Photoproduction of Mesons from the Quasi–Free Nucleons

Presented by Irakli Keshelashvili

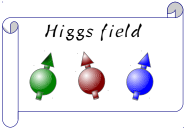
University of Basel

May 29^{th}, 2014

Outline

1. Motivation
2. Experiment
   - Crystal Ball / TAPS at MAMI (Uni. Mainz)
   - Crystal Barrel / TAPS at ELSA (Uni. Bonn)
3. $N\pi^o$
   - $\gamma d \rightarrow N\pi^0(N_{sp.})$...
4. $N\eta$
   - $\gamma d \rightarrow N\eta(N_{sp.})$ and $\gamma^3He \rightarrow N\eta(X_{sp.})$...
   - $\vec{\gamma}\vec{d} \rightarrow N\eta(N_{sp.})$...
5. $N\pi^o\pi^x$
   - $\vec{\gamma}d \rightarrow N\pi^0\pi^0(N_{sp.})$ and $N\pi^0\pi^\pm(N_{sp.})$...
6. $N\pi^o\eta$
   - $\gamma d \rightarrow N\pi^0\eta(N_{sp.})$...
7. Summary

First Level of Complication / Unknown NDF



The mass of the 3 quarks

together in the nucleons

weighs only about 2 %

Properties of Hadrons

M, Γ_i, $A_{1/2}$, $A_{3/2}$, ...

Hadron Models

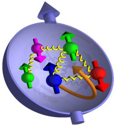
Reaction Models

P W A

QCD

Exp. Observables

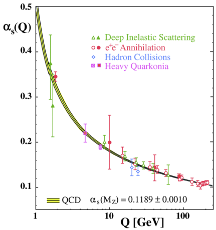
$d\sigma/d\Omega$, Σ, P, T, ...



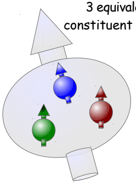
Many body ⇒ complex

valence quarks

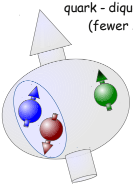
sea quarks & gluons



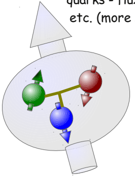
3 equivalent constituent quarks



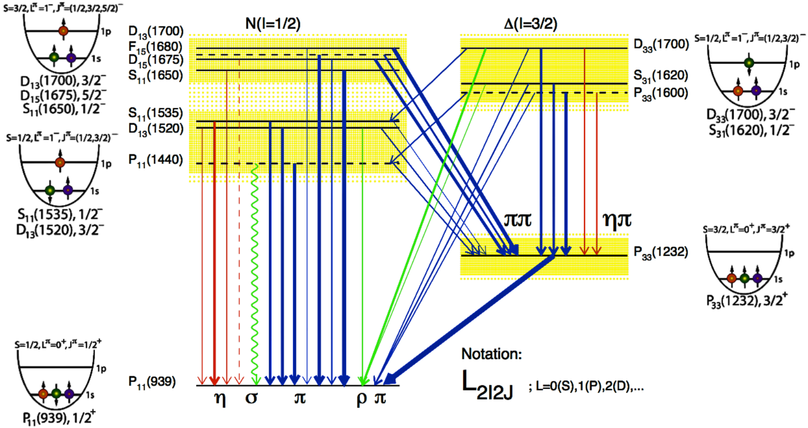
quark - diquark models (fewer states)



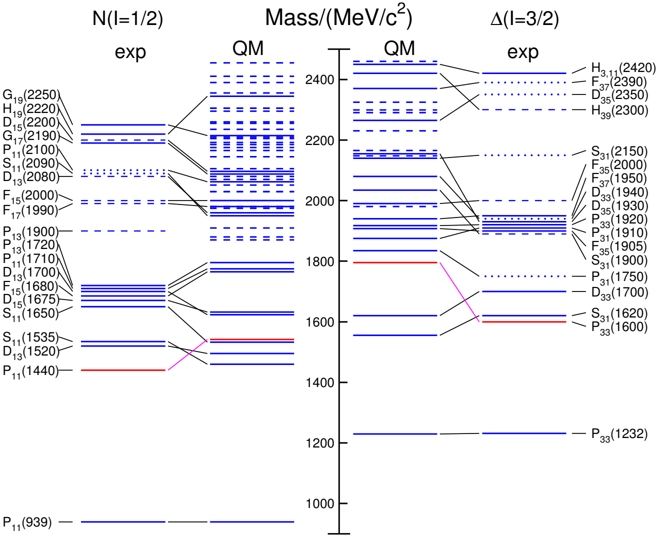
quarks - flux tubes etc. (more states)



Low – Lying Excited States and η as an Isospin Filter

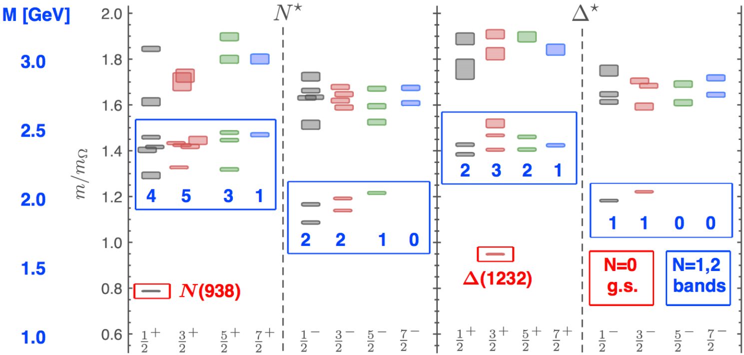


Known Excited States - Constituent Quark Model (S. Capstick and W. Roberts)



Nucleon Resonances from Lattice QCD

(R.G. Edwards et al., PRD84 (2011) 074508)



Basic features agree with expectations from $SU(3) \otimes O(3)$ symmetry:

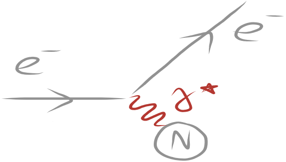
- **counting of levels consistent with non-relativistic quark model**
- **no parity doublets**

- **Lattice results of course in very early state, m_π =400 MeV...**

Experiment

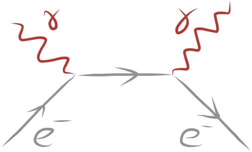
Experiment: Setup

Electron scattering



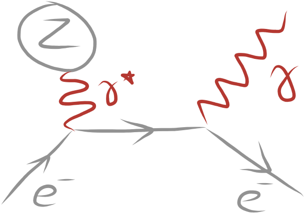
Compton[(N)] scattering

1906 Thomson[(N)]



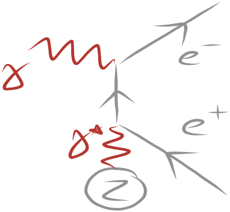
Bremsstrahlung

1895 Röntgen[(N)]

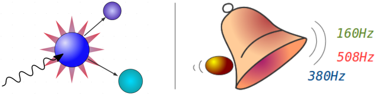


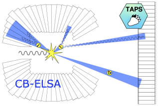
Bethe[(N)] - Heitler

1932 Anderson[(N)]

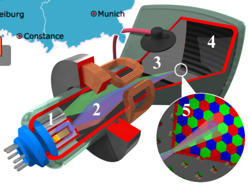



3.5 GeV
1.6 GeV


160Hz
508Hz
380Hz

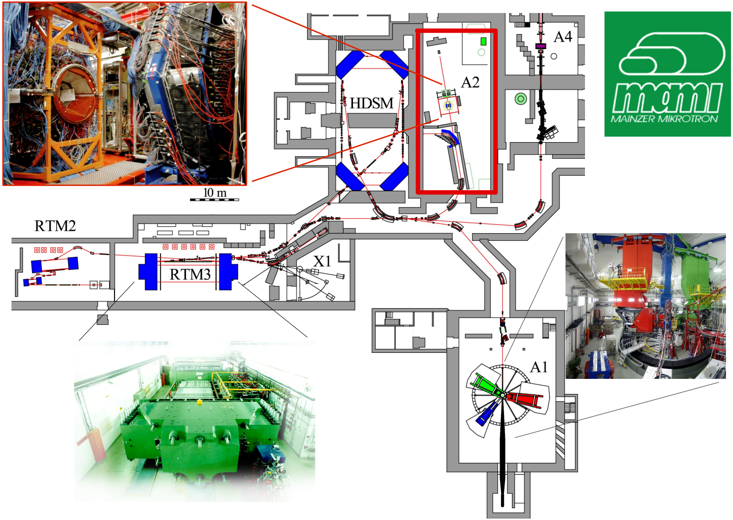

TAPS
CB-ELSA


DESY
Greifswald
Rostock
mburg
Berlin
Frankfurt (Oder)
Münster
Witten/Herdecke
Göttingen
Hagen
Cologne
Bonn
Mainz
Jena
Dresden
ankfurt a.M.
Würzburg
Mannheim
Heidelberg
Erlangen-Nuremberg
Stuttgart
Tübingen
Freiburg
Munich
Constance
Basel

