

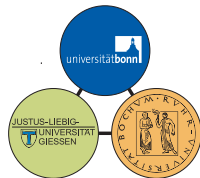
# Baryon Spectroscopy: Recent Results from Double Polarisation Data with the CBELSA/TAPS Experiment

Jonas Müller

for the CBELSA/TAPS collaboration

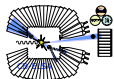


Helmholtz-Institut für Strahlen- und  
Kernphysik



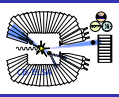
supported by SFB/TR16

23. September 2013



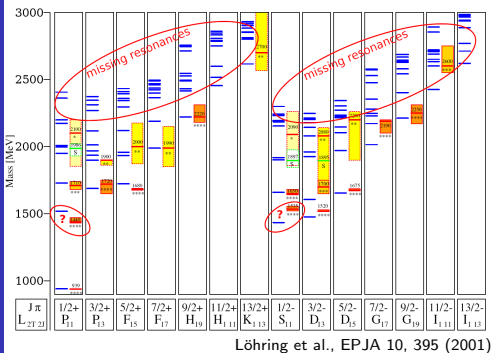
# Baryon Spectroscopy: Recent Results from Double Polarisation Data with the CBELSA/TAPS Experiment

- 1 Motivation
- 2 Experiment
- 3 Results
  - Single pseudoscalar mesons
  - Double mesons

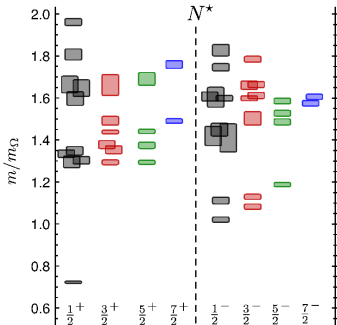


Aim: Good understanding of the spectrum and properties of baryon resonances — the bound states of strong QCD

Constituent quark model

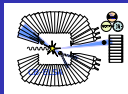


Lattice QCD  
( $m(\pi) = 396$  MeV)



R.G. Edwards et al.,  
Phys.Rev.D 84, 074508 (2011)

- Mass difference  $P_{11}(1440) / S_{11}(1535)$ ?
- Missing resonances?
- Lattice "Level counting" consistent with QM



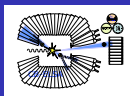
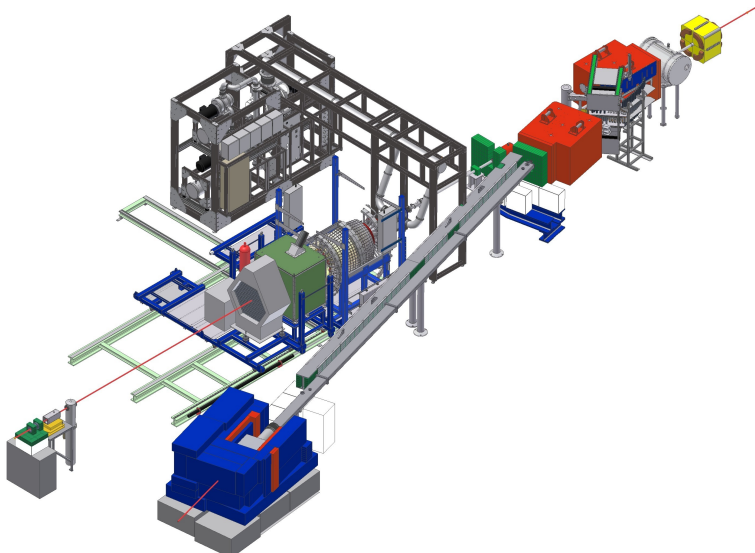
Motivation

