

Recent results and future plans at MAX-lab

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KFOTO Group



LUNDS
UNIVERSITET

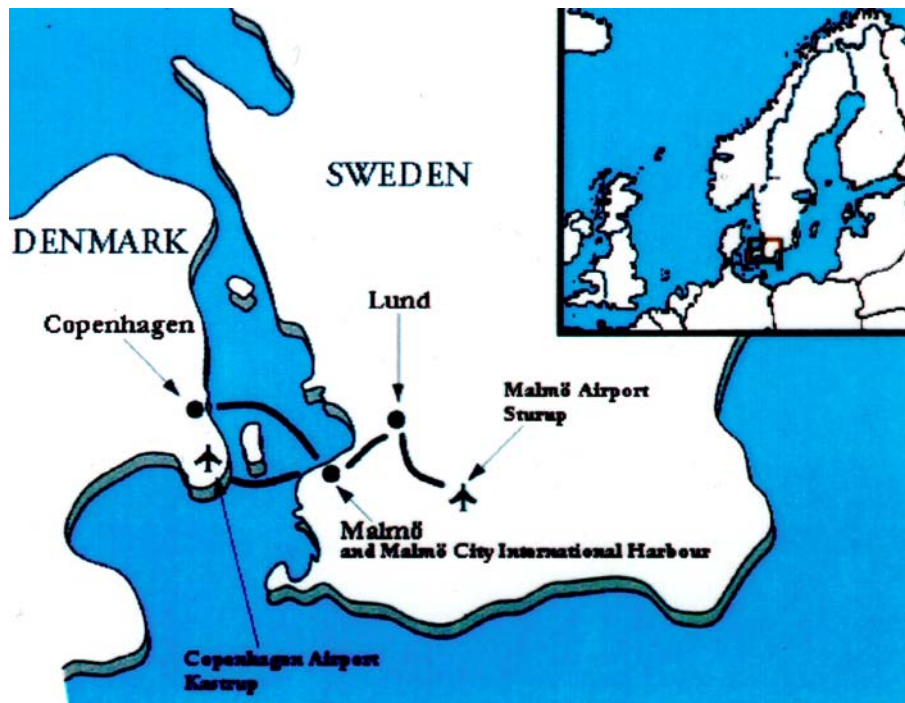


Chiral Dynamics 2006 • Durham/Chapel Hill, USA • 2006-09-21

Presentation Outline

- background – the Tagged-Photon Facility at MAX-lab
- selected recent results – ${}^4\text{He}(\gamma, n)$ from $23 < E_\gamma < 70$ MeV
- future plans – ${}^2\text{H}(\gamma, \gamma)$ from $40 < E_\gamma < 110$ MeV

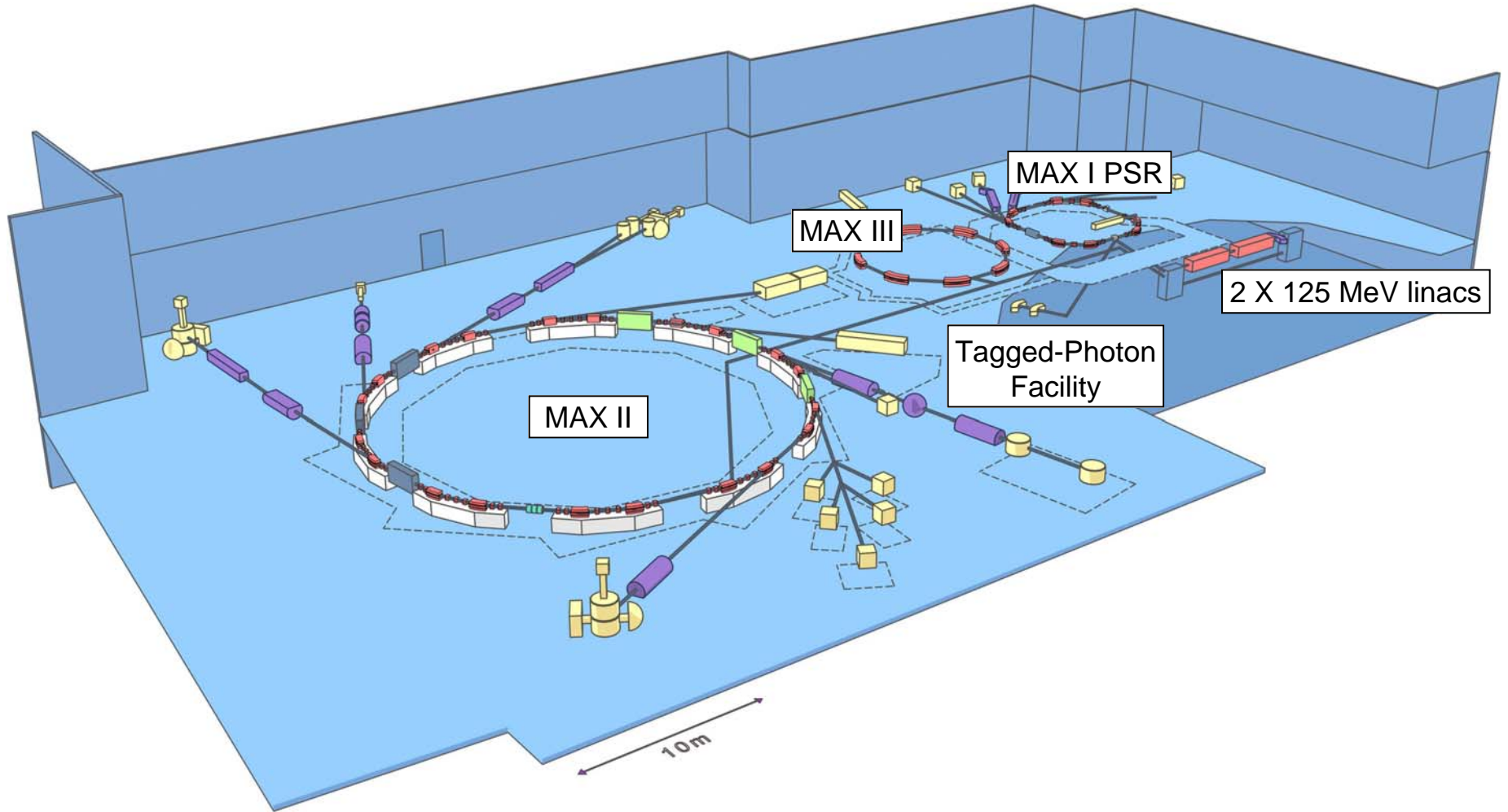
Locating MAX-lab



Swedish National Electron
Accelerator Laboratory

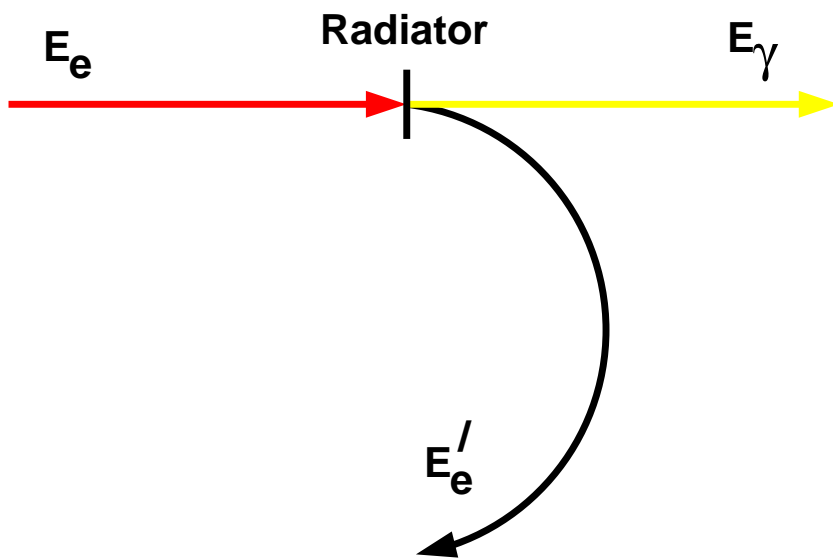
- Synchrotron Radiation Physics
- Photonuclear Physics
(40% @ MAXI PSR)
- Accelerator Physics

