Recent Results from the CB@MAMI Collaboration

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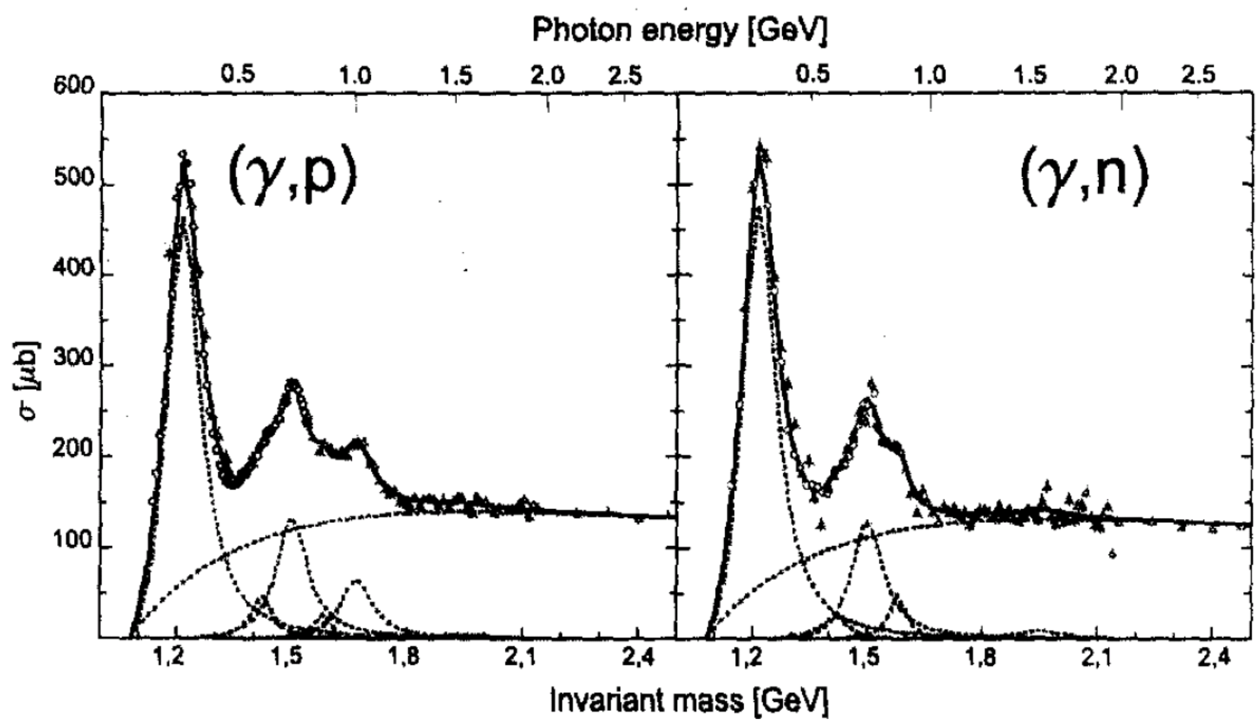
EMIN
October 2009

Outline

- Introduction & Motivation
- Experimental setup
- Recent results: $P_{33}(1232)$, $S_{11}(1535)$, $D_{33}(1700)$
- Future highlights: Vector polarizabilities of the nucleon
- Conclusion

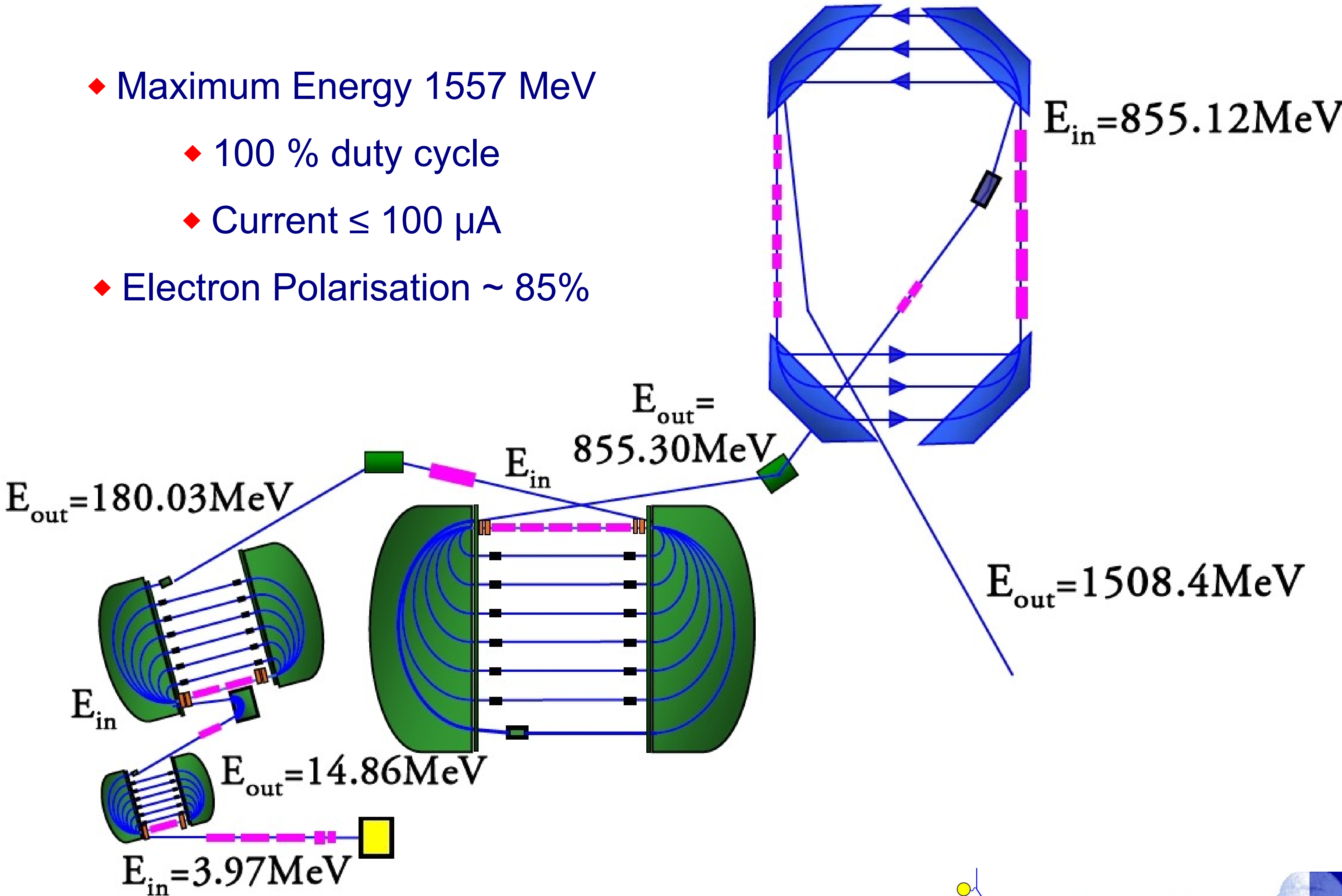
Introduction



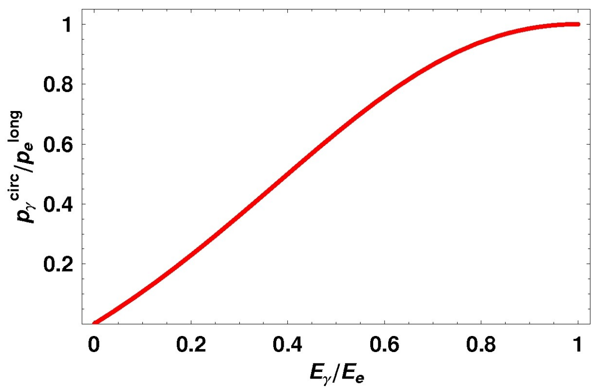
- Photon provides well understood probe
- Accurate separation of final states → good detector resolution
- Sensitivity to small σ processes → 4π detector acceptance, large γ flux
- Access to polarisation observables → polarised beam, target, recoil

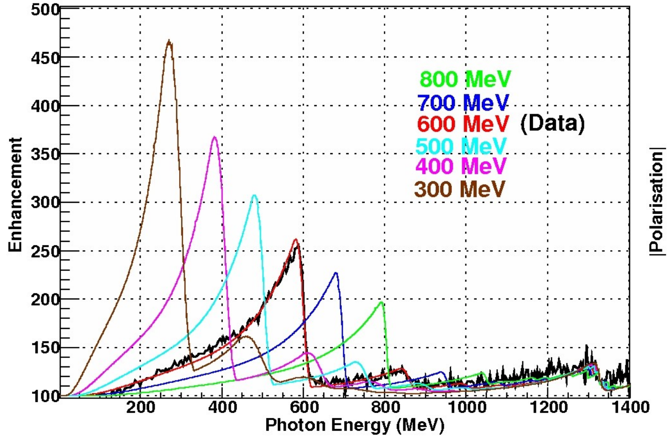
MAMI

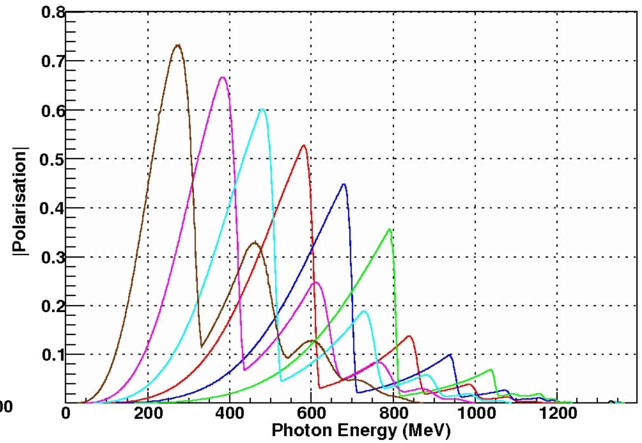
- Maximum Energy 1557 MeV
  - 100 % duty cycle
  - Current ≤ 100 µA
- Electron Polarisation ~ 85%

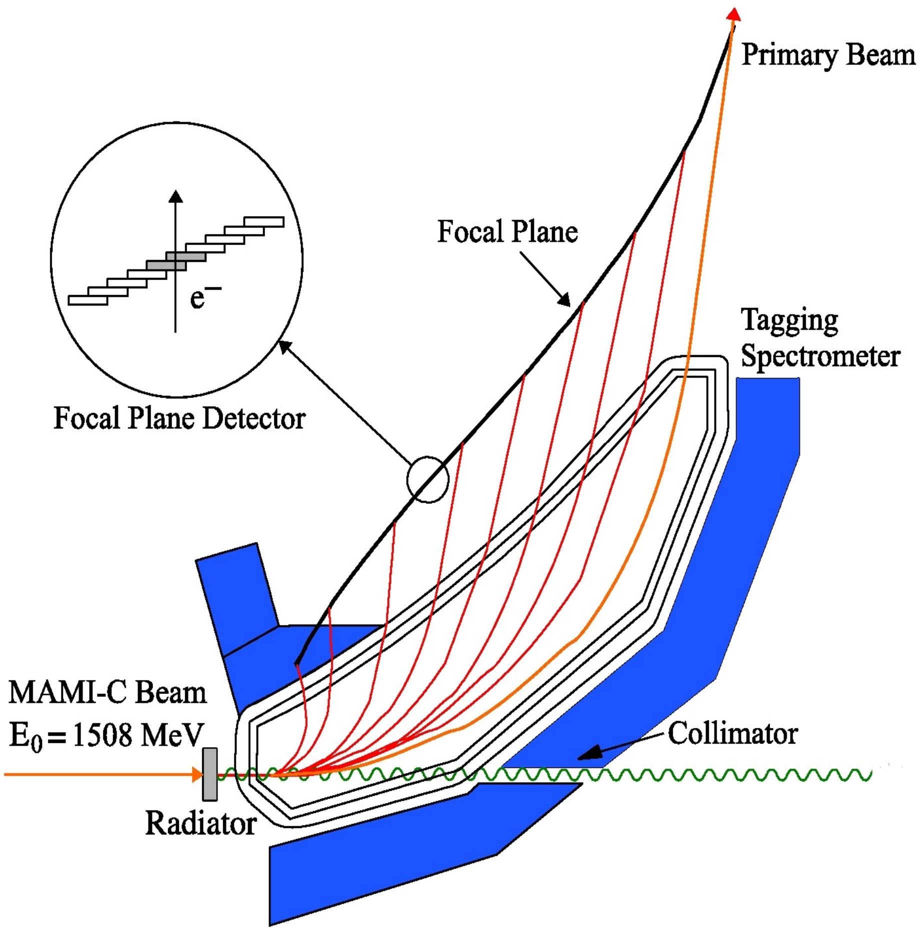


Glasgow Photon Tagger



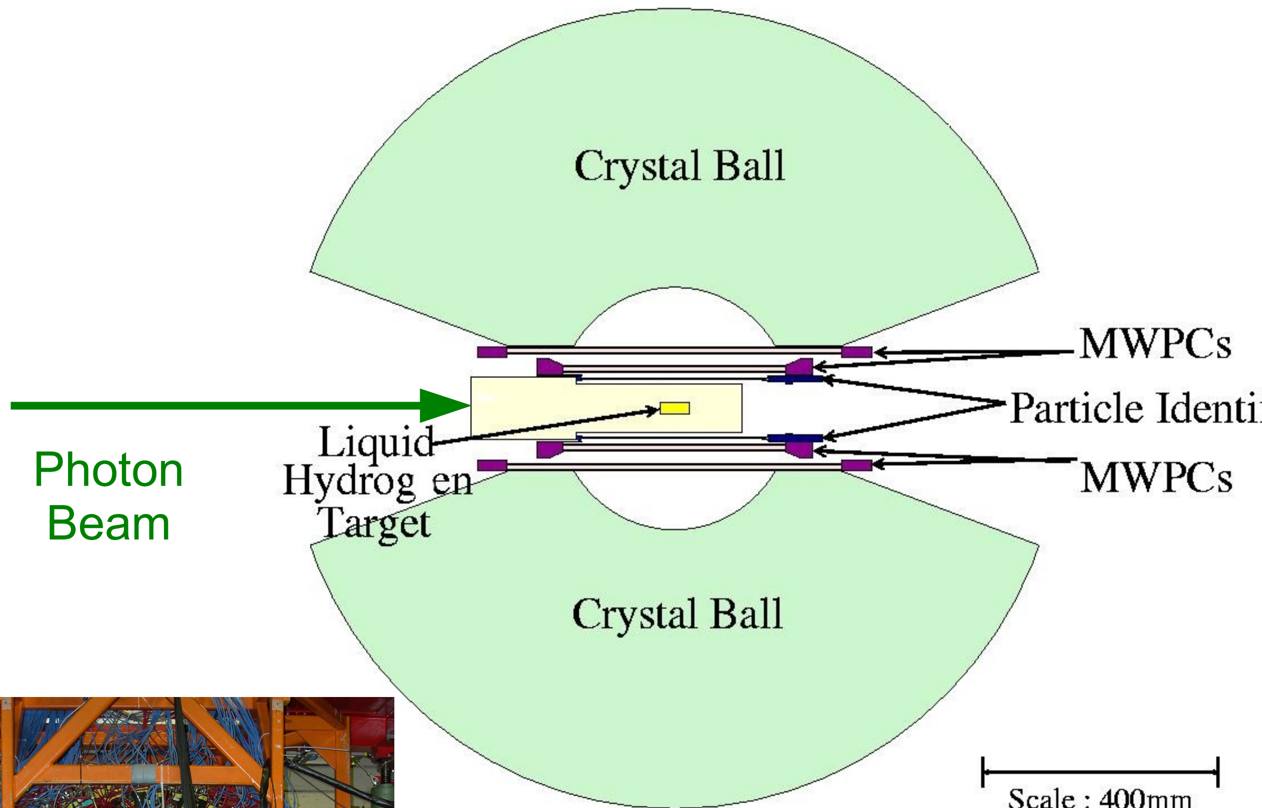


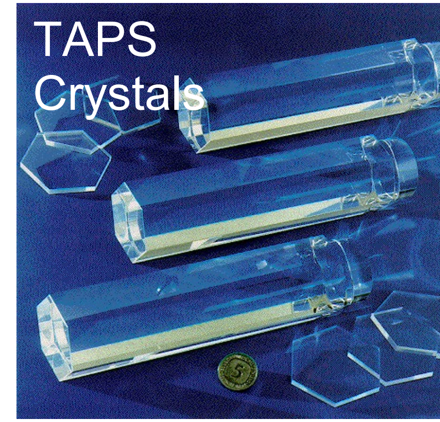


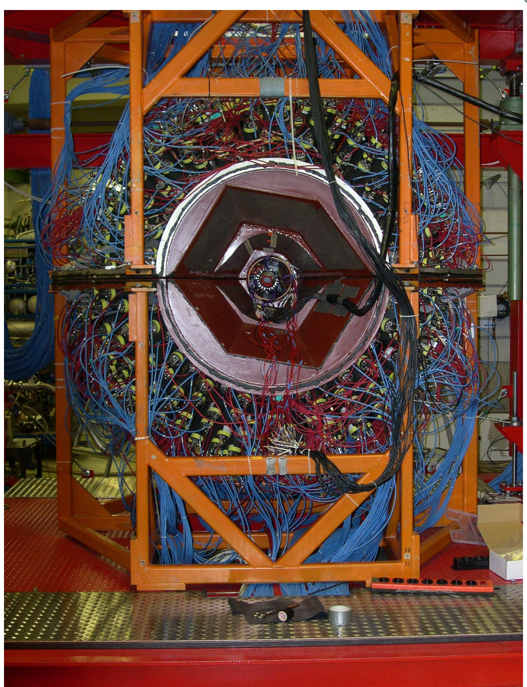


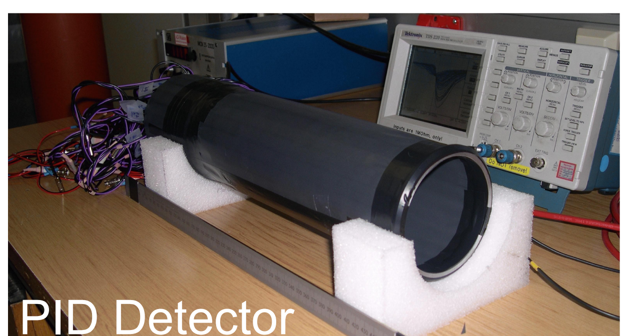
- Detection of radiating electrons: $E_\gamma = E_e - E_e'$
- Energy resolution 2-4 MeV
- Tagger Microscope ~6x better E res.
- Circularly pol. γ from e^- pol
- Linearly pol. γ from crystalline rad.
- Collimation upgrade will give +5% pol.

