Ideas for Fundamental Polarized Electron Scattering at the S-DALINAC

Joachim Enders, Technische Universität Darmstadt

TECHNISCHE UNIVERSITÄT DARMSTADT

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

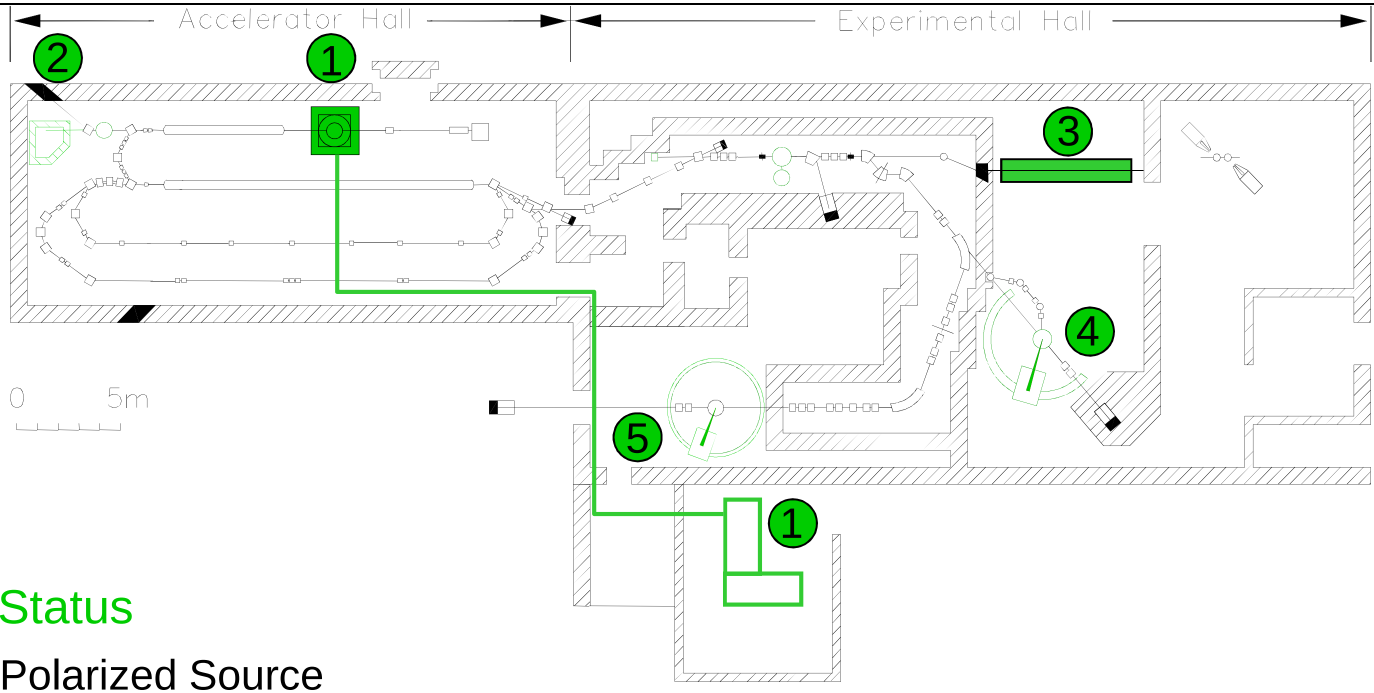
SFB 634

DFG

HIC for FAIR Helmholtz International Center

LOEWE Exzellente Forschung für Hessens Zukunft

S-DALINAC

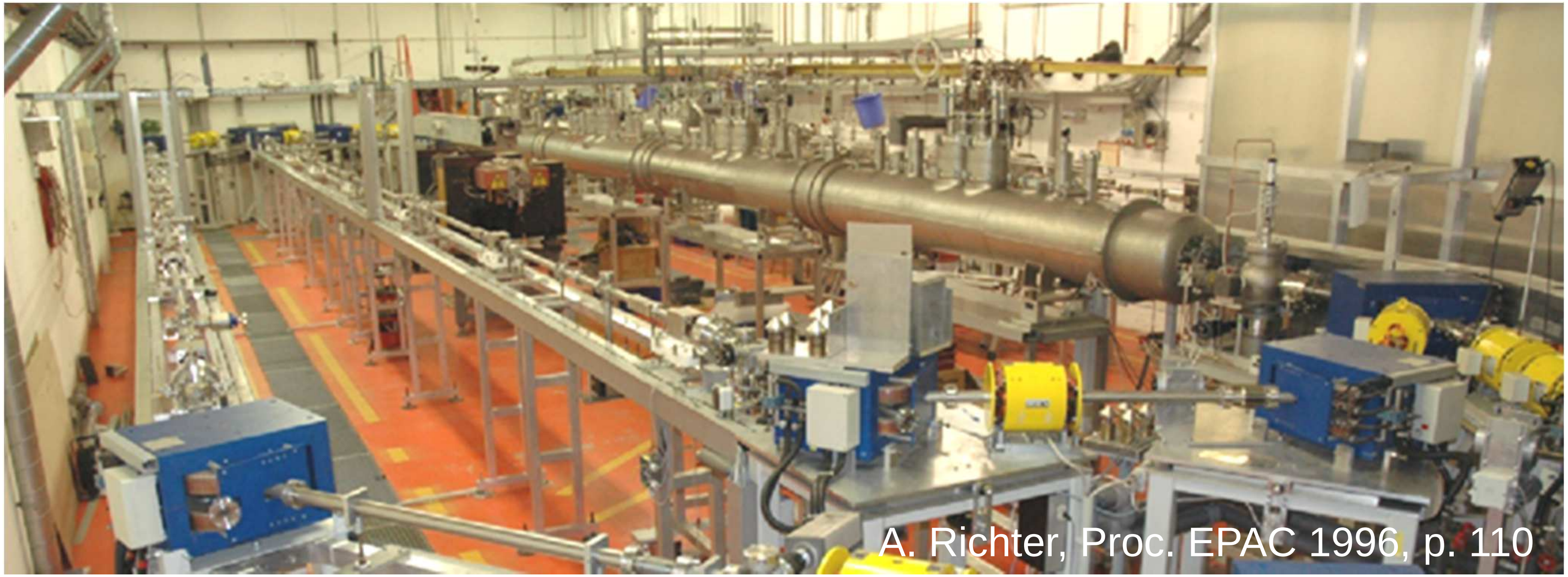


Status

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

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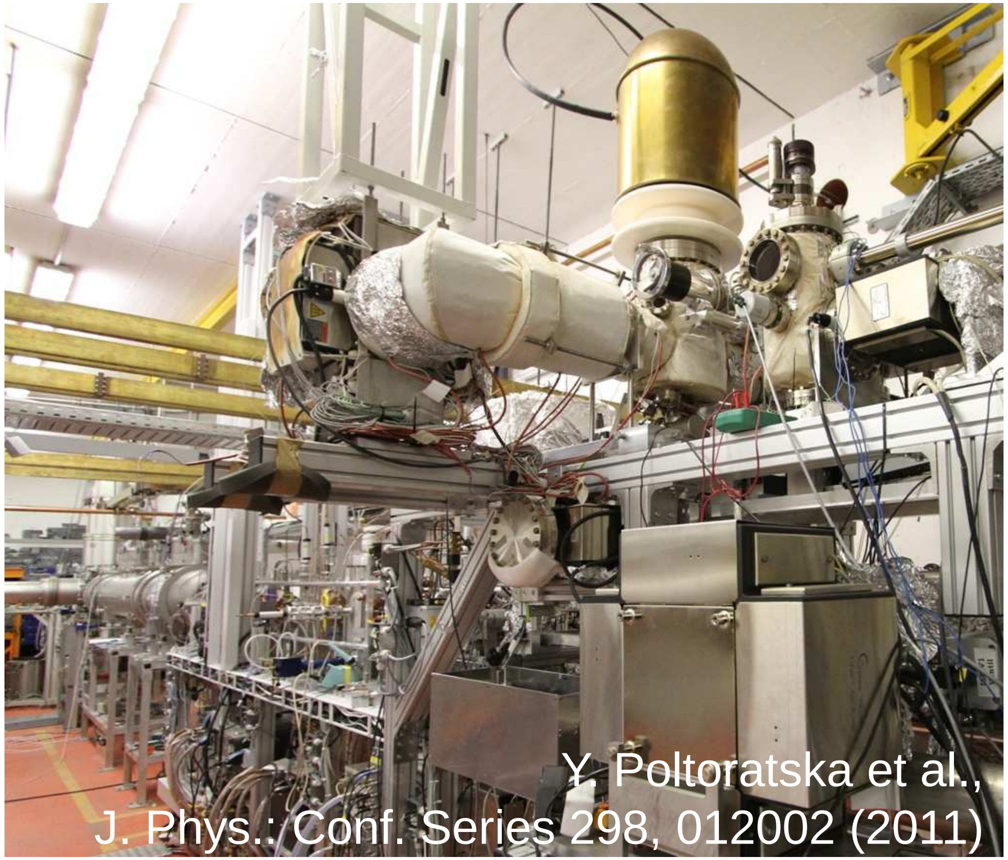

Y. Poltoratska et al., J. Phys.: Conf. Series 298, 012002 (2011)

Implementation complete: ready for first experiments

- **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

Ultra-fast Studies of NEA Photocathodes

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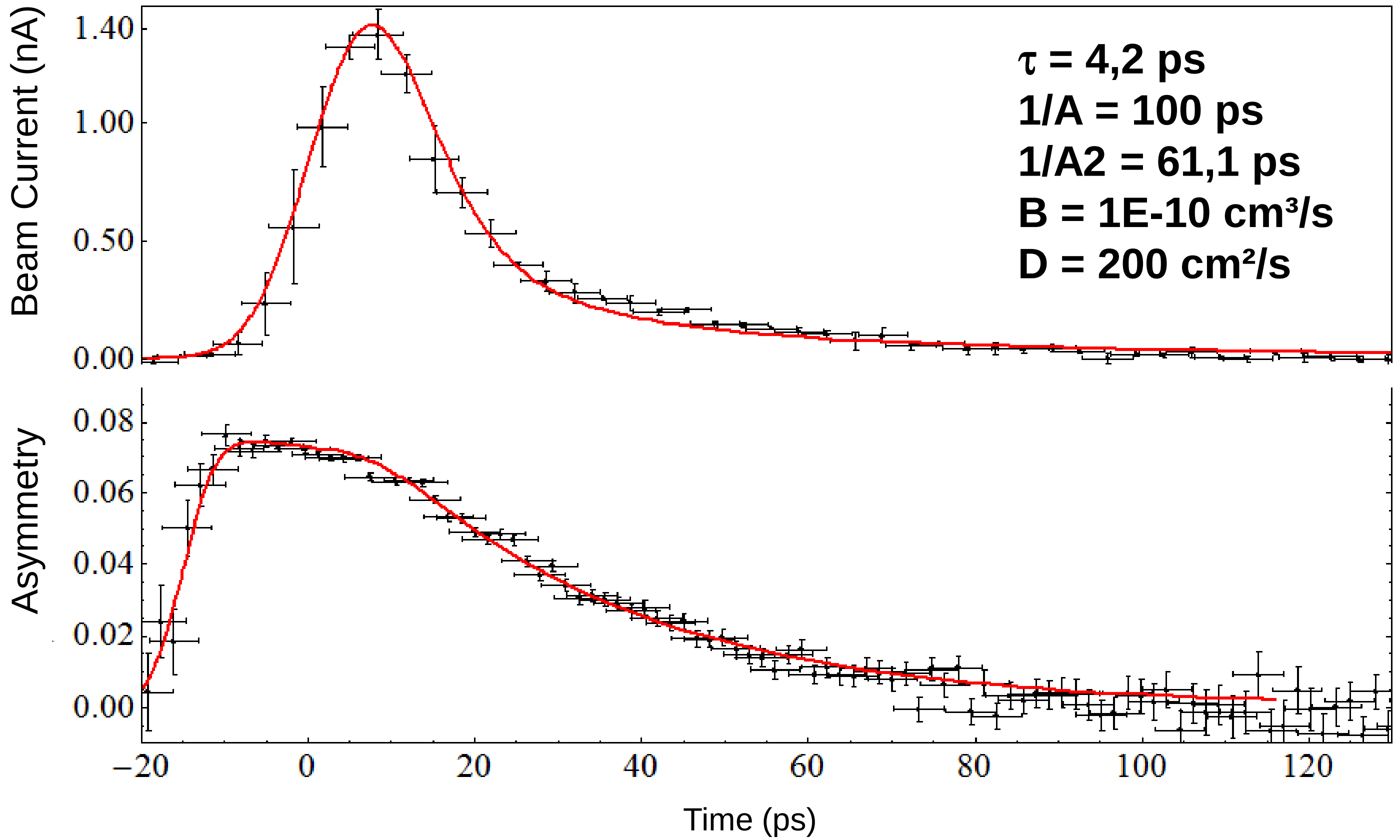
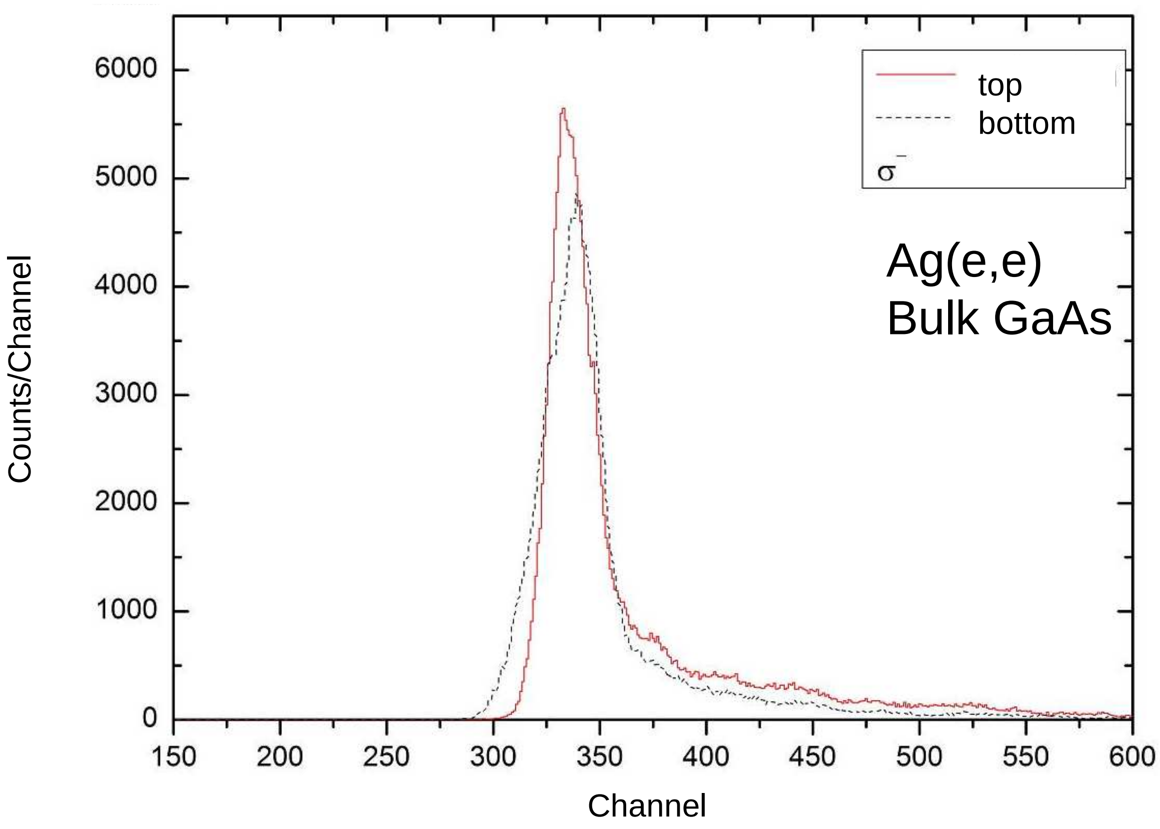
Bulk-GaAs Photocathode