MAX-lab Layout

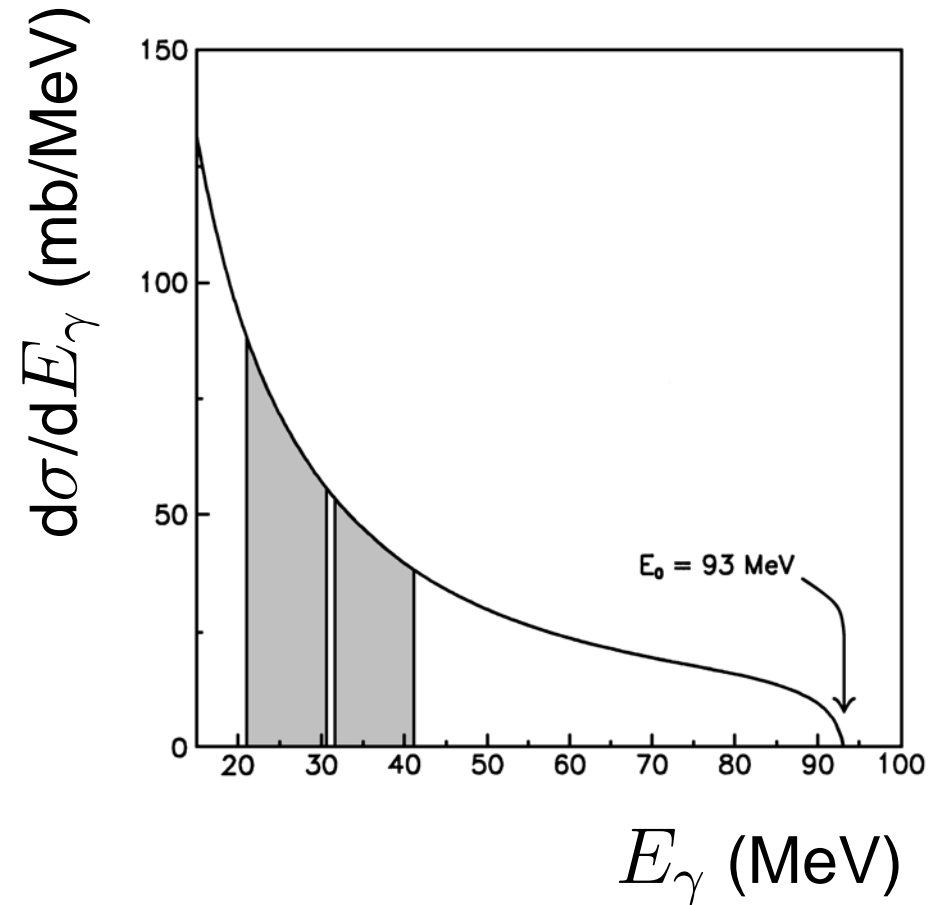


Recent results and future plans at MAX-lab

Photon Tagging



$$E_\gamma = E_e - E'_e$$



${}^4\text{He}(\gamma, n)$ from $23 < E_\gamma < 70$ MeV

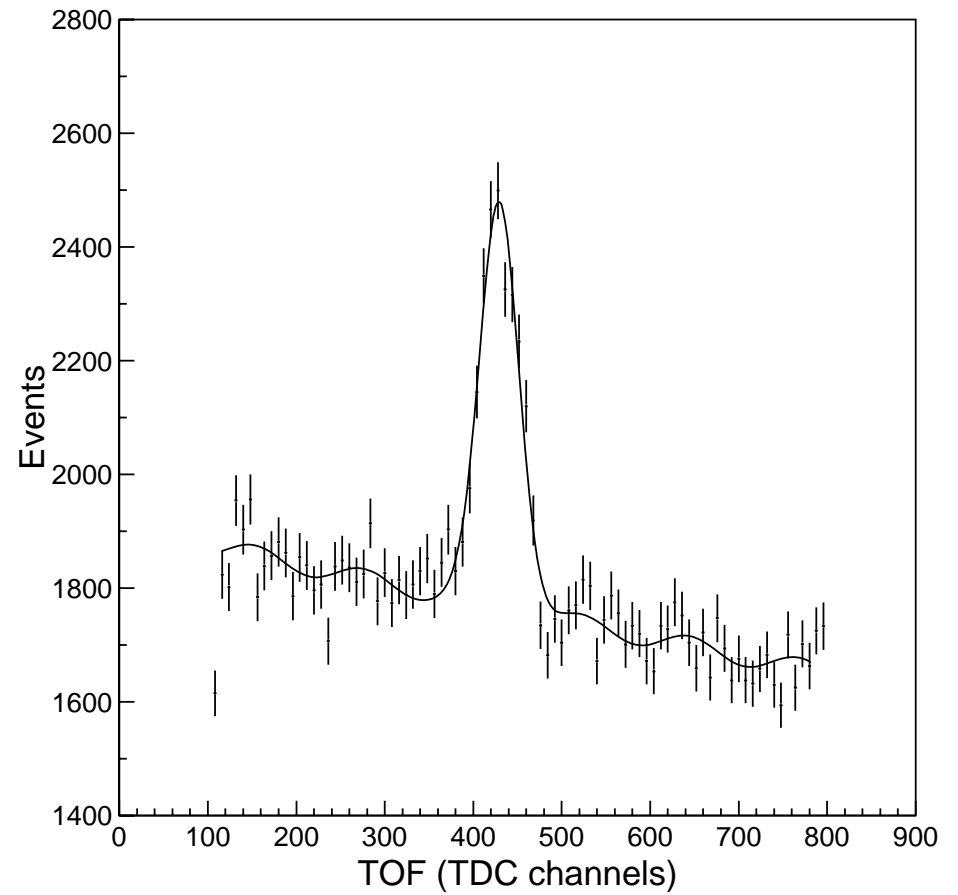
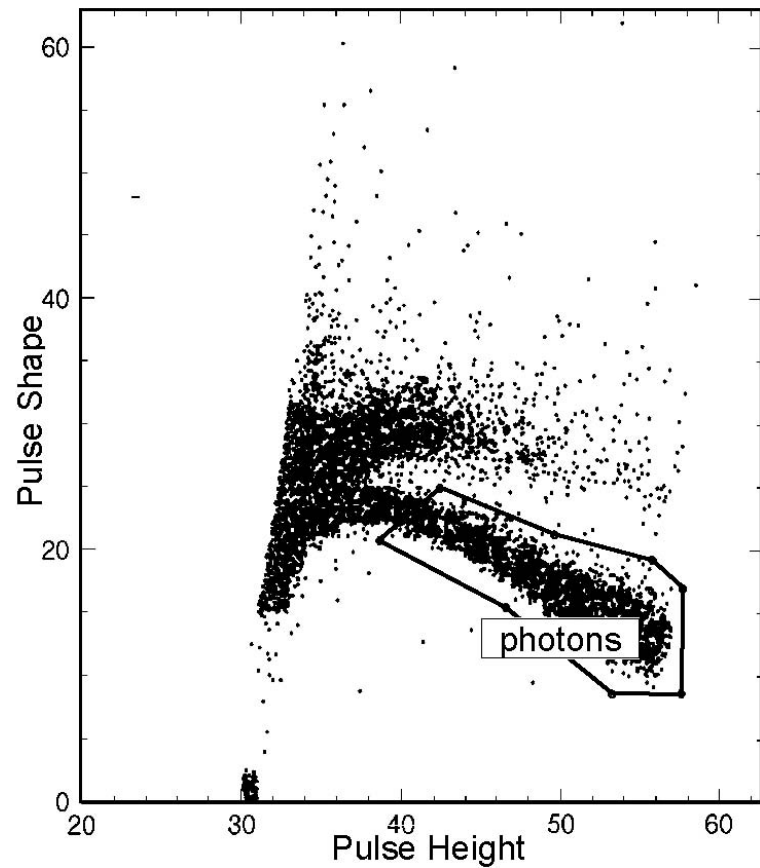
- used tagged photons to knock out neutrons from ${}^4\text{He}$ over a definitive range of angles and energies
- neutron ID was performed via n/γ pulse-shape discrimination and time-of-flight
- first-ever cross-section data differential in angle