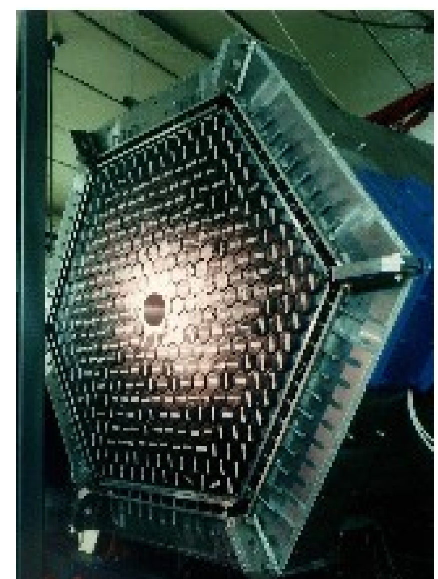
CB@MAMI Detector System



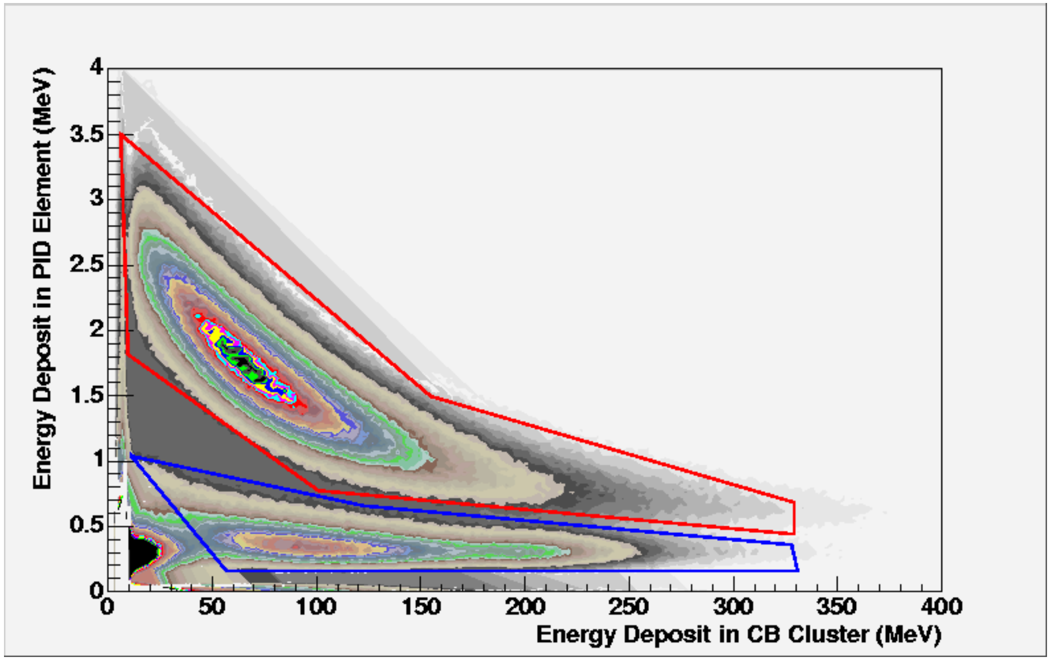


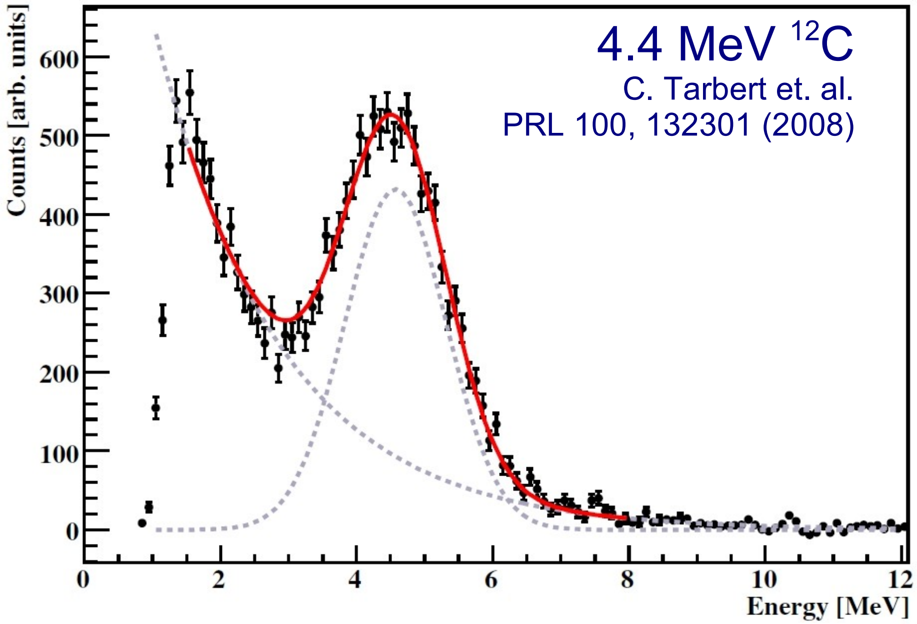




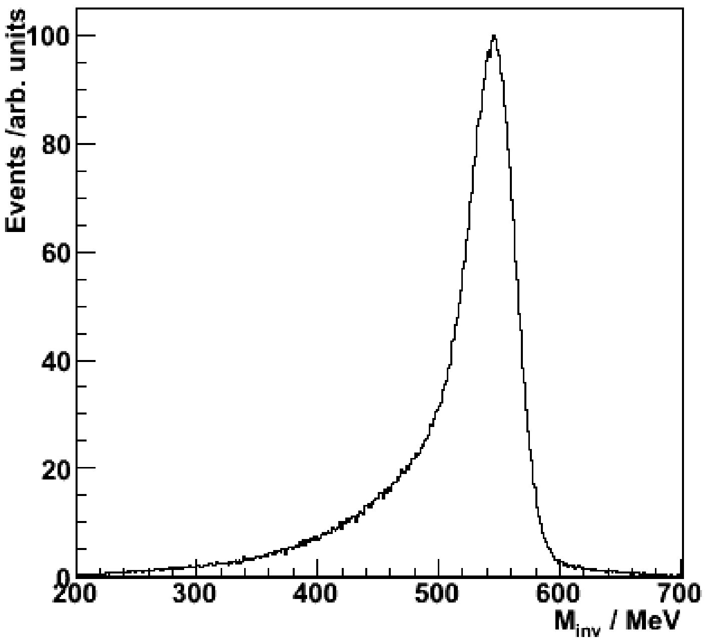


Crystal Ball: Particle Calorimetry and Identification

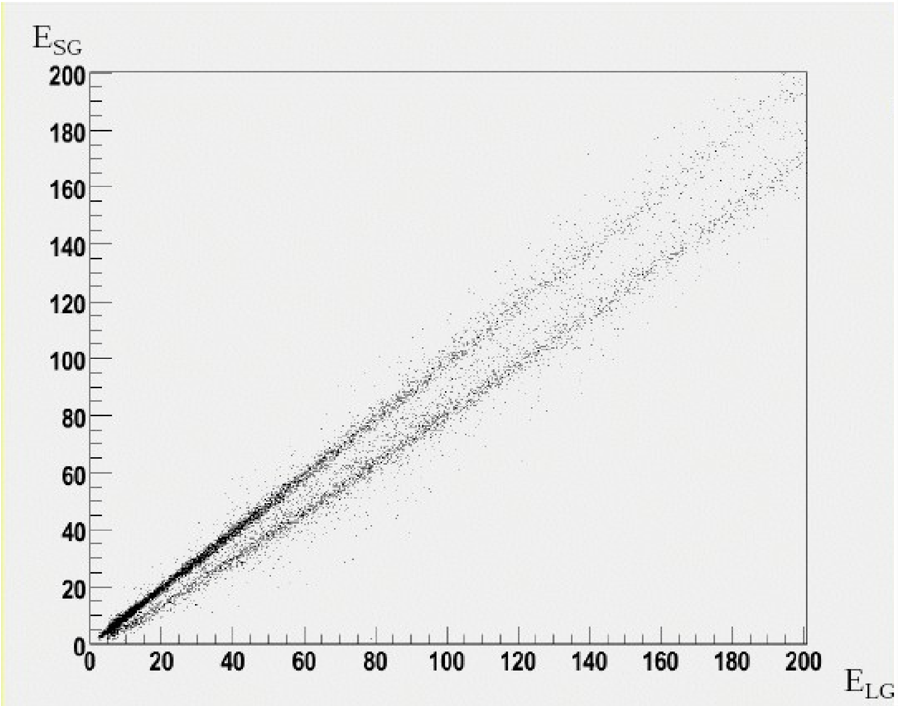


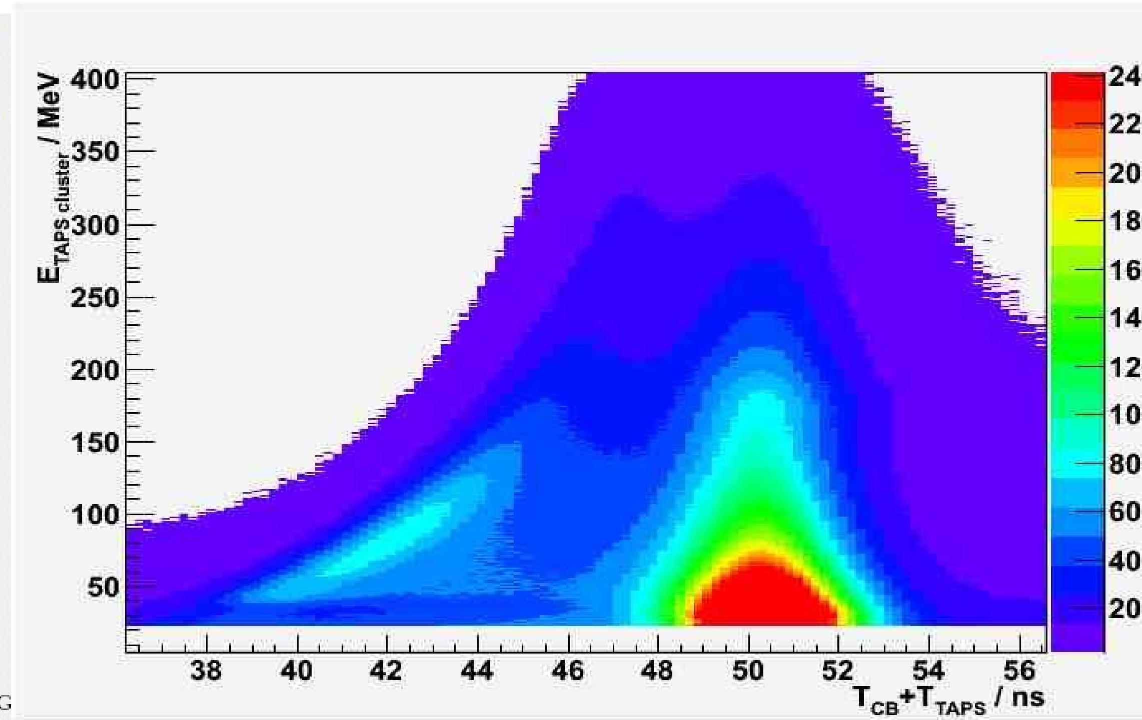


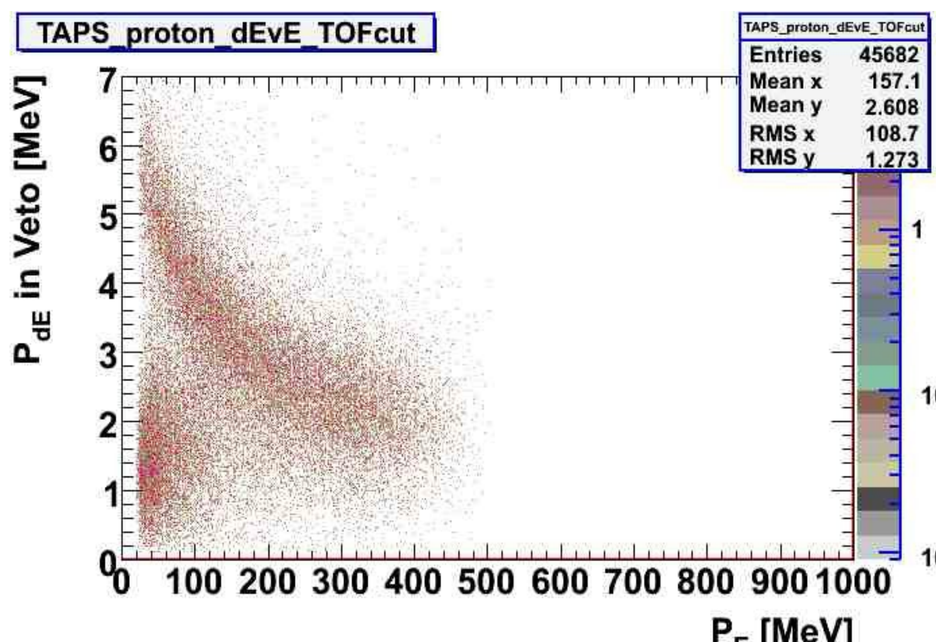
- Wide energy range with good resolution
- Energy resolution: $\Delta E/E = 0.020 \cdot E[\mathrm{GeV}]^{0.36}$
- Angular resolution: σ_θ = 2-3° $\sigma_\varphi = \sigma_\theta / \sin(\theta)$
- MWPC → Charged particle tracking
- ΔE (PID) / E (CB) locus → particle id.
- n / γ separation from kinematics
- High photon & neutron efficiency



TAPS: Particle Calorimetry and Identification







- Pulse-shape analysis: N/γ
- Plastic veto detectors: n/p, e^-/γ
- Δ E (Veto) / E (BaF2): cleaning TOF
- Time of flight, $\sigma_t = 0.2$ ns: n/γ, p/$e^{+/-}$
- $\Delta E/E = 0.018 + 0.008/E[\mathrm{GeV}]^{0.5}$
- Angular Resolution: $\sigma_\theta < 1°$; $\sigma_\varphi < 1/R[\mathrm{cm}]$