M. Wagner, Dissertation in preparation

Polarized Electron Beam at 6.2 MeV



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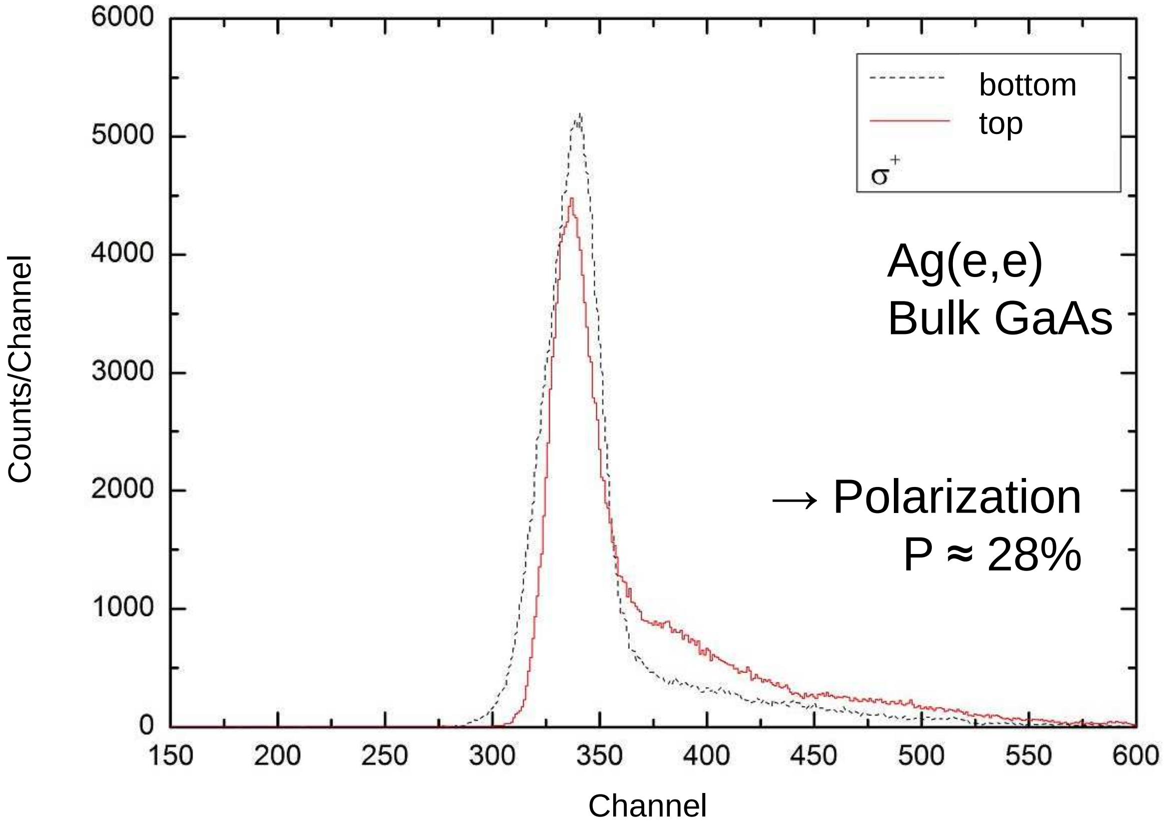
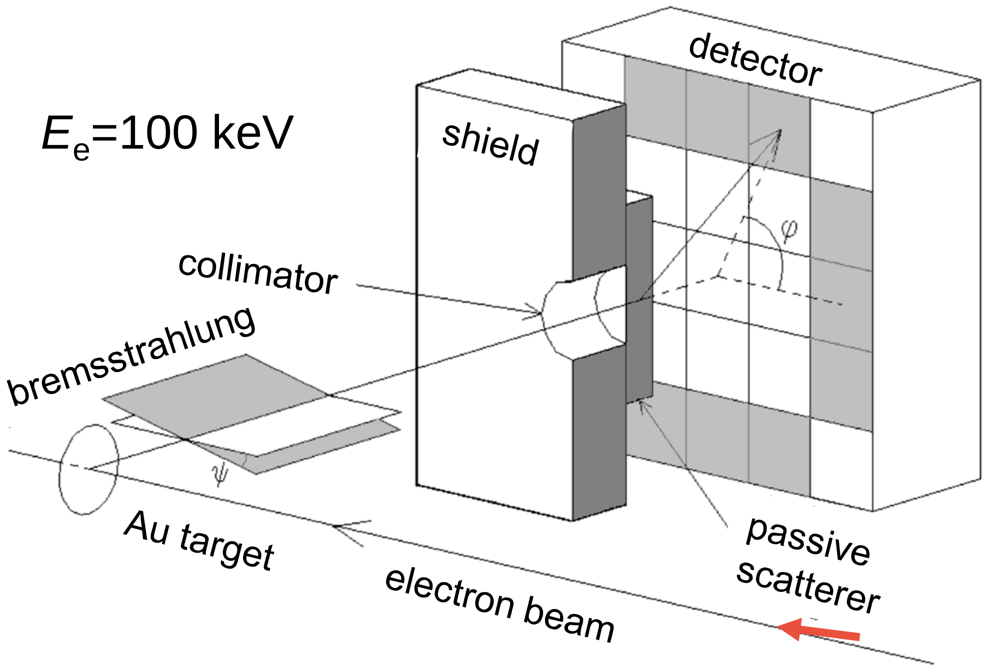


Ideas

- **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**



S. Tashenov et al., PRL 107, 173201 (2011)

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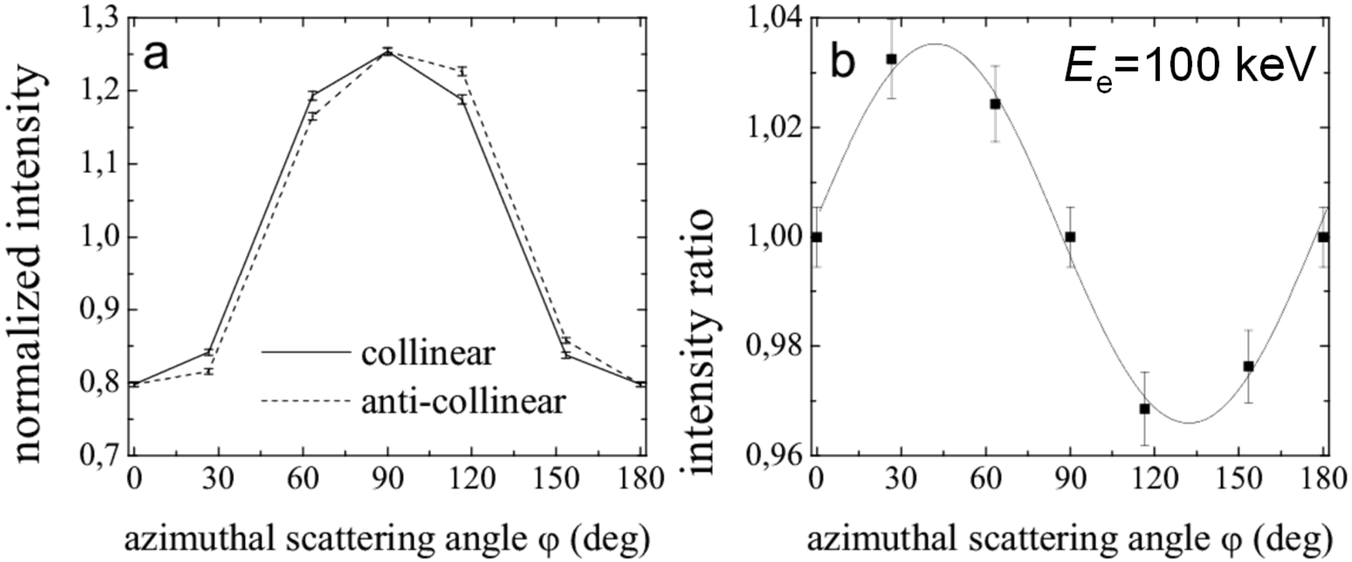
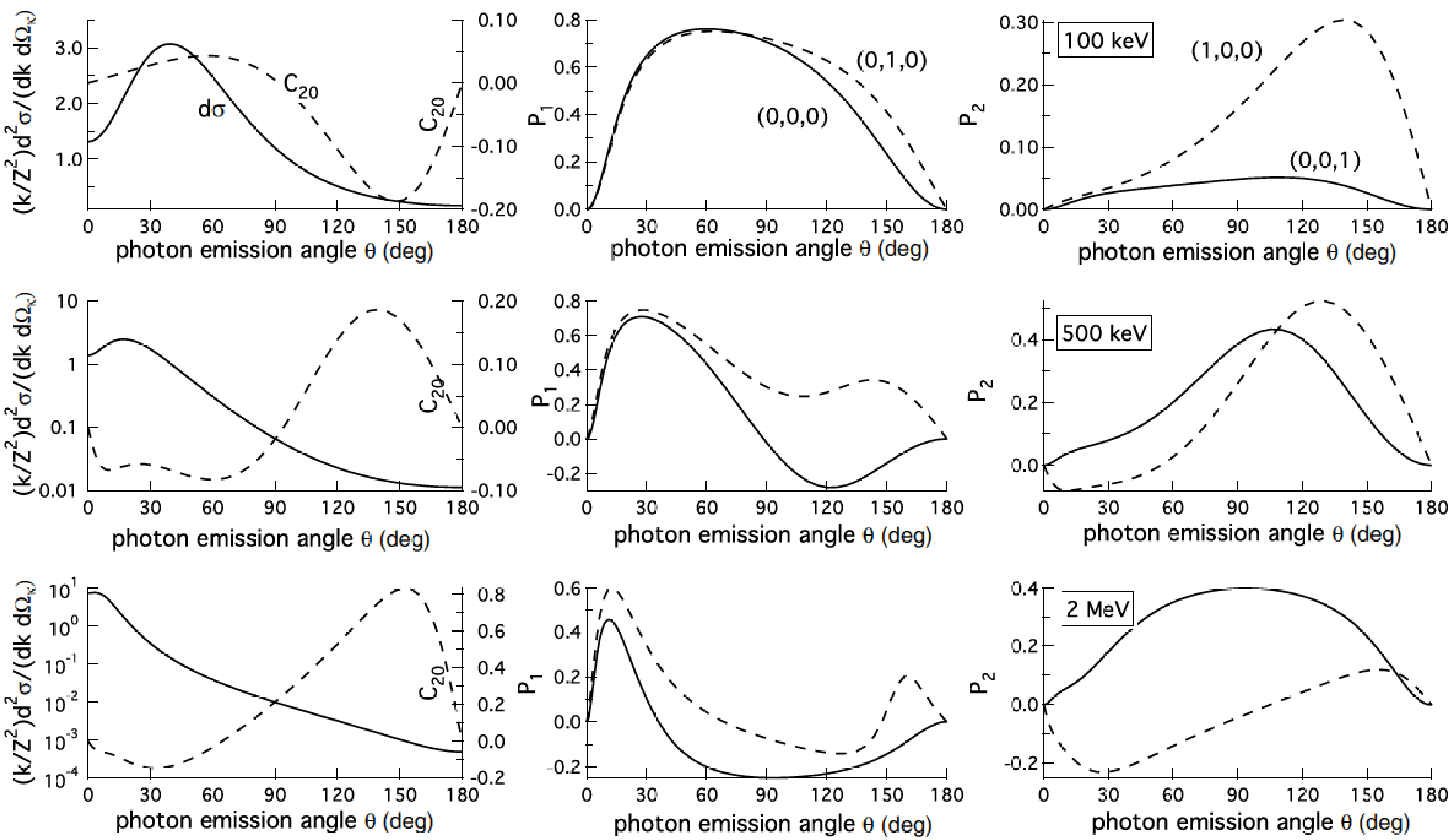