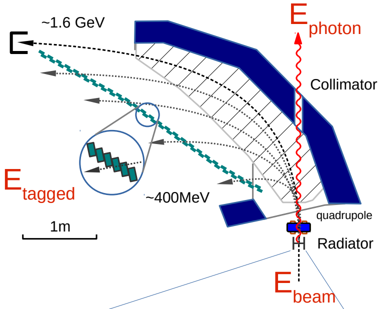

1
2
3
4
5

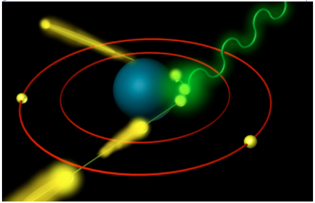
MAinzer MIcrotron - MAMI (Continuous wave elecron accelerator)

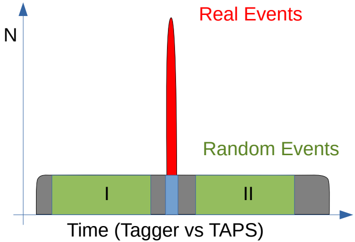
$E_e \approx 1.6$ GeV ($I_{unp.} < 100\mu$A or $I_{pol.} < 20\mu$A)

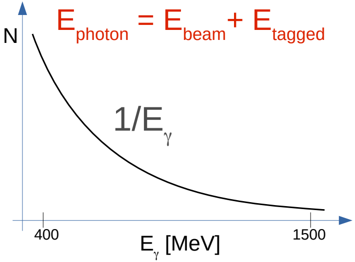


Glasgow Tagger System







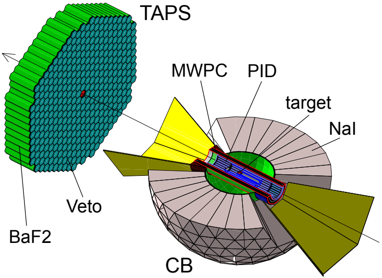


The Crystal Ball / TAPS Detector at MAMI

- **Crystal Ball**: 672×NaI ($16X_0$)
  PMT read-out
- **PID**: 24×[4mm] ϕ symetric
  Plastic scintillator barrel
- **MWPC**: 2×3 layer

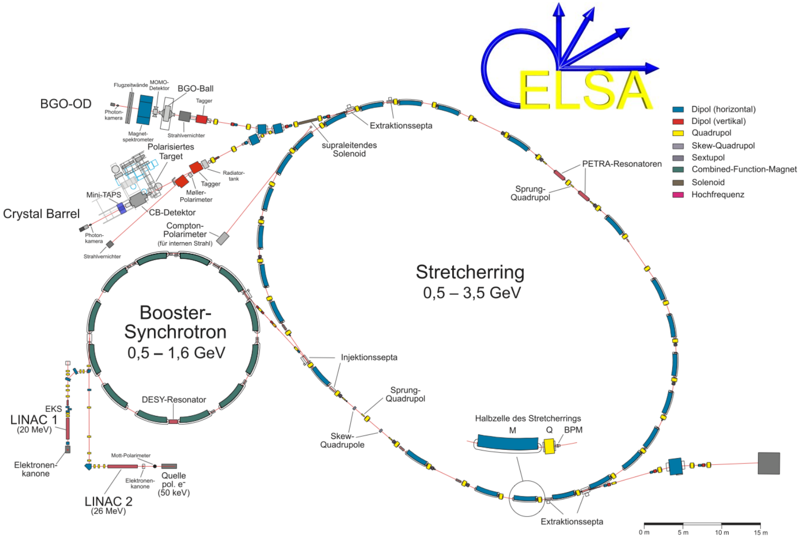
- **TAPS**: 370×BaF_2 & 72×$PbWO_4$
  PMT read-out
- **VETO**: 384×[5mm]
  Plastic scintillator wall

- **Hardware trigger**
  $L1$-ΣE_i & $L2$-Multi.

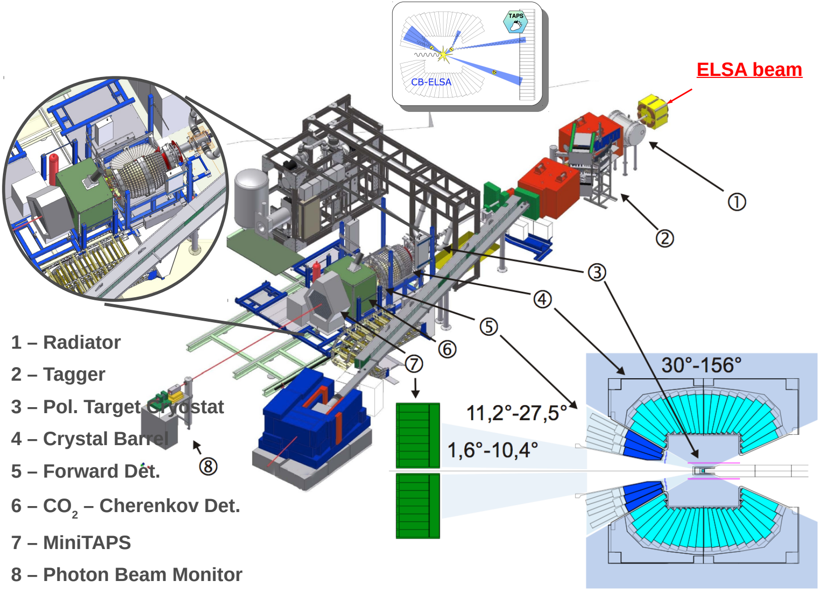


$\sim 4\pi$ acceptance

Electron Stretcher Accelerator – **ELSA**



The Crystal Barrel / TAPS Detector at ELSA



1 – Radiator

2 – Tagger

3 – Pol. Target Cryostat

4 – Crystal Barrel

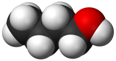
5 – Forward Det.

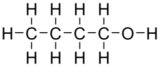
6 – CO_2 – Cherenkov Det.

7 – MiniTAPS

8 – Photon Beam Monitor

Frozen Spin Target @ Uni. Bonn





Bonn: H. Dutz, S. Goertz

Bochum: W. Meyer, S. Reichertz

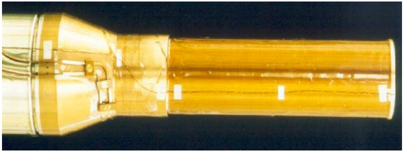
Target: Butanol (10 H/D + 4 C + O)

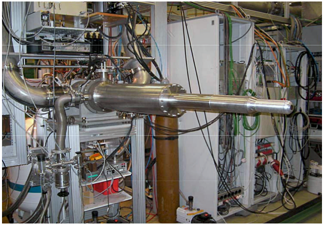
Dilution refrigerator ($^3He/^4He$)

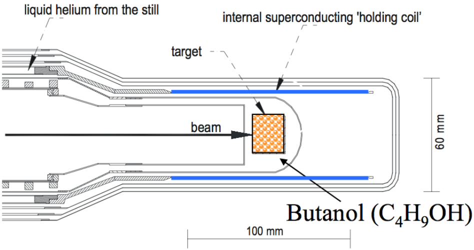
Integrated solenoid long./trans. (0.4 T)

Relaxation time T ~1000h

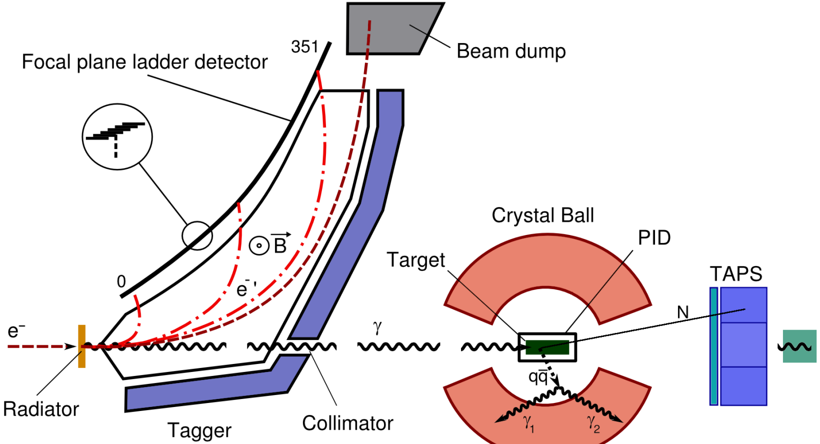
Polarization ~80 %







Simplified Overview



Reaction Identification

Neutral and charged particles:

decay channel	σ_p $\gamma p \to \eta p$	σ_n $\gamma n \to \eta n$	$\sigma_{\mathbf{incl}}$ $\gamma N \to \eta N$
$\eta \to 2\gamma$	$2n_\eta$ & $1c_p$	$2n_\eta$ & $1n_n$	$2n$ | σ_p | σ_n
$\eta \to 6\gamma$	$6n_\eta$ & $1c_p$	$6n_\eta$ & $1n_n$	$6n$ | σ_p | σ_n