**Experiment**

Results

Single Mesons

Double Mesons

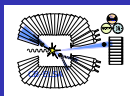
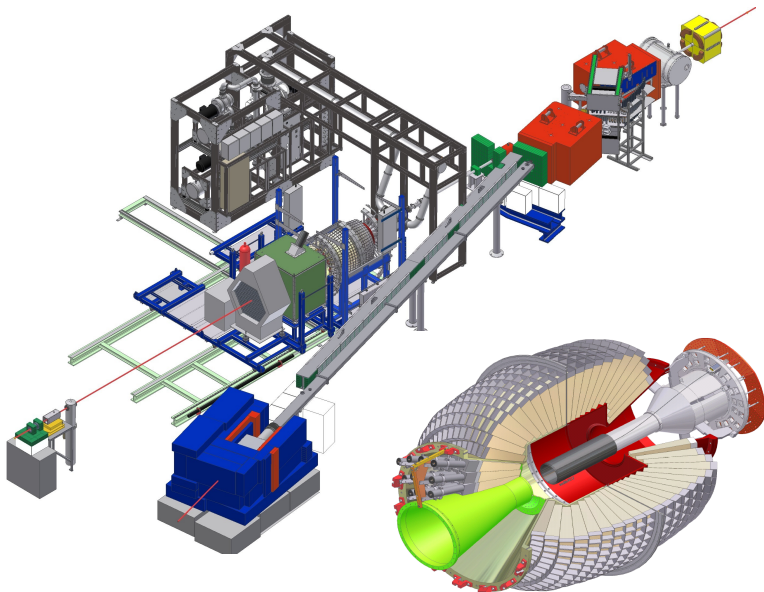


Motivation

Experiment

Results

Single Mesons  
Double Mesons



# Data quality

CB-Experiment is very well suited to measure final states with neutral mesons

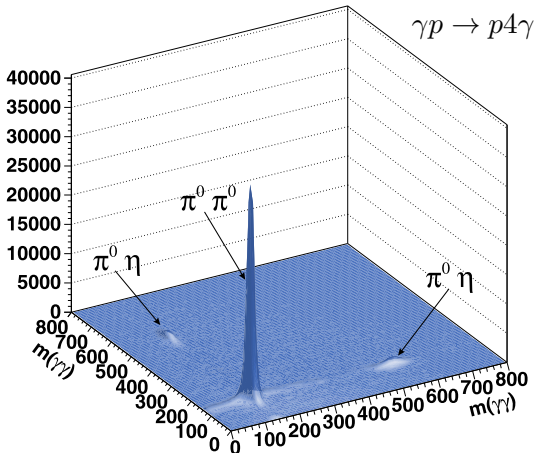
Motivation

Experiment

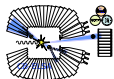
Results

Single Mesons

Double Mesons



Polarised target and beam provide access to polarisation observables



# Polarisation observables

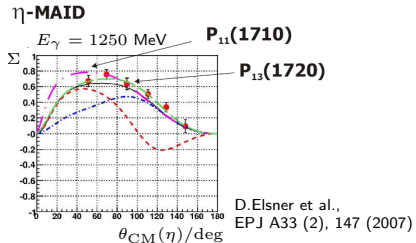
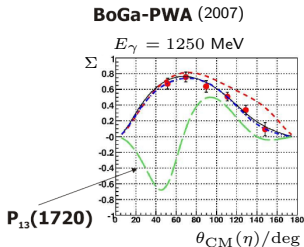
Partial wave analyses contain ambiguities:  $\Sigma$  in  $\gamma p \rightarrow p\eta$

Motivation

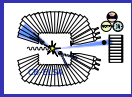
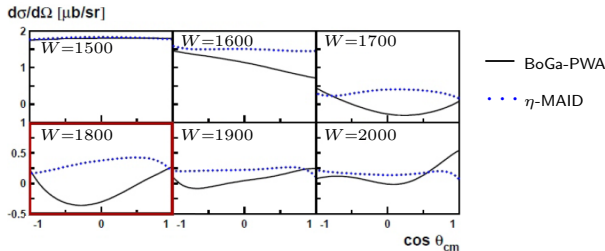
Experiment