S. Tashenov et al., PRL 107, 173201 (2011)

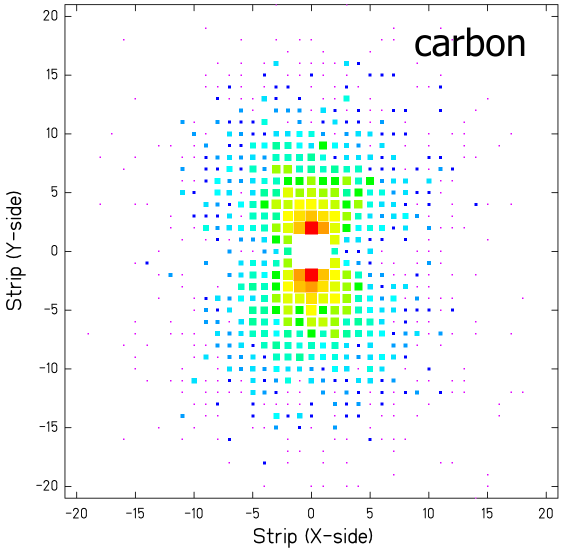
Predicted Cross Sections and Stokes Parameters for Linear Polarizations

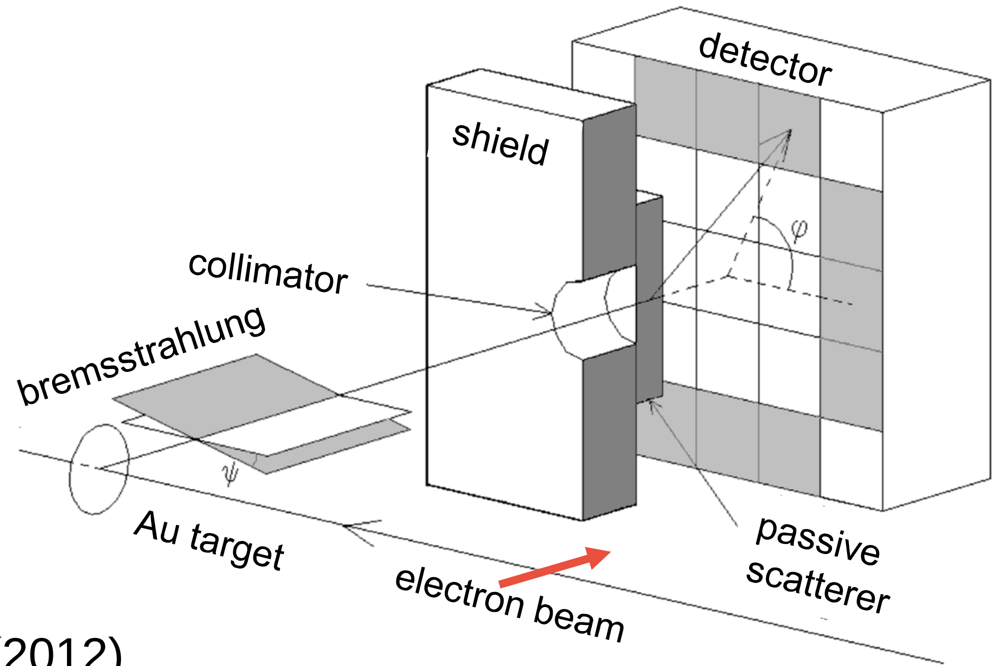


S. Tashenov et al., PRA 87, 022707 (2013)

Linear Polarization of Bremsstrahlung from Transversely Polarized Electrons

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





R. Märtin et al., PRL 108, 264801 (2012)

Linear Polarization of Bremsstrahlung from Transversely Polarized Electrons

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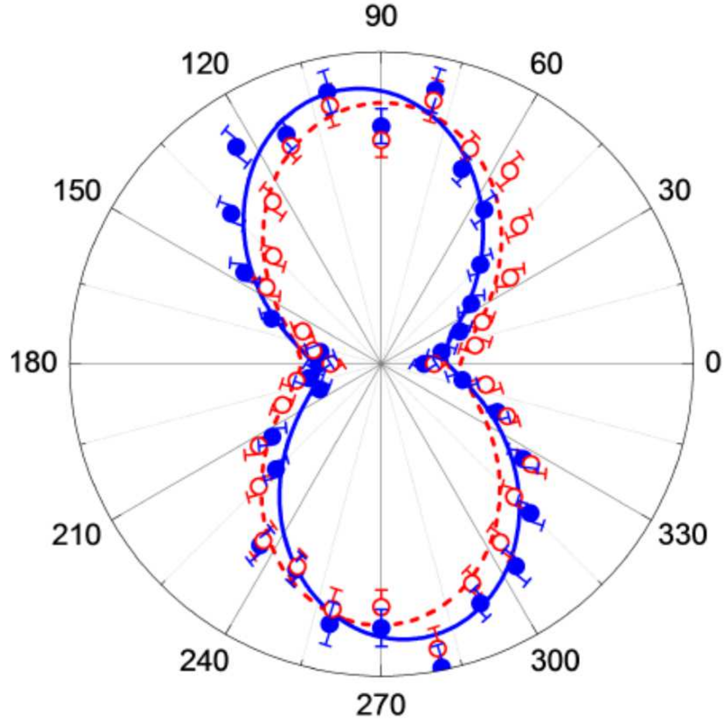
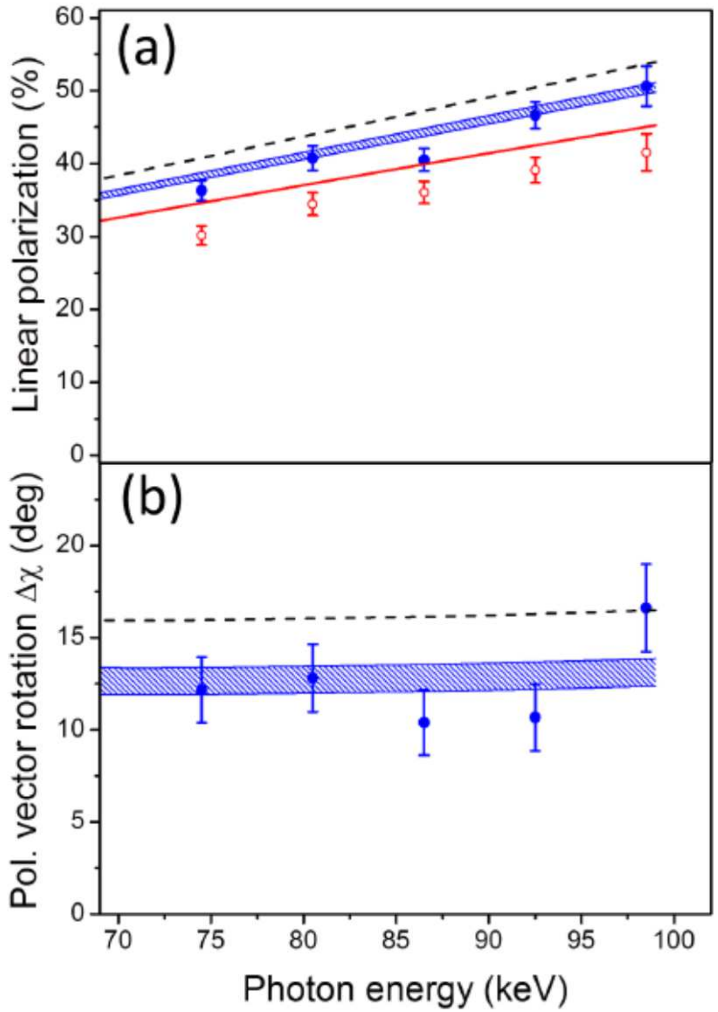
- Transverse electon polarization (in scattering plane)
- 32 x 32 planar pixel Si(Li): active scatterer
  - **degree of linear polarization**
  - **rotation** of polarization axis



R. Märtin et al., PRL 108, 264801 (2012)

Linear Polarization of Bremsstrahlung from Transversely Polarized Electrons

- Transverse electon polarization (in scattering plane)
- 32 x 32 planar pixel Si(Li): active scatterer
  - **degree of linear polarization**
  - **rotation** of polarization axis
- **Target-thickness** effects



R. Märtin et al., PRL 108, 264801 (2012)

Circular Polarization of Bremsstrahlung from Polarized Electrons

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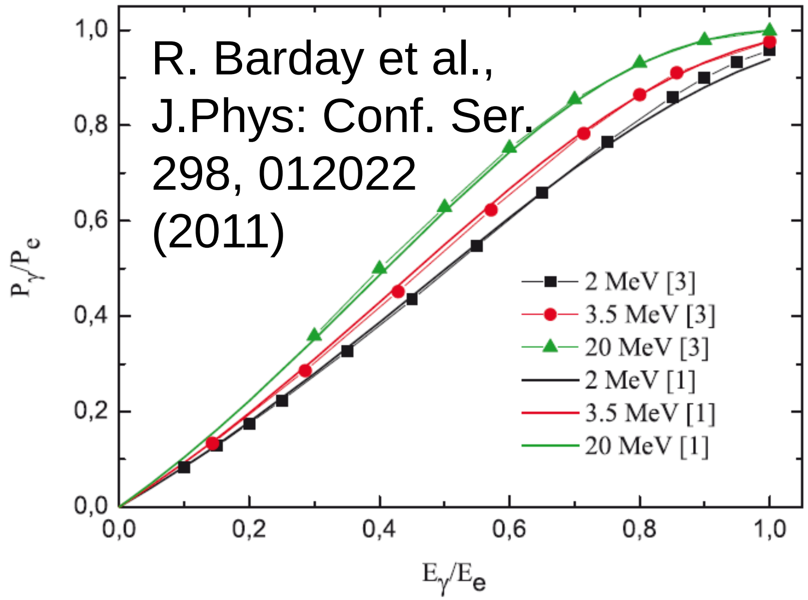
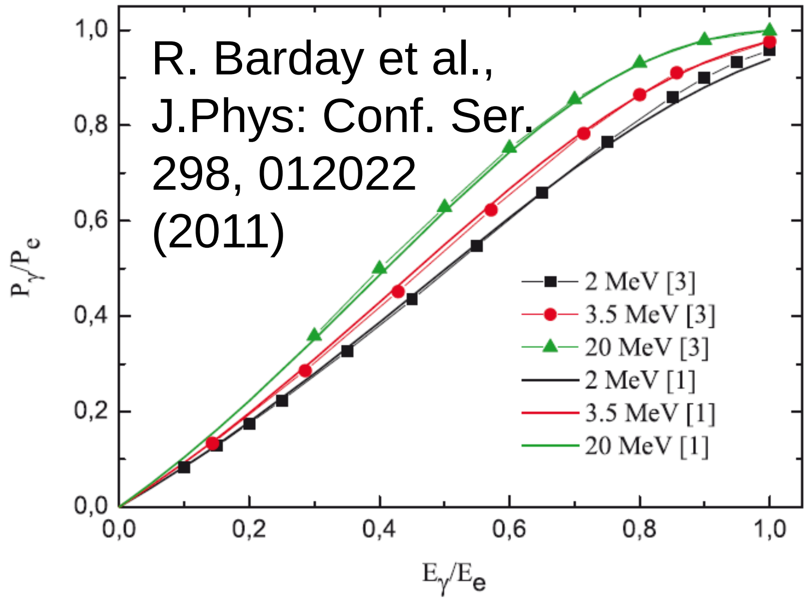
- Energy-dependent **bremsstrahlung circular** polarization of **longitudinally polarized electrons**

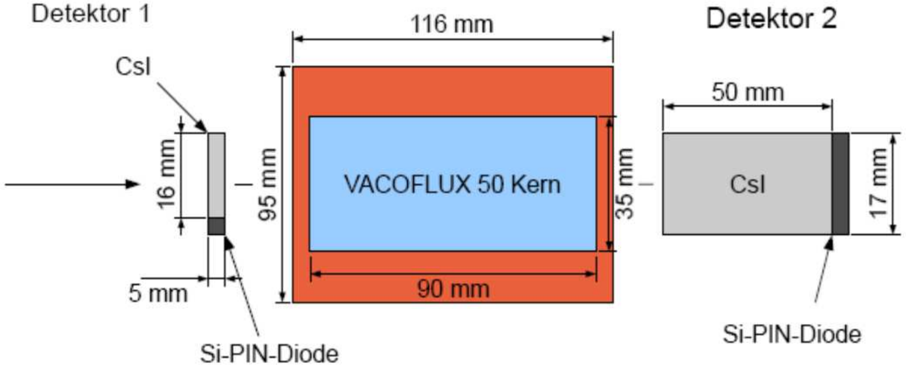


Circular Polarization of Bremsstrahlung from Polarized Electrons

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

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





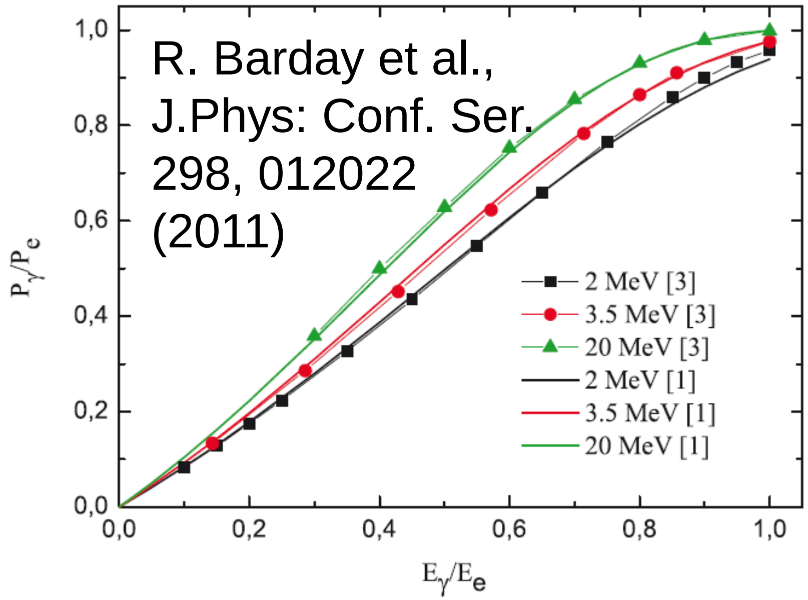
P. Bangert, Bachelor Thesis (2010)