A2 Collaboration

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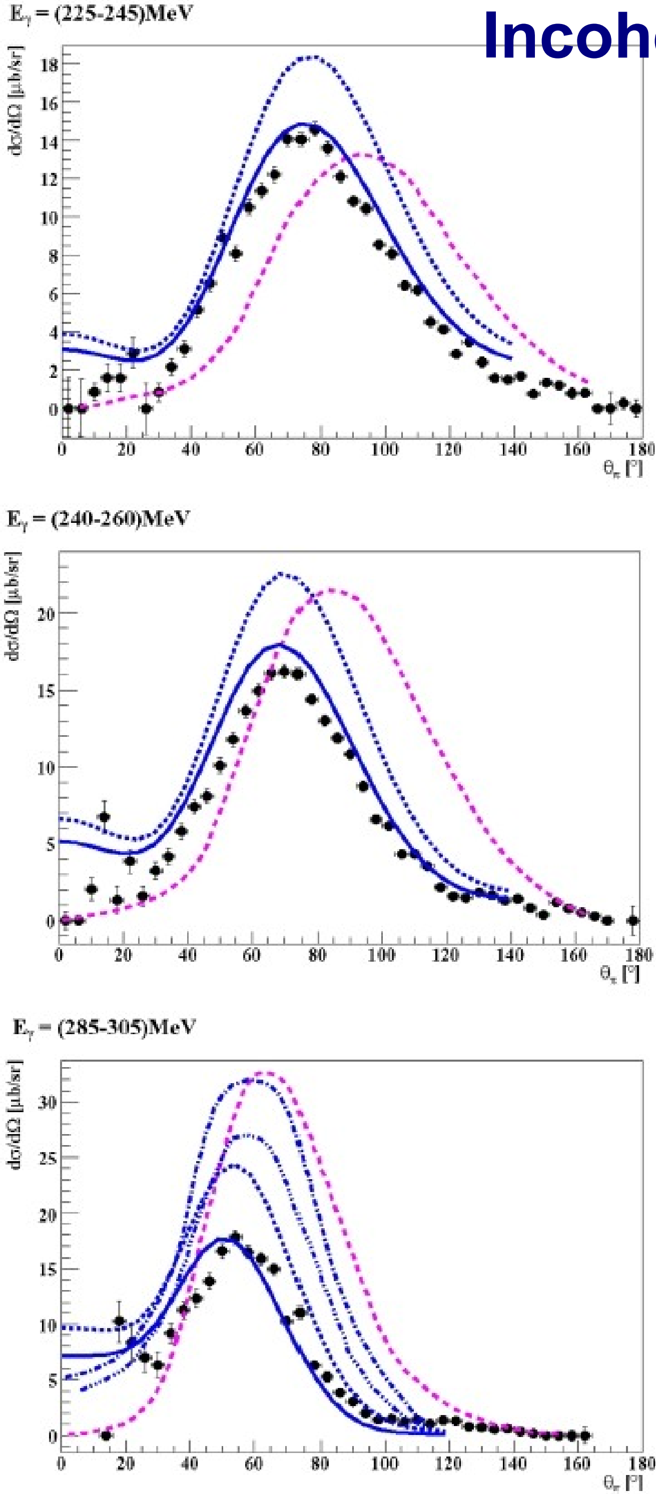
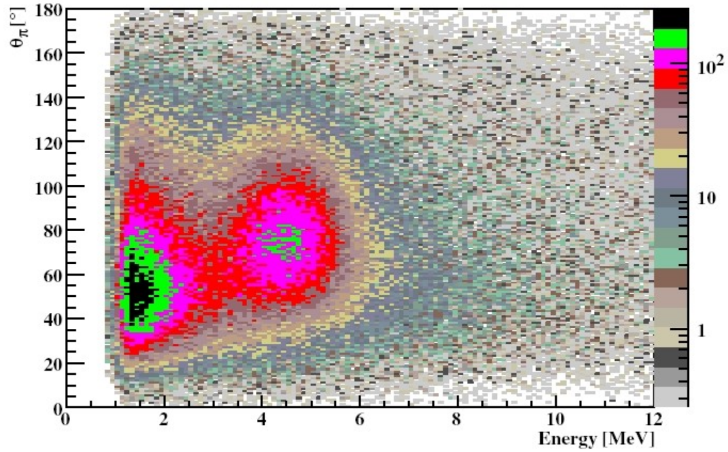
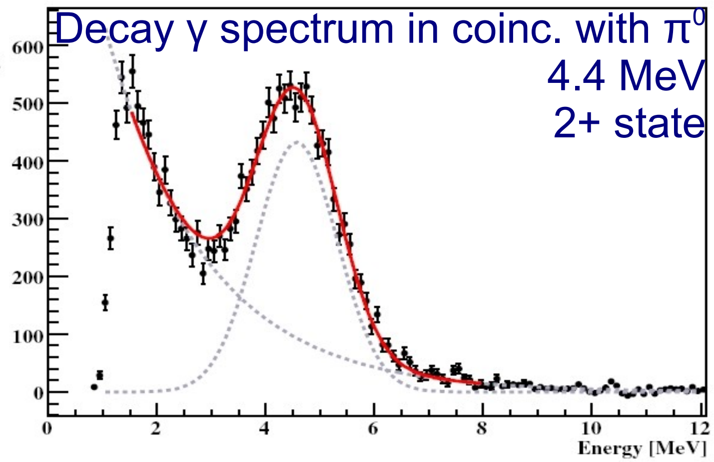
Incoherent π^0 photoproduction on ^{12}C

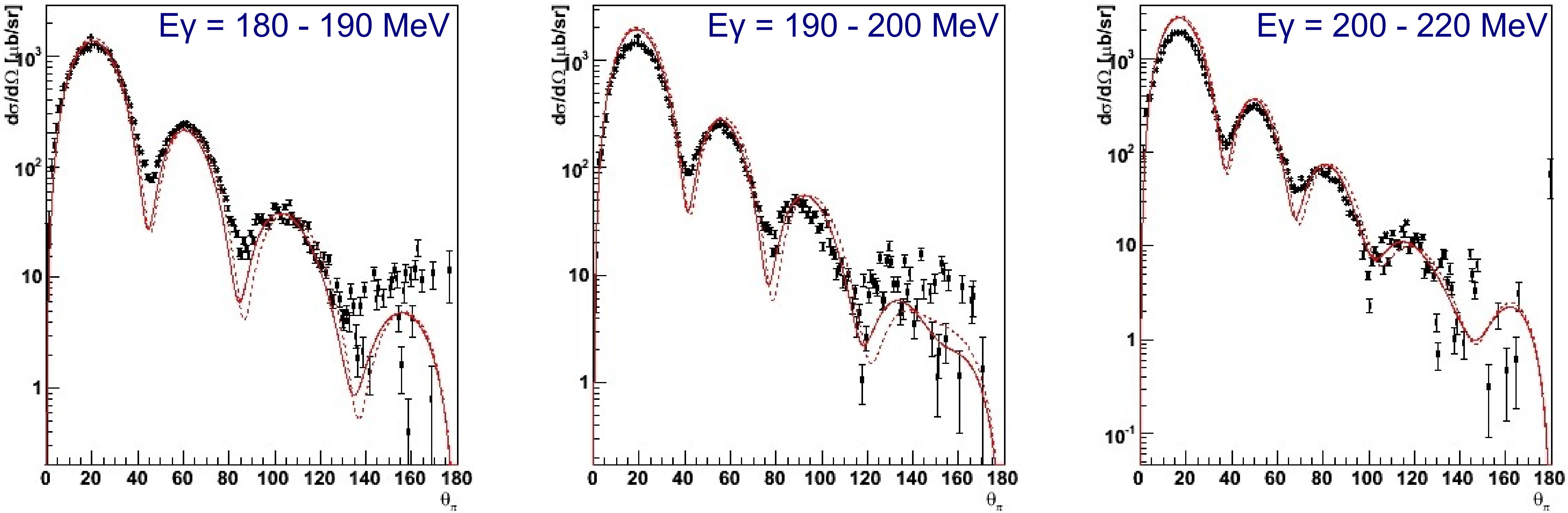






- Sensitive to NΔ transition mechanisms
- First report of $\sigma(\gamma,\pi^0)$ for a specific excited state
- Simultaneous detection of π^0 and decay γ in CB
- Favourable comparison to Δ-hole model (left)
- Important first step in isolation of coherent process
- PRL **100**, 132301 (2008)

Coherent π^0 photoproduction on ^{208}Pb



- Do heavy stable nuclei have a neutron skin?
- Fundamental property of nuclear physics
- Size of skin gives direct information on equation of state of n-rich matter
- Skin size gives important new insights into neutron star physics (cooling mechanisms, mass radii relationships)
- Accuracy ~0.05fm
- Publication in preparation: D. P. Watts and C. Tarbert, Edinburgh Uni.

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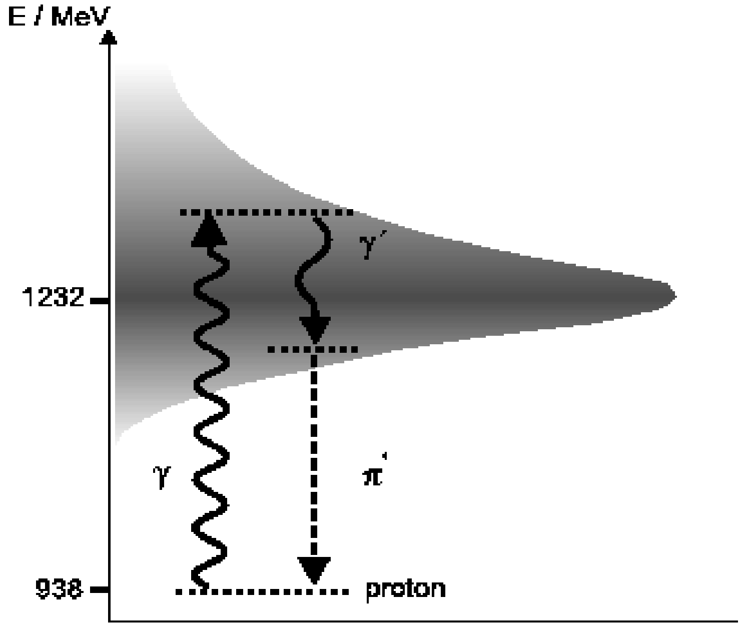
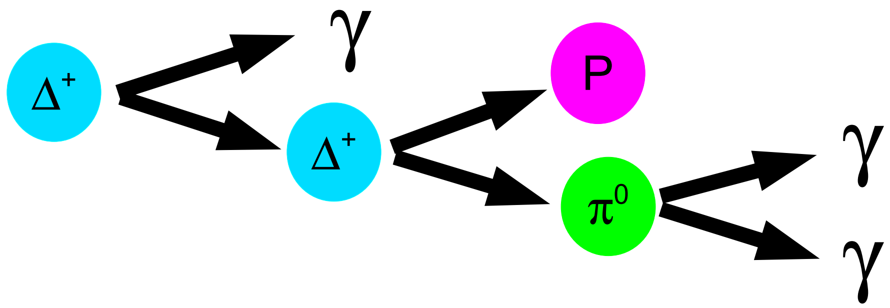
Radiative π^0 photoproduction





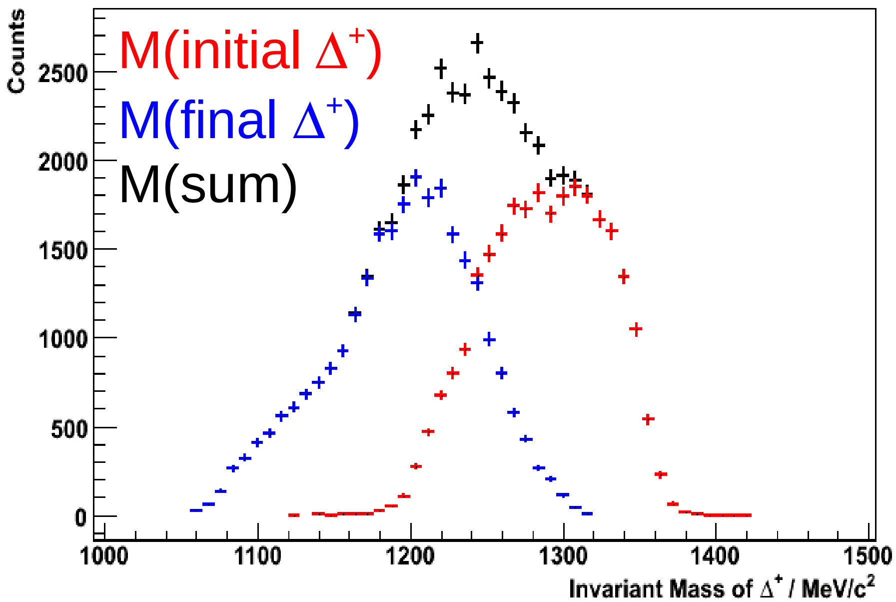
- Tagged photon beam on liquid H2
- Δ^+ lifetime 10^{-24}s $\rightarrow$ large Breit-Wigner width
- Created Δ^+ at upper end of B-W width
- Δ^+ radiatively decays to another Δ^+

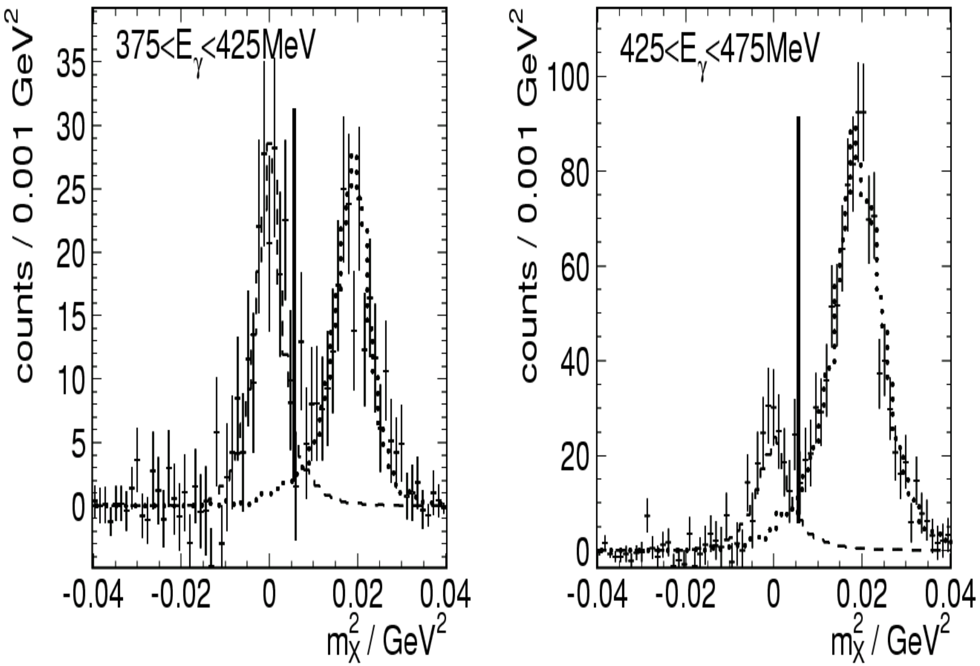
Radiative π^0 photoproduction

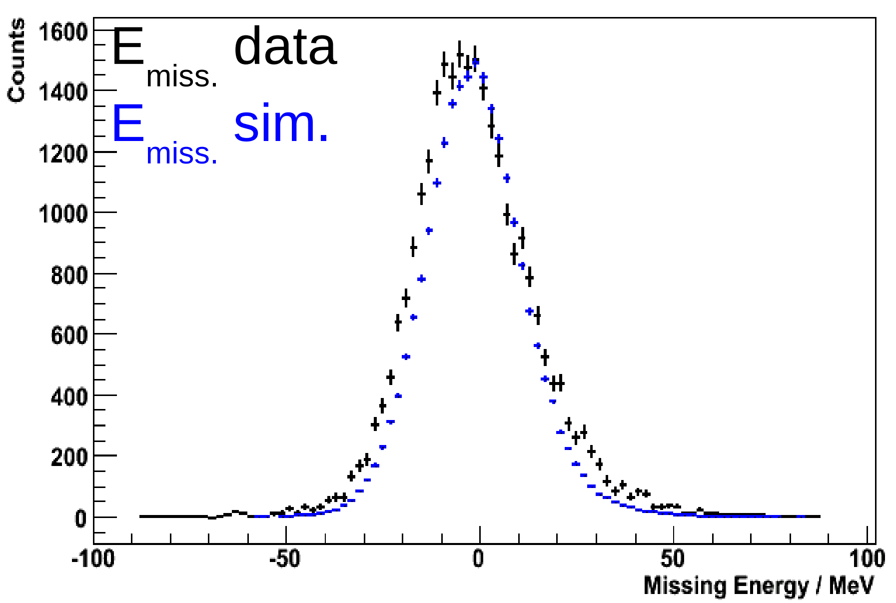
- **$p(\gamma,\pi^0\gamma p)$ Experimentally difficult channel**
  - ~50 nb total cross section
  - Backgrounds: $p(\gamma,\pi^0 p)$, 318 μb; $p(\gamma,\pi^0\pi^0 p)$, 1.5 μb

