Ideas for **Fundamental Polarized Electron Scattering at the S-DALINAC**

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Workshop to Explore **Physics Opportunities**
with **Intense Polarized Electron Beams**
up to **300 MeV**
Cambridge, MA, March 2013

not quite so intense:  
< 60 µA

even less:  
< 130 MeV
S-DALINAC

**Status**

1. Polarized Source
2. 10 MeV Bremsstrahlung
3. Photon Tagger
4. (e,e'x) Experiments & 180°Scattering
5. (e,e') with High Resolution
S-DALINAC

Operational parameters

- 100 keV polarized beam, 250 keV beam from thermionic gun, < 300 µA
- 3 – 10 (14) MeV behind superconducting injector linac, < 60 (150) µA
- 15 – 80 (120) MeV after main accelerator, < 15 µA (typical 1 µA)

Source of Polarized Electrons

- **Bulk and Superlattice** GaAs
- **Titanium-Sapphire** Laser:
  - 380 fs pulse length
  - 75 MHz repetition rate
  - 40 m fibre/stabilized transfer
- **Diode laser**: DC or 3 GHz
- Load-lock system
- Total height ~ 1.8 m
- Vacuum < $10^{-11}$ mbar

**Performance**
- Vacuum lifetime ~ 1000 h
- Charge lifetime ~ 10 C @ 7 µA
- 90-115 keV, I < 50 µA
- 86% polarization
- 0.15 mm mrad emittance

Implementation complete: ready for first experiments

Ultra-fast Studies of NEA Photocathodes

Bulk-GaAs Photocathode

- Time (ps)
- Beam Current (nA)
- Asymmetry

- $\tau = 4.2 \text{ ps}$
- $1/A = 100 \text{ ps}$
- $1/A^2 = 61.1 \text{ ps}$
- $B = 1 \times 10^{-10} \text{ cm}^3/\text{s}$
- $D = 200 \text{ cm}^2/\text{s}$

M. Wagner, Dissertation in preparation
Polarized Electron Beam at 6.2 MeV

Ag(e,e) Bulk GaAs
Polarized Electron Beam at 6.2 MeV

Ag(e,e) Bulk GaAs

→ Polarization
P ≈ 28%
Ideas

- Bremsstrahlung Polarization Correlations

- MeV Mott Scattering Analyzing Strength

- Fifth Structure Function of Electron Scattering

- Parity Violation in Photofission?
Linear Polarization of Bremsstrahlung from Longitudinally Polarized Electrons

- Linear polarization: segmented (planar pixel) HPGe detector, 5x5 pixels
- Polarized electrons: rotation of bremsstrahlung linear polarization

\[ E_e = 100 \text{ keV} \]

S. Tashenov et al., PRL 107, 173201 (2011)
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S. Tashenov et al., PRL 107, 173201 (2011)
Predicted Cross Sections and Stokes Parameters for Linear Polarizations

S. Tashenov et al., PRA 87, 022707 (2013)
Linear Polarization of Bremsstrahlung from Transversely Polarized Electrons

- Transverse electron polarization (in scattering plane)
- $32 \times 32$ planar pixel Si(Li): active scatterer
  - degree of linear polarization

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  - degree of linear polarization
  - rotation of polarization axis
- Target-thickness effects

Circular Polarization of Bremsstrahlung from Polarized Electrons

- Energy-dependent \textit{bremsstrahlung} \textit{circular} polarization of \textit{longitudinally polarized electrons}

Circular Polarization of Bremsstrahlung from Polarized Electrons

- Energy-dependent *bremsstrahlung circular* polarization of *longitudinally polarized electrons*
- Compton transmission polarimeter
- Commissioning experiment at MAMI (3.5 MeV, 2010)


P. Bangert, Bachelor Thesis (2010)
Circular Polarization of Bremsstrahlung from Polarized Electrons

- Energy-dependent *bremsstrahlung circular* polarization of *longitudinally polarized electrons*

- *Compton transmission* polarimeter
- Commissioning experiment at *MAMI* (3.5 MeV, 2010)

- Towards a *complete characterization of the Stokes parameters* of bremsstrahlung
- *Polarization transfer function* $C_{32}$

*P. Bangert, Bachelor Thesis (2010)*
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Analyzing Strength of Elastic Electron Scattering: The Sherman Function