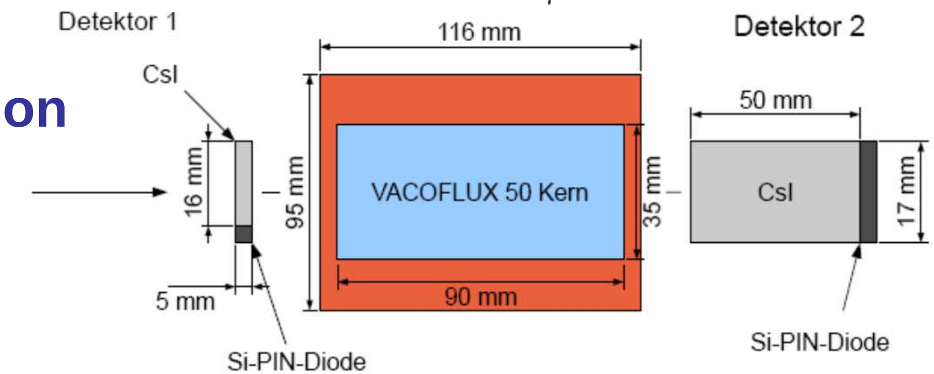
Circular Polarization of Bremsstrahlung from Polarized Electrons

- 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}





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Ideas

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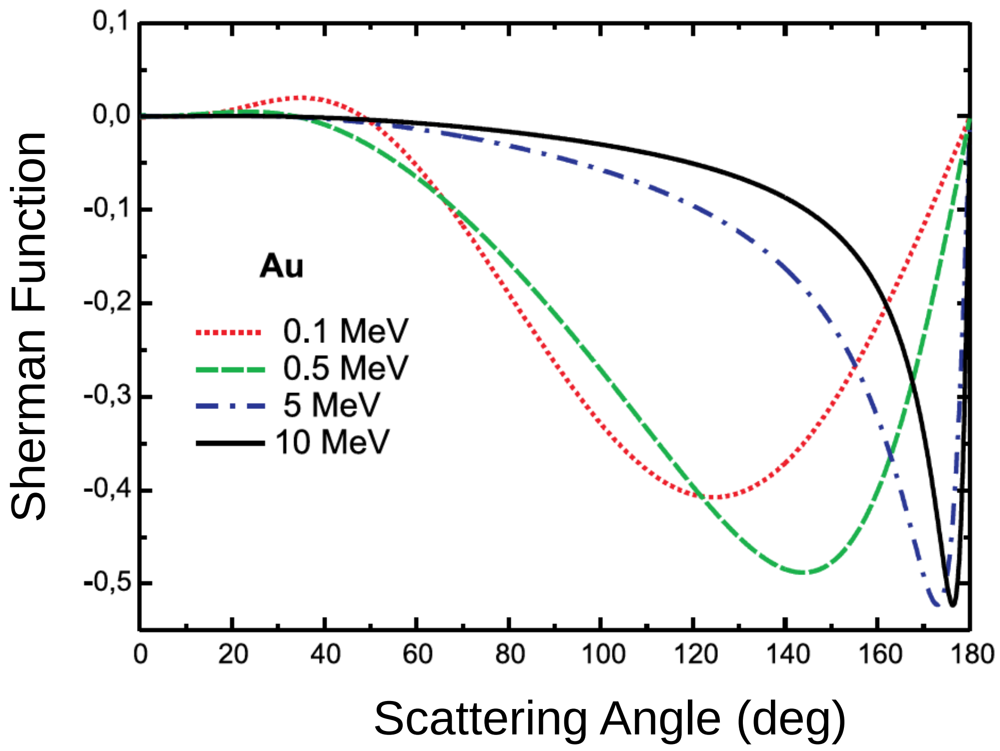
- Bremsstrahlung Polarization Correlations
- MeV Mott Scattering Analyzing Strength
- Fifth Structure Function of Electron Scattering
- Parity Violation in Photofission?

Analyzing Strength of Elastic Electron Scattering: The Sherman Function

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

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



Analyzing Strength of Elastic Electron Scattering: The Sherman Function

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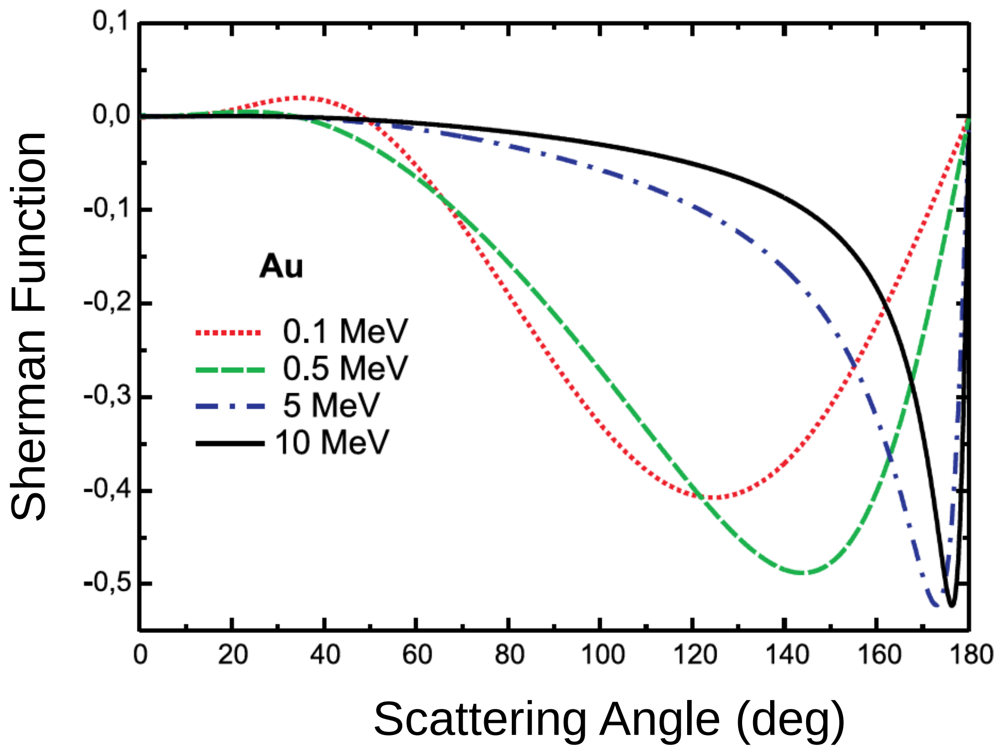

- At energies E > 10 MeV
  - minimum **close to 180°**
  - $S \approx 0$ else
- At energies E > 15 MeV
  - **cross section** mod. by **form factor**: charge & magnetization distribution
  - **Sherman function**: nuclear **charge & magnetization** distribution

Predictions

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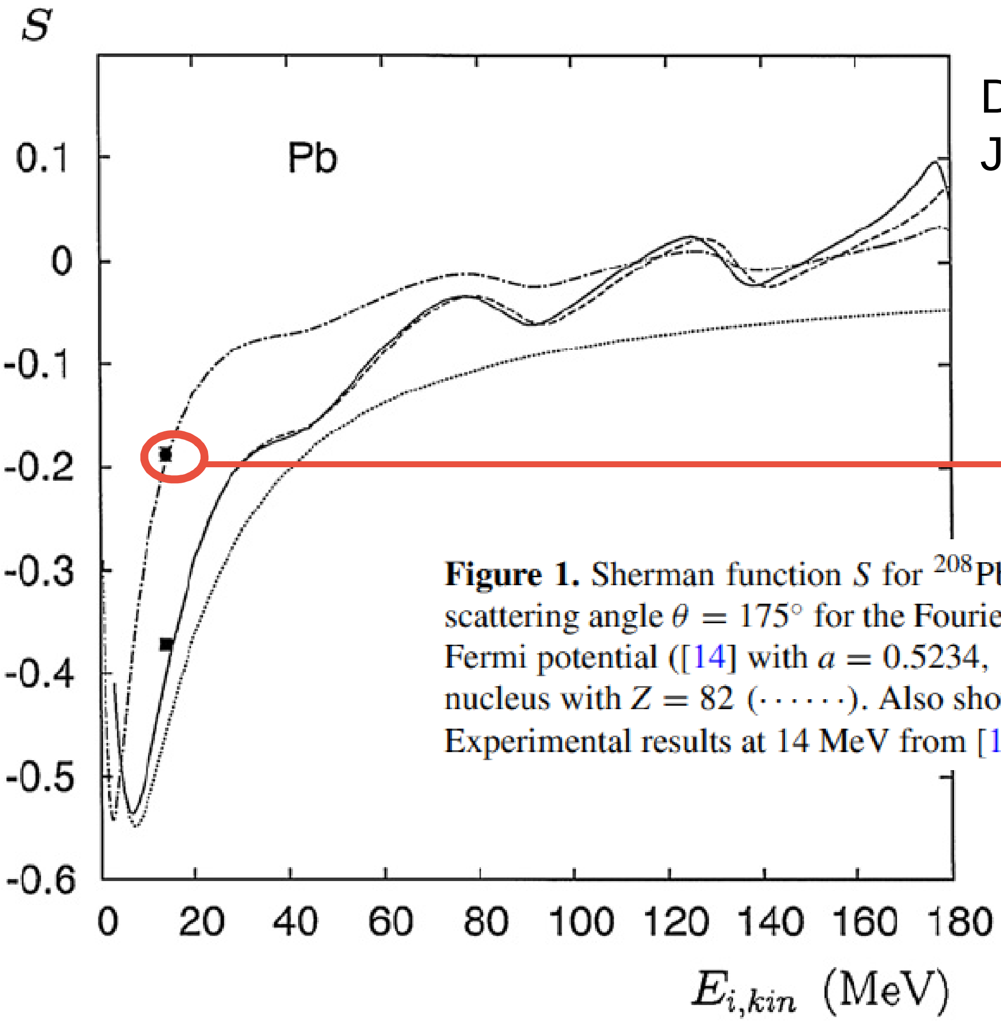


Figure 1. Sherman function S for ^{208}Pb ($Z = 82$) as a function of collision energy $E_{i,\mathrm{kin}}$ at the scattering angle $\theta = 175°$ for the Fourier–Bessel potential ([34] with $N = 13$, see [37], ———), Fermi potential ([14] with $a = 0.5234$, $c_0 = 6.4582$ (in fm), − − − − −), as well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

D. H. Jakubassa-Amundsen, R. Barday, J. Phys. G 39, 025102 (2012)

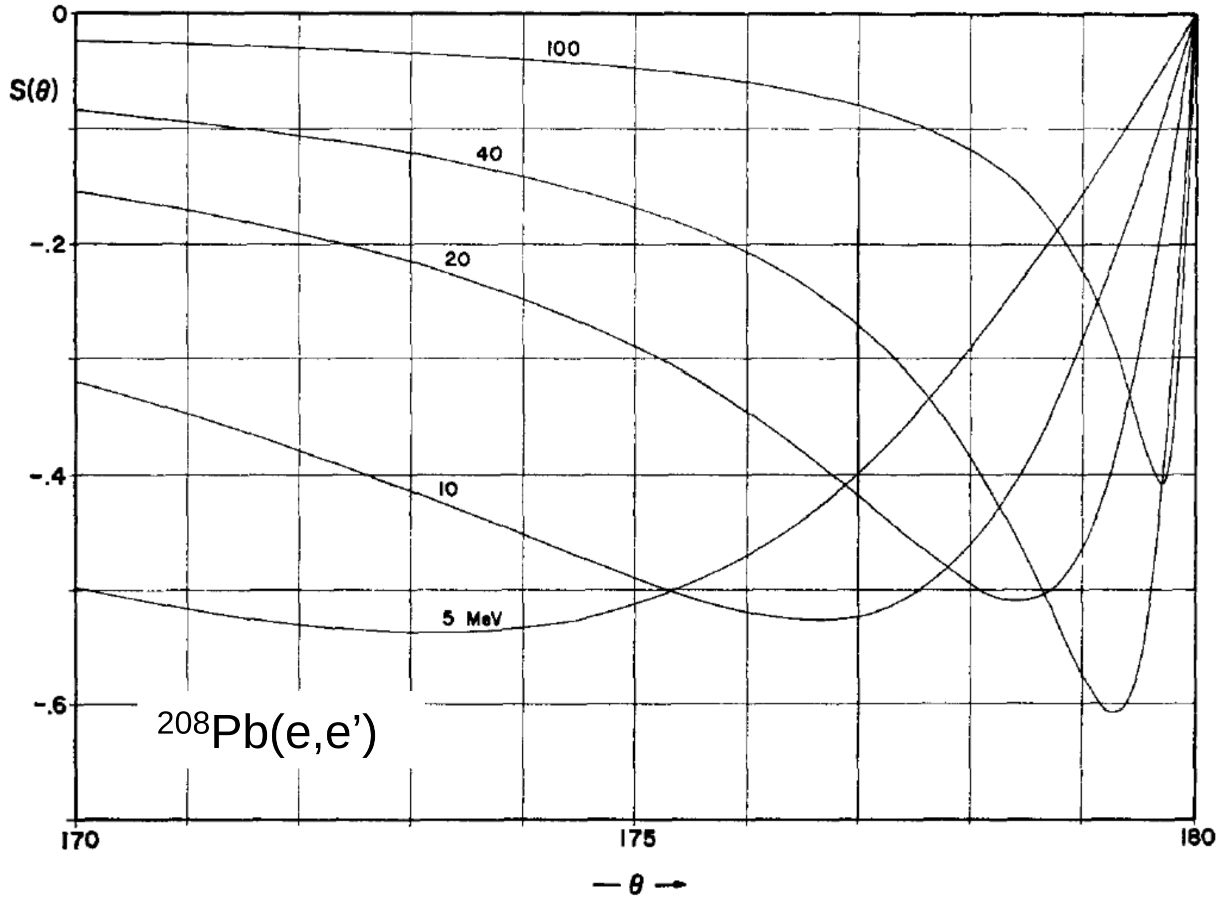
→ (Basically) no data!