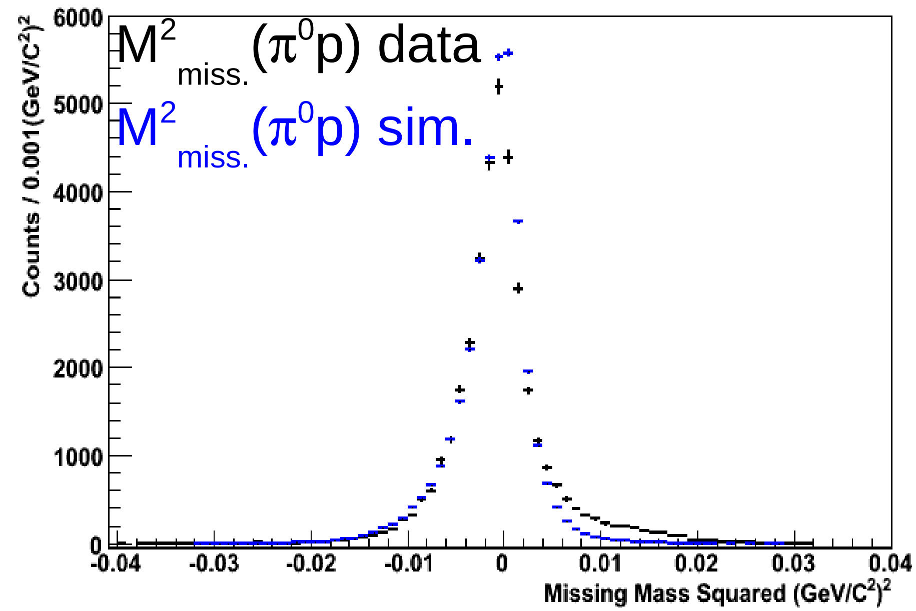
- **Comprehensive measurement required:**
  - Measure two channels: $p(\gamma,\gamma'\pi^0 p)$, $p(\gamma,\gamma'\pi^+ n)$
  - Measure several observables:
    - Five-fold differential cross section
    - Linearly polarised photon asymmetry
    - Circularly polarised photon asymmetry

Radiative π^0 photoproduction



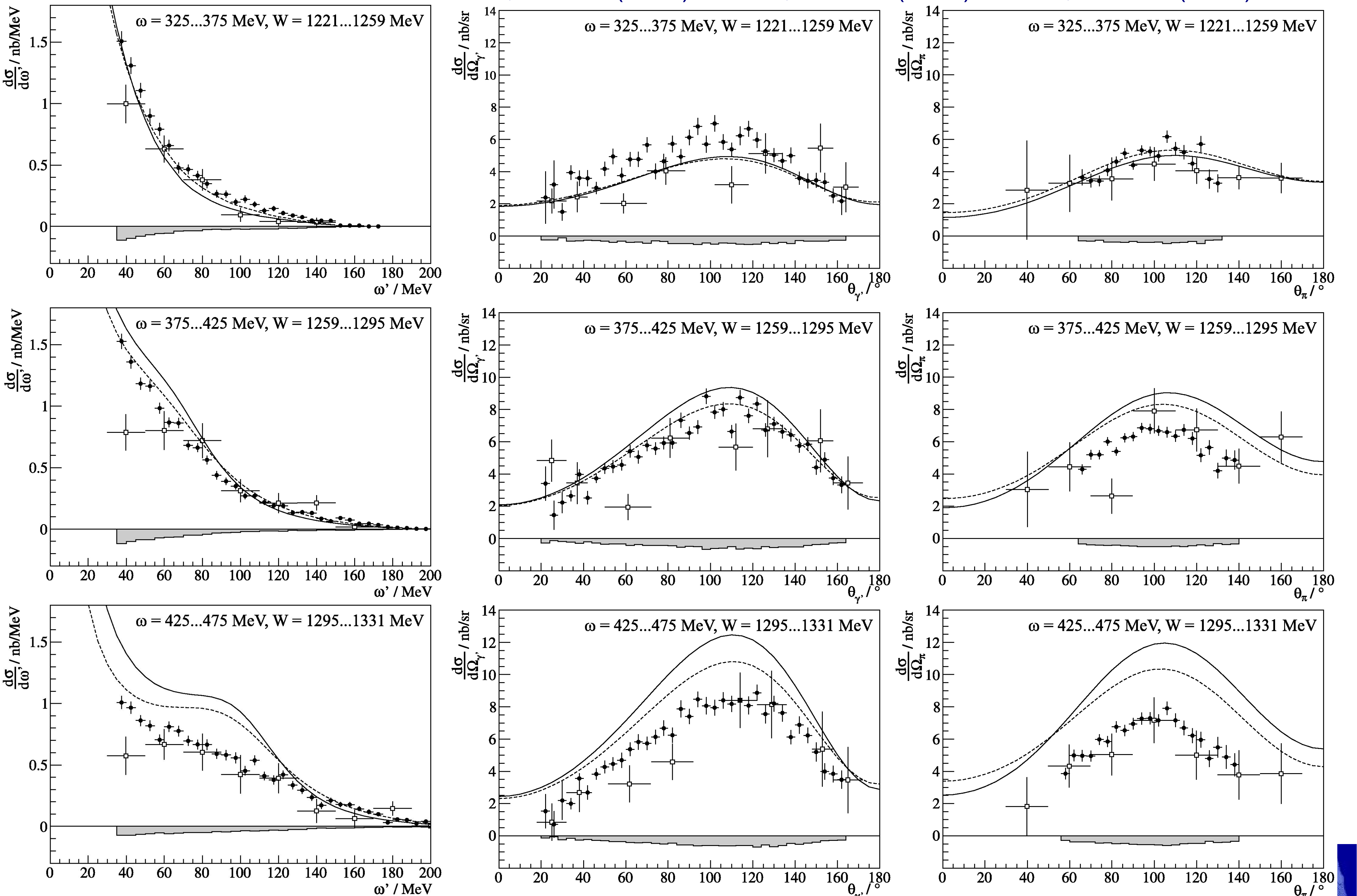






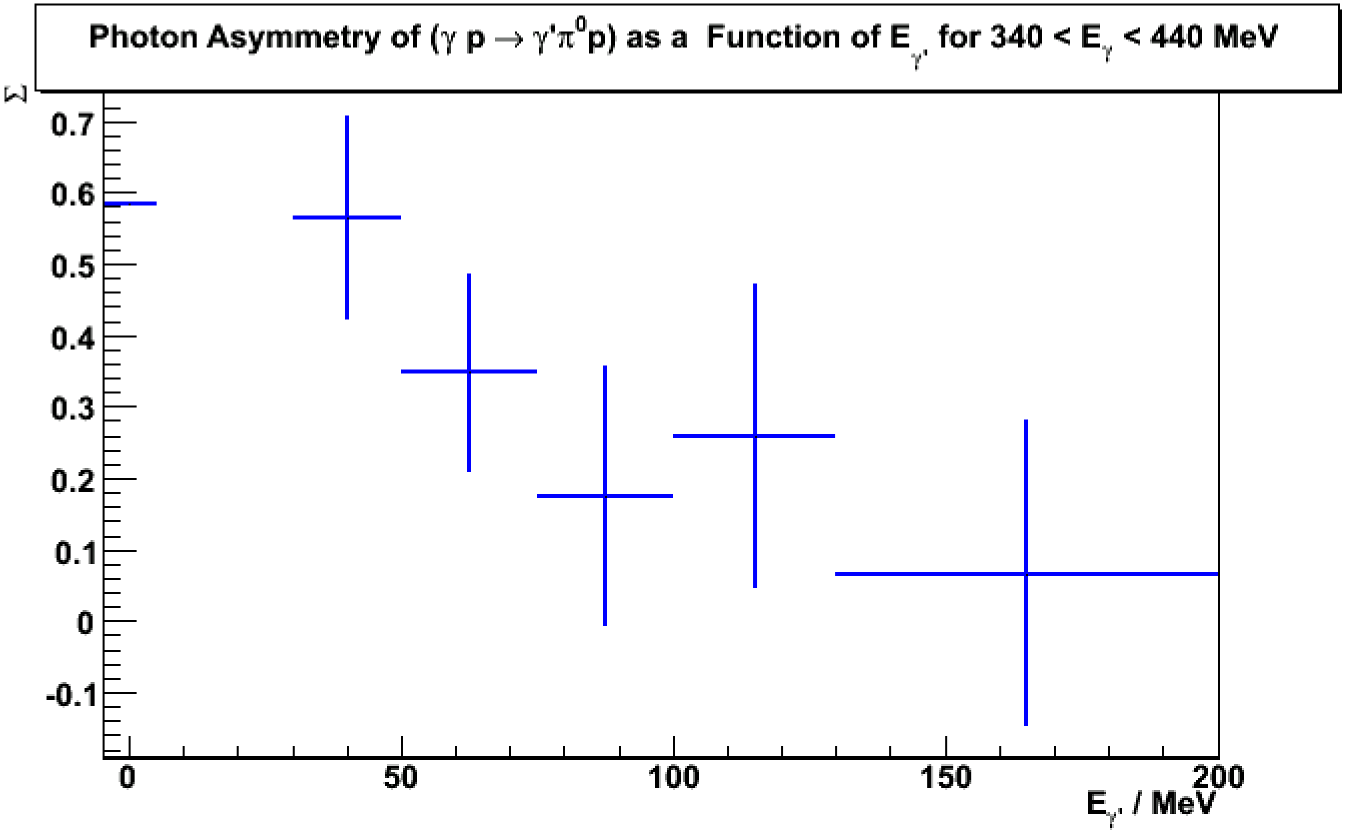
Radiative π^0 photoproduction

Article In Preparation: S. Schumann, Mainz, PRL **89** (2002) 272001, PRC **71** (2005) 015204, PRD **77** (2008) 034003



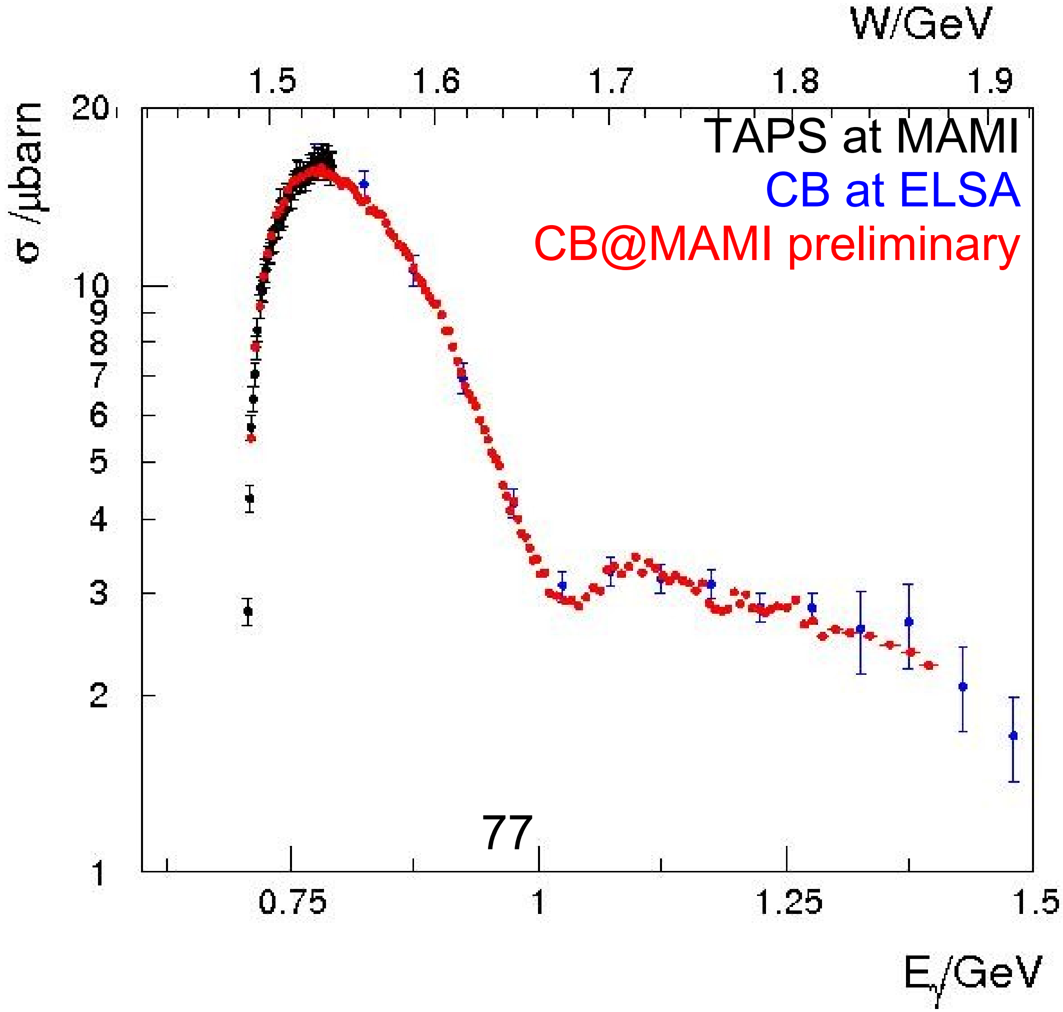
Collaboration UNIVERSITAT MAINZ

Radiative π^0 photoproduction



- **$p(\gamma,\gamma'\pi^0 p)$ linearly polarised photon asymmetry**
  - First ever measurement!
  - Plot above based on ~50% of available data
  - Improvements in normalisation etc. expected
- MAMI-C looking at radiative η-photoproduction for $\mu(S_{11}(1530))$

η photoproduction

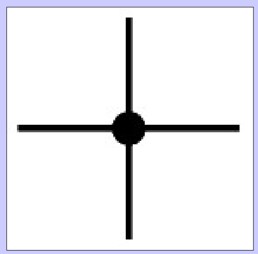


- S_{11}(1535) dominant resonance in η production
- Photoproduction and decay amplitudes of described in ChiPT
- Rare decays of η test higher orders of ChiPT
- Lowest order ChiPT amplitude of $\eta \to 3\pi^0$ proportional to $(m_u - m_d)$
- Lots to study!

Dalitz plot parameter α in $\eta\rightarrow 3\pi^0$

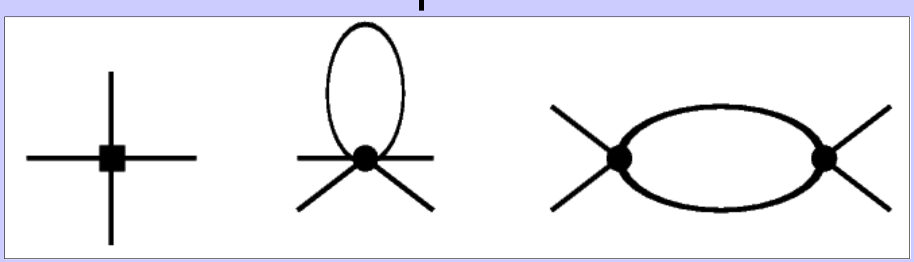
- Decay is isospin violating: get special term in Hamiltonian
- $H_{\Delta I=1}=\frac{1}{2}(m_u-m_d)(\bar{u}u-\bar{d}d)$
- Theories: Three orders of ChiPT calcs., dispersion relations, Bete Saltpeter

