Low-Energy Photonuclear Reactions—A Review

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Monoenergetic Photon Beams

- Positron Annihilation in Flight
  - Livermore, Saclay

- Tagged Photons
  - Illinois, Saskatchewan, MAX-lab at Lund
    - [High-Energy: MAMI, Jefferson Lab]

- Compton Back-Scattering
  - LEGS at BNL, HlỳS at TUNL
    - [High-Energy: GRAAL, SPRing-8]
Polarized Photon Beams

• Positron Annihilation in Flight
  – Unpolarized

• Tagged Photons
  – Polarized at High-Energy Facilities Only

• Compton Back-Scattering
  – Polarized
MAX-lab accelerator system

Parallel operation of the three rings
Nuclear Physics: ~45% of beam-time at MAX1

Thanks to Kevin Fissum
Research program

Present experimental programme

- Compton scattering
- Pion photoproduction
- Photoreactions on He isotopes
- Total photoabsorption cross-section of $^6$Li
- Detector tests (PANDA electromagnetic calorimeter)
- Commissioning of linearly polarized photons

Participating institutes

1. Duke University, USA
2. University of Edinburgh, U.K.
3. University of Frankfurt, Germany
4. George Washington University, USA
5. University of Glasgow, U.K.
6. University of Illinois at Urbana-Champaign, USA
7. University of Kentucky, USA
8. Kharkov Institute of Physics and Technology, Ukraine
9. University of Lund, Sweden
10. University Complutense Madrid, Spain
11. University of Mainz, Germany
12. University of Manchester, UK
13. Massachusetts Institute of Technology, USA
14. University of Massachusetts Dartmouth, USA
15. University of Melbourne, Australia
16. MAX-IAB, Sweden
17. Mount Allison University, Canada
18. University of New Hampshire, USA
19. Ohio University, USA
20. Pakistan Institute of Engineering and Science, Pakistan
21. Petersburg Nuclear Physics Institute, Russia Federation
22. Rhodes University, South Africa
23. Russian Academy of Sciences, Russia Federation
24. University of Saskatchewan, Canada
25. Stockholm University, Sweden
26. Sabanci University, Turkey
27. University of Regensburg, Germany
28. University of Trento, Italy
29. University of Tübingen, Germany
30. Uppsala University, Sweden
31. Yerevan Physics Institute, Armenia
32. Weizmann Institute of Science, Israel
O’Rielly et al. (SAL, 2004)
$^3\text{He}(\gamma,d)$ – see arXiv:0903.2943
Elastic Compton Scattering on D

- **Motivation**
  - \textit{sum} of proton and neutron polarizabilities
  - \( \sigma_D(\omega) \approx r_0^2 - 2 r_0 (\alpha_p + \alpha_n) \omega^2 \)

- **Requirements**
  - must separate \textit{elastic} from \textit{breakup}!
    - \checkmark\ monoenergetic (tagged) photons
    - \checkmark\ high-resolution photon detector (\( \Delta E/E < 2\% \) at 100 MeV)

- **Data**
  - Lucas – Illinois (1994) \( E_\gamma = 49, 69 \) MeV
  - Hornidge – SAL (2000) \( E_\gamma = 85-105 \) MeV
  - Lundin – Lund (2003) \( E_\gamma = 55, 66 \) MeV

- **Theory**
  - diagrammatic approach (Levchuk/L’vov)
  - EFT (Hildebrandt, Grieshammer, Hemmert, Phillips, …)
Experiment at Lund

- **energies:** \( E_\gamma = 60-115 \text{ MeV using tagged photons} \)
  - two tagger settings: 115-95 and 97-60 MeV
  - bin data in 5 MeV energy bins (with 5% statistics)

- **angles:** \( \theta_\gamma = 60^\circ, 120^\circ, 150^\circ \)
  - with 3 NaI detectors simultaneously

- **detectors:** 3 large-volume (50 cm × 50 cm) NaI’s
  - excellent photon energy resolution (\( \Delta E_\gamma / E_\gamma \sim 2\% \))
World Data Set

- **Lucas – Illinois (1994)**
  \[ E_\gamma = 49, 69 \text{ MeV} \]

  \[ E_\gamma = 85-105 \text{ MeV} \]

- **Lundin – Lund (2003)**
  \[ E_\gamma = 55, 66 \text{ MeV} \]

Thanks to Jerry Feldman
• Upgraded HIγS Facility

• RF System with HOM Damping

• 1.2-GeV Booster Injector

Thanks to Henry Weller

Berman--AccApp--May 5, 2009
HI$_\gamma$S

• *Nearly Mono-energetic $\gamma$-rays from 2 to 160 MeV*
  —Tunable Energies
  —Energy resolution selected by collimator size

• *Linearly and Circularly Polarized $\gamma$-rays*

• *High Beam Intensities*

• *Pulsed Beam*
  —TOF Techniques to reduce non-beam related backgrounds
Two Bunch Mode
Experimental Setup

BC-501A Liquid scintillators

γ-ray beam direction into the screen

1 meter flightpath

Target at \( \theta = 45^\circ, \phi = 45^\circ \) to make the out-going path material length similar for all \( \theta = 90^\circ \) detectors

Using 1” collimator
Approximate flux: \( 1 \times 10^7 \) γ/s

Thanks to Sean Stave
$^{238}\text{U, 15.5 MeV Circ. pol.}$

Preliminary
Preliminary
$^{238}\text{U}$, 15.5 MeV
Lin. pol.

Preliminary
Ratio: $^{238}$U, 15.5 MeV, Lin. pol.

Preliminary
Preliminary
Elemental Identification

Preliminary

![Graph showing elemental identification data](image-url)
**Summary and Prospects for the Future**

- Although the main efforts in photonuclear physics have shifted to higher energies (notably at Jefferson Lab) in the past 25 years, the new facilities at MAX-lab and H1γS are now beginning to produce significant low-energy photonuclear data.

- At both MAX-lab and H1γS, important experiments on few-body nuclei have been done or are under way.

- At MAX-lab, the Compton-scattering experiments that are underway promise to help us to understand and quantify the hitherto elusive nucleon polarizabilities.

- At H1γS, Compton-scattering experiments with polarized photons will enable us to quantify their spin polarizabilities as well.

- At H1γS, new data on photoneutron spectra from heavy nuclei enable one to distinguish fissionable nuclei from others.

- Most exciting, the fact that we now have polarized monoenergetic photon beams with intensities comparable to or greater than the unpolarized beams of the past means that virtually the entire field of low-energy photonuclear reactions can be re-done, with the expectation of uncovering a wholly new generation of both basic and applied physics results.
–To be continued…