Find best combination with χ^2 test:

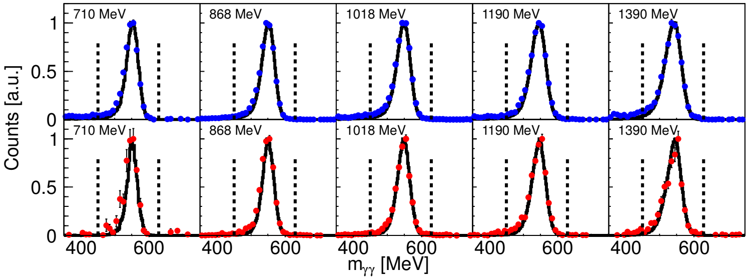
$\eta \to 2\gamma$ (σ_n, σ_{incl}):

$$\chi^2 = \frac{(m_k(\gamma\gamma) - m_\eta)^2}{(\Delta m_k(\gamma\gamma))^2} \quad k = 1, ..., 3$$

$\eta \to 6\gamma$:

$$\chi^2 = \sum_{k=1}^{3} \frac{(m_k(\gamma\gamma) - m_{\pi^0})^2}{(\Delta m_k(\gamma\gamma))^2}$$

Invariant Mass Distributions (shown for ^{3}He - data)



- Nntegrate $M_{\gamma\gamma}\,(E, \cos(\theta))$ between 450 and 630 MeV
- Normalize with photon flux
- Detection efficiency correction (MC)
- Nucleon detection efficiency correction (hydrogen data)

$$\gamma + p \to \eta(6g) + p \qquad \gamma + p \to \pi^0(2\gamma) + \pi^+ + n$$

Results

- $\gamma d \rightarrow N\pi^0(N_{sp.})$
- $\gamma d \rightarrow N\eta(N_{sp.})$ and $\gamma^3He \rightarrow N\eta(X_{sp.})$
- $\vec{\gamma}\vec{d} \rightarrow N\eta(N_{sp.})$
- $\vec{\gamma}d \rightarrow N\pi^0\pi^0(N_{sp.})$ and $N\pi^0\pi^\pm(N_{sp.})$
- $\gamma d \rightarrow N\pi^0\eta(N_{sp.})$

Ph.D. Work of Manuel Dieterle

PRL **112,** 142001 (2014) PHYSICAL REVIEW LETTERS week ending 11 APRIL 2014

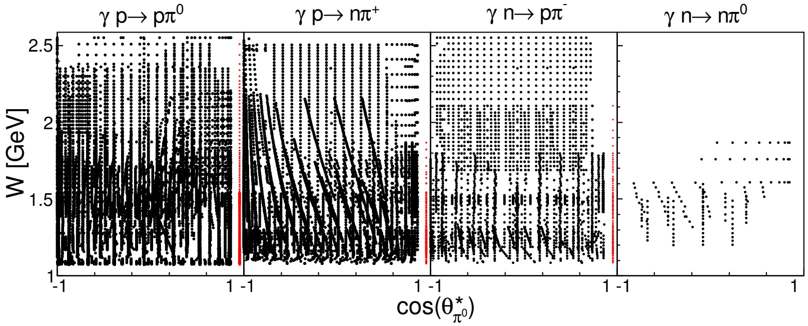
Photoproduction of π^0 Mesons off Neutrons in the Nucleon Resonance Region

M. Dieterle,[1] I. Keshelashvili,[1] J. Ahrens,[2] J. R. M. Annand,[3] H. J. Arends,[2] K. Bantawa,[4] P. A. Bartolome,[2] R. Beck,[2,5] V. Bekrenev,[6] A. Braghieri,[7] D. Branford,[8] W. J. Briscoe,[9] J. Brudvik,[10] S. Cherepnya,[11] B. Demissie,[9] E. J. Downie,[2,3,9] P. Drexler,[12] L. V. Fil'kov,[11] A. Fix,[13] D. I. Glazier,[8] D. Hamilton,[3] E. Heid,[2] D. Hornidge,[14] D. Howdle,[3] G. M. Huber,[15] I. Jaegle,[1] O. Jahn,[2] T. C. Jude,[8] A. Käser,[1] V. L. Kashevarov,[2,11] R. Kondratiev,[16] M. Korolija,[17] S. P. Kruglov,[6] B. Krusche,[1,*] A. Kulbardis,[6] V. Lisin,[16] K. Livingston,[3] I. J. D. MacGregor,[3] Y. Maghrbi,[1] J. Mancell,[3] D. M. Manley,[4] Z. Marinides,[9] M. Martinez,[2] J. C. McGeorge,[3] E. McNicoll,[3] D. Mekterovic,[17] V. Metag,[12] S. Micanovic,[17] D. G. Middleton,[14] A. Mushkarenkov,[7] B. M. K. Nefkens,[10] A. Nikolaev,[2,5] R. Novotny,[12] M. Oberle,[1] M. Ostrick,[2] B. Oussena,[2,9] P. Pedroni,[7] F. Pheron,[1] A. Polonski,[16] S. N. Prakhov,[10] J. Robinson,[3] G. Rosner,[3] T. Rostomyan,[1] S. Schumann,[2,5] M. H. Sikora,[8] D. Sober,[18] A. Starostin,[10] I. Supek,[17] M. Thiel,[2,12] A. Thomas,[2] M. Unverzagt,[2,5] D. P. Watts,[8] D. Werthmüller,[1] and L. Witthauer[1]
(Crystal Ball/TAPS experiment at MAMI, A2 Collaboration)

[1]*Department of Physics, University of Basel, Switzerland*

World Pion Differential/Total Cross Section Data

Three of four reactions enough?



SAID Data Base - `http://gwdac.phys.gwu.edu/`

Multipole Amplitudes

- Neutron measurement required for complete multipole decomposition

η (Isoscalar):

$$A(\gamma p \to \eta p) = A^{IS} + A^{IV}$$
$$A(\gamma n \to \eta n) = A^{IS} - A^{IV}$$

π (Isovector):

$$A(\gamma p \to \pi^+ n) = -\sqrt{\frac{1}{3}}A^{V3} + \sqrt{\frac{2}{3}}\left(A^{IV} - A^{IS}\right)$$
$$A(\gamma p \to \pi^0 p) = +\sqrt{\frac{2}{3}}A^{V3} + \sqrt{\frac{1}{3}}\left(A^{IV} - A^{IS}\right)$$
$$A(\gamma n \to \pi^- p) = +\sqrt{\frac{1}{3}}A^{V3} - \sqrt{\frac{2}{3}}\left(A^{IV} + A^{IS}\right)$$

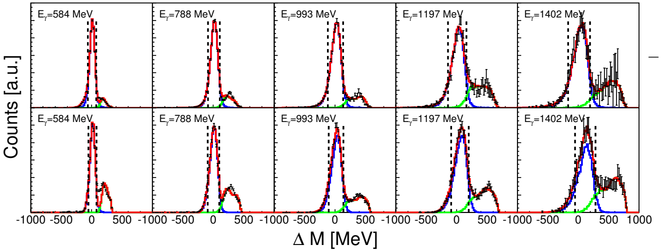
— — — — — — —

$$A(\gamma n \to \pi^0 n) = +\sqrt{\frac{2}{3}}A^{V3} + \sqrt{\frac{1}{3}}\left(A^{IV} + A^{IS}\right)$$