First Order: p^2

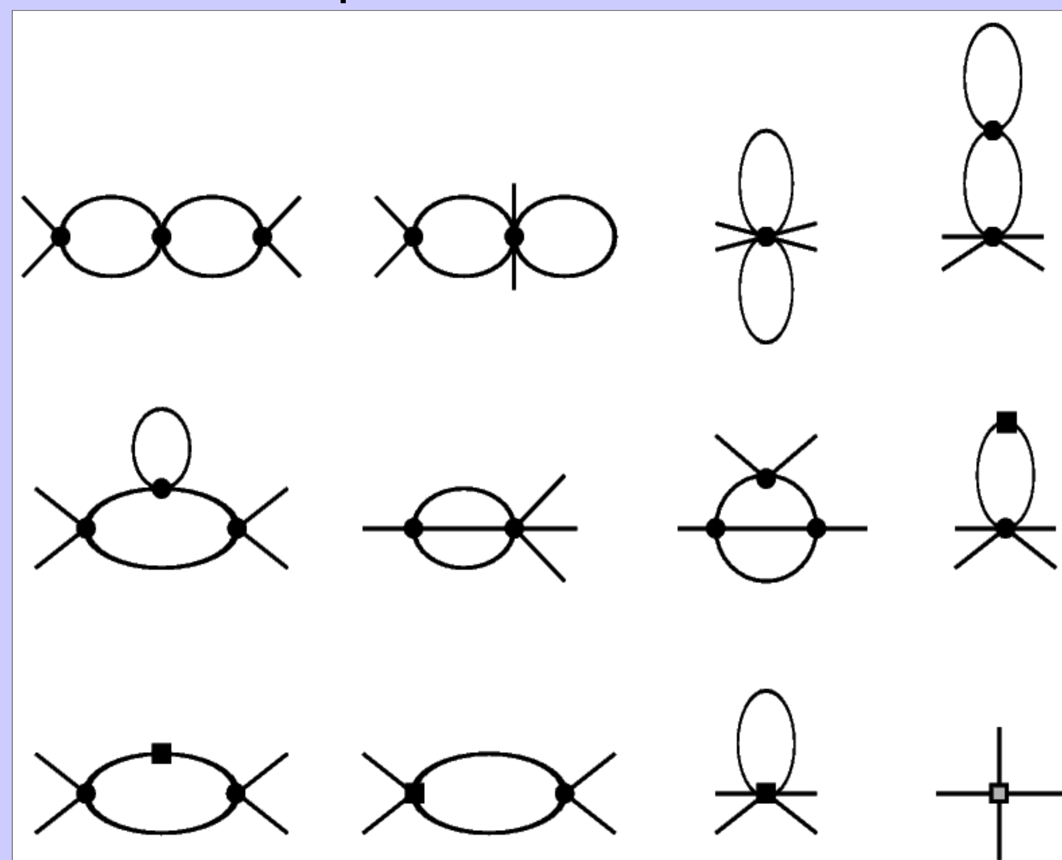


$$A(\eta\rightarrow 3\pi^0)=\frac{B_0(m_u-m_d)}{3\sqrt{3}F_\pi^2}\sim m_u-m_d$$

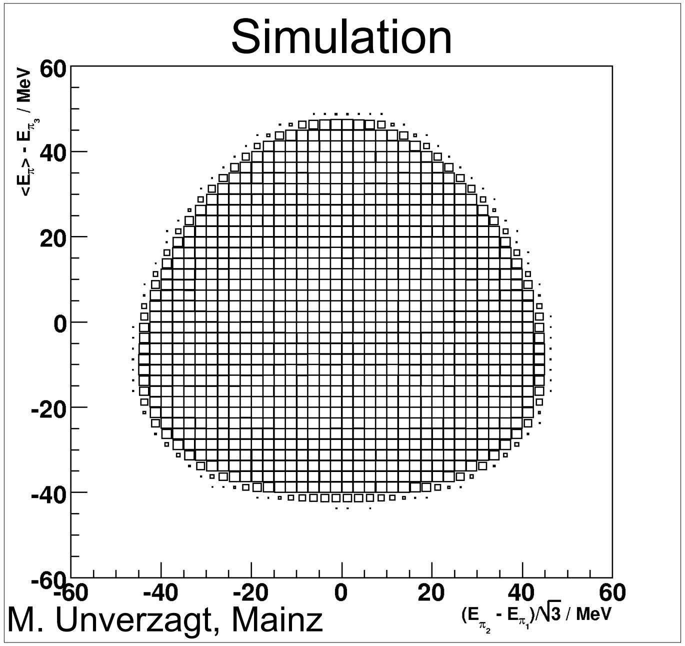
Second Order: p^4



Third Order: p^6

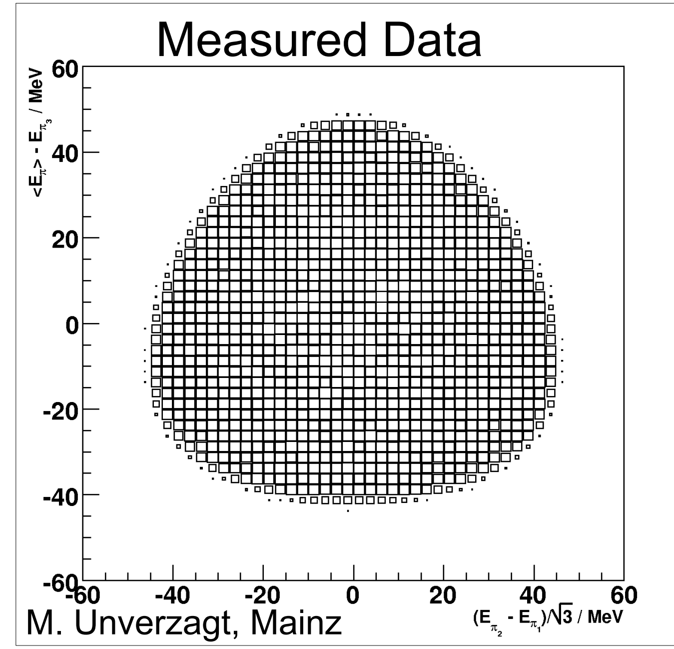


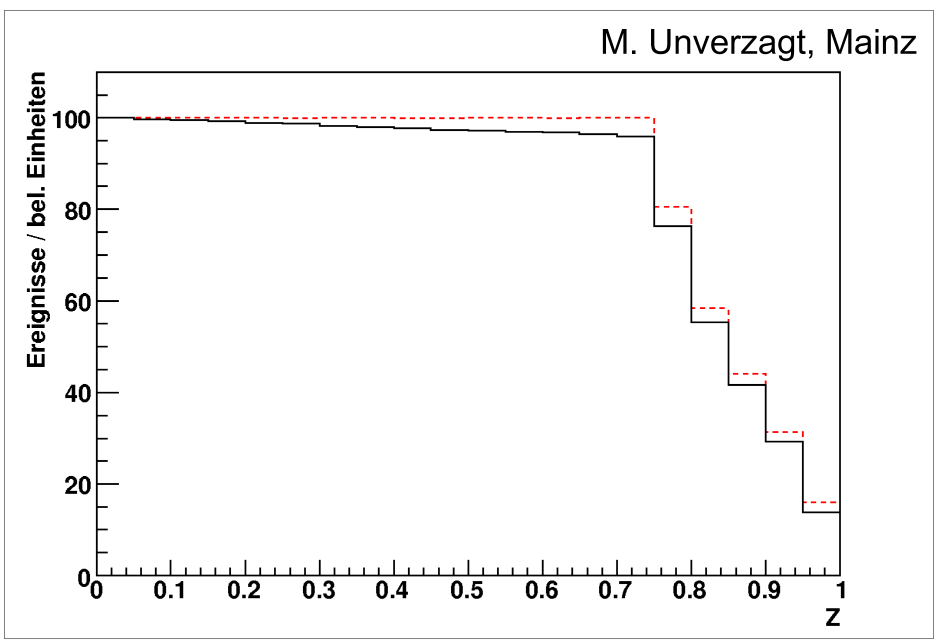
Dalitz plot parameter α in $\eta \rightarrow 3\pi^0$

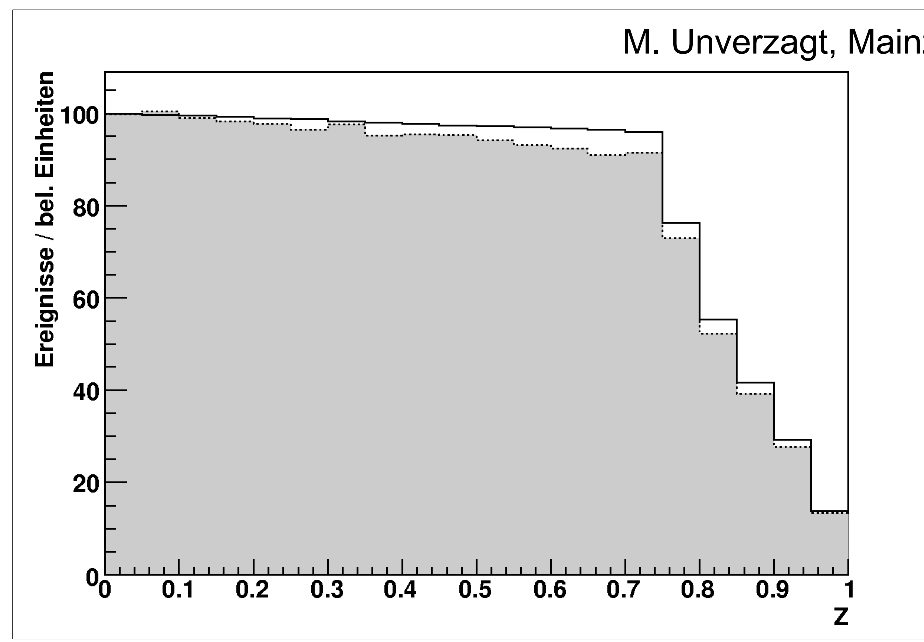


$$|A(\eta \rightarrow 3\pi^0)|^2 \sim [1 + 2\alpha z]$$

$$z = 6\sum_{i=1}^{3}\left(\frac{E_i - m_\eta/3}{m_\eta - 3m_{\pi^0}}\right)^2 = \frac{\rho^2}{\rho_{max}^2}$$







M. Unversagt, Mainz

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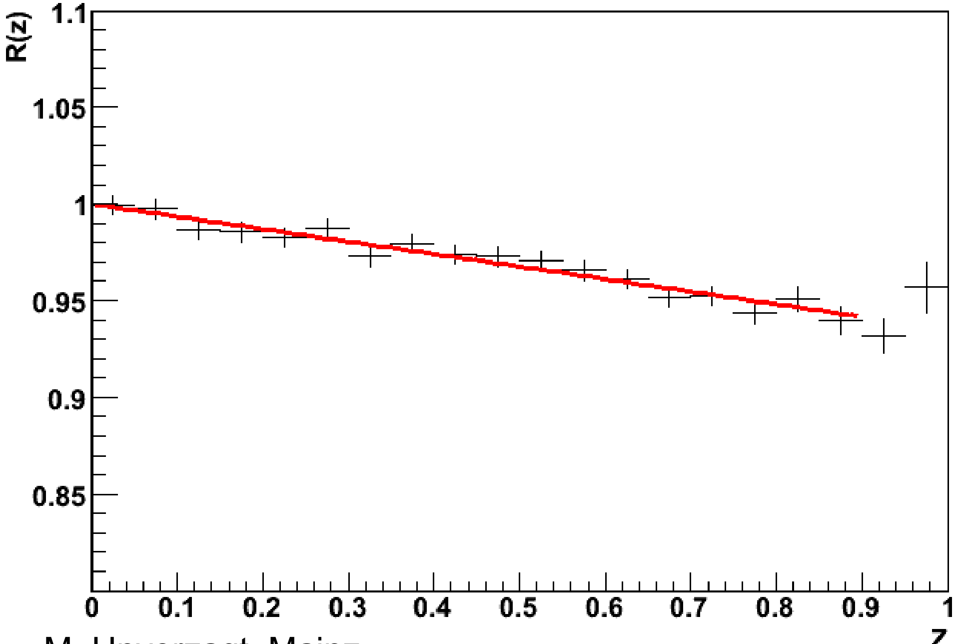
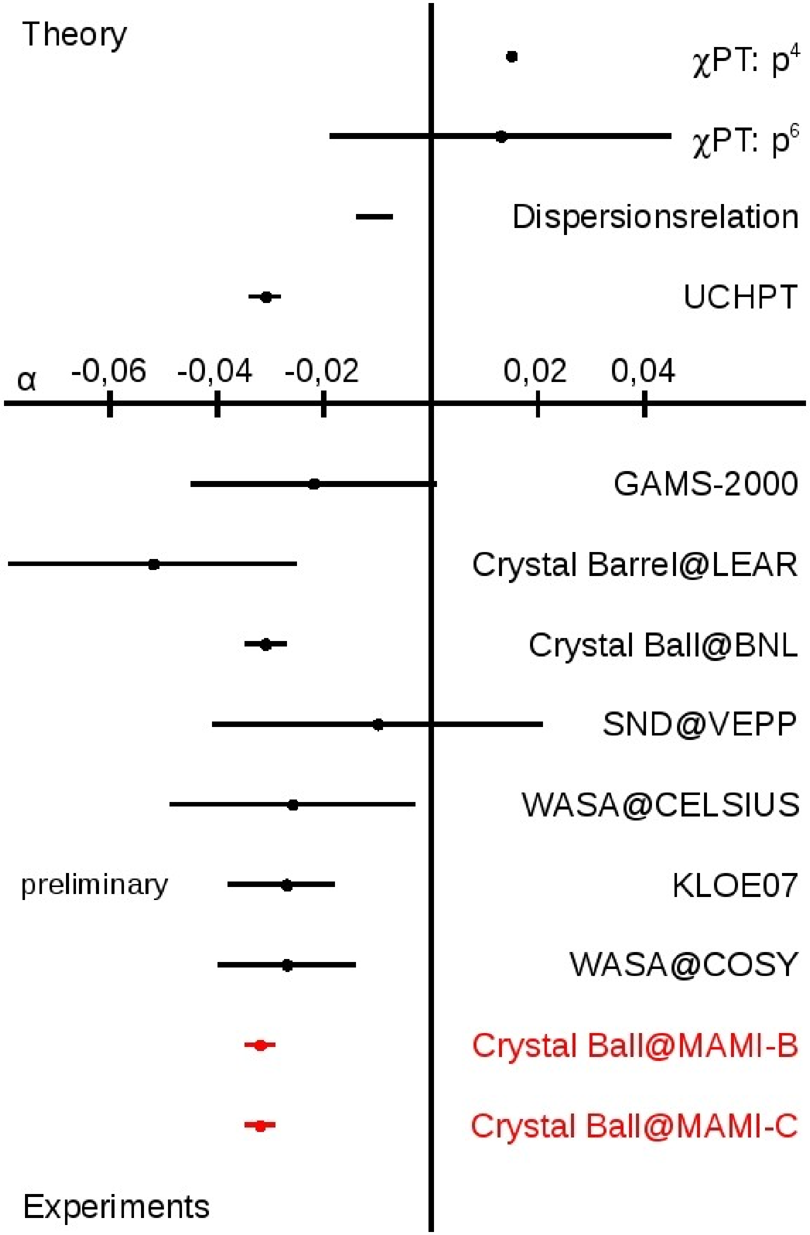
Dalitz plot parameter α in $\eta \to 3\pi^0$