B. Nilsson, Ph.D. Lund (2003) – <http://maxlab.lu.se/kfoto/publications/nilsson.pdf>

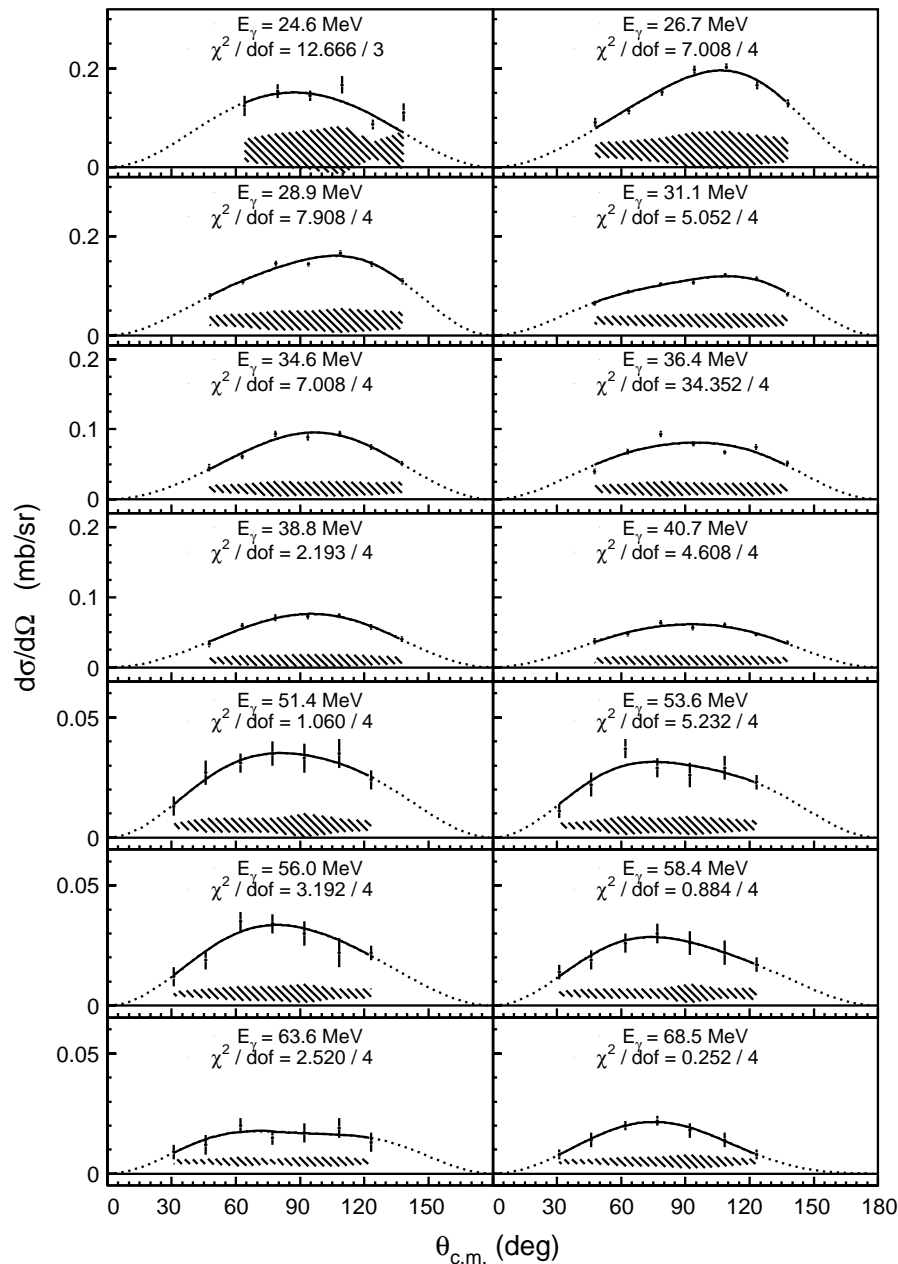
B. Nilsson *et al.*, Phys. Lett. **B626**, 65 (2005)

B. Nilsson *et al.*, Phys. Rev. C (submitted), see nucl-ex/0603030

(see also M. Karlsson, Ph.D. Lund (2005) – <http://maxlab.lu.se/kfoto/publications/karlsson.pdf>)



- this was not an easy measurement!
- kinematic-dependent corrections
 - neutron-detection efficiency
 - neutron-inscattering
 - neutron-yield attenuation
 - tagger focal-plane livetime
 - neutron-detector livetime
 - photon-beam attenuation
 - 3bbu contamination
- scale corrections
 - tagging efficiency
 - geometrical acceptance
 - target density
 - particle misidentification
- 97 differential cross-section data



Transition-coefficient approach:

$$\frac{d\sigma}{d\Omega}(\theta_{\text{c.m.}}) = \alpha \left\{ \sin^2(\theta_{\text{c.m.}}) [1 + \beta \cos(\theta_{\text{c.m.}}) + \gamma \cos^2(\theta_{\text{c.m.}})] + \delta + \epsilon \cos(\theta_{\text{c.m.}}) \right\}$$

“vanishing” constraint: $\delta = \epsilon = 0$

Legendre approach:

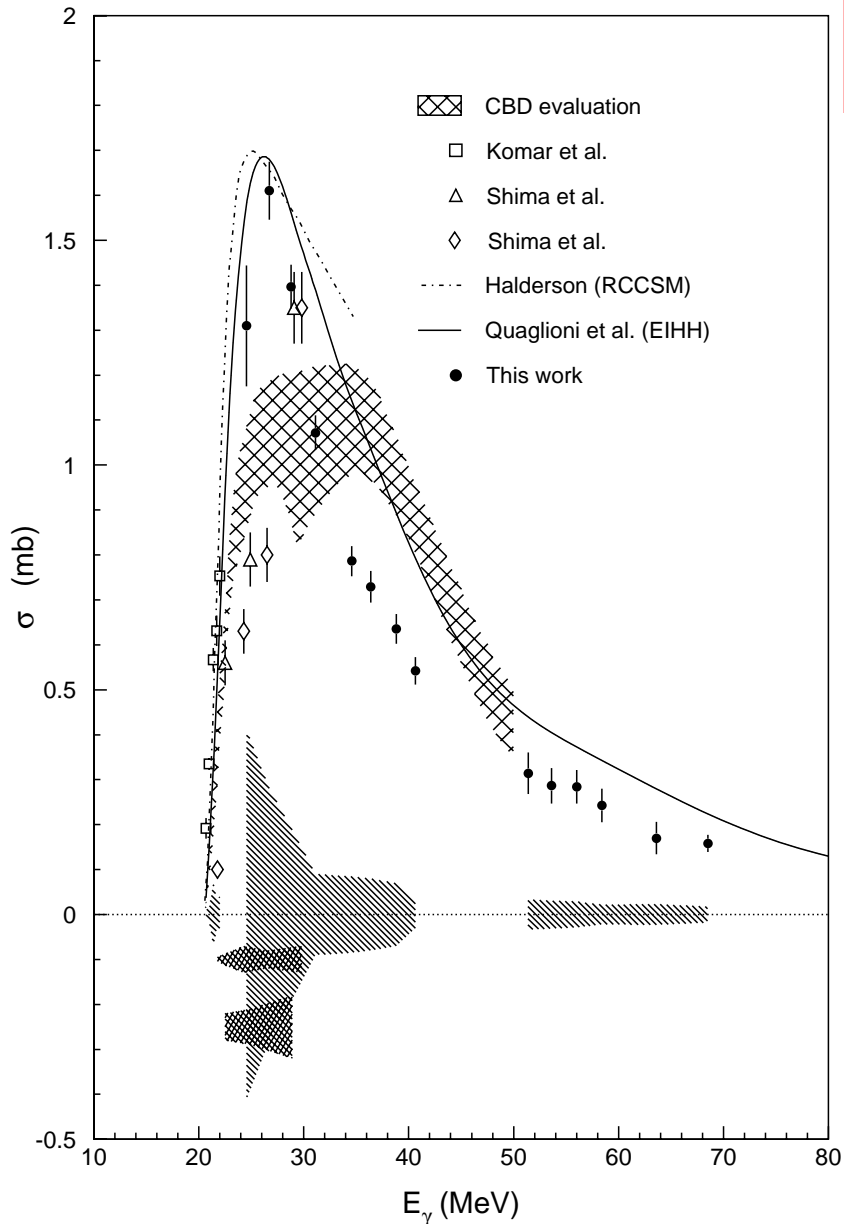
$$\frac{d\sigma}{d\Omega}(\theta_{\text{c.m.}}) = A_0 \left[1 + \sum_{i=1}^4 a_n P_n(\cos(\theta_{\text{c.m.}})) \right]$$

“vanishing” constraint: $a_2 = -(1 + a_4)$

Recent results and future plans at MAX-lab

${}^4\text{He}(\gamma, n) - \sigma_{\text{TOTAL}}$ results

- consistent with capture data and recent calcs
- inconsistent with CBD and active-target data
- EIHH development continues:
see nucl-th/0512038 and nucl-th/0607011
- a loud call for quality data
- experimental development continues:
 ${}^3,4\text{He}$ active target for MAX-lab (Annand)
 ${}^3\text{He}, {}^3\text{H}$ spectrometer for MAX-lab (Margaryan)



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- J. Calarco *et al.*, Phys. Rev. C. **27**, 1866 (1983)
 R. J. Komar *et al.*, Phys. Rev. C. **48**, 2375 (1993)
 T. Shima *et al.*, Nucl. Phys. **A687**, 127c (2001)
 T. Shima *et al.*, Phys. Rev. C. **72**, 044004 (2005)
 D. Halderson *et al.*, Phys. Rev. C. **70**, 034607 (2004)
 S. Quaglioni *et al.*, Phys. Rev. C. **69**, 044002 (2004)

${}^2\text{H}(\gamma, \gamma)$ from $40 < E_\gamma < 110$ MeV

- testing Chiral Dynamics is the mission statement of the upgraded Tagged-Photon Facility at MAX-lab
 - Compton scattering and pion production dominate the PAC-approved experiments
- Compton program extends to higher A
- foresee a close cooperation between HIGS and MAX-lab in the future

M. Lundin, Ph.D. Lund (2002) – see <http://maxlab.lu.se/kfoto/publications/lundin.pdf>

M. Lundin *et al.*, Phys. Rev. Lett. **90**, 192501 (2003)

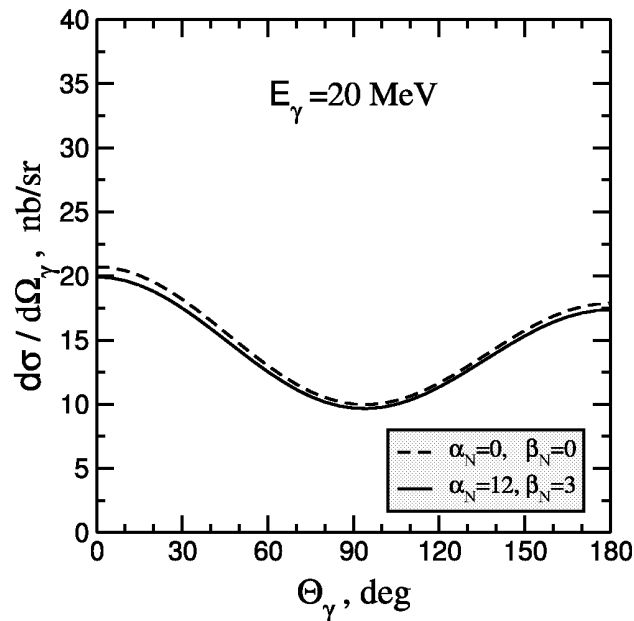
Compton@MAX-lab Collaboration – see <http://maxlab.lu.se/kfoto/props04/proposal04-nr6.pdf>

Background:

- the polarizabilities α_p and β_p of the free proton are well known
- the polarizabilities α_n and β_n of the neutron are not
- consider instead the deuteron, and define isospin-averaged quantities:

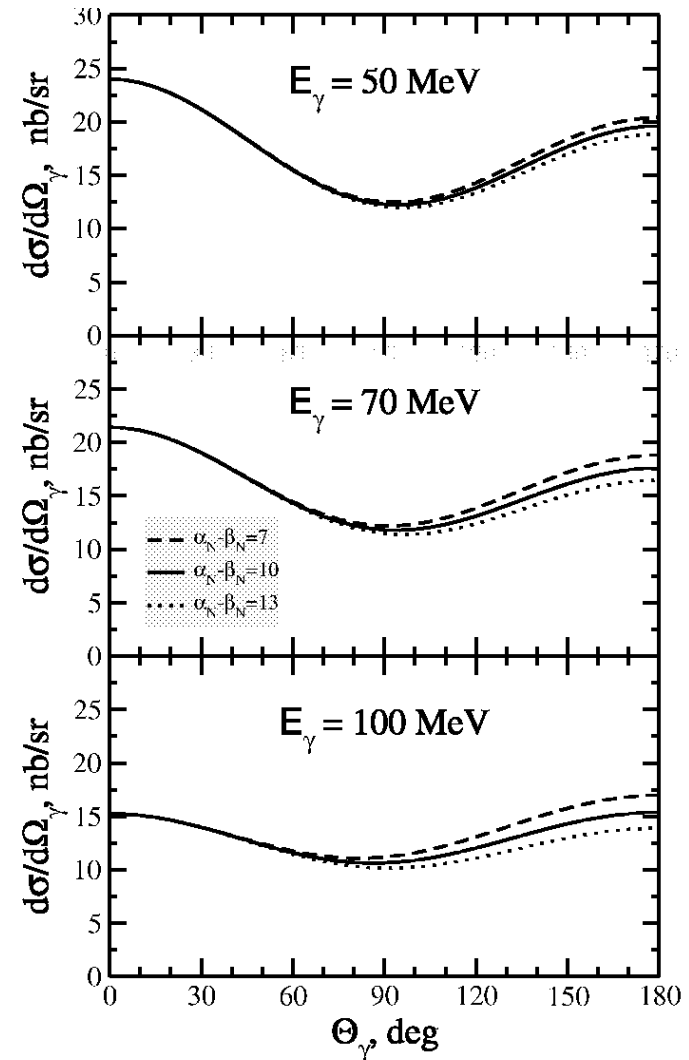
$$\alpha_N = (\alpha_p + \alpha_n)/2 \qquad \beta_N = (\beta_p + \beta_n)/2$$