Missing Mass

+ Data – MC signal – MC bg – MC total – 1.5σ cut

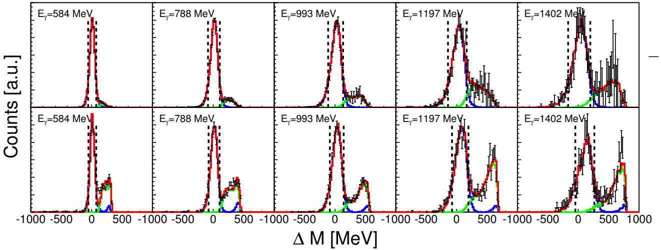
p



$-0.4 < \cos(\theta^*_{\pi^0}) < -0.2$

$0.6 < \cos(\theta^*_{\pi^0}) < 0.8$

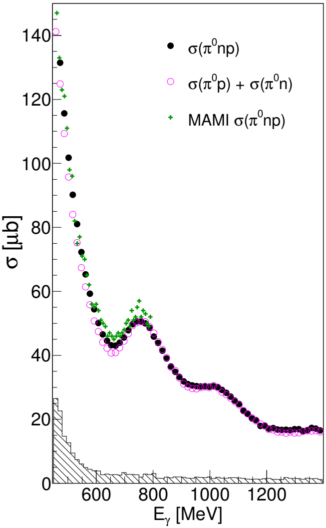
n



$-0.4 < \cos(\theta^*_{\pi^0}) < -0.2$

$0.6 < \cos(\theta^*_{\pi^0}) < 0.8$

Analysis Cross Check - QF-Inclusive

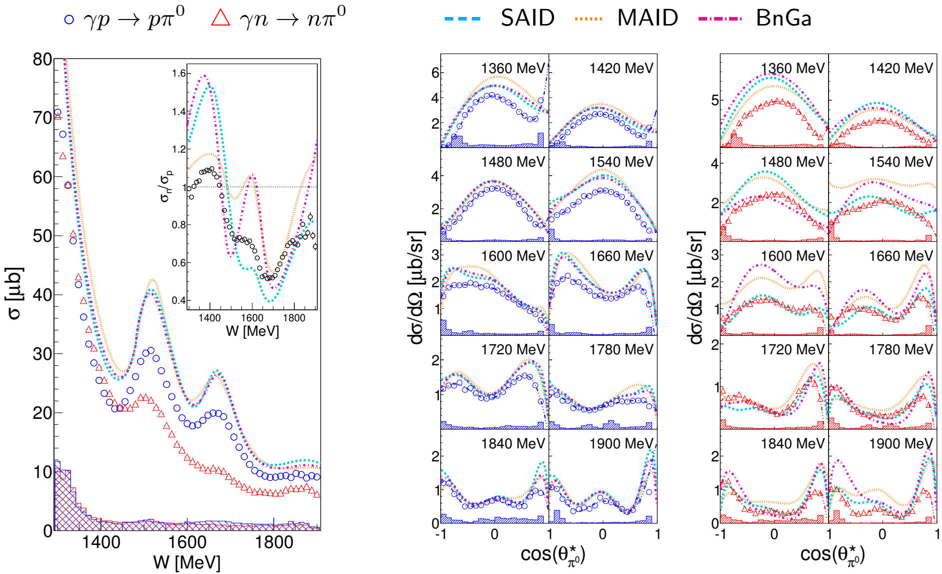


- Compare Q.F.-inclusive cross section with sum of proton and neutron cross sections

$$\sigma(\gamma n \to n\pi^0) + \sigma(\gamma p \to p\pi^0) \approx$$
$$\approx \sigma(\gamma N \to \pi^0 X)$$

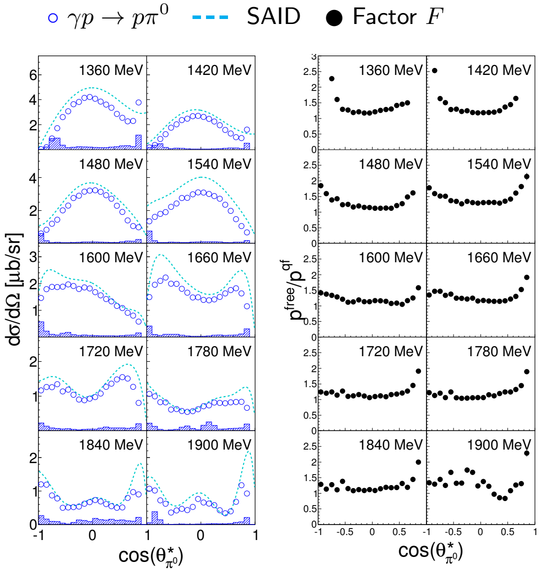
- Good agreement between two reconstructions
- Good agreement with previous data
- Neutron identification/detection under control

Proton Quasi-Free Cross Sections

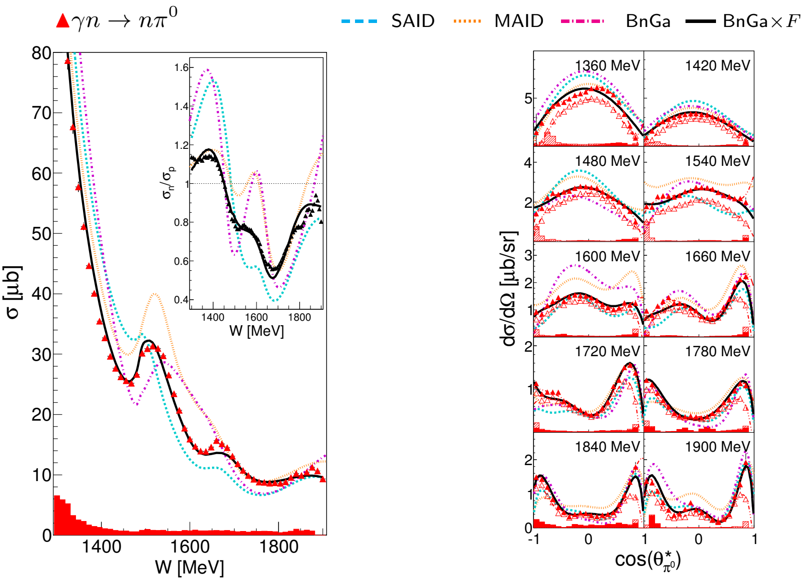


Correcting Final State Effects

- Assuming similar effects $\gamma p(n) \to p(n)\pi^0$ as for $\gamma n(p) \to n(p)\pi^0$
- Normalize to SAID
  $$F = \frac{Q.F.(\gamma p \to p\pi^0)}{SAID(\gamma p \to p\pi^0)}$$
- Apply to quasi-free neutron data!!!

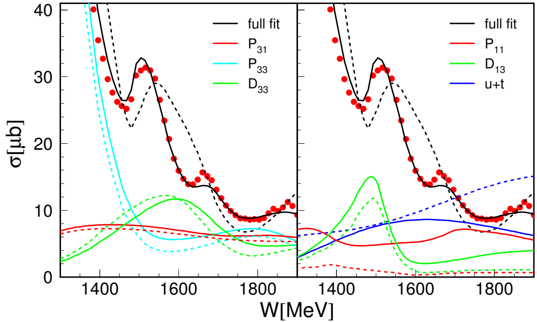


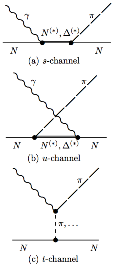
Neutron Quasi-Free Cross Sections



Impact of the Data

$\Delta\ (I = 3/2)$ $\qquad$ $N^*\ (I = 1/2)$





- Small changes for $I = 3/2$ low order resonant partial waves (fixed from $\gamma p \to p\pi^0$)
- Big change: $I = 1/2 P_{11}(1440)$, $D_{13}(1700)$ (photon coupling changes sign) and non-resonant background contributions from $u-$ & $t-$channel (mostly t-channel, i.e. vector-meson exchange)

Results

- $\gamma d \rightarrow N\pi^0(N_{sp.})$
- $\gamma d \rightarrow N\eta(N_{sp.})$ and $\gamma^3He \rightarrow N\eta(X_{sp.})$
- $\vec{\gamma}\vec{d} \rightarrow N\eta(N_{sp.})$
- $\vec{\gamma}d \rightarrow N\pi^0\pi^0(N_{sp.})$ and $N\pi^0\pi^{\pm}(N_{sp.})$
- $\gamma d \rightarrow N\pi^0\eta(N_{sp.})$