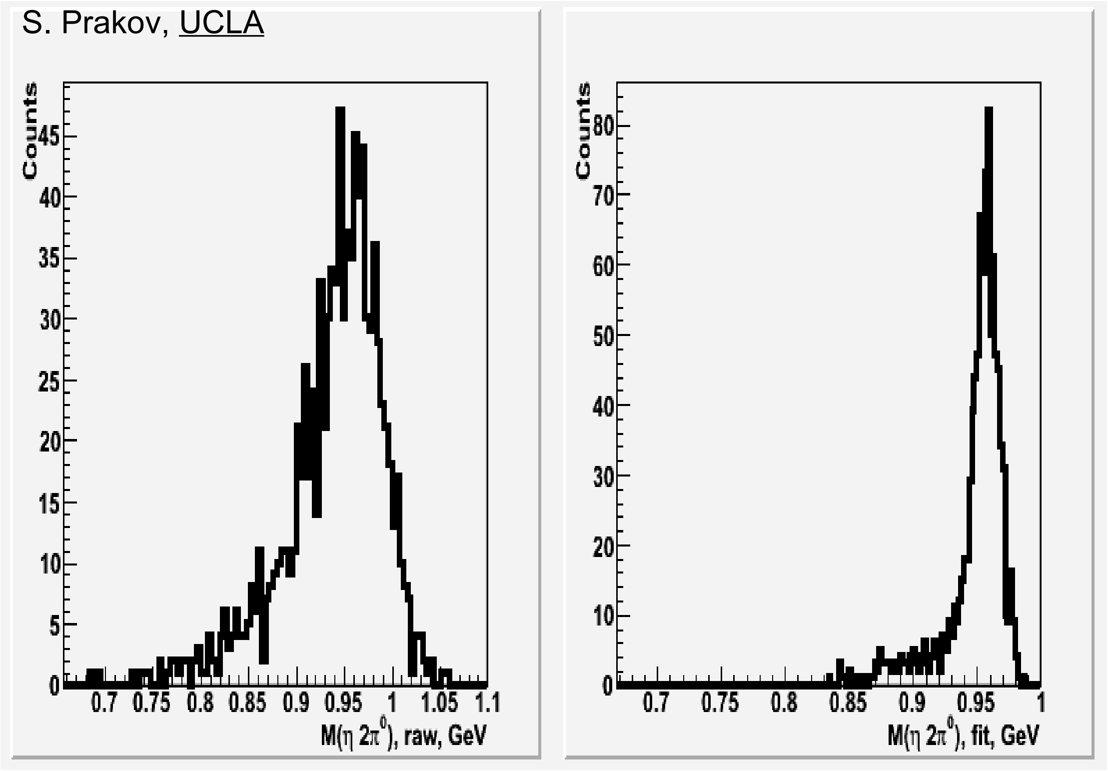


M. Unverzagt, Mainz



M. Unverzagt, Mainz

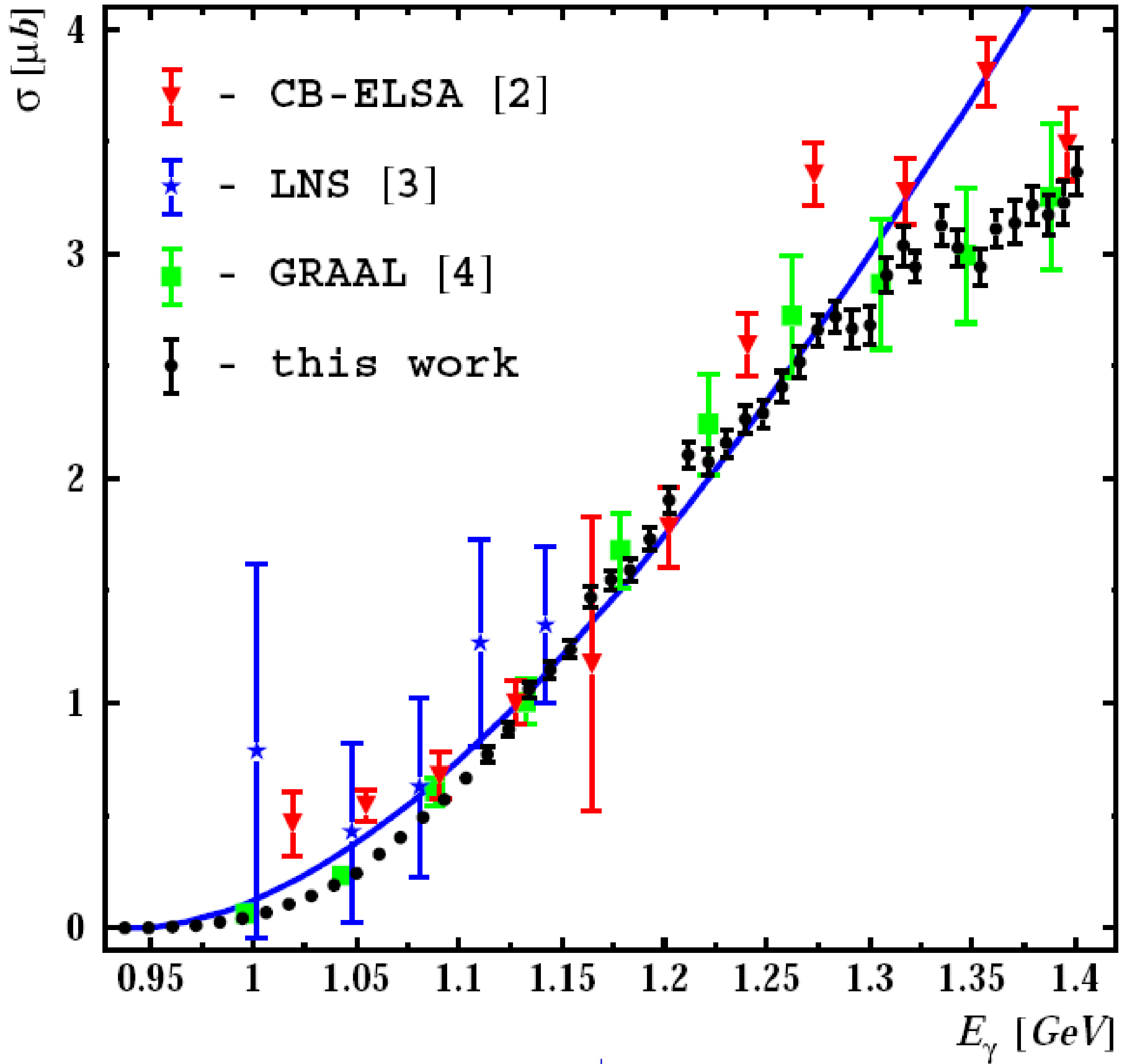
Decays of the η and η'



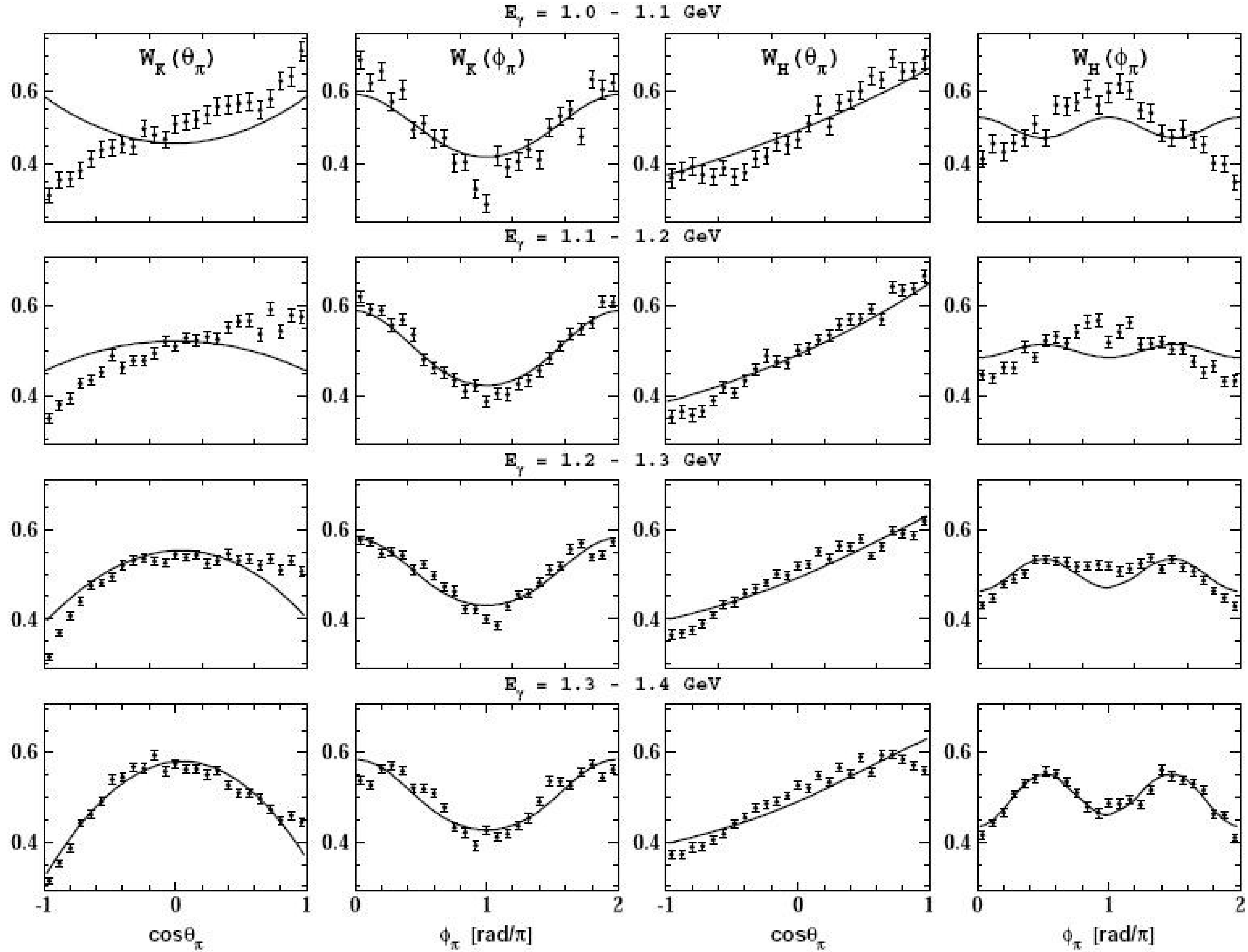
- Decay $\eta\rightarrow\pi^0\gamma\gamma$ test of higher orders of ChiPT
- Also studying: $\eta\rightarrow e^+e^-\gamma$, $4\pi^0$, $\pi^0\gamma$, $2\pi^0\gamma$, $3\pi^0\gamma$
- Ratio of decays: $\eta'\rightarrow\pi^0\pi^0\pi^0$ and $\eta'\rightarrow\eta\pi^0\pi^0$ gives information on $\eta\pi^0$ mixing
- Also studying: $\eta'\rightarrow\pi^0e^+e^-$, 3γ, $4\pi^0$ (CP violation)
- CB@MAMI will produce about $3\text{x}10^8$ η in a few years and $3\text{x}10^6$ η'

$\gamma p \to \pi^0 \eta p$

- Data: V. Kashevarov et. al, accepted for publication in EPJA, arXiv:0901.3888
- $\gamma p \to \pi^0 \eta p$ in $D_{33}(1700)$ region



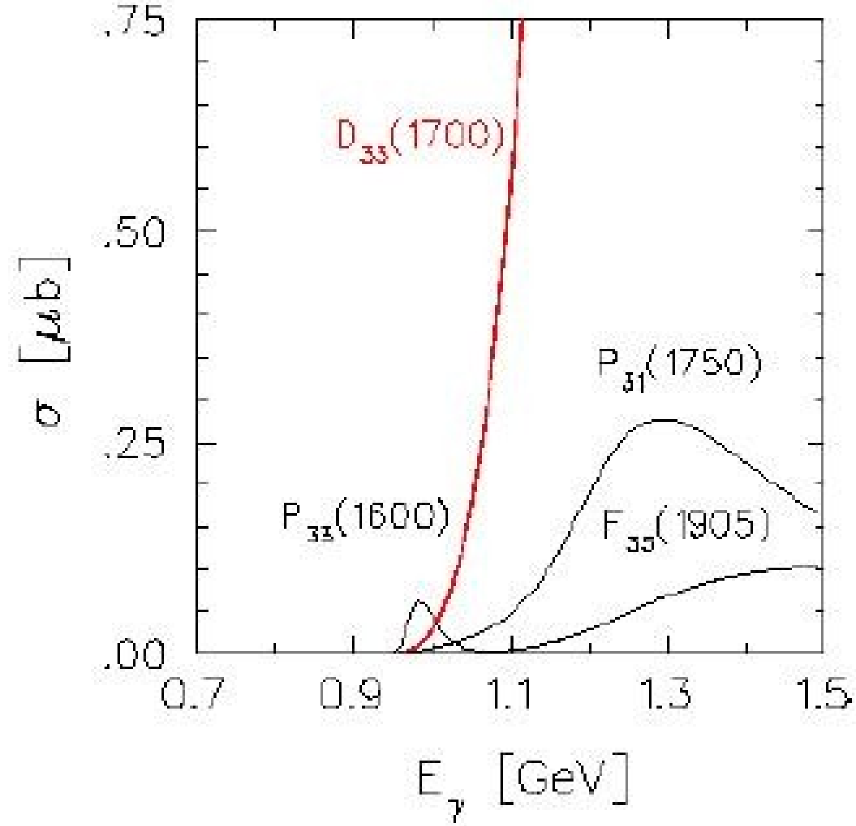
$\gamma p \rightarrow \pi^0 \eta p$



- Well described by simple model, including ONLY $D_{33}(1700)$

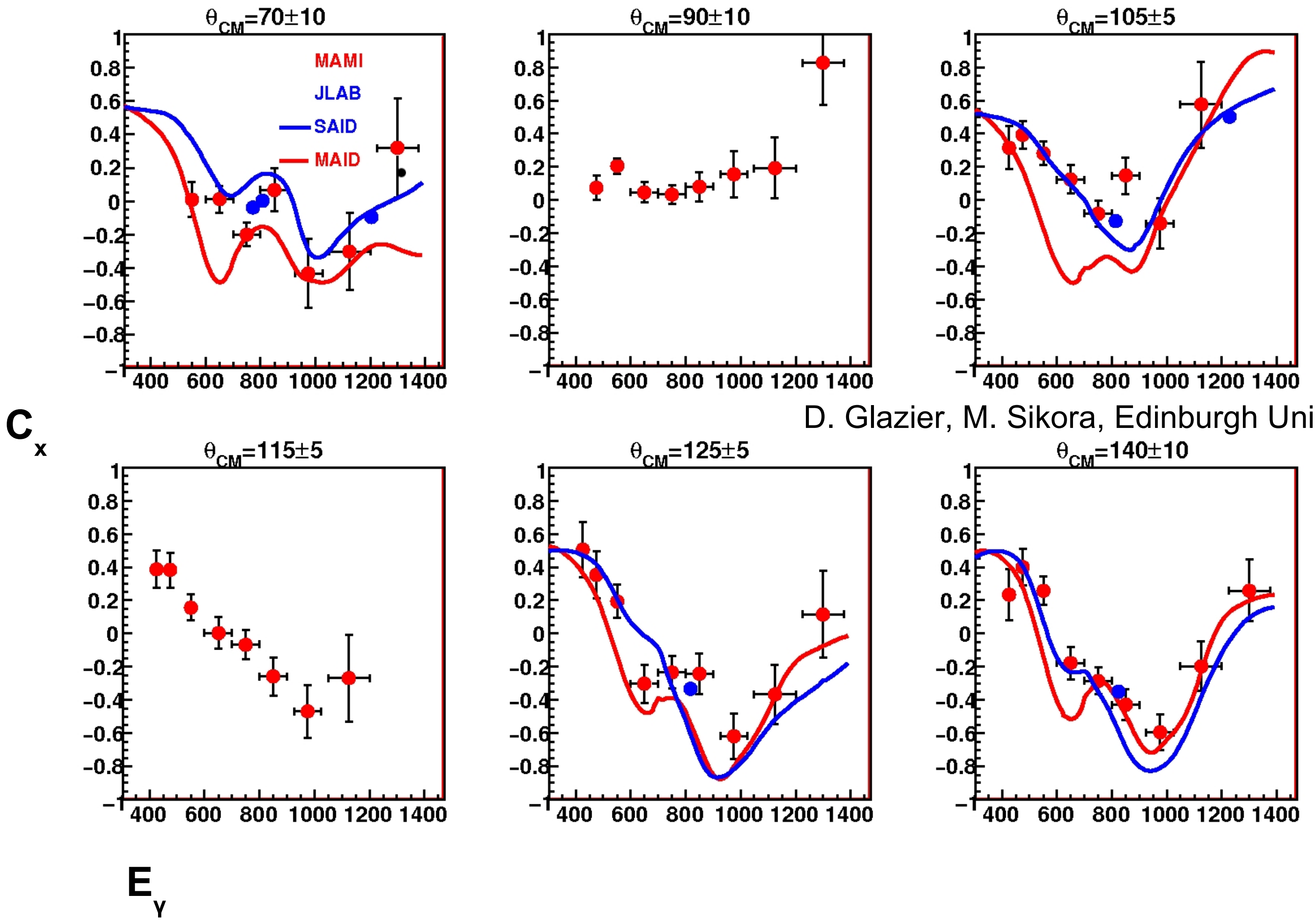
- Fix et. al EPJ A36,61-72 (2008)

$\gamma p \rightarrow \pi^0 \eta p$



- Well described by simple model, including ONLY $D_{33}(1700)$
- Same kind of dominance as Δ(1232) in π production and $S_{11}(1535)$ in η production
- Future: determine p-wave contributions
- Needs: full angular distributions and spin observables E,F and T

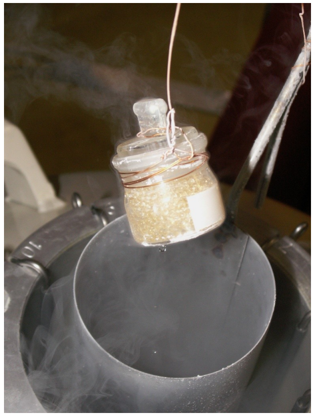
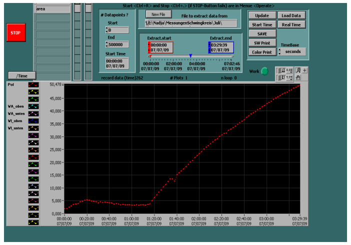
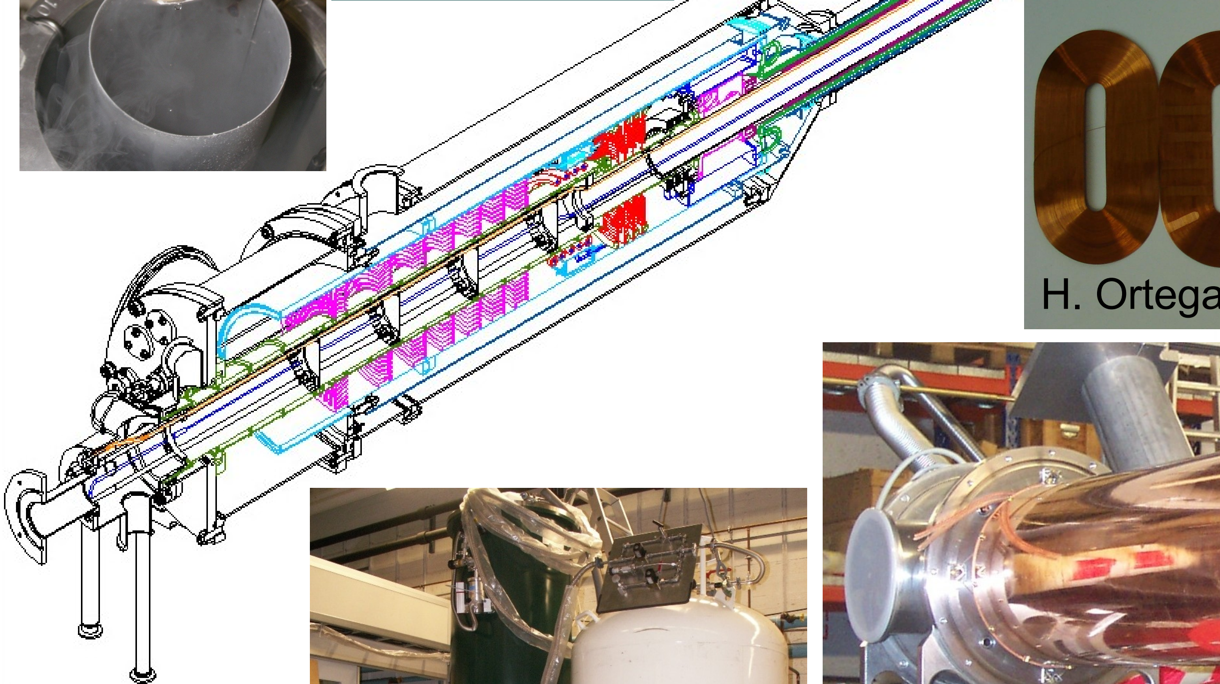
And lots more...