Results

Single Mesons  
Double Mesons



Prediction for polarisation observable:  $E$  in  $\gamma p \rightarrow p\eta$



## Single pseudoscalar mesons

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

$$\gamma p \rightarrow p\eta$$

$$\gamma p \rightarrow p\eta'$$

Photon		Target			Recoil			Target-Recoil								
		<i>x</i>	<i>y</i>	<i>z</i>	<i>x'</i>	<i>y'</i>	<i>z'</i>	<i>x'</i>	<i>x'</i>	<i>x'</i>	<i>y'</i>	<i>y'</i>	<i>y'</i>	<i>z'</i>	<i>z'</i>	<i>z'</i>
unpolarised	$\sigma$	-	$T$	-	-	$P$	-	$T_{x'}$	-	$L_{x'}$	-	$\Sigma$	-	$T_{z'}$	-	$L_{z'}$
linearly	$\Sigma$	$H$	$P$	$G$	$O_{x'}$	$T$	$O_{z'}$	$L_{z'}$	$C_{z'}$	$T_{z'}$	$G$	$\sigma$	$F$	$L_{x'}$	$C_{x'}$	$T_{x'}$
circularly	-	$F$	-	$E$	$C_{x'}$	-	$C_{z'}$	-	$O_{z'}$	-	$E$	-	$H$	-	$O_{x'}$	-

published, submitted  
in preparation  
planned

### Vectormesons

$$\gamma p \rightarrow p\omega$$

### Strangeness production

$$\gamma p \rightarrow K^0\Sigma^+$$

$$\gamma p \rightarrow K^*\Sigma$$

### Multimesons

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

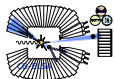
$$\gamma p \rightarrow p\pi^0\eta$$

plus photoproduction off the neutron...

(Mo, 11:00) Reinhard Beck: CB-ELSA contribution to the spectroscopy

(Mo, 15:00) Hartmut Schmieden: New results on  $K^0\Sigma^+$  photoproduction

(Mo, 16:30) Valentina Vegna: New results on omega photo-production





## Single pseudoscalar mesons

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

$$E, T, P, H$$

$$\gamma p \rightarrow p\eta$$

$$E, T, P, H$$

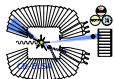
Photon		Target			Recoil			Target-Recoil								
		<i>x</i>	<i>y</i>	<i>z</i>	<i>x'</i>	<i>y'</i>	<i>z'</i>	<i>x'</i>	<i>x'</i>	<i>x'</i>	<i>y'</i>	<i>y'</i>	<i>y'</i>	<i>z'</i>	<i>z'</i>	<i>z'</i>
unpolarised	$\sigma$	-	$T$	-	-	$P$	-	$T_{x'}$	-	$L_{x'}$	-	$\Sigma$	-	$T_{z'}$	-	$L_{z'}$
linearly	$\Sigma$	$H$	$P$	$G$	$O_{x'}$	$T$	$O_{z'}$	$L_{z'}$	$C_{z'}$	$T_{z'}$	$G$	$\sigma$	$F$	$L_{x'}$	$C_{x'}$	$T_{x'}$
circularly	-	$F$	-	$E$	$C_{x'}$	-	$C_{z'}$	-	$O_{z'}$	-	$E$	-	$H$	-	$O_{x'}$	-

published, submitted  
in preparation  
planned

## Multimesons

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

- (Mo, 11:00) Reinhard Beck: CB-ELSA contribution to the spectroscopy
- (Mo, 15:00) Hartmut Schmieden: New results on K0 Sigma+ photoproduction
- (Mo, 16:30) Valentina Vegna: New results on omega photo-production



# Double Polarisation Observable E

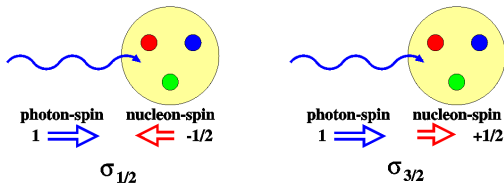
Motivation

Experiment

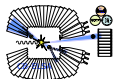
Results

Single Mesons

Double Mesons



$$E_{(\theta, E_\gamma)} = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} = \frac{1}{P_\gamma \cdot P_t \cdot f_{\text{dil}}} \frac{N_{1/2} - N_{3/2}}{N_{1/2} + N_{3/2}}$$



