cross checks**
1.) measurement: Pol beam on second target

\[ A_1 = S_{\text{eff}} P_0 \]

2.) with 'auxiliary target': \( S_T \): + \( P_0 \)

\[ A_2 = P_T S_{\text{eff}} = \frac{S_T + \alpha P_0}{1 + S_T P_0} S_{\text{eff}} \]

\( \alpha \) = Depolarization factor for first Target

3. with 'auxiliary target': \( S_T \): - \( P_0 \)

\[ A_3 = P_T S_{\text{eff}} = \frac{S_T - \alpha P_0}{1 - S_T P_0} S_{\text{eff}} \]

4. unpolarized beam on auxiliary target

\[ A_4 = S_T S_{\text{eff}} \]

5. Scattering asymmetry from auxiliary target

\[ A_5 = P_0 S_T \]

5 equations with four unknowns \( \rightarrow \) consistency check for apparative asymmetries!

\( \rightarrow \) Results achieved by Kessler were consistent < 0.3%
More remarks

Auxiliary target method was limited by statistical efficiency (today about 5 times better!)

DSP invasive, but fast.

Probably not feasible to operate DSP at $> 100\mu A$ current level, requires 'linking Polarimeter'

Linking with high precision polarimeters to be installed at 5MeV (Mott/Compton-combination

Mott/Compton combination invasive but extremely fast ($O(\text{seconds}) < 1\%$ stat. accuracy), also control of spin angle
MAMI ca. 1995:
Aufgebaut wird der
r.f.-synchrostreak
Apparatur zur
polarisationsaufgelösten
Messung der Impulsantwort
von Halbleiterphotokathoden

7.1.7. Impulsantwort von NEA Photokathoden

P. Hartmann et. al.
Schichtdickenabhängigkeit

Zeitskala: 90% der Ladung im Puls ($t_{90}$)
Dicke: 100nm

Gauss mit 2.5ps FWHM

limitiert durch experimentelle Auflösung von etwa 2.5ps.
Experimentelles Resultat:

\[ D_{\text{hom}} = 24 \text{cm}^2/\text{s} \]

\[ D_{\text{grad}} = 40 \text{cm}^2/\text{s} \]

Diffusionsmodell: Modellvorhersage

\[ \langle t \rangle \approx \frac{d^2}{12 \cdot D} \]

7.2. „Technische Effizienz‘ (Verfügbarkeit)
der pol. NEA-Photo-Elektronenquellen

1.) Problem ist Herstellung der richtigen Oberflächenrekonstruktion + Aufbringen der Dipolschicht.

2.) Deutlich schwieriger ist die **Erhaltung** der NEA-Verhältnisse im Betrieb

'Doppel-Dipolmodell'
(nach Spicer)
Polarisierte Elektronen an MAMI in schrittweiser Vergrösserung:

Gesamtanlage, Injektion, Photoquelle, Photokathode

RTM1-3

HDSM (1.5 GeV): Fertigstellung 2005

Elektronenquellen und Injektorlinearbeschleuniger

Strahltransport zu den Experimenten

A1 Spektrometer Halle
Life time effects: transmission loss

Electron beam out

Measure loss:
- 5\times10^{-4} nude
- 1\times10^{-6} anodized
- <1\times10^{-7} masked

Nude cathode
- Cs:0 Layer

Anodized cathode:
- pioneered at TJNAF
- anodized layer 100nm thick

Mask activated
- (separate chamber)
- Monoatomic Cesium
- only on small spot:
  - direct comparison with nude!
Einschub: Feldemission

Achtung: Feldemission ist de facto ein Transmissionsverlust!

- 100nA Feldemission limitieren die Lebensdauer
- HV-Überschläge sind das Ende einer Kathode....
- Bau von Quellen mit höheren Spannungen/Feldern erwünscht aber „Tanz auf dem Vulkan“
- 200kV Quelle für MESA angedacht.

Nun weiter zu Transmissionsverlusten
• Photocathode gets activated in conical mask (‘flower-pot’) with small hole in the bottom.
• 2.5 mm diameter covered with Cs only,
• no chemical treatment necessary
• direct comparison with ‘nude’ operation possible
• Cs does not ‘creep’ noticeably on surface.
- direct comparison shows large improvement
- best nude operation lifetime: 22C
- with mask: lifetime 115C
- mask activated strained layer cathode used since spring 2002
- limited possibly by ‘hole burning’ (ion back-bombardment) to 30C/per laser spot (40000 C/cm²)
Multi MeV Mott capabilities

Dynamic Range:


Stability:


Demonstration of constant polarization over large interval in intensities

Polarization Drift consistently observed in transverse AND longitudinal observable at the <0.5% level

12.09.2013
Different ERL Applications

- low and a high energy polarimeter cross-check: negl. depolarization due to low energy gain of MESA
- Monitoring, stability and cross calibration can be supported by extremely precise Mott/Compton combination.
- Hydro Möller + DSP may obtain $\Delta P/P < 0.5\%$ each,

**Conclusion:**