- results from the deuteron can lead to information on the neutron since MECs can be addressed
- requires systematically precise cross-section data at the 20 nb/sr level over a range of angles and energies

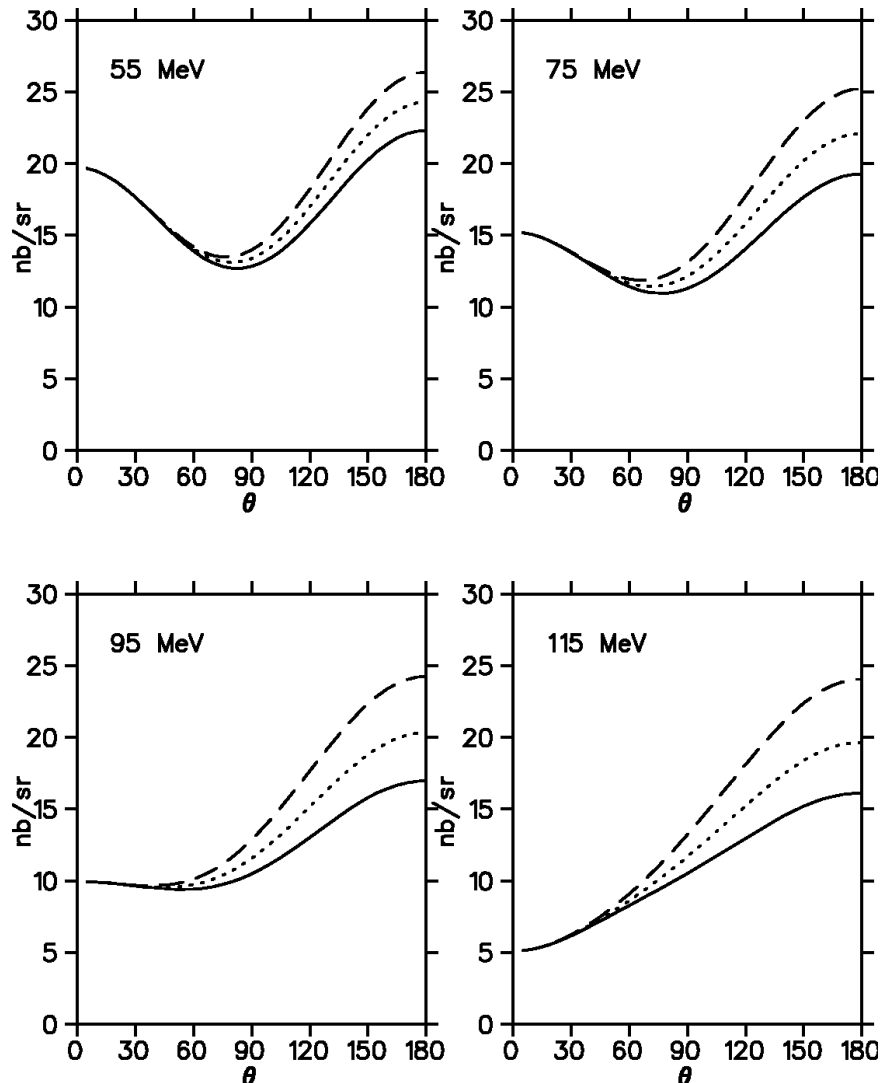


Potential Model Calcs

- backward angles:
sensitive to $\alpha_N - \beta_N$
- forward angles:
insensitive to $\alpha_N - \beta_N$
yields $\alpha_N + \beta_N$; also from σ_γ via Baldin
- low E_γ : little or no sensitivity



Levchuk and L'vov, Nucl. Phys. **A674**, 449 (2000) – potential model treatment; includes both 1-body and 2-body currents



Phillips and Choudhury, private communication to the
Compton@MAX-lab Collaboration (2004) – ChPT to $O(Q^4)$

ChPT to $O(Q^4)$ Calcs

$$\alpha_N + \beta_N = 15 \text{ (Baldin)}$$

$$(\alpha_N, \beta_N) = (12, 3) \text{ (solid)}$$

$$(\alpha_N, \beta_N) = (6, 9) \text{ (dashed)}$$

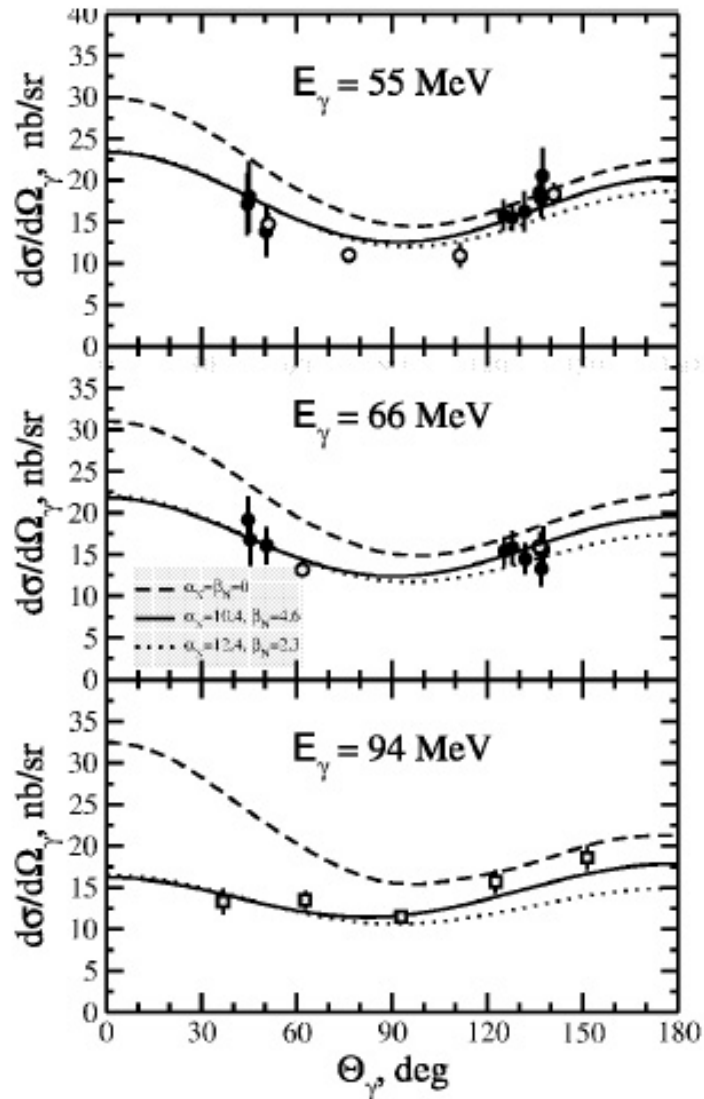
$$(\alpha_N, \beta_N) = (9, 6) \text{ (dotted)}$$

(units of 10^{-4} fm^3)

“model independence” of

$$\sigma = \sigma(\alpha_N - \beta_N) \text{ for}$$

low E_γ and forward θ_γ



Potential Model Calcs

- solid circles – Lund

Lundin *et al.*, Phys. Rev. Lett. **90**, 192501 (2003)

- open circles – Illinois (energy extrapolated)

Lucas, PhD. thesis, University of Illinois, USA (1994)

- open squares – SAL

Hornidge *et al.*, Phys. Rev. Lett. **84**, 2334 (2000)

- calculations:

Levchuk and L'vov, Nucl. Phys. **A674**, 449 (2000)