η – Ph.D. Work of Dominik Werthmüller and Lilian Witthauer

PRL 111, 232001 (2013) PHYSICAL REVIEW LETTERS week ending 6 DECEMBER 2013

Narrow Structure in the Excitation Function of η Photoproduction off the Neutron

D. Werthmüller,[1] L. Witthauer,[1] I. Keshelashvili,[1] P. Aguar-Bartolomé,[2] J. Ahrens,[2] J. R. M. Annand,[3] H. J. Arends,[2] K. Bantawa,[4] R. Beck,[2,5] V. Bekrenev,[6] A. Braghieri,[7] D. Branford,[8] W. J. Briscoe,[9] J. Brudvik,[10] S. Cherepnya,[11] B. Demissie,[9] M. Dieterle,[1] E. J. Downie,[2,3,9] P. Drexler,[12] L. V. Fil'kov,[11] A. Fix,[13] D. I. Glazier,[8] D. Hamilton,[3] E. Heid,[2] D. Hornidge,[14] D. Howdle,[3] G. M. Huber,[15] I. Jaegle,[1] O. Jahn,[2] T. C. Jude,[8] A. Käser,[1] V. L. Kashevarov,[2,11] R. Kondratiev,[16] M. Korolija,[17] S. P. Kruglov,[6] B. Krusche,[1,*] A. Kulbardis,[6] V. Lisin,[16] K. Livingston,[3] I. J. D. MacGregor,[3] Y. Maghrbi,[1] J. Mancell,[3] D. M. Manley,[4] Z. Marinides,[9] M. Martinez,[2] J. C. McGeorge,[3] E. F. McNicol
A. Nikolaev,[2,5] R. Novotny,[12] M.
S. N. Prakhov,[2,9,10] J. Ro
D. Sober,[18] A. Starostin,[10] I

(Crystal

[1]Dep

Eur. Phys. J. A (2013) 49: 154
DOI 10.1140/epja/i2013-13154-0

THE EUROPEAN PHYSICAL JOURNAL A

Regular Article – Experimental Physics

Quasi-free photoproduction of η-mesons off ^{3}He nuclei

Crystal Ball/TAPS experiment at MAMI, the A2 Collaboration

L. Witthauer[1], D. Werthmüller[1], I. Keshelashvili[1], P. Aguar-Bartolomé[2], J. Ahrens[2], J.R.M. Annand[3], H.J. Arends[2], K. Bantawa[4], R. Beck[2,5], V. Bekrenev[6], A. Braghieri[7], D. Branford[8], W.J. Briscoe[9], J. Brudvik[10], S. Cherepnya[11], B. Demissie[9], M. Dieterle[1], E.J. Downie[2,3,9], P. Drexler[12], L.V. Fil'kov[11], A. Fix[13], D.I. Glazier[8], D. Hamilton[3], E. Heid[2], D. Hornidge[14], D. Howdle[3], G.M. Huber[15], I. Jaegle[1], O. Jahn[2], T.C. Jude[8], A. Käser[1], V.L. Kashevarov[2,11], R. Kondratiev[16], M. Korolija[17], S.P. Kruglov[6], B. Krusche[1,a], A. Kulbardis[6], V. Lisin[16], K. Livingston[3], I.J.D. MacGregor[3], Y. Maghrbi[1], J. Mancell[3], D.M. Manley[4], Z. Marinides[9], M. Martinez[2], J.C. McGeorge[3], E. McNicoll[3], V. Metag[12], D.G. Middleton[14], A. Mushkarenkov[7], B.M.K. Nefkens[10], A. Nikolaev[2,5], R. Novotny[12], M. Oberle[1], M. Ostrick[2], B. Oussena[2,9], P. Pedroni[7], F. Pheron[1], A. Polonski[16], S. Prakhov[2,9,10], J. Robinson[3], G. Rosner[3], M. Rost[2], T. Rostomyan[1], S. Schumann[2,5], M.H. Sikora[8], D. Sober[18], A. Starostin[10], I. Supek[17], M. Thiel[2,12], A. Thomas[2], M. Unverzagt[2,5], and D.P. Watts[8]

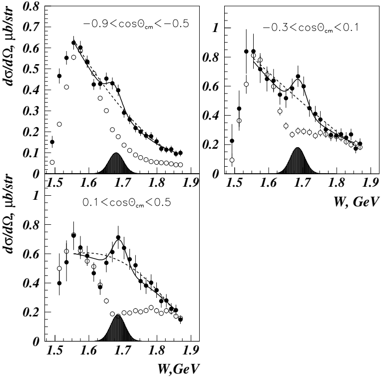
[1] Department of Physics, University of Basel, CH-4056 Basel, Switzerland

Experimental Evidence

GRAAL collaboration

narrow structure in the XS

$$\gamma + d \rightarrow \eta + n(p)$$

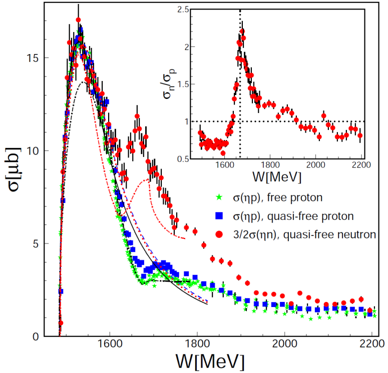


GRAAL, V.Kuznetsov et al., hep-ex 0606065

LNS @ Sendai (ELPH)

CBELSA/TAPS @ Bonn

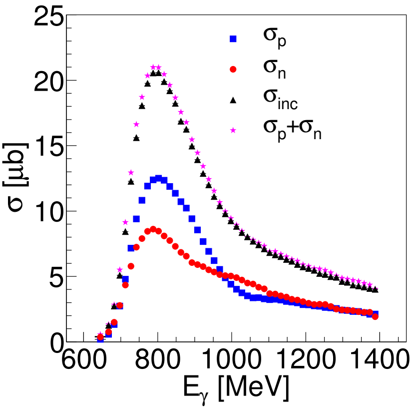
$W = 1660\text{MeV}$ & $\Gamma \approx (25 \pm 12\ \text{MeV})$



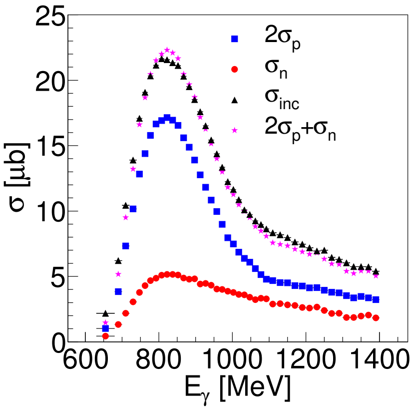
ELSA, I.Jaeglé et al. Eur. Phys. J A47 (2011) 89

Total Cross Sections Vs Incident E_γ

^{2}**H** D. Werthmüller, PhD thesis

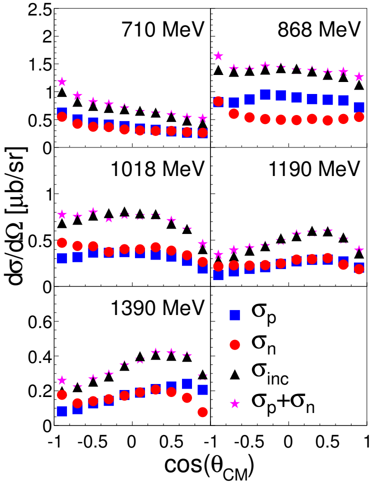


^{3}**He** L. Witthauer, PhD thesis

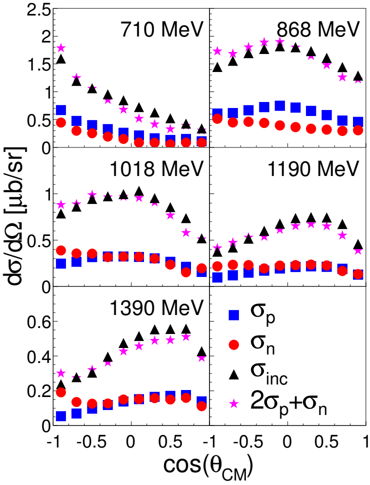


Differential Cross Sections Vs Incident E_γ

^{2}H D. Werthmüller, PhD thesis



^{3}He L. Witthauer, PhD thesis



Incident E_γ Vs Reconstructed IM of ηN (W)

Cross Sections as function of...