# $\sigma_{1/2}$ and $\sigma_{3/2}$ in $\gamma p \rightarrow p\pi^0$

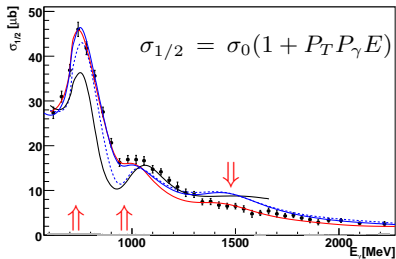
Motivation

Experiment

Results

Single Mesons

Double Mesons



PWAs:

--- SAID (SN11)

— SAID (CM12)

— MAID (2007)

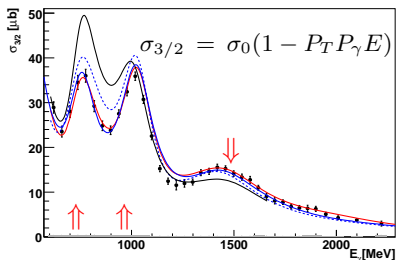
— BnGa (2011-02)

describe the so far existing photoproduction data, but ...

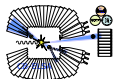
large deviations observed

Differences even at low energies where everything was thought to be well understood!

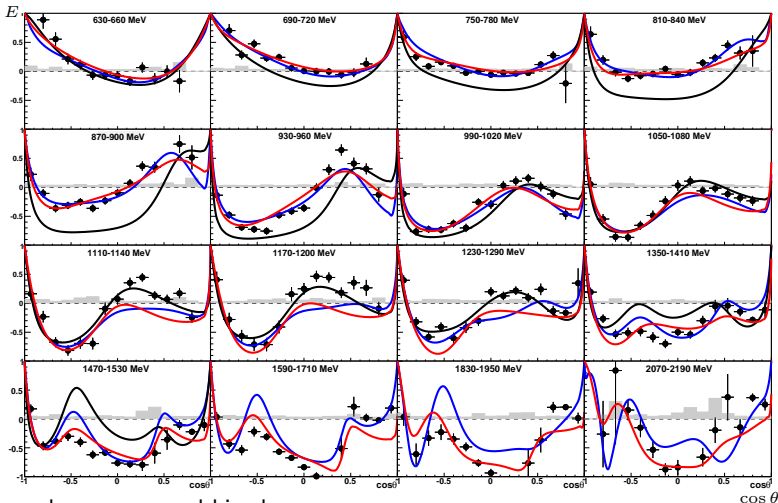
→ sensitivity on high mass resonances!



M.Gottschall (submitted to PRL)



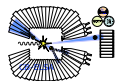
Angular dependency for different energies



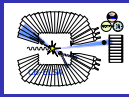
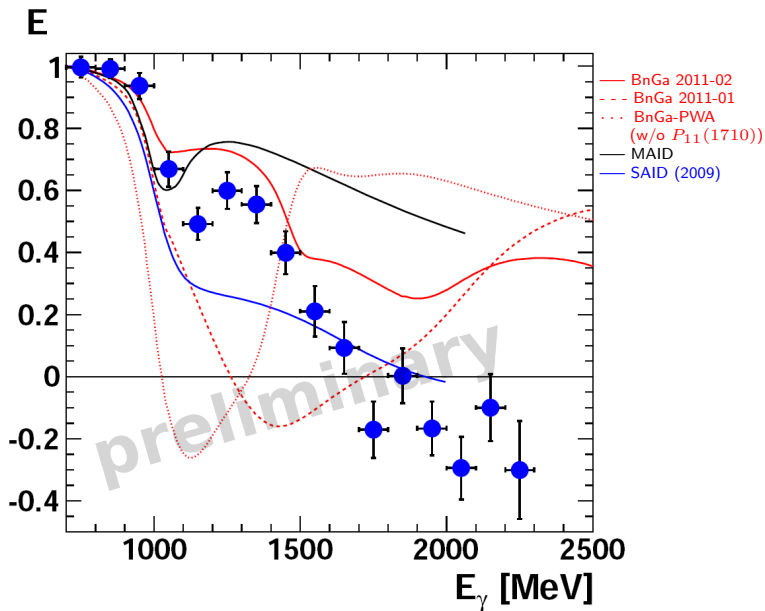
only every second bin shown