----- $\alpha_N = 0.0$; $\beta_N = 0$

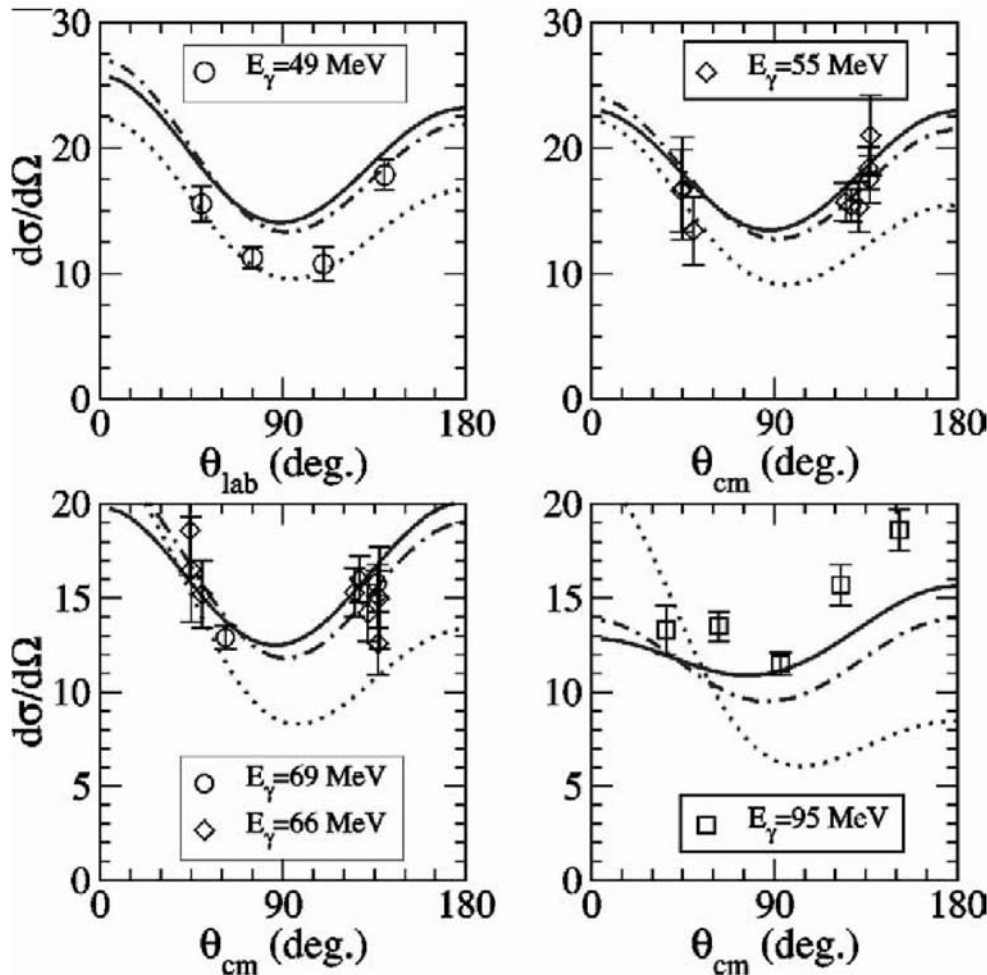
———— $\alpha_N = 10.4$; $\beta_N = 4.6$ (their best)

..... $\alpha_N = 12.4$; $\beta_N = 2.3$ (recent)

- note:

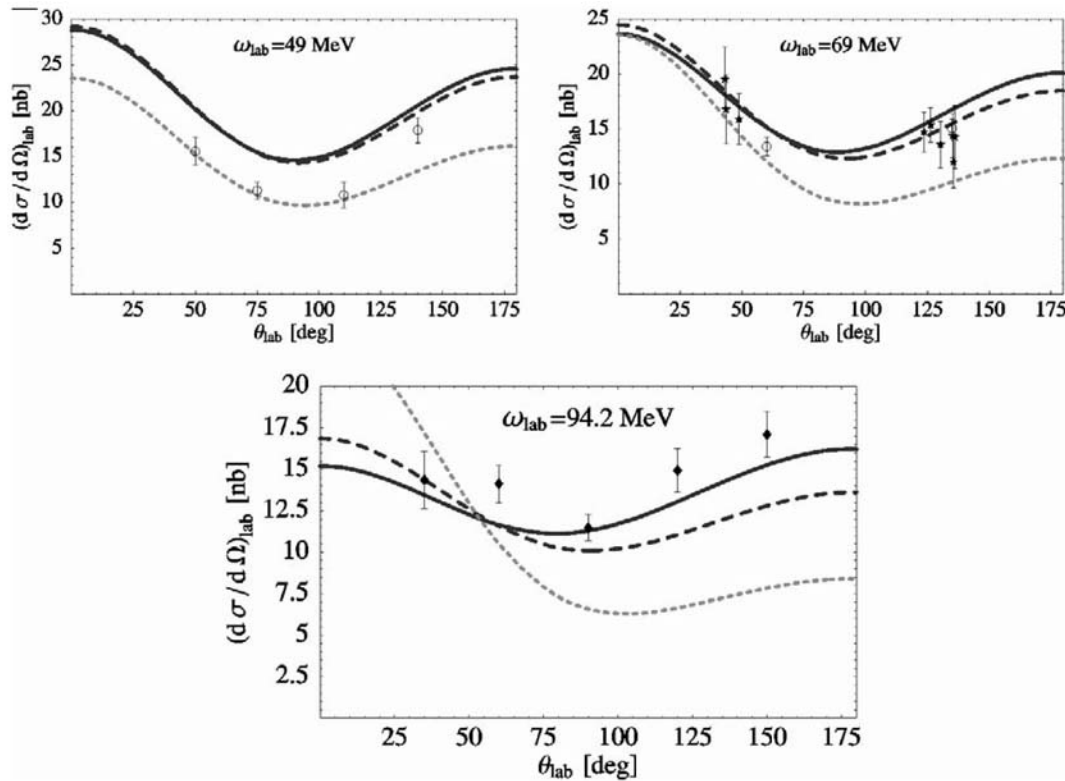
total uncertainties shown

strong agreement between Lund and Illinois



ChPT to $O(Q^4)$ Calcs

- open circles – Illinois
Lucas, PhD. thesis, University of Illinois, USA (1994)
- open diamonds – Lund
Lundin *et al.*, Phys. Rev. Lett. **90**, 192501 (2003)
- open squares – SAL
Hornidge *et al.*, Phys. Rev. Lett. **84**, 2334 (2000)
- calculations:
Beane *et al.*, Nucl. Phys. **A747**, 311 (2005)
 - $O(Q^4)$; $\alpha_N = 13.6$; $\beta_N = 0.1$
 - · · · · $O(Q^3)$ (no free parameters)
 - · · · · $O(Q^2)$
- note:
 α_N & β_N only free parameters
results are wave-function dependent (moreso α_N)
 $O(Q^5)$ probably necessary



Explicit Δ attached

to HBChPT $O(Q^3)$ Calcs

- open circles – Illinois

Lucas, PhD. thesis, University of Illinois, USA (1994)

- filled stars – Lund

Lundin *et al.*, Phys. Rev. Lett. **90**, 192501 (2003)

- filled diamonds – SAL

Hornidge *et al.*, Phys. Rev. Lett. **84**, 2334 (2000)

- calculations:

Hildebrandt *et al.*, Nucl. Phys. **A748**, 573 (2005)

—— $O(\epsilon^3)$ (below plus explicit Δ)

----- $O(Q^3)$ HBChPT:

$$\alpha_p = 11.04; \beta_p = 2.76$$

..... $O(Q^2)$

- note:

Δ becomes important by $E_\gamma \sim 70$ MeV

The Compton@MAX-lab Collaboration:

Lund University

University of Illinois

University of Kentucky

The George Washington University

University of Edinburgh

University of Glasgow

University of Göttingen

Mount Allison University

University of Saskatchewan

HIGS

Duke University

University of Kharkov

- 3 of the largest NaI detectors worldwide are at MAX-lab
 - CATS (Mainz); BUNI (Boston); DIANA (Kentucky)
- must separate elastics from breakup
 - detector ($\Delta E / E$) < 2% @ 100 MeV
 - monoenergetic (tagged) photons

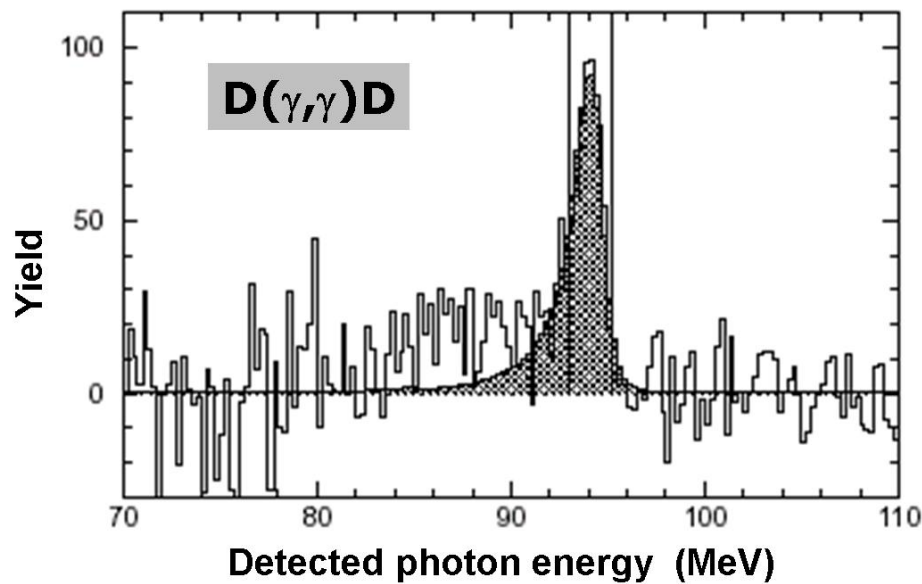
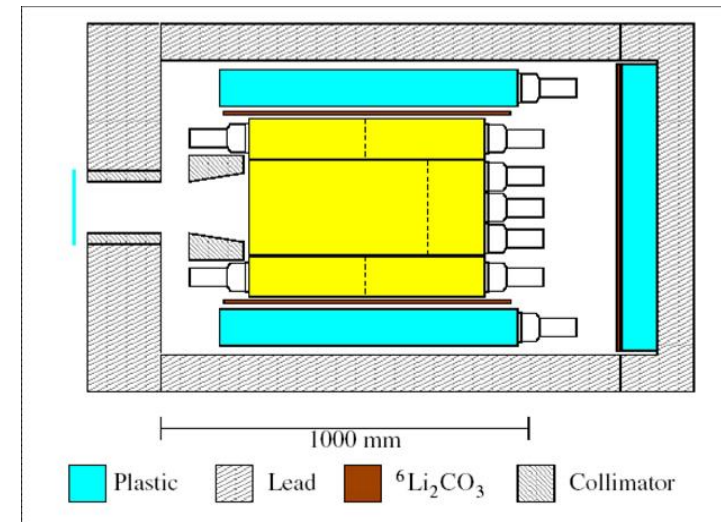


figure courtesy D. Hornidge – BUNI @ SAL

CATS



Kinematic coverage:

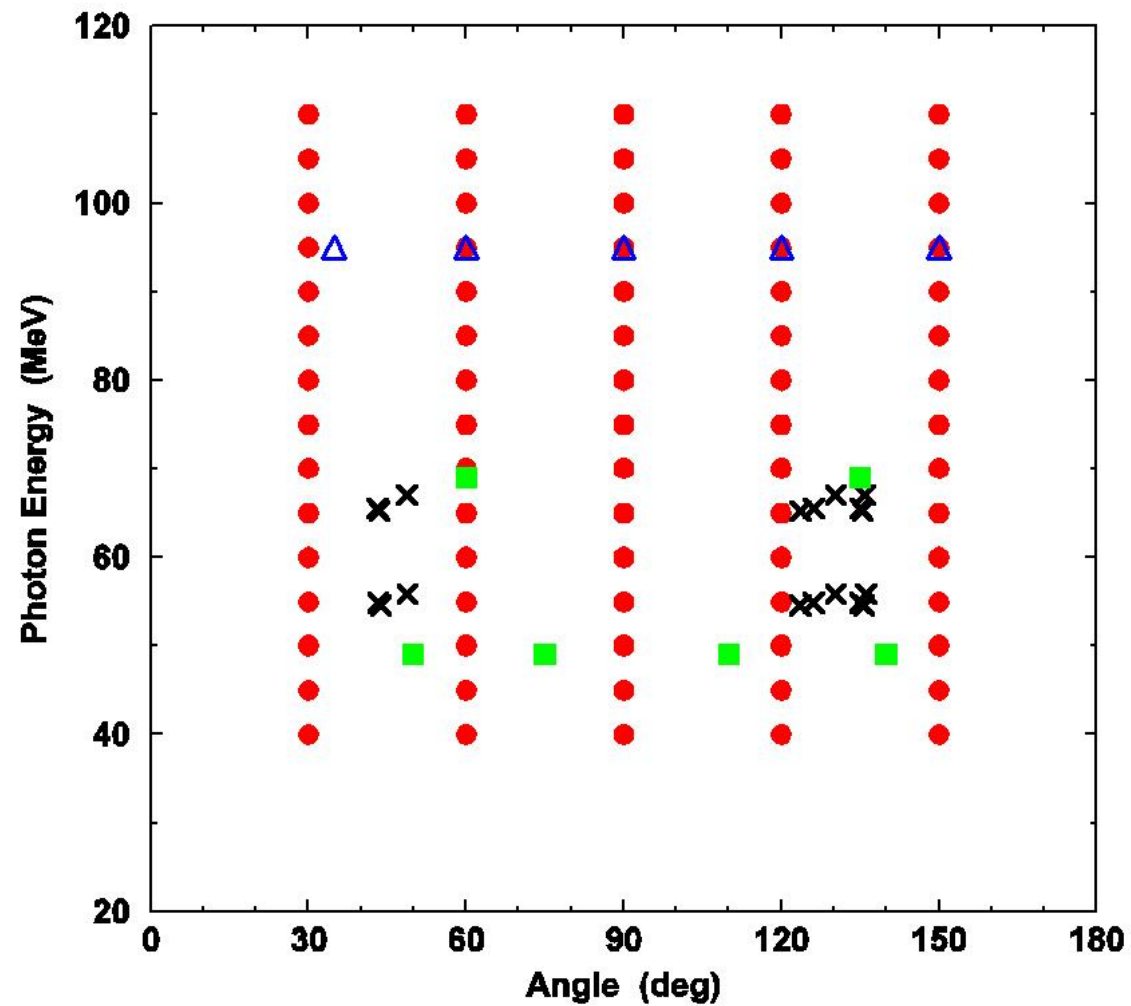
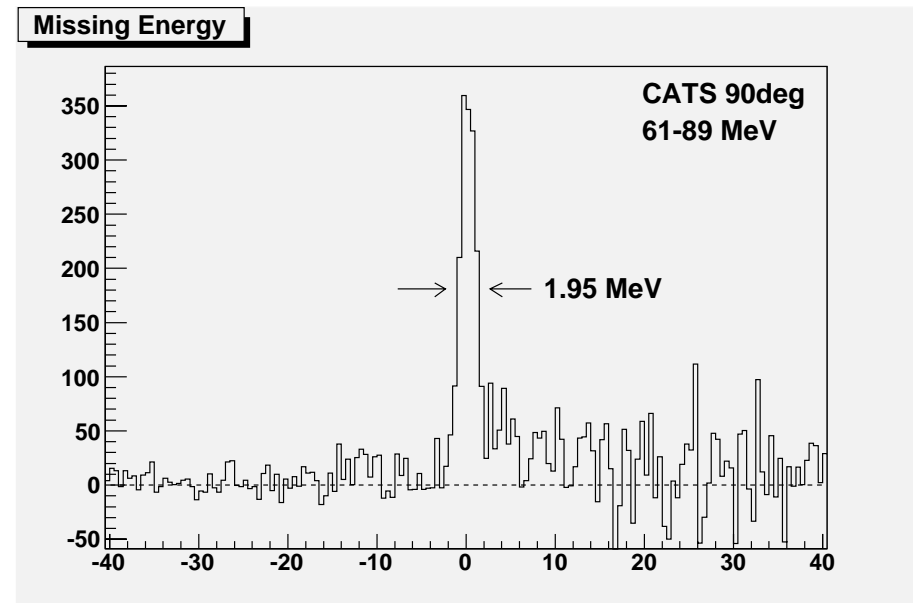
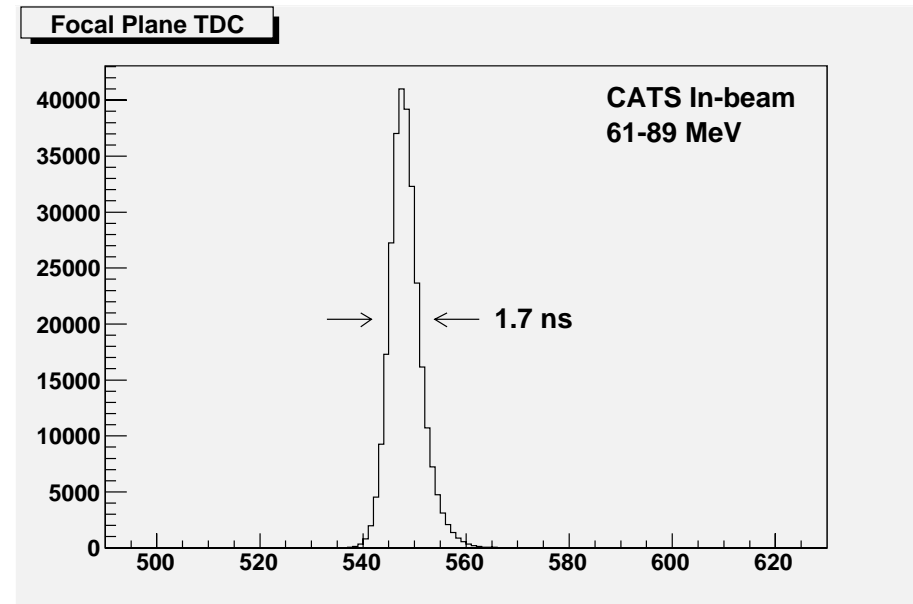
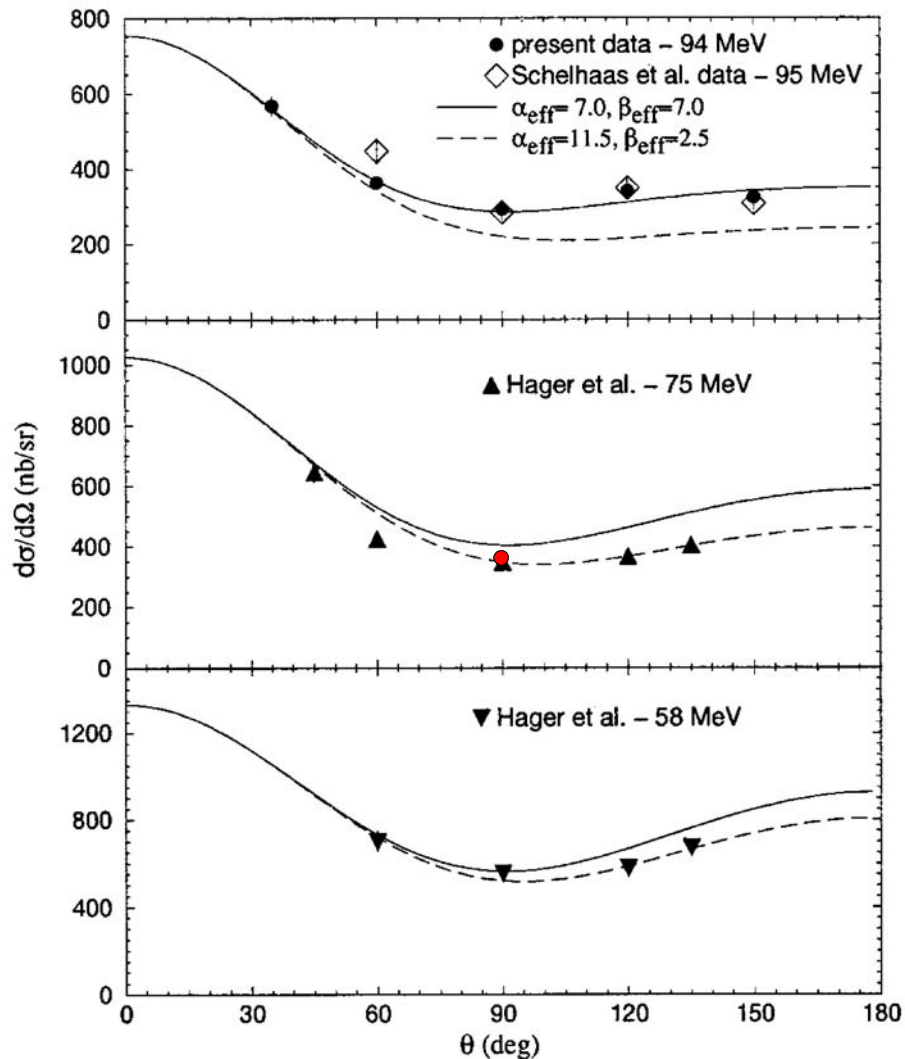


figure courtesy J. Feldman

- program is underway!
 - systematic series of targets of increasing complexity and decreasing cross section:
- $$\text{H}_2\text{O} \rightarrow {}^{12}\text{C} \rightarrow \ell({}^4\text{He}) \rightarrow \ell({}^2\text{H})$$
- first production Compton scattering data are under analysis
 - FWHM coincidence time resolution: 1.7 ns
 - FWHM elastic peak resolution: better than 2 MeV



$^{12}\text{C}(\gamma, \gamma)$:

- Warkentin *et al.*, SAL

94 MeV 292 ± 5 nb/sr

- ▲ Häger *et al.*, Lund

75 MeV 348 ± 11 nb/sr

- This measurement

75 MeV 367 ± 19 nb/sr

In conclusion

- recent comprehensive ${}^4\text{He}(\gamma, n)$ results from MAX-lab demonstrate resonant behaviour at $E_\gamma \sim 28$ MeV
 - consistent with modern calculations
 - precision to be improved via complementary experimental techniques
- upgraded Tagged-Photon Facility is operational and the (γ, γ) program has commenced
 - $3 \times 2\%$ @ 100 MeV Nals onsite and operating simultaneously
 - consistency checks via ${}^{12}\text{C}(\gamma, \gamma)$ underway
 - anticipate first measurements on ${}^2\text{H}$ by fall, 2006

These projects have been made possible by:

- The Swedish Research Council
- The Royal Swedish Academy of Sciences
- The Crafoord Foundation
- The Royal Physiographic Society in Lund
- The Wenner-gren Foundations
- The Marcus and Amalia Wallenberg Memorial Fund
- The Knut and Alice Wallenberg Foundation
- The European Union Integrated Infrastructures Initiative I3HP