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

Predictions

$$\frac{d\sigma}{d\Omega} = \left| f(\vartheta) \right|^2 + \left| g(\vartheta) \right|^2$$

$$S(\vartheta) = i\,\frac{fg^* - f^* g}{\left| f \right|^2 + \left| g \right|^2}$$



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

Predictions

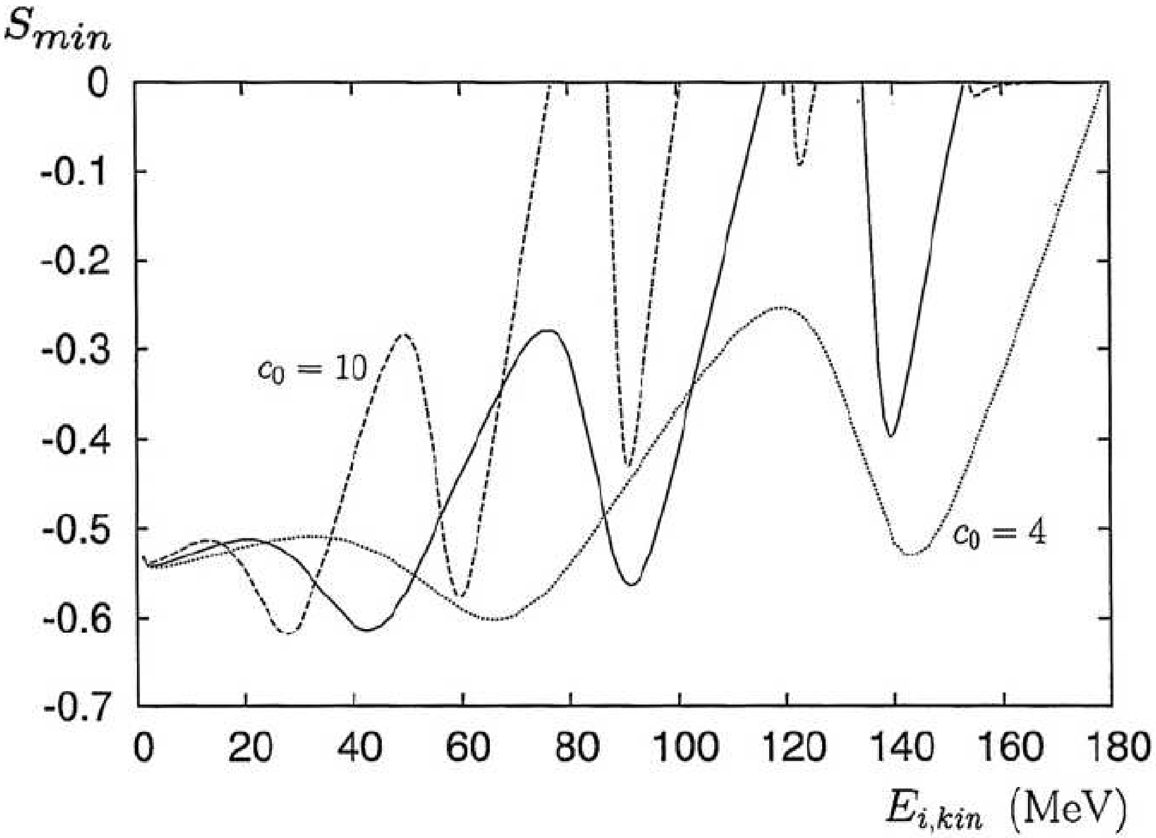


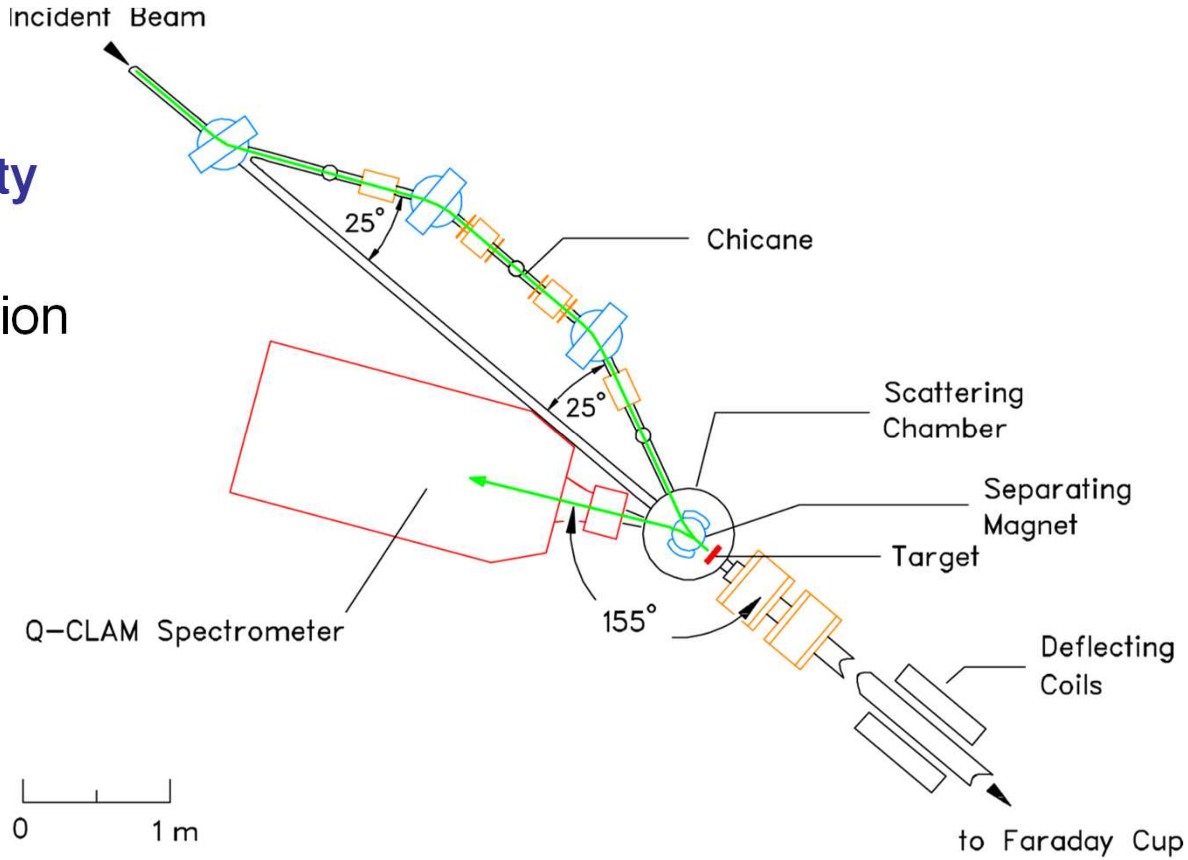
Figure 2. Energy dependence of the backward minimum S_{min} of the Sherman function for $Z = 82$ and a Thomas–Fermi nuclear potential. Parameters $a = 0.5234$ as well as $c_0 = 6.4582$ for ^{208}Pb from [14] (———), $c_0 = 10$ (– – –) and $c_0 = 4$ $(\cdots\cdots)$ (in fm).

- Access to **details of the charge distribution** at low q?
- **But**: Need to measure
  - very close to 180°
  - at energies between 25 and 100 MeV

D. H. Jakubassa-Amundsen and R. Barday, J. Phys. G 39, 025102 (2012)

Electron Scattering at 180°

- **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}Pb

Polarized Elastic Scattering Around 180°

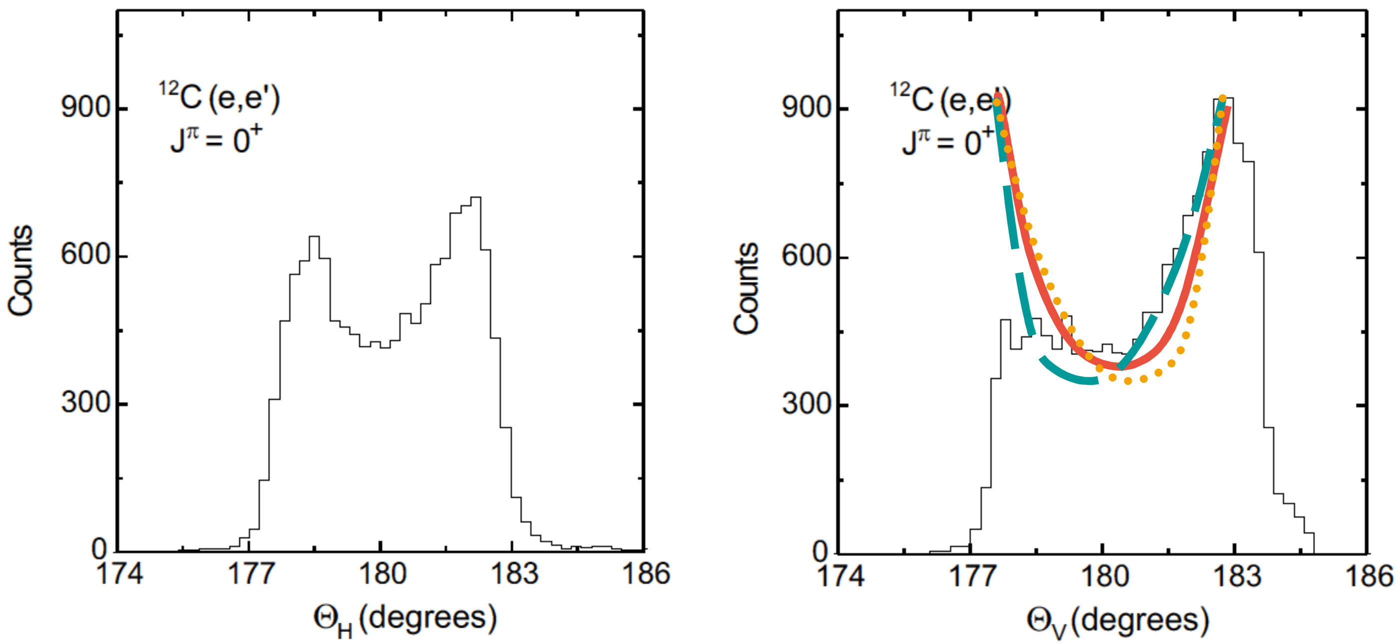


Fig. 11.4: Distribution of the reconstructed horizontal (left) and vertical (right) scattering angles with an excitation energy less than 100 keV for the ^{12}C elastic line in CD_2.

N. Ryezayeva, Dissertation, TU Darmstadt (2006)
C. Lüttge et al., NIMA 366, 325 (1995)

Ideas

- Bremsstrahlung Polarization Correlations
- MeV Mott Scattering Analyzing Strength
- Fifth Structure Function of Electron Scattering
- Parity Violation in Photofission?