— BnGa-PWA (2011-02) — MAID (2007) — SAID (CM12)

M.Gottschall (submitted to PRL)

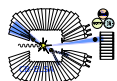
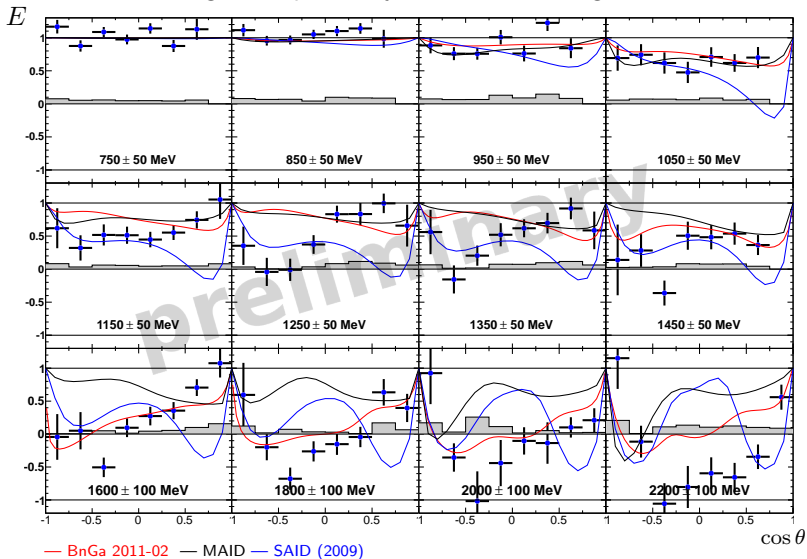


# Energy dependency of E in $\gamma p \rightarrow p\eta$



# $E$ in $\gamma p \rightarrow p\eta$

Angular dependency for different energies



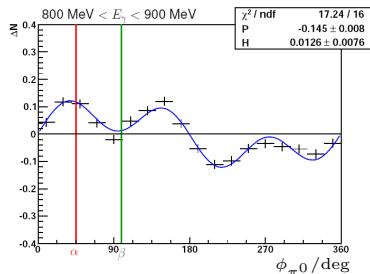
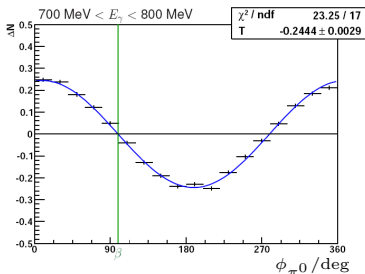
# T-, P-, H-Extraction

- Transversely polarised target, unpolarised beam:  $T$

$$\Delta N = \frac{1}{f_{\text{dil}} \cdot P_{\text{target}}} \cdot \frac{N_{\uparrow} - N_{\downarrow}}{N_{\uparrow} + N_{\downarrow}} = T \sin(\phi - \beta)$$

- Transversely polarised target, linearly polarised beam:  $P, H$

$$\begin{aligned} \Delta N &= \frac{1}{f_{\text{dil}} \cdot P_{\text{target}} \cdot P_{\text{beam}}} \cdot \frac{(N_{\uparrow\perp} - N_{\downarrow\perp}) - (N_{\uparrow\parallel} - N_{\downarrow\parallel})}{(N_{\uparrow\perp} + N_{\downarrow\perp}) + (N_{\uparrow\parallel} + N_{\downarrow\parallel})} \\ &= P \sin(\phi - \beta) \cos(2(\phi - \alpha)) + H \cos(\phi - \beta) \sin(2(\phi - \alpha)) \end{aligned}$$

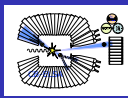