- **Elastic electron scattering**
  - polarization dependency
  - transverse spin orientation

\[
\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega}_{Mott} \cdot \left(1 - S(E, \vartheta, Z) \cdot \vec{P} \cdot \vec{n}\right)
\]
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\]

- At energies \( E > 10 \text{ MeV} \)
  - minimum close to \( 180^\circ \)
  - \( S \approx 0 \) else

- At energies \( E > 15 \text{ MeV} \)
  - cross section mod. by form factor: charge & magnetization distribution
  - Sherman function: nuclear charge & magnetization distribution
Predictions


→ (Basically) no data!

J. Sromicki et al., PRL 82, 57 (1999)

Figure 1. Sherman function $S$ for $^{208}$Pb ($Z = 82$) as a function of collision energy $E_{i,\text{kin}}$ at the scattering angle $\theta = 175^\circ$ for the Fourier–Bessel potential ([34] with $N = 13$, see [37]), Fermi potential ([14] with $a = 0.5234$, $c_0 = 6.4582$ (in fm), $- - - - -$), as well as for a point nucleus with $Z = 82$ ($\cdots \cdots$). Also shown is the Fourier–Bessel result for $\theta = 168^\circ$ ($\cdots \cdots$). Experimental results at 14 MeV from [10] for $\theta = 168^\circ$ (-hash-1) and extrapolated to $175^\circ$ (■).
Predictions

\[ \frac{d\sigma}{d\Omega} = |f(\vartheta)|^2 + |g(\vartheta)|^2 \]

\[ S(\vartheta) = i \frac{fg^* - f^*g}{|f|^2 + |g|^2} \]

\[ ^{208}\text{Pb}(e,e') \]

P. Uginčius, H. Überall, G.H. Rawitscher,
NPA 158, 418 (1970)
Predictions

Access to details of the charge distribution at low $q$?

But: Need to measure
- very close to $180^\circ$
- at energies between 25 and 100 MeV


Figure 2. Energy dependence of the backward minimum $S_{\text{min}}$ of the Sherman function for $Z = 82$ and a Thomas–Fermi nuclear potential. Parameters $a = 0.5234$ as well as $c_0 = 6.4582$ for $^{208}\text{Pb}$ from [14] (——), $c_0 = 10$ (——) and $c_0 = 4$ (· · · · · ·) (in fm).
180° scattering facility at the S-DALINAC
- transverse polarization
- angle resolution in dispersive direction crucial: $\Delta \theta < 0.5°$

- Possible first experiment(s)
  - 40 MeV and 70 MeV, $^{208}\text{Pb}$
Polarized Elastic Scattering Around 180°

Fig. 11.4: Distribution of the reconstructed horizontal (left) and vertical (right) scattering angles with an excitation energy less than 100 keV for the $^{12}$C elastic line in CD$_2$.

C. Lüttege et al., NIMA 366, 325 (1995)
Ideas

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Polarized Structure Functions \((e, e'x)\)

\[
\frac{d\sigma}{d\Omega} = \left. \frac{d\sigma}{d\Omega} \right|_{Mott} \left( v_L W_L + v_T W_T + v_{LT} W_{LT} + v_{TT} W_{TT} + v_{LT'} W_{LT'} + v_{T'} W_{T'} \right)
\]

- Fifth structure function in electron scattering depends on beam helicity
- No data at momentum transfers below 1.5 \(\text{fm}^{-1}\)
Polarized Structure Functions of $^2\text{H}$, $^3\text{He}$

- $^2\text{H}$: Comparison with **Bates data** and with predictions

S. M. Dolfini et al., PRC 60, 064622 (1999)  
Polarized Structure Functions of $^2\text{H}$, $^3\text{He}$

- $^2\text{H}$: Comparison with Bates data and with predictions
- $^2\text{H}$: Comparison with earlier S-DALINAC data

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- $^3\text{He}$: Sensitivity to 3N force predicted

J. Golak, private communication
Polarized Structure Functions of $^2$H, $^3$He

- $^2$H: Comparison with Bates data and with predictions
- $^2$H: Comparison with earlier S-DALINAC data
- $^3$He: Sensitivity to $3N$ force predicted
- $^{12}$C: from $(\text{CH}_2)_n$ target → Bates