- $\mathbf{W_B(E_\gamma)}$: $\sqrt{s}$ calculated with 4-momenta of initial state particles:

$$W_B^2 = (P_\gamma + P_{N,i})^2 = 2E_\gamma m_N + m_N^2$$

- Structures are smeared out because of Fermi motion

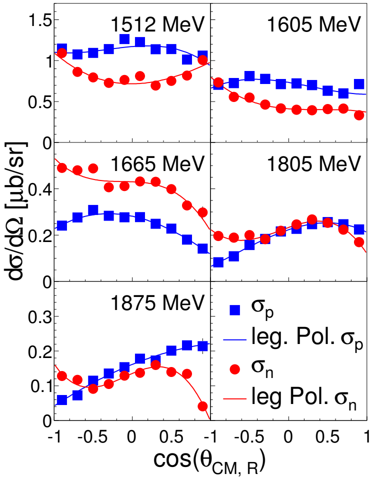
- $\mathbf{W_R(\eta N)}$: $\sqrt{s}$ calculated with measured 4-momenta of final state particles (η, participant nucleon):

$$W_R^2 = (P_\eta + P_{N,f})^2$$

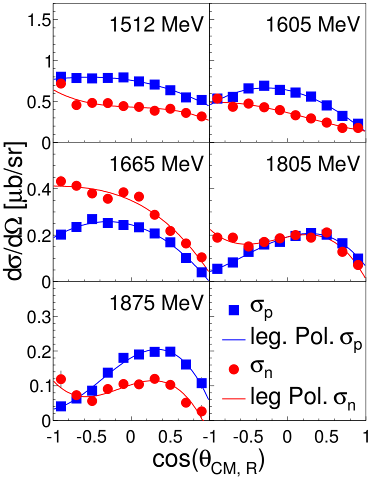
- No effects from Fermi motion, but exp. resolution for recoil η & N

Differential Cross Sections Vs Reconstructed IM of ηN (W)

^{2}H D. Werthmüller, PhD thesis

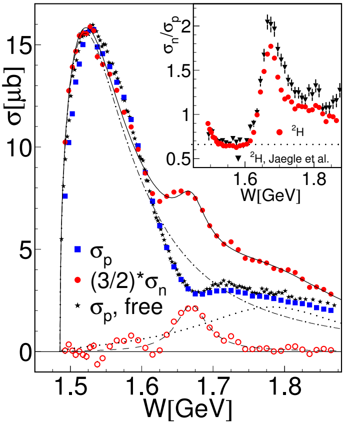


^{3}He L. Witthauer, PhD thesis



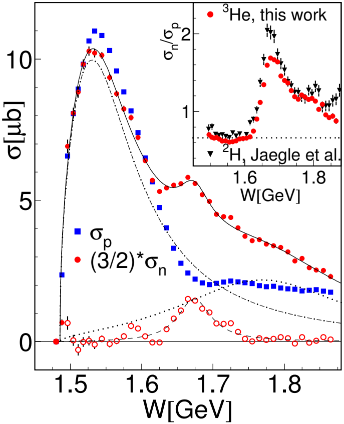
Total Cross Sections Vs Reconstructed IM of ηN (W)

^{2}**H** D. Werthmüller, PhD thesis



W [MeV]	Γ [MeV]	$\sqrt{b_\eta} A^n_{1/2}$
1669 ± 2	53 ± 9	13.5 ± 1.4

^{3}**He** L. Witthauer, PhD thesis



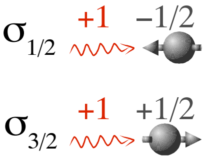
W [MeV]	Γ [MeV]	$\sqrt{b_\eta} A^n_{1/2}$
1671 ± 4	53 ± 14	10.4 ± 2.5

Results

- $\gamma d \rightarrow N\pi^0(N_{sp.})$
- $\gamma d \rightarrow N\eta(N_{sp.})$ and $\gamma^3He \rightarrow N\eta(X_{sp.})$
- $\vec{\gamma}\vec{d} \rightarrow N\eta(N_{sp.})$
- $\vec{\gamma}d \rightarrow N\pi^0\pi^0(N_{sp.})$ and $N\pi^0\pi^{\pm}(N_{sp.})$
- $\gamma d \rightarrow N\pi^0\eta(N_{sp.})$

Motivation for Double Polarized Experiment

E for $\vec{\gamma}\vec{d} \rightarrow N\eta(N_{sp.})$

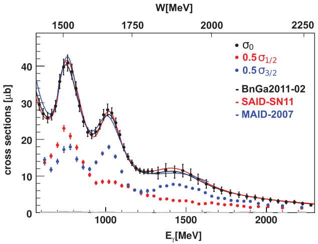


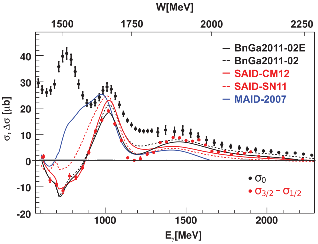
- Circularly polarized photons
- Longitudinally polarized target

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega}(1 \pm P_T P_\odot E)$$

$$E = \frac{N_{1/2} - N_{3/2}}{N_{1/2} + N_{3/2}} \frac{1}{P_\odot P_T} \frac{1}{d}$$

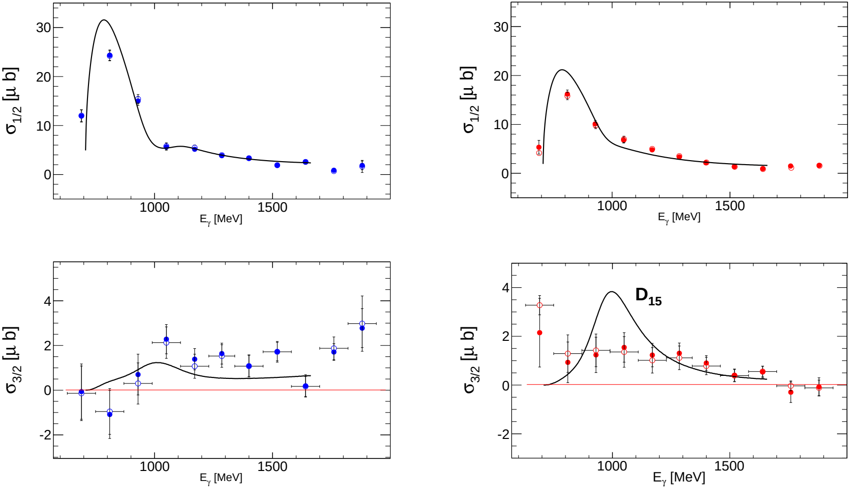
E for $\vec{\gamma}\vec{p} \rightarrow p\pi^0$, M. Gottschall et al., PRL 112, 012003 (2014)



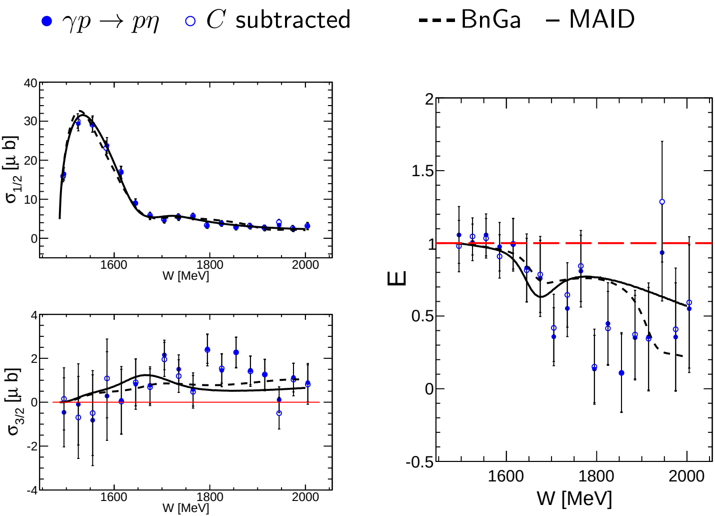


Double Polarization Observable E (Preliminary) – Ph.D.: L. Witthauer, M. Dieterle

● $\gamma p \to p\eta$ ○ C subtracted ●, ○ $\gamma n \to n\eta$ – MAID



Double Polarization Observable E – Exclusive (Preliminary)



Results

- $\gamma d \rightarrow N\pi^0(N_{sp.})$
- $\gamma d \rightarrow N\eta(N_{sp.})$ and $\gamma^3He \rightarrow N\eta(X_{sp.})$
- $\vec{\gamma}\vec{d} \rightarrow N\eta(N_{sp.})$
- $\vec{\gamma}d \rightarrow N\pi^0\pi^0(N_{sp.})$ and $N\pi^0\pi^\pm(N_{sp.})$
- $\gamma d \rightarrow N\pi^0\eta(N_{sp.})$

Ph.D. Work of Markus Oberle

Physics Letters B 721 (2013) 237–243

Contents lists available at SciVerse ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Measurement of the beam-helicity asymmetry $I^\odot$ in the photoproduction of π^0-pairs off the proton and off the neutron

M. Oberle [a,*], B. Krusche [a,*], J. Ahrens [b], J.R.M. Annand [c], H.J. Arends [b], K. Bantawa [d], P.A. Bartolome [b],
R. Beck [e], V. Bekrenev [f], H. Berghäuser [g], A. Braghieri [h], D. Branford [i], W.J. Briscoe [j], J. Brudvik [k]
S. Cherepnya [l], B. Demissie [j], I
E. Heid [b], D. Hornidge [n], D. H
V.L. Kashevarov [l,b], I. Keshela
K. Livingston [c], I.J.D. MacGreg
J.C. McGeorge [c], E. McNicoll [c],
A. Mushkarenkov [h], B.M.K. Ne
F. Pheron [a], A. Polonski [p], S.N.
M.H. Sikora [i], D.I. Sober [r], A. S
D. Werthmüller [a], L. Witthau