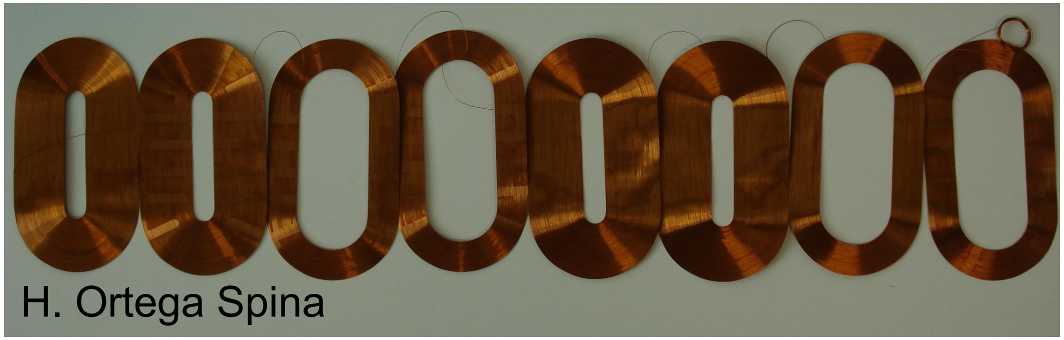


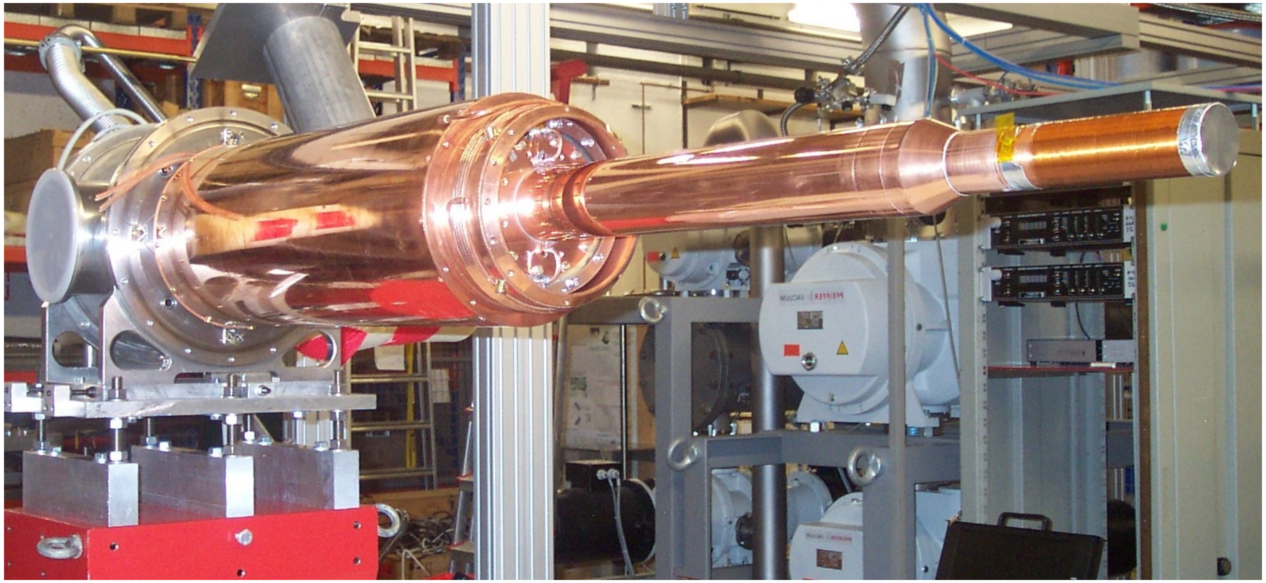
D. Glazier, M. Sikora, Edinburgh Uni.

- No time left to discuss: Recoil polarimetry: γN→πN', γN→ηN', determination of η mass, GDH integral on the neutron, in-medium modification of mesons, threshold hyperon production, double pion production and so much more...

Polarised Target

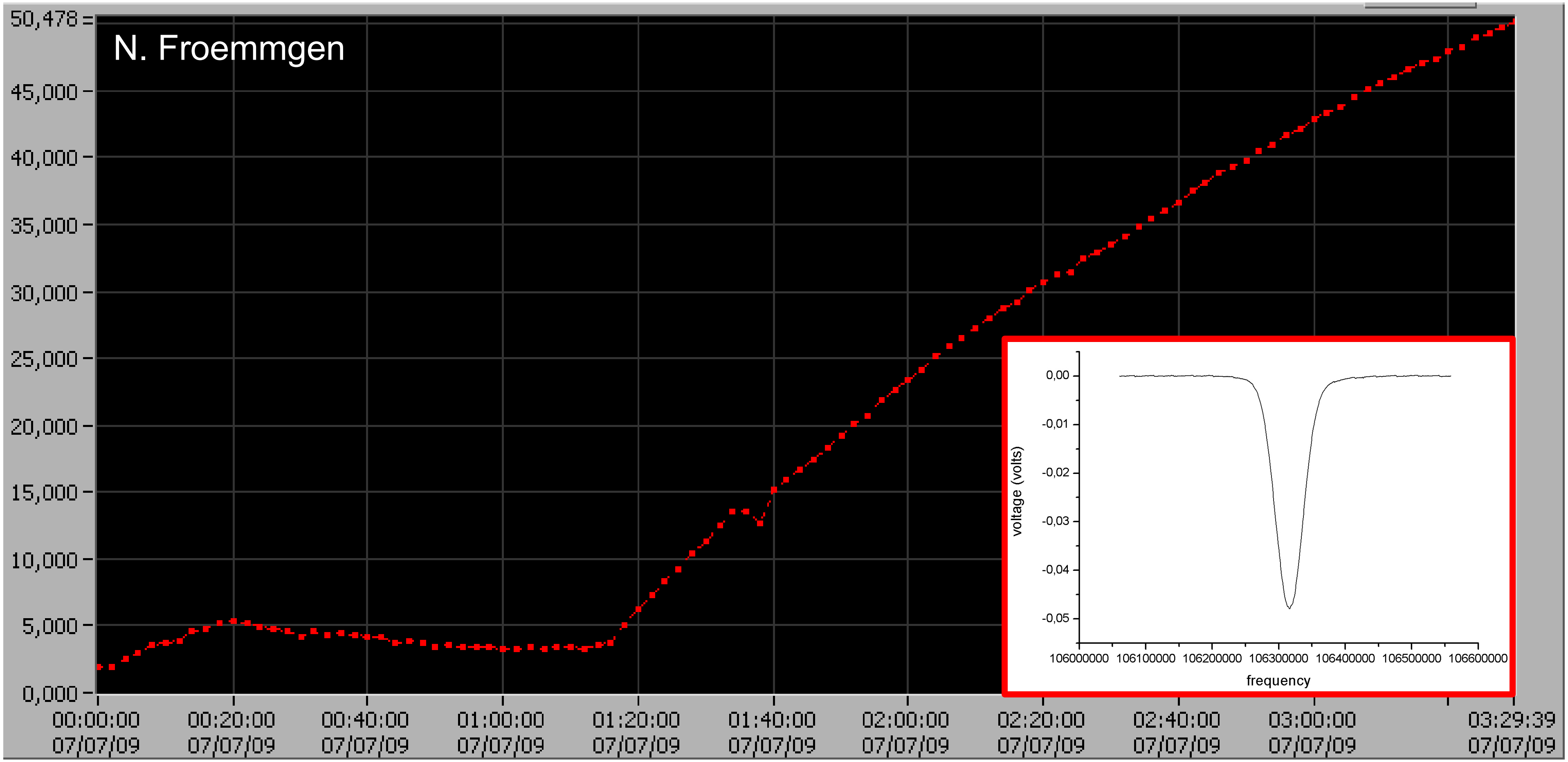






- Uses DNP to achieve ~ 90 % proton, 80 % deuteron, 50% neutron pol.
- Needs: Horiz. Dilution cryostat, polarising magnet, microwave, NMR
- Two holding coils: solenoid → longitudinal, saddle coil → transverse
- See Grigory M. Gurevich

Polarised Target



- Frozen spin target assembled: - 50 % polarisation achieved in test
- Rail system assembly in progress, detectors being made mobile
- Target to be moved into in Tagger hall

Future Highlights: Nucleon Vector Spin Polarisibilities

- Polarizabilities are fundamental structure constants of the nucleon
- Scalar polarizabilities (α, β) describe spin response to static EM field
- Vector polarizabilities describe spin response to an incident photon
- Four vector pol. (γ_{E1E1} γ_{M1M1} γ_{E1M2} γ_{M1E2}) appear at 3rd order in eff. Hamiltonian

- Scalar polarizabilities are well known:

$$\alpha^p_{E1} = [12.21 \pm 0.3(stat.) \mp 0.4(syst.) \pm 0.3(mod.)] \times 10^{-4} fm^3$$
$$\beta^p_{M1} = [1.6 \pm 0.4(stat.) \pm 0.4(syst.) \pm 0.4(mod.)] \times 10^{-4} fm^3$$

- Only two linear combinations of vector polarizabilities measured:

$$\gamma_0 = -\gamma_{E1E1} - \gamma_{M1M1} - \gamma_{E1M2} - \gamma_{M1E2} = -1.01 \pm 0.08 \pm 0.10 \times 10^{-4} fm^4$$
$$\gamma_\pi = -\gamma_{E1E1} + \gamma_{M1M1} - \gamma_{E1M2} + \gamma_{M1E2} = 8.0 \pm 1.8 \times 10^{-4} fm^4$$

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γ	Theory / 10^{-4}fm^4								Experiment / 10^{-4}fm^4
	$\mathcal{O}(p^4)$ [1]	$\mathcal{O}(p^5)$ [2]	LC4 [3]	SSE [4]	BGLMN [5]	HDPV [6]	KS [7]	DPV [8]	
E1E1	-1.4	-1.8	-2.8	-5.7	-3.4	-4.3	-5.0	-4.3	no data
M1M1	3.3	2.9	-3.1	-3.1	2.7	2.9	3.4	2.9	no data
E1M2	0.2	0.7	0.8	0.98	0.3	-0.01	-1.8	0	no data
M1E2	1.8	1.8	0.3	0.98	7.9	2.1	1.1	2.1	no data
0	3.9	-3.6	4.8	0.64	-1.5	-0.7	2.3	-0.7	$-1.01 \pm 0.08 \pm 0.13$ [9]
π	6.3	5.8	-0.8	8.8	7.7	9.3	11.3	9.3	8.0 ± 1.8 [10]

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Future Highlights: Nucleon Vector Spin Polarisibilities

- Linearly polarised photons, parallel and perpendicular to the scattering plane, unpolarised target

$$\Sigma_3 = \frac{\sigma^{\parallel} - \sigma^{\perp}}{\sigma^{\parallel} + \sigma^{\perp}}$$

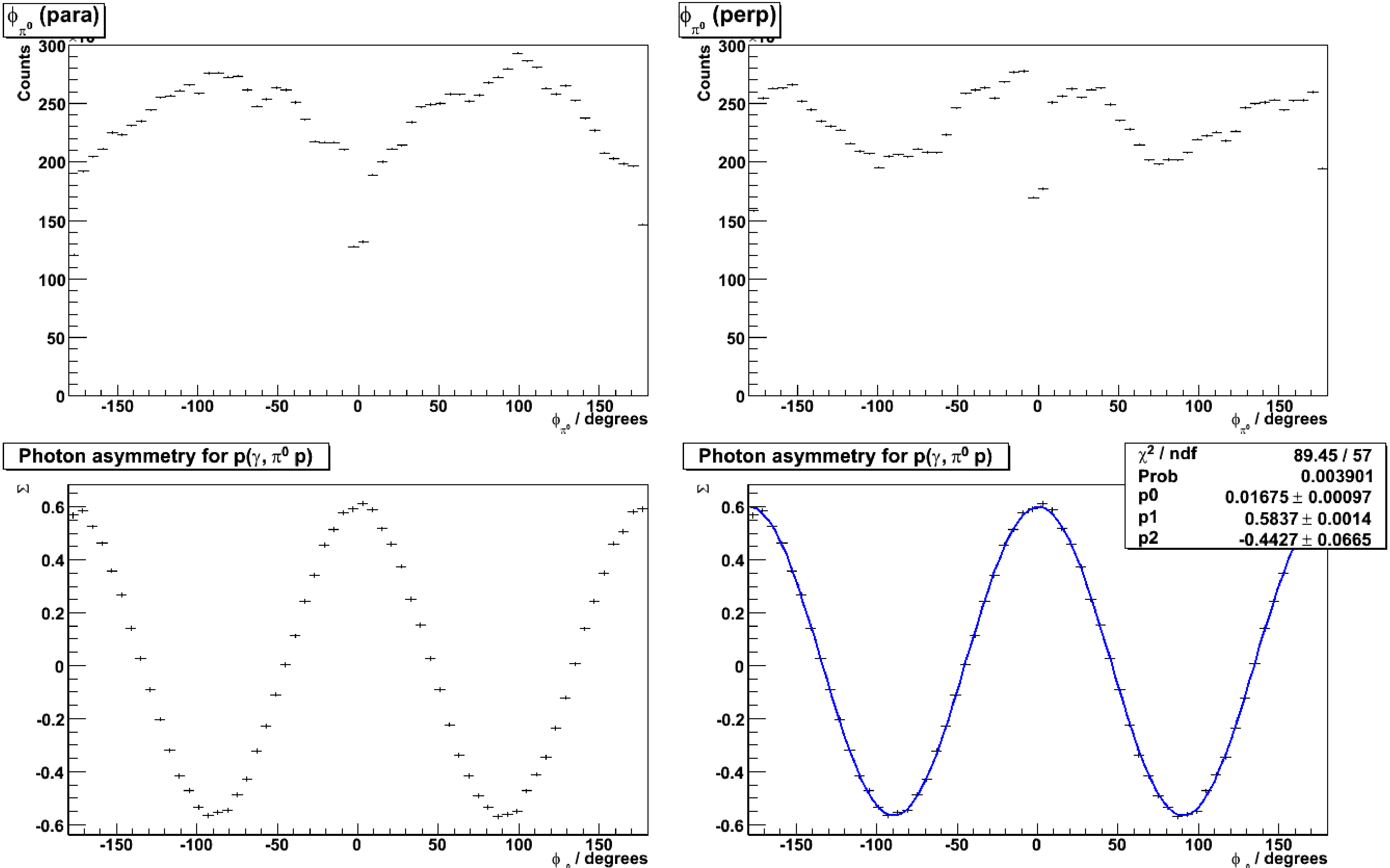
- Circularly polarised photons (left-handed (L) and right-handed (R)), longitudinally polarised target

$$\Sigma_{2z} = \frac{\sigma^R_{+z} - \sigma^L_{+z}}{\sigma^R_{+z} + \sigma^L_{+z}} = \frac{\sigma^R_{+z} - \sigma^R_{-z}}{\sigma^R_{+z} + \sigma^R_{-z}}$$

- Circularly polarised photons (left-handed (L) and right-handed (R)), transversely polarised target