Challenge to theory: Most important information concerning LT’?
Ideas

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Parity Non-conservation in Photofission

- **Weak interaction** in complex nuclei: expect effect $\sim 10^{-8}$
- **Neutron-induced fission**: observe $10^{-4}$
  - Enhancement effects? Use different probe: photons

- Fission-fragment **masses** and **angular distribution** with high accuracy
- **Dilution** of effect size due to simultaneous excitation of many resonances
  - $10^{-5}$ effect requires **very high luminosities**
  - **active target**, high demands on accelerator
Active Target for PNC in Photofission

- **Active UF\textsubscript{6} gas target**
  - Counting gas properties
  - Active target design
  - Data acquisition and analysis
  - Mass and angular resolution
  - PNC experiment
Active Target for PNC in Photofission

- **Active UF₆ gas target**
  - Counting gas properties
  - Active target design
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- **UF₆ gas properties**
  - Solid at room temp., sublim. at 56.5°C
  - High vapor pressure: 153 mbar @ 25°C
  - UF₆ + H₂O → HF

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13.03.2013 | Fachbereich Physik | Institut für Kernphysik | Joachim Enders | 35
Argon as a Detector Gas

Test alpha source
good resolution
Argon + 2% UF₆ as a Detector Gas
Argon + 18% UF6 as a Detector Gas

- Indications for quenching
- Resolution deteriorates
- Residual $^{238}$U a activity following evacuation
- Next days will show if UF$_6$ can be used
Summary

- **S-DALINAC**: polarized electrons of \( \sim \mu A \) at \( 0.1 - 100 \text{ MeV} \)
- **Bremsstrahlung polarization correlations**
  - ... first investigations, determine Stokes parameters
- **Sherman function** at some 10s of MeV
  - ... may depend on **details** of the charge/magnetization distributions
  - ... promises **large effects at 180°**
- **Fifth structure function**
  - ... foreseen to be studied in **light nuclei**
  - ... so far **only two** MIT-Bates data sets
  - ... **what can we learn** from it in heavier nuclei?
- **Parity non-conservation in photofission**
  - ... is very **challenging**!
Collaborations

- **S-DALINAC Polarized Injector**

- **Bremsstrahlung Experiments**
  S. Tashenov, A. Surzhykov – U Heidelberg,
  D. H. Jakubaßa-Amundsen – LMU München
  K. Aulenbacher – U Mainz, V. A. Yerokhin – St. Petersburg

- **Analyzing Strength of Mott Scattering**

- **Fifth Structure Function**
  P. von Neumann-Cosel, T. Kröll, N. Pietralla – TU Darmstadt
  J. Golak – JU Crakow, H. Arenhövel – U Mainz

- **Parity Violation in Photofission**
  S. Oberstedt, A. Göök – EC JRC IRMM Geel
  A. Oberstedt – CEA DAM Bruyères-le-Châtel
Ideas

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- The QUEST for Spin Correlations in Møller Scattering: → Jacek Ciborowski
Spare Slides for Discussion

PEB Workshop @ MIT
March 2013
Bulk vs. Strained Superlattice

M. Wagner, Dissertation in preparation
Future Teststand / Atomic Hydrogen Cleaning

- **Quantum efficiency decrease**
  - deterioration of CsO NEA layer
  - C, AsOₓ, Ga₂O₃ reduce quantum efficiency

- Atomic hydrogen cleaning
  \[
  \text{As}_2\text{O}_3 + 6 \text{ H} \cdot \rightarrow 3 \text{ H}_2\text{O} \uparrow + \frac{1}{2} \text{As}_4 \uparrow \\
  \text{Ga}_2\text{O}_3 + 4 \text{ H} \cdot \rightarrow 2 \text{ H}_2\text{O} \uparrow + \text{Ga}_2\text{O} \uparrow \
  \]
Cleaning & Preparation Test System

M. Espig et al., Proc. IPAC 2012, p. 2642
Magnetic Scattering?

Fig. 13. $S(\theta)$ for point nuclei of $^{31}$V, at $E = 40$ and 100 MeV. Curve 1: Coulomb scattering only (phase-shift results); curve 2: Born approximation ($\mu = 0$); curve 3: Born approximation ($\mu = 5.1478$).