[a] Department of Physics, University of Basel, Ch-405

Eur. Phys. J. A (2014) 50: 54
DOI 10.1140/epja/i2014-14054-5

THE EUROPEAN PHYSICAL JOURNAL A

Regular Article – Experimental Physics

Measurement of the beam-helicity asymmetry $I^\odot$ in the photoproduction of $\pi^0\pi^\pm$ pairs off protons and off neutrons

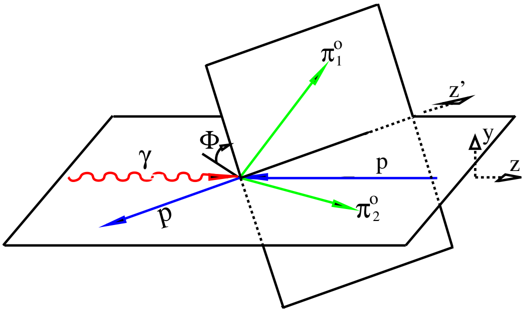
The Crystal Ball at MAMI, TAPS and A2 Collaborations

M. Oberle[1], J. Ahrens[2], J.R.M. Annand[3], H.J. Arends[2], K. Bantawa[4], P.A. Bartolome[2], R. Beck[5], V. Bekrenev[6], H. Berghäuser[7], A. Braghieri[8], D. Branford[9], W.J. Briscoe[10], J. Brudvik[11], S. Cherepnya[12], B. Demissie[10], M. Dieterle[1], E.J. Downie[2,3,10], P. Drexler[7], L.V. Fil'kov[12], A. Fix[13], D.I. Glazier[9], E. Heid[2], D. Hornidge[14], D. Howdle[3], G.M. Huber[15], O. Jahn[2], I. Jaegle[1], T.C. Jude[9], A. Käser[1], V.L. Kashevarov[12,2], I. Keshelashvili[1], R. Kondratiev[16], M. Korolija[17], S.P. Kruglov[6], B. Krusche[1,a], A. Kulbardis[6], V. Lisin[16], K. Livingston[3], I.J.D. MacGregor[3], Y. Maghrbi[1], J. Mancell[3], D.M. Manley[4], Z. Marinides[10], M. Martinez[2], J.C. McGeorge[3], E. McNicoll[3], D. Mekterovic[17], V. Metag[7], S. Micanovic[17], D.G. Middleton[14], A. Mushkarenkov[8], B.M.K. Nefkens[11], A. Nikolaev[5], R. Novotny[7], M. Ostrick[2], B. Oussena[2,10], P. Pedroni[8], F. Pheron[1], A. Polonski[16], S.N. Prakhov[11], J. Robinson[3], G. Rosner[3], T. Rostomyan[1,8], S. Schumann[2], M.H. Sikora[9], D.I. Sober[18], A. Starostin[11], I. Supek[17],

The Beam-Helicity Asymmetry

- **Circularly polarized** photon beam
- **3 body** final state necessary
- **Reaction plane:** incoming photon and recoil nucleon
- **Production plane:** outgoing meson-pair
- Parity conservation
  $\Rightarrow \quad I^{\odot}(\Phi) = -I^{\odot}(2\pi - \Phi)$
- For randomised pions
  $\Rightarrow \quad I^{\odot}(\Phi) = I^{\odot}(\Phi + \pi)$
- Mass ordering:
  $m(\pi^0_1, N) \geq m(\pi^0_2, N)$

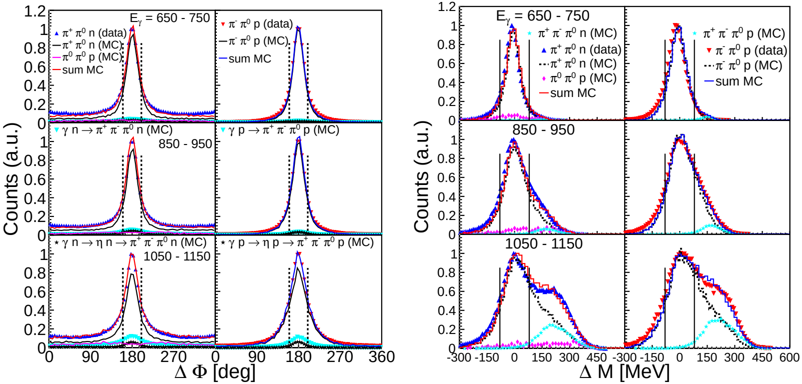
$$I^{\odot}(\Phi) = \frac{1}{P_\gamma}\,\frac{d\sigma^+ - d\sigma^-}{d\sigma^+ + d\sigma^-} = \frac{1}{P_\gamma}\,\frac{N^+ - N^-}{N^+ + N^-}$$



Δm and $\Delta\phi$ for the Charged Channel

Coplanarity: $\Delta\phi$ of nucleon and meson

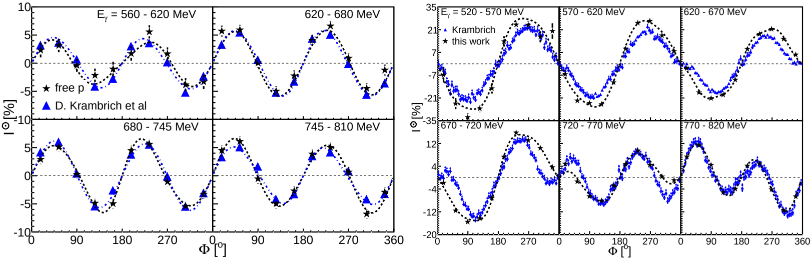
Missing Mass: $\Delta m(\pi\pi) = \left| P_\gamma + P_N - P_{\pi_1^0} - P_{\pi_2^0} \right| - m_N$



Neutral channel doesn't suffer from the background !!!

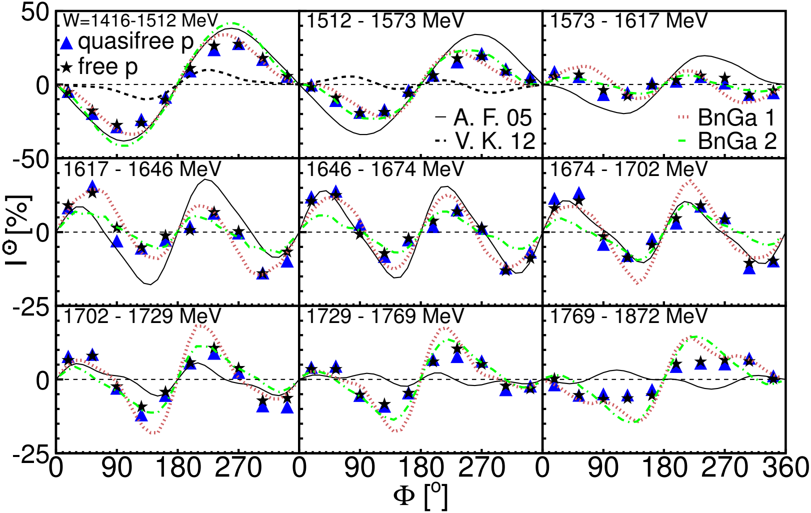
Comparison to Previous Results

$\pi^0\pi^0$ $\pi^0\pi^+$



D. Krambrich et al., Phys. Rev. Lett. 103 (2009) 052002

$\pi^0\pi^0 p$ for Free and Quasi-free Proton

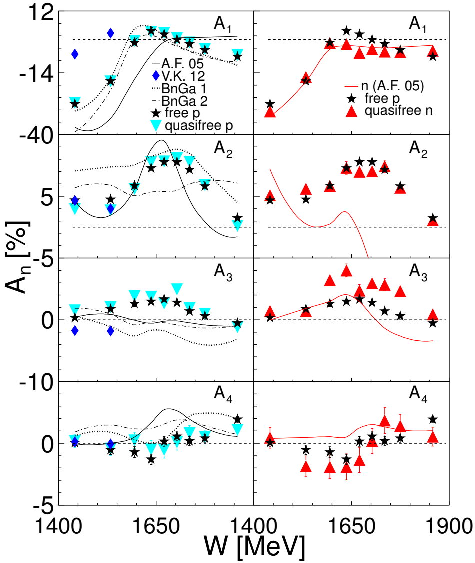


Parameters A_n for Neutral Channels ($\pi^0\pi^0$)