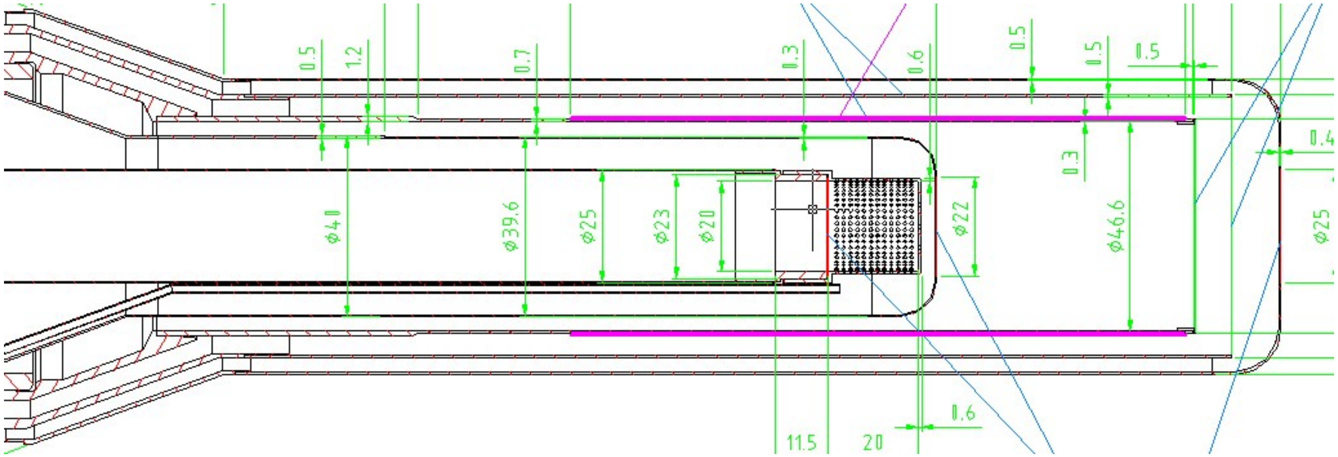
$$\Sigma_{2x} = \frac{\sigma^R_{+x} - \sigma^L_{+x}}{\sigma^R_{+x} + \sigma^L_{+x}} = \frac{\sigma^R_{+x} - \sigma^R_{-x}}{\sigma^R_{+x} + \sigma^R_{-x}}$$

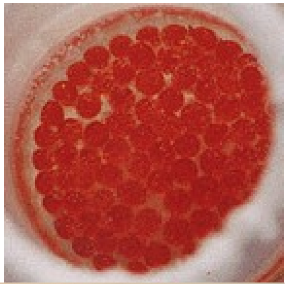
Future Highlights: Nucleon Vector Spin Polarisibilities

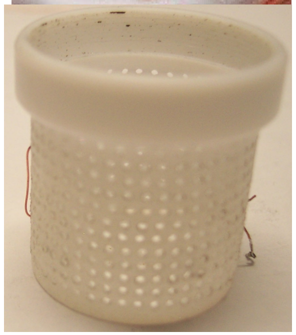


- Σ_3 for π^0 photoproduction – September 2004

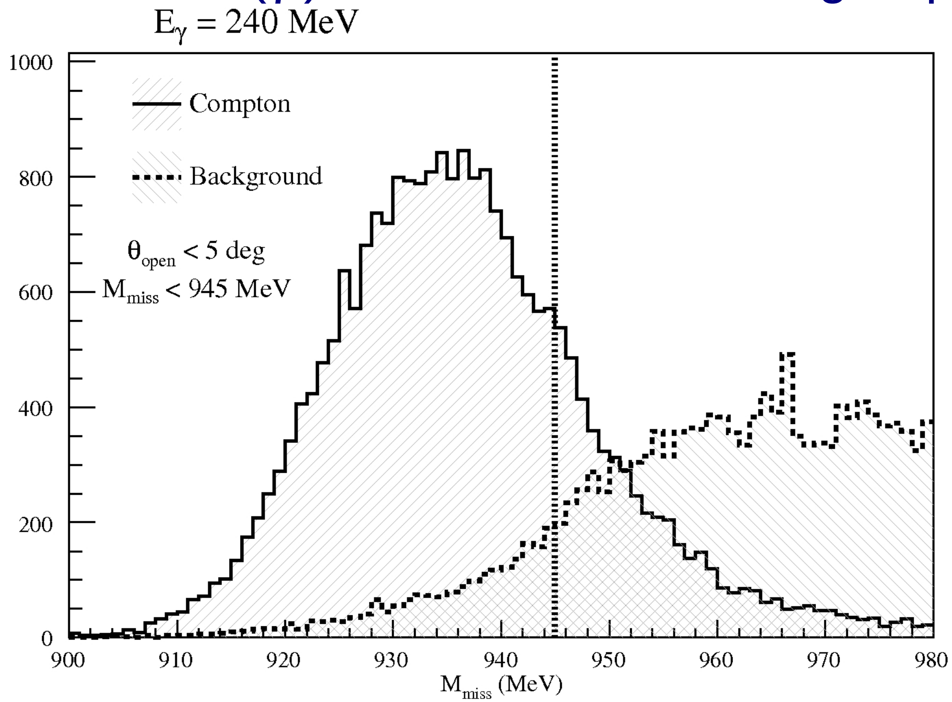
Future Highlights: Nucleon Vector Spin Polarisibilities

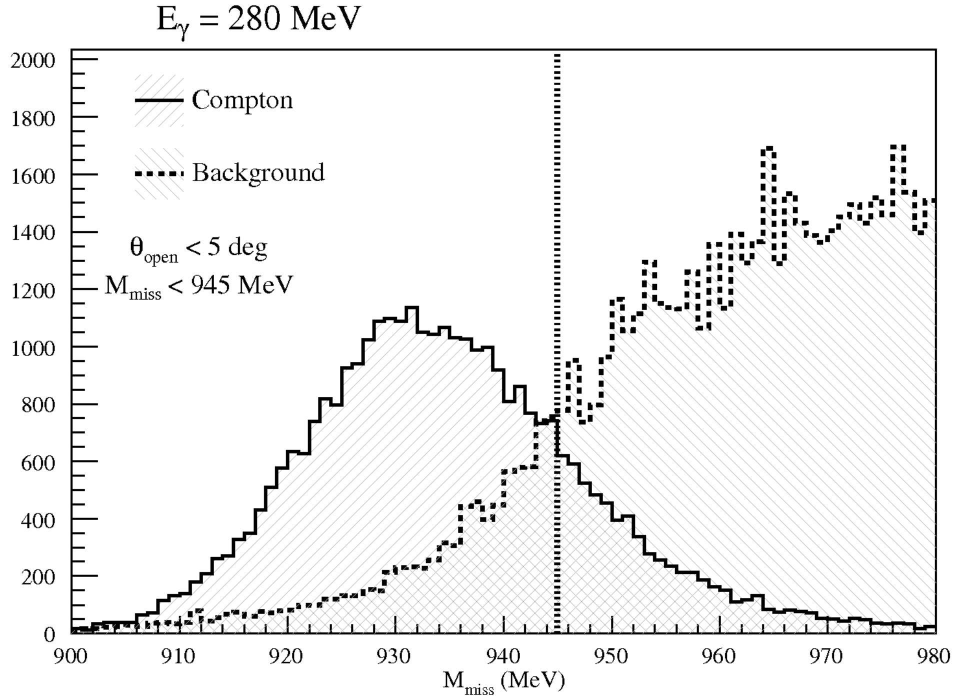




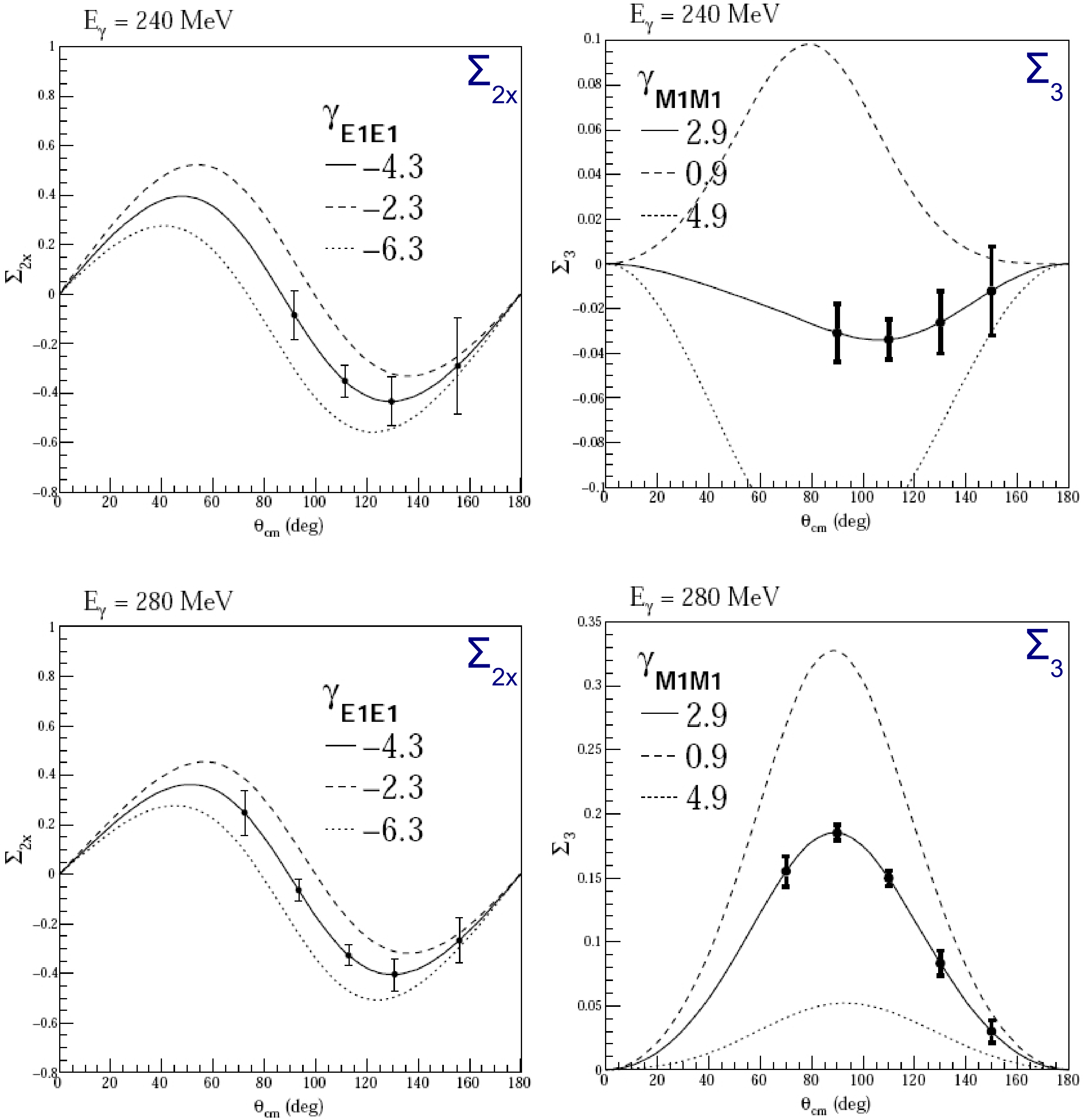


Sim. MM(γ') on Butanol – showing π^0 photoproduction and Compton contributions





Future Highlights: Nucleon Vector Spin Polarisibilities

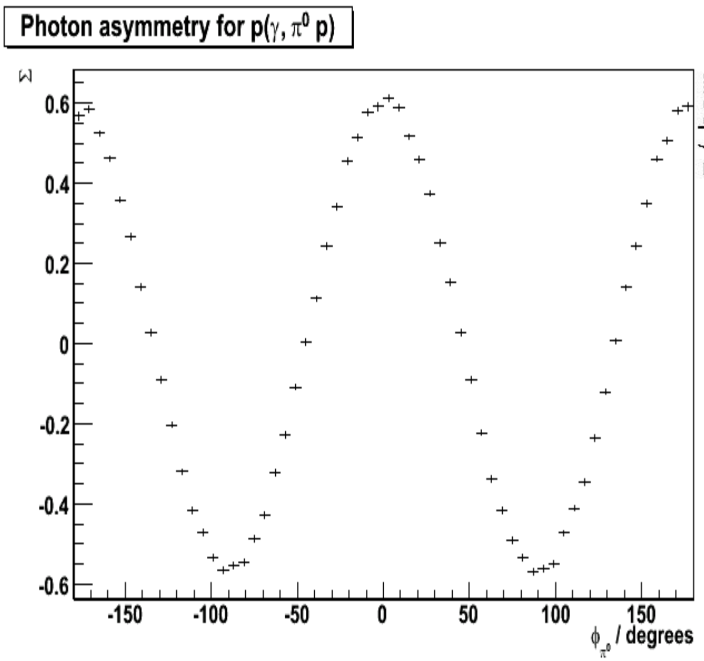


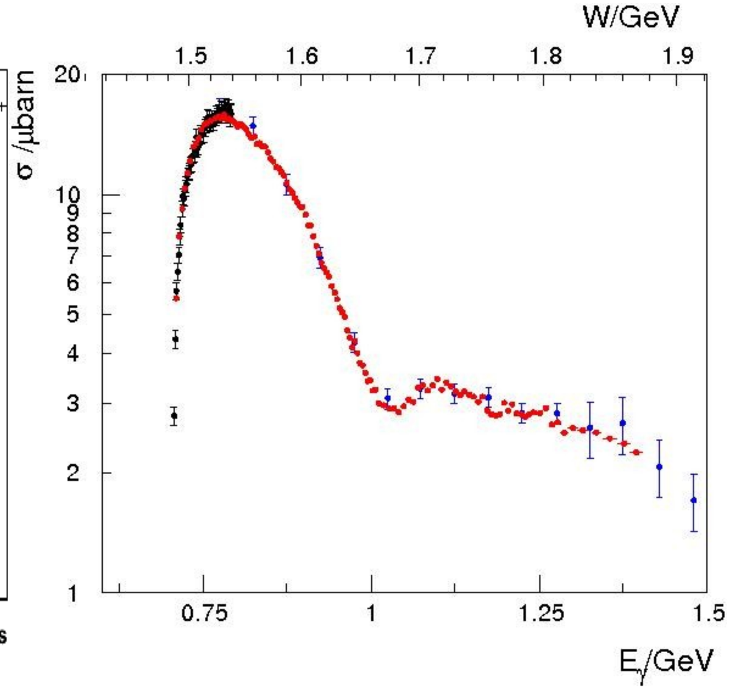
- Σ_3 100 hours measurement
- Σ_{2x} 300 hours measurement
- Curves from:-

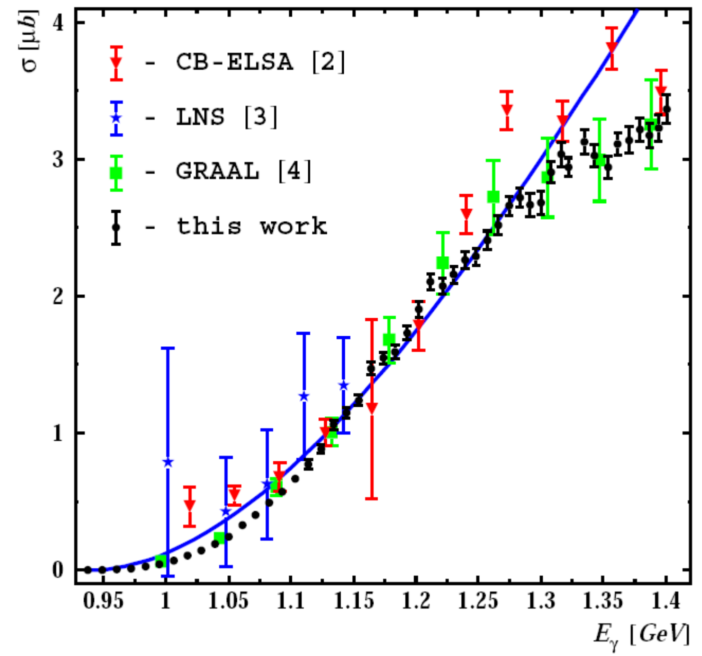
B. Pasquini, D. Drechsel, M. Vanderhaeghen, Phys. Rev. C **76** 015203 (2007)

B. Pasquini, D. Drechsel, M. Vanderhaeghen, Phys. Rept. **378** 99 (2003)

Conclusions







- The CB@MAMI experimental setup is a highly flexible 4π detector system
- Ideal for studies of nucleon resonances and polarisation observables and rare final states
- "η-factory" to test fundamental symmetries
- Investigating properties of nucleon, nucleon resonances and nuclei using a high quality photon beam
- New polarised target and recoil polarimetry → broad range of new resonance studies $P_{33}(1232)$, $S_{11}(1535)$, $D_{33}(1700)$