Polarized Structure Functions (e,e’x)

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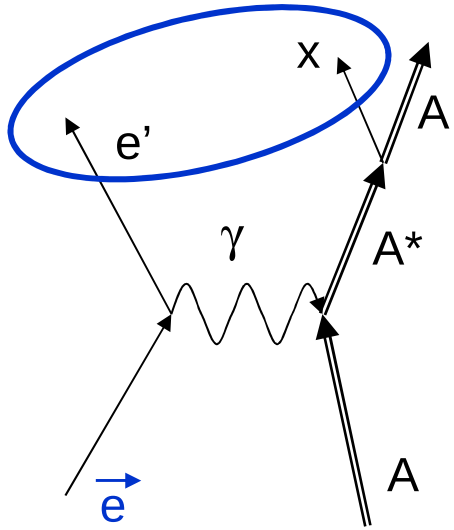
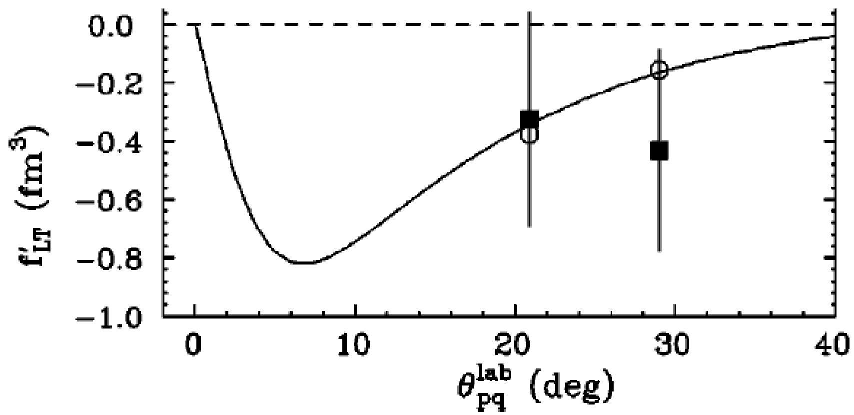
$$\frac{d\sigma}{d\Omega} = \left.\frac{d\sigma}{d\Omega}\right|_{Mott} \left(v_L W_L + v_T W_T + v_{LT} W_{LT} + v_{TT} W_{TT} + \underline{v_{LT'} W_{LT'}} + v_{T'} W_{T'} \right)$$

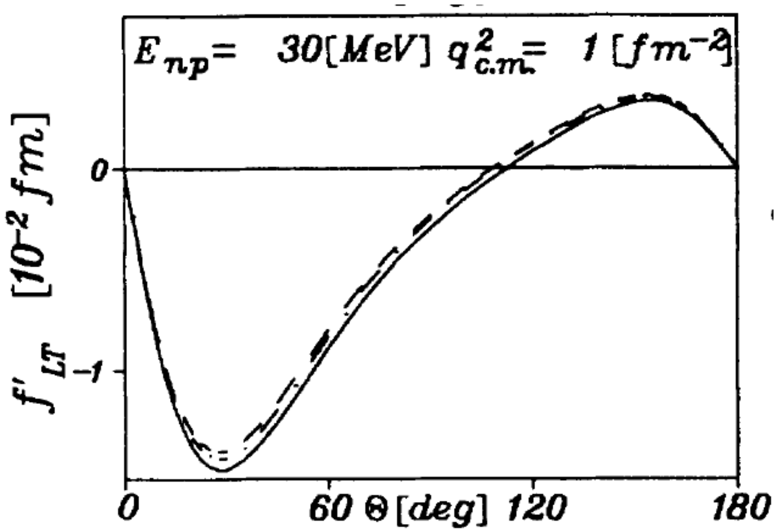
- **Fifth structure function**
  in electron scattering
  depends on beam helicity
- No data at momentum transfers
  below 1.5 fm^{-1}



Polarized Structure Functions of ^{2}H, ^{3}He

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





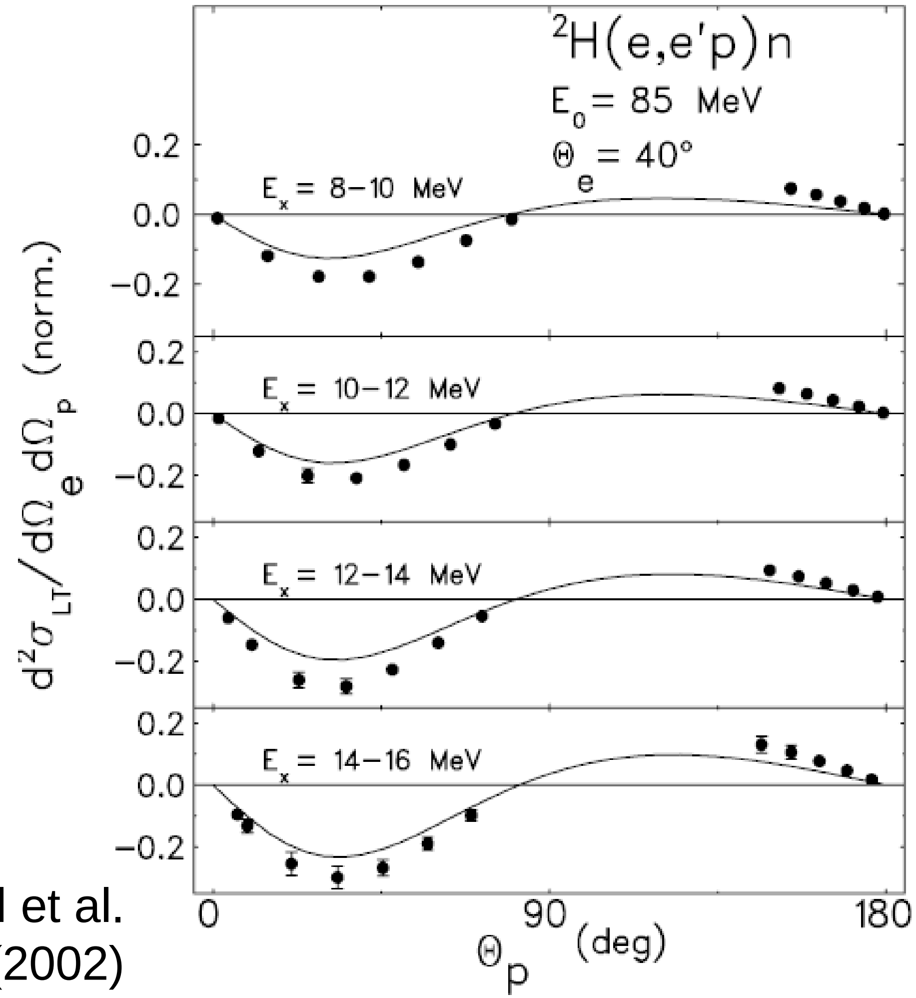
S. M. Dolfini et al.,
PRC 60, 064622 (1999)

H. Arenhövel, W. Leidemann,
E. L. Tomusiak, PRC 46, 455 (1992)

Polarized Structure Functions of ^{2}H, ^{3}He

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

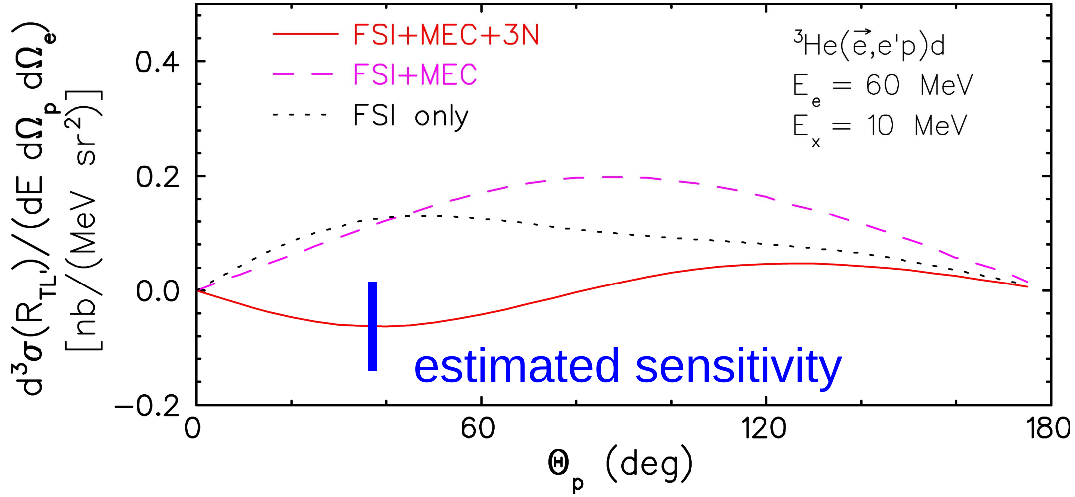
- **^{2}H**: Comparison with earlier **S-DALINAC data**



P. von Neumann-Cosel et al.
PRL 88, 202304 (2002)

Polarized Structure Functions of ^{2}H, ^{3}He

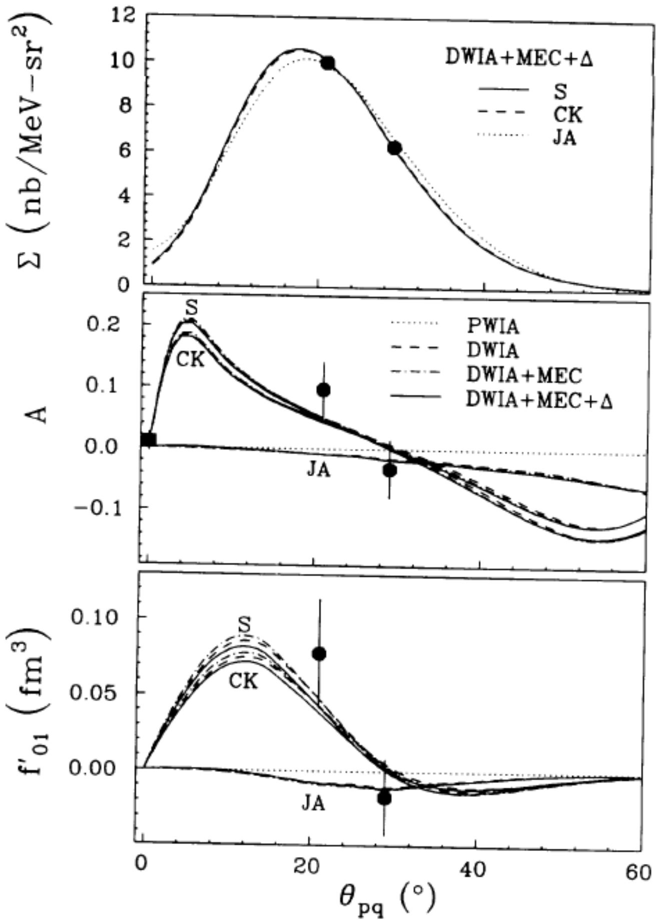
- **^{2}H**: Comparison with **Bates data** and with predictions
- **^{2}H**: Comparison with earlier **S-DALINAC data**
- **^{3}He**: Sensitivity to **3N** force predicted



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 $(CH_2)_n$ target → Bates



J. Mandeville et al., PRL 72, 3325 (1994)

Challenge to **theory**: Most **important** information concerning **LT'**?

Ideas

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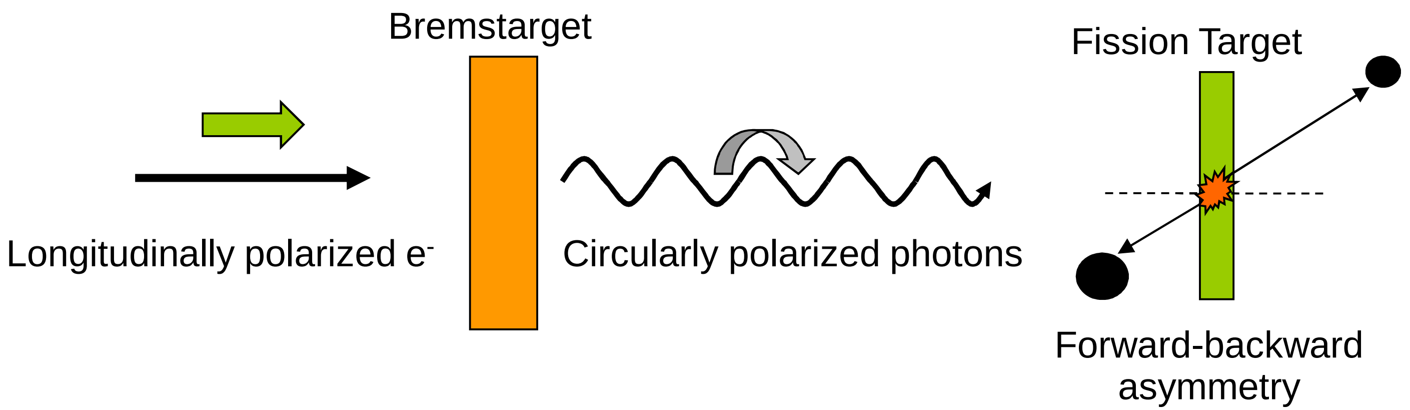
Parity Non-conservation in Photofission

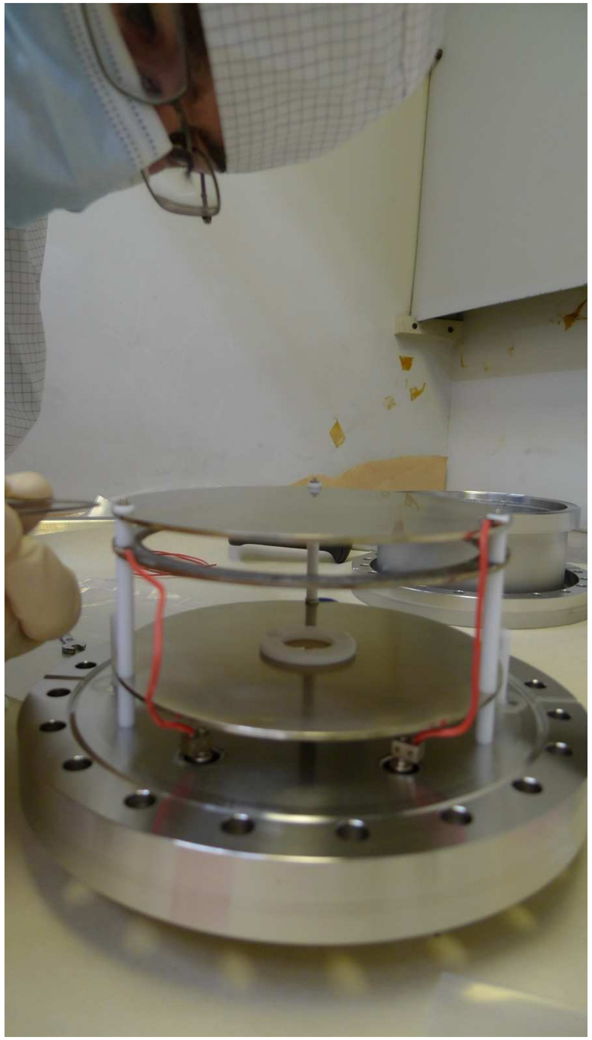
- **Weak interaction** in complex nuclei: expect effect ~ 10^{-8}
- **Neutron-induced fission**: observe 10^{-4}
  - Enhancement effects? Use different probe: photons



- 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_6 gas target**
  - Counting gas properties
  - Active target design
  - Data acquisition and analysis
  - Mass and angular resolution
  - PNC experiment