- $I^{\odot}(\Phi) = \sum_{n=1}^{4} A_n \sin(n\Phi)$
- Plot A_n as function of W
- $m(\pi_1^0, N) \geq m(\pi_2^0, N)$

- A_1 for **proton** reproduced good by most models
- A_2 for **proton** much less

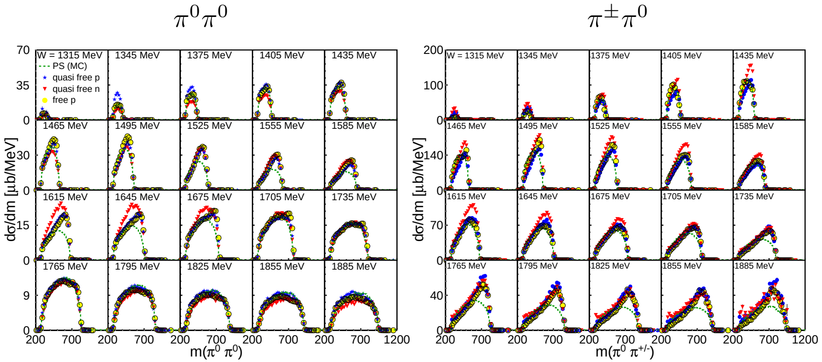
- A_1 for neutron reproduced very good by A. Fix
- A_2 for neutron very poor



Invariant Mass Distributions (Preliminary)

Comparison between:

--- P.S. (M.C.) ★ Q.F. proton ▼ Q.F. neutron ● free proton

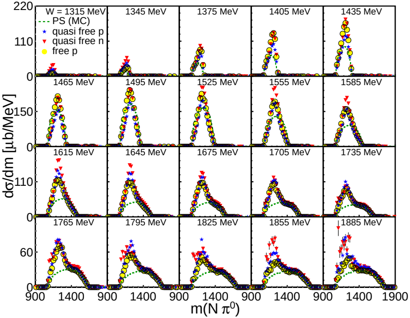


Invariant Mass Distributions (Preliminary)

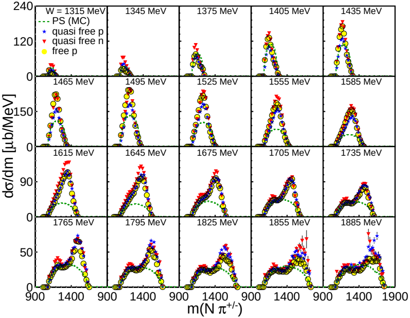
Comparison between:

--- P.S. (M.C.) ★ Q.F. proton ▼ Q.F. neutron ● free proton

$N\pi^0$



$N\pi^\pm$

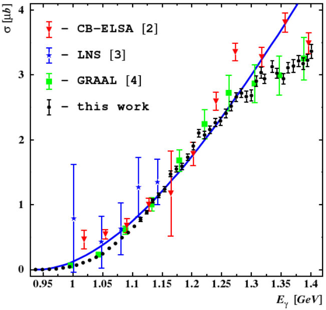


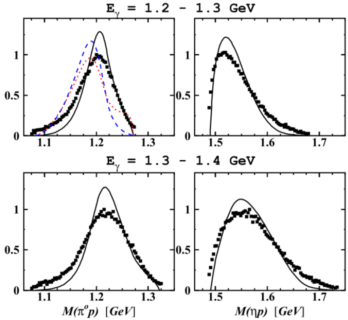
Results

- $\gamma d \to N\pi^0(N_{sp.})$
- $\gamma d \to N\eta(N_{sp.})$ and $\gamma^3He \to N\eta(X_{sp.})$
- $\vec{\gamma}\vec{d} \to N\eta(N_{sp.})$
- $\vec{\gamma}d \to N\pi^0\pi^0(N_{sp.})$ and $N\pi^0\pi^\pm(N_{sp.})$
- $\gamma d \to N\pi^0\eta(N_{sp.})$

Previous Results – V. Kashevarov et al.

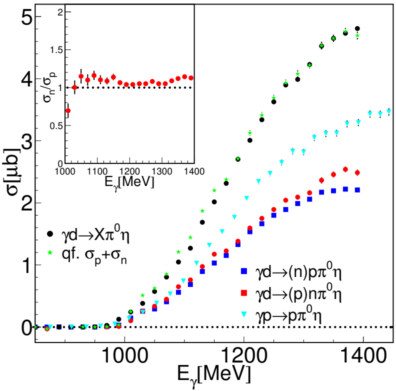
- Investigated channel: $\gamma p \to \eta\pi^0 p$
- Result: Reaction is dominated by: $D_{33} \to \eta\Delta$
- Solid lines are theoretical calculations including only the D_{33}



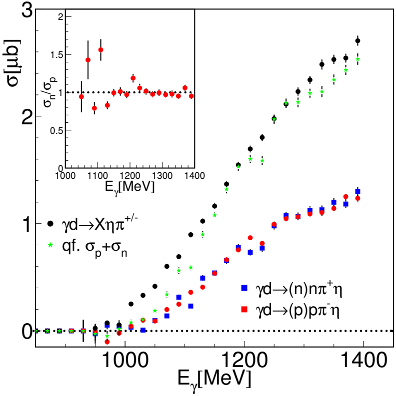


Total Cross Section Vs. E_γ (Preliminary) – Ph.D. Work of Alexander Käser

Neutral Channels

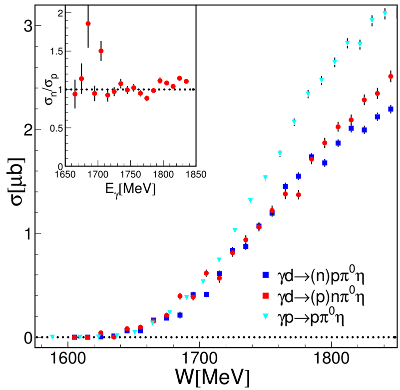


Charged Channels

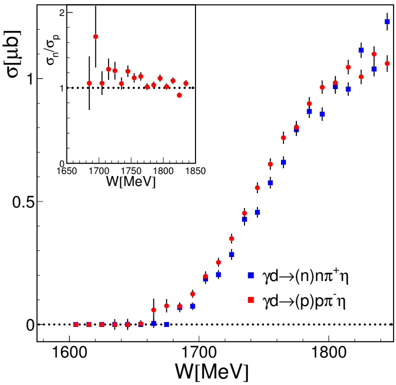


Total Cross Section Vs. W (Preliminary) – Ph.D. Work of Alexander Käser

Charged Channels



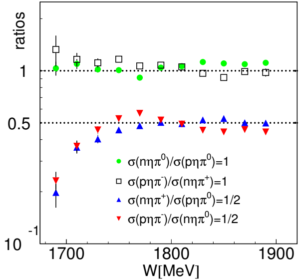
Neutral Channels



Ratios of the Total Cross Section (Preliminary) – Ph.D. Work of Alexander Käser

- $$\sigma(\pi^c p) = \sigma(\pi^c n) =$$
  $$= \tfrac{1}{2}\sigma(\pi^0 p) = \tfrac{1}{2}\sigma(\pi^0 n)$$
- A simple theoretical calculation, considering only the Clebsch Gordan coefficients for the isospin couplings shows, that these ratios of the total cross sections suggest a decay-cascade of the form:

  $\Delta^* \rightarrow \eta + \Delta^* \rightarrow \eta + \pi + N$ or
  $\Delta^* \rightarrow \pi + N^* \rightarrow \eta + \pi + N$
- The specific channel can than be identified via invariant mass distributions



Summary & Outlook

- $\gamma d \to N\pi^0(N_{sp.})$ – First and very important measurement.
- $\gamma d \to N\eta(N_{sp.})$ and $\gamma^3He \to N\eta(X_{sp.})$ – First extraction of diff. distributions and two different nucleus.
- $\vec{\gamma}\vec{d} \to N\eta(N_{sp.})$ – Polarization observable E.
- $\vec{\gamma}d \to N\pi^0\pi^0(N_{sp.})$ and $N\pi^0\pi^{\pm}(N_{sp.})$ – Beam–Helicity Asymmetry.
- $\gamma d \to N\pi^0\eta(N_{sp.})$ – First measurement on quasi–free neutron and proton.

Thanks for your attention!

M. Dieterle, D. Werthmüller, L. Witthauer, M. Oberle,

A. Käser and I. Keshelashvili

Group of Prof. B. Krusche

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and Deutsche Forschungsgemeinschaft (DFG)