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- **Active UF_6 gas target**
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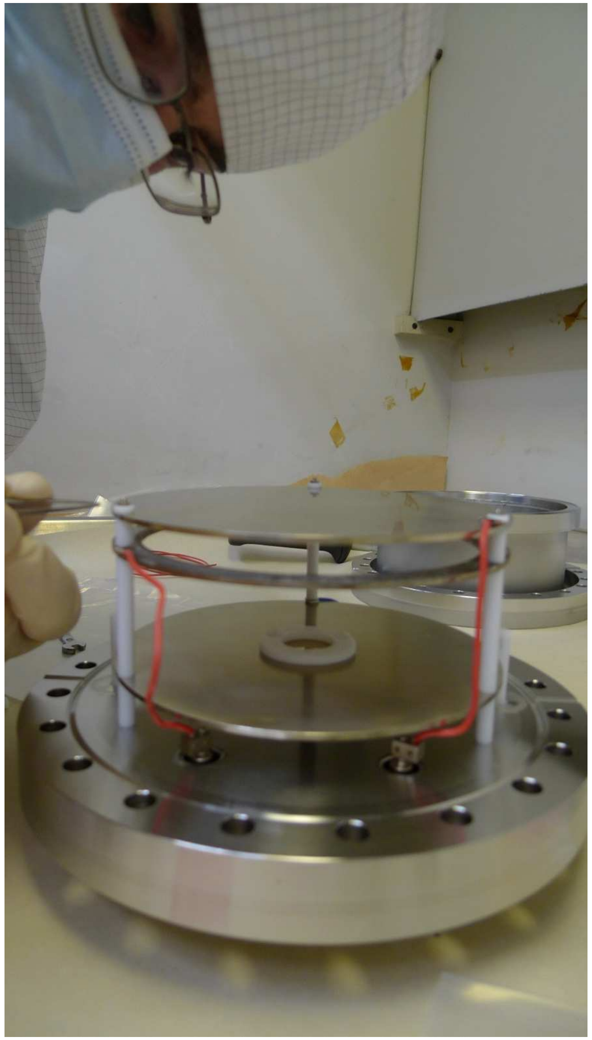
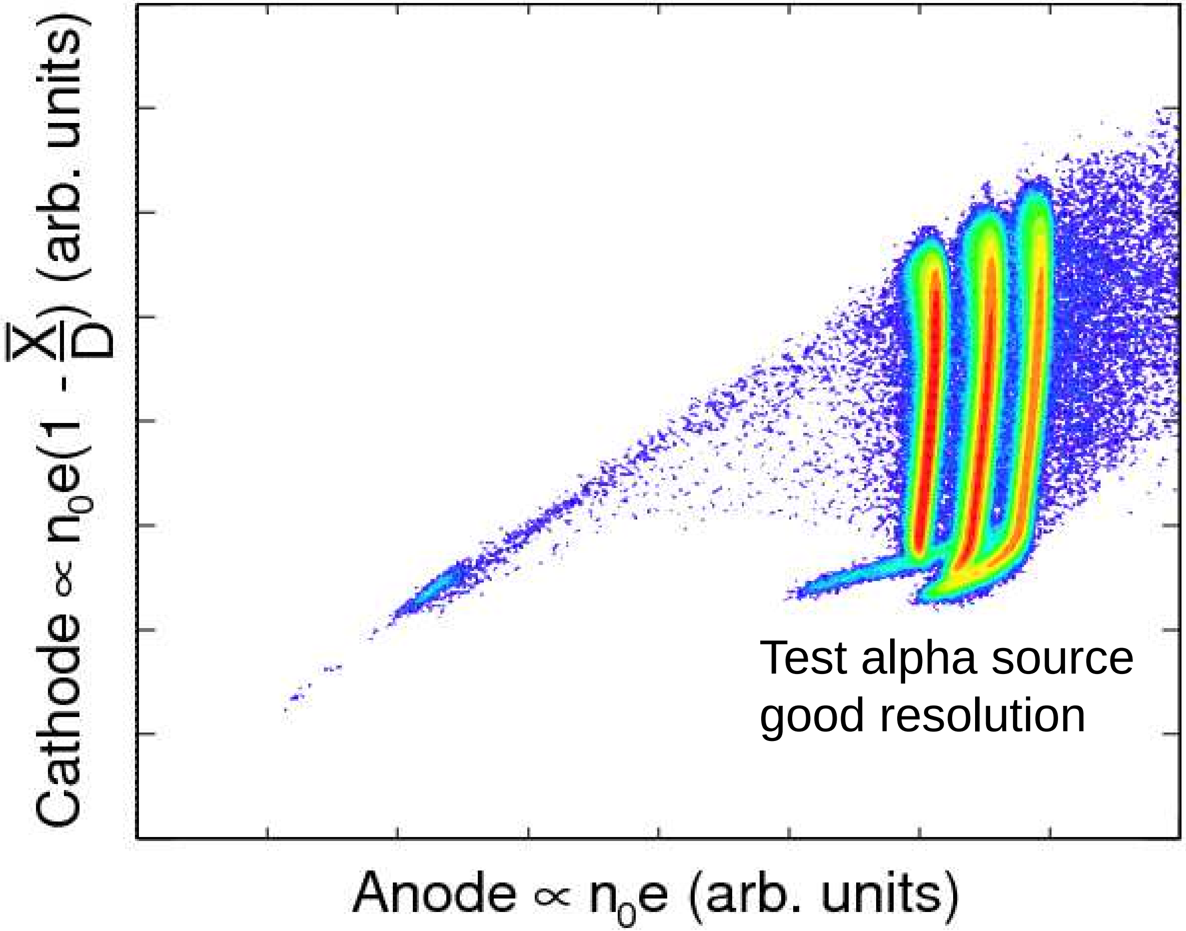
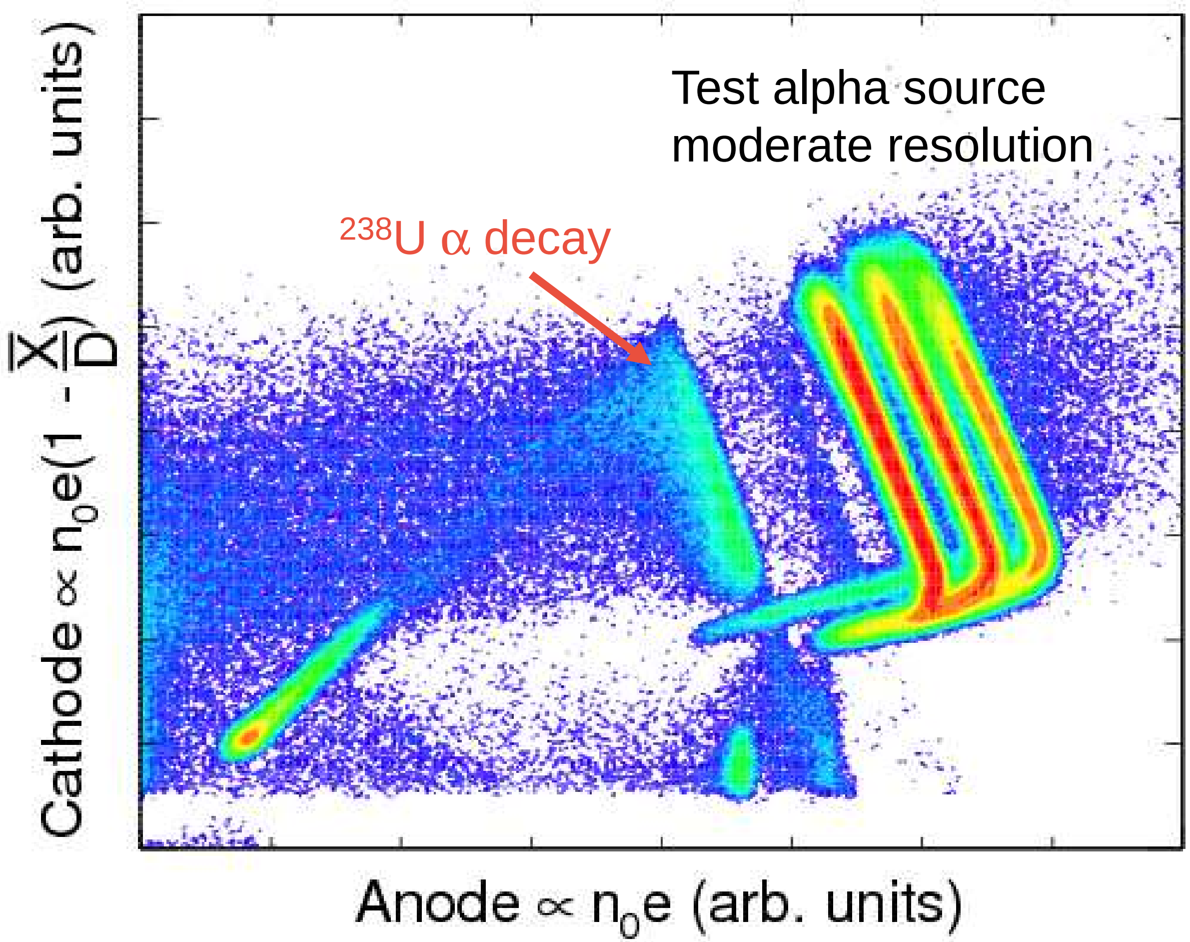
- **UF_6 gas properties**
  - Solid at room temp., sublim. at 56.5°C
  - High vapor pressure: 153 mbar @ 25°C
  - $UF_6 + H_2O \rightarrow HF$
  - 



Argon as a Detector Gas

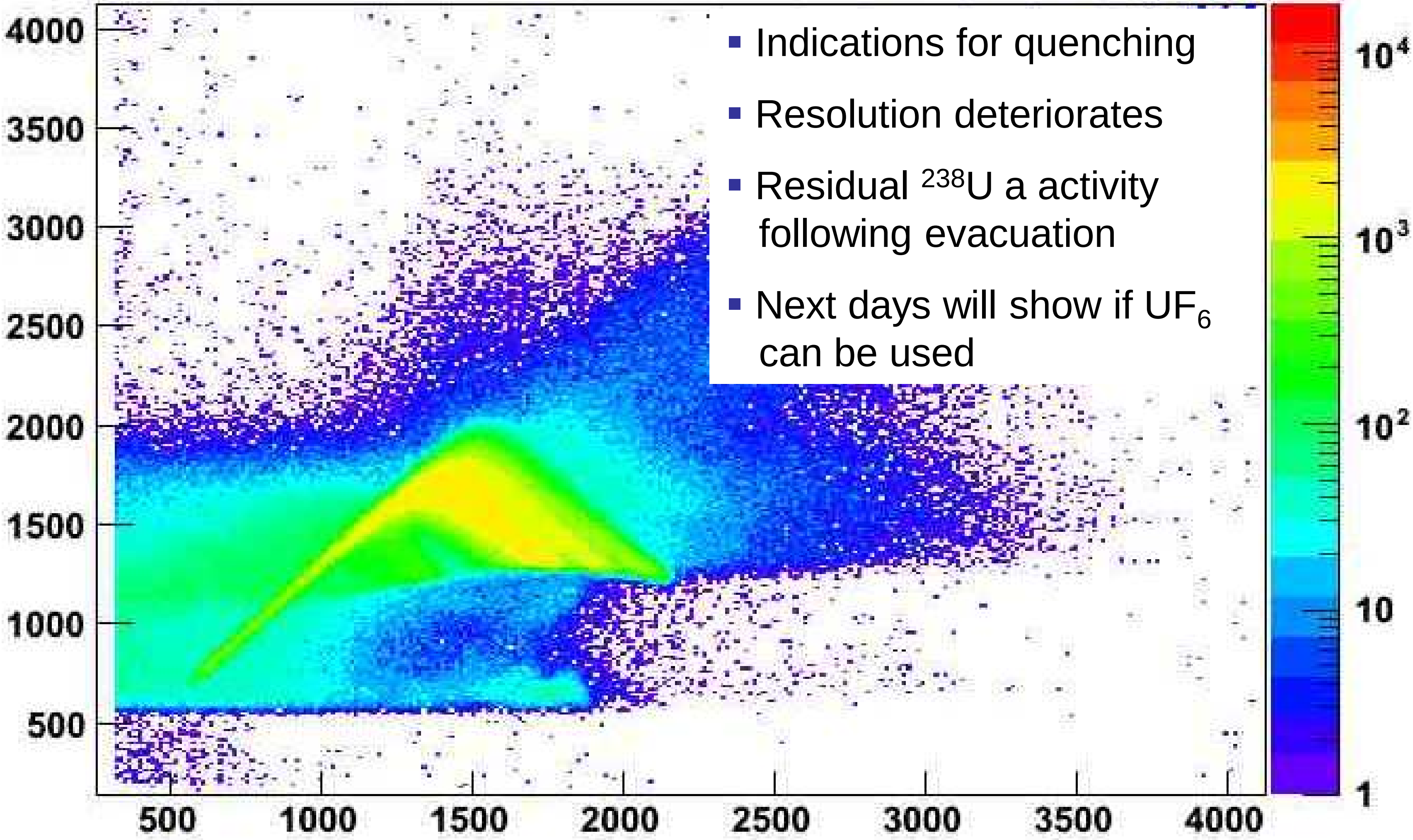


Argon + 2% UF_6 as a Detector Gas



C. Eckardt et al.,
Phys. Procedia 31,141 (2012)

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 ~ μA at 0.1 – 100 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**
  C. Eckardt, M. Espig, Y. Fritzsche, F. Hug, Neeraj K., J. Lindemann,
  M. Wagner – TU Darmstadt
- **Bremsstrahlung Experiments**
  S. Tashenov, A. Surzhykov – U Heidelberg,
  D. H. Jakubaßa-Amundsen – LMU München
  S. Märtin, T. Stöhlker, G. Weber – HI Jena & GSI Darmstadt
  K. Aulenbacher – U Mainz, V. A. Yerokhin – St. Petersburg
- **Analyzing Strength of Mott Scattering**
  D. H. Jakubaßa-Amundsen – LMU München, R. Barday – Helmholtzzentrum Berlin
- **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**
  A. Richter, P. von Neumann-Cosel, C. Eckardt, M. Freudenberger – TU Darmstadt
  S. Oberstedt, A. Göök – EC JRC IRMM Geel
  A. Oberstedt – CEA DAM Bruyeres-le-Châtel

Ideas

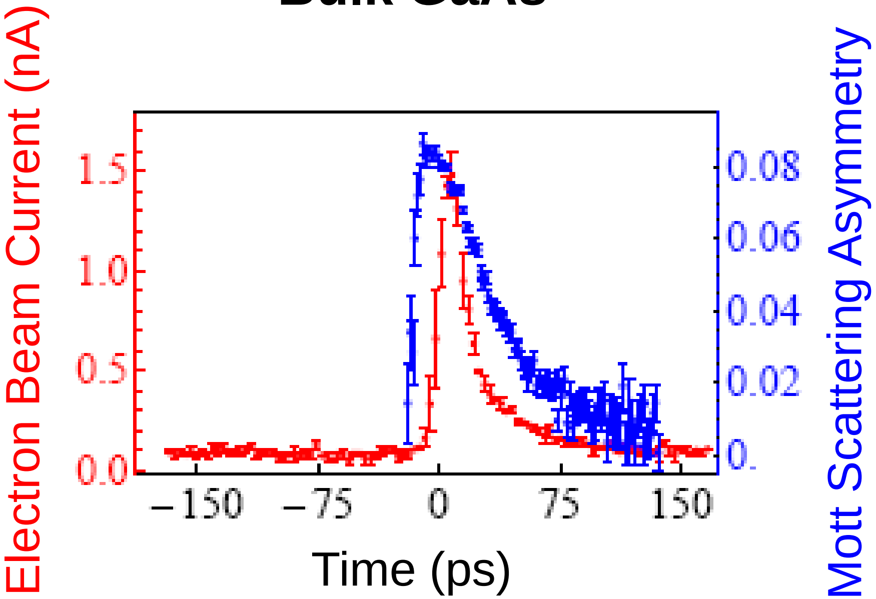
- Bremsstrahlung Polarization Correlations
- MeV Mott Scattering Analyzing Strength
- Fifth Structure Function of Electron Scattering
- Parity Violation in Photofission?
- **The QUEST for Spin Correlations in Møller Scattering:**
  → Jacek Ciborowski

Spare Slides for Discussion

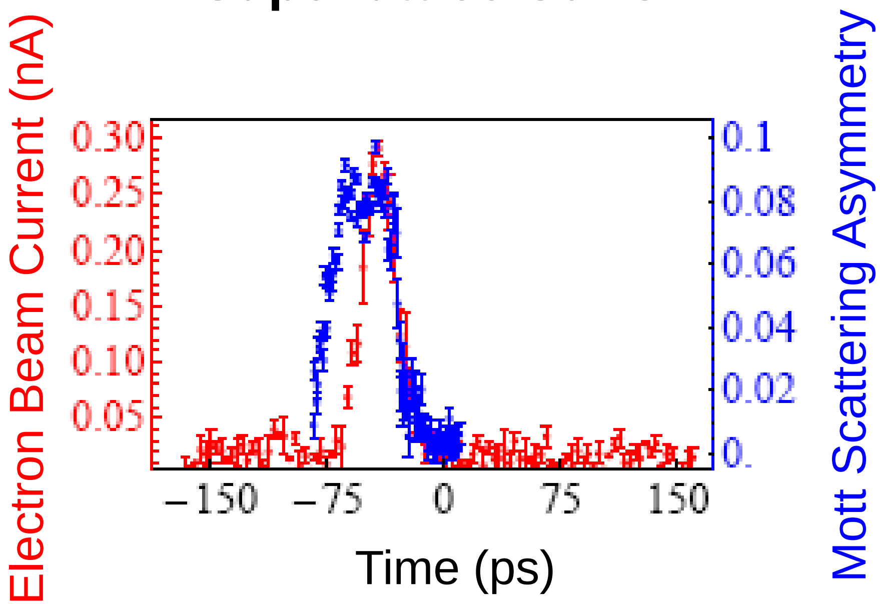
PEB Workshop @ MIT
March 2013

Bulk vs. Strained Superlattice

Bulk GaAs



Superlattice GaAs



M. Wagner, Dissertation in preparation

Future Teststand / Atomic Hydrogen Cleaning

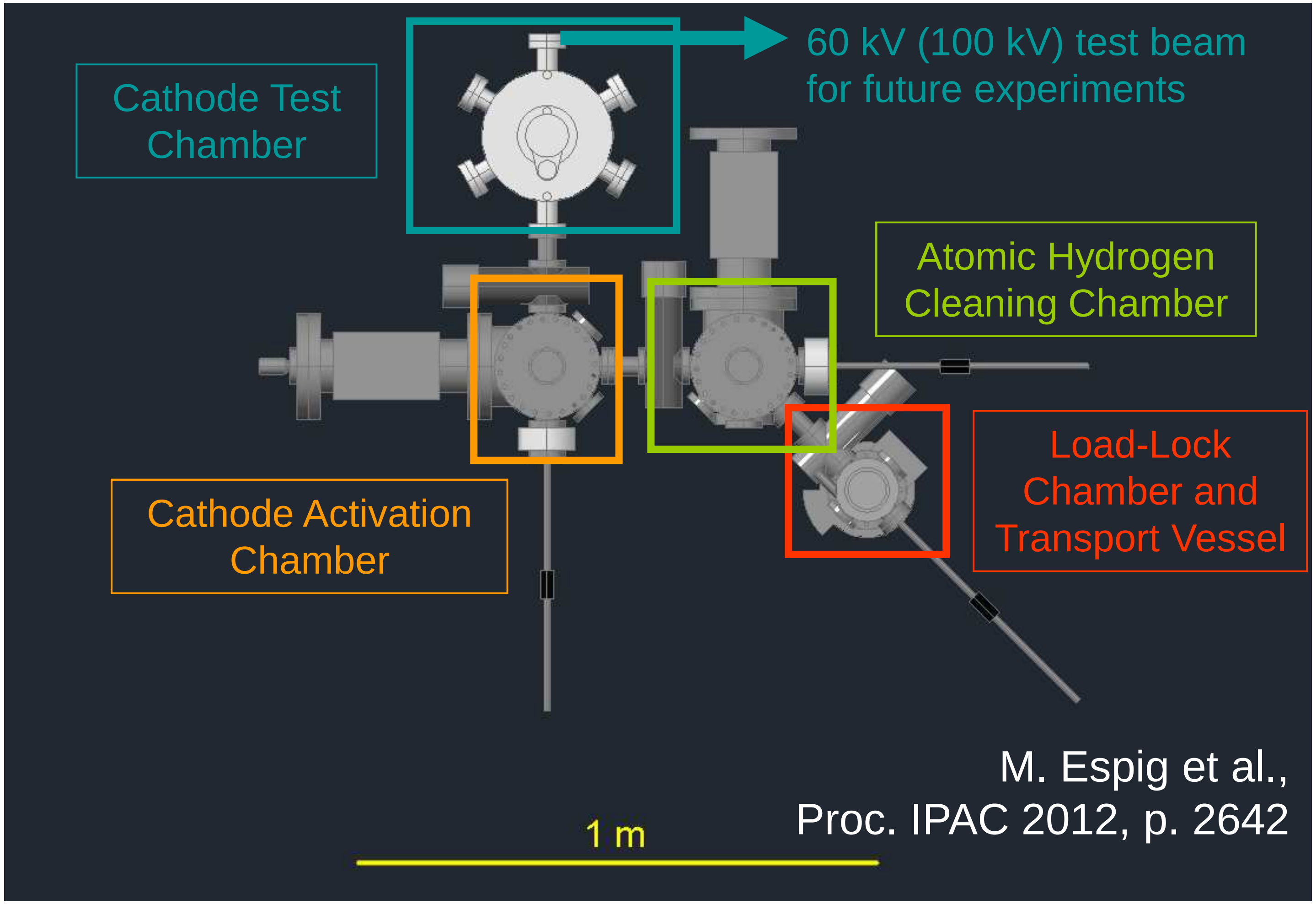
- **Quantum efficiency decrease**
  - deterioration of CsO NEA layer
  - C, AsO_x, Ga_2O_3 reduce quantum efficiency

- Atomic hydrogen cleaning

$$As_2O_3 + 6\,H\cdot \rightarrow 3\,H_2O\uparrow + \frac{1}{2}As_4\uparrow$$

$$Ga_2O_3 + 4\,H\cdot \rightarrow 2\,H_2O\uparrow + Ga_2O\uparrow$$

Cleaning & Preparation Test System



Magnetic Scattering?

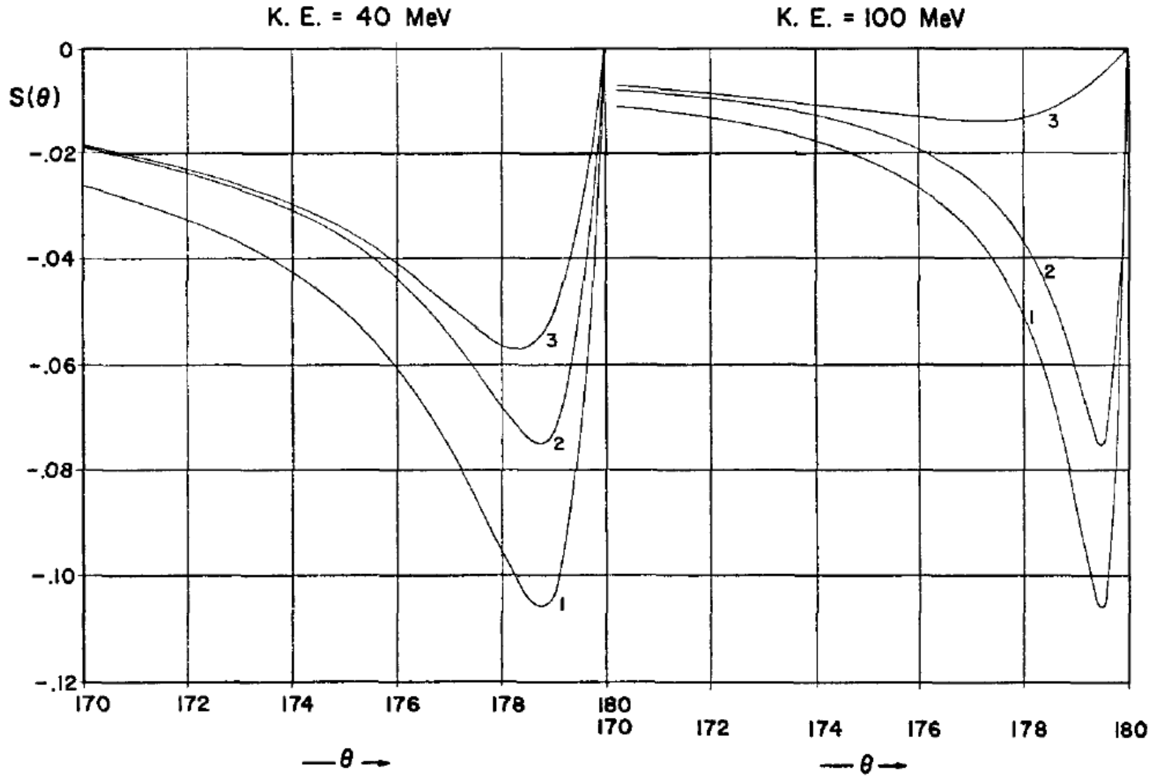
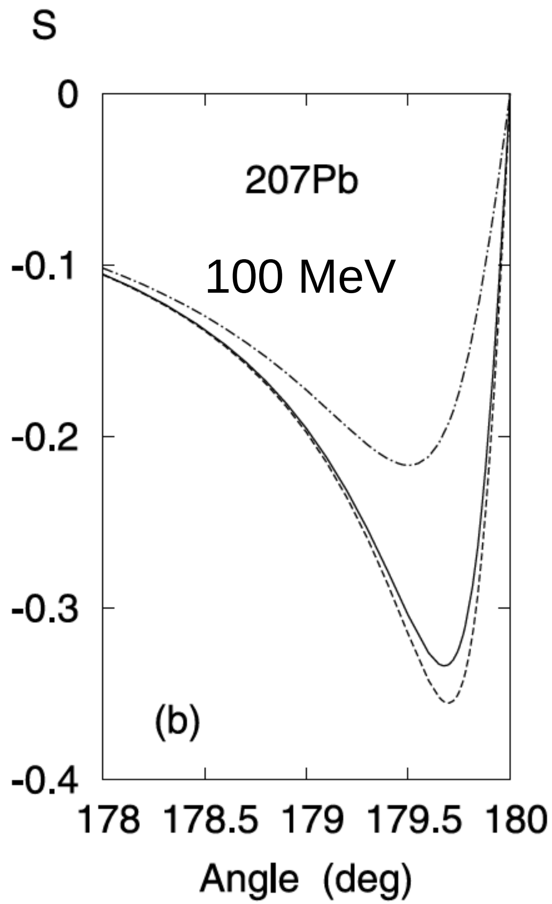


Fig. 13. $S(\theta)$ for point nucleus of ^{51}V, at $E = 40$ and 100 MeV. Curve 1: Coulomb scattering only (phase-shift results); curve 2: Born approximation ($\mu = 0$); curve 3: Born approximation ($\mu = 5.1478$).



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

D. H. Jakubassa-Amundsen, NPA 896, 59 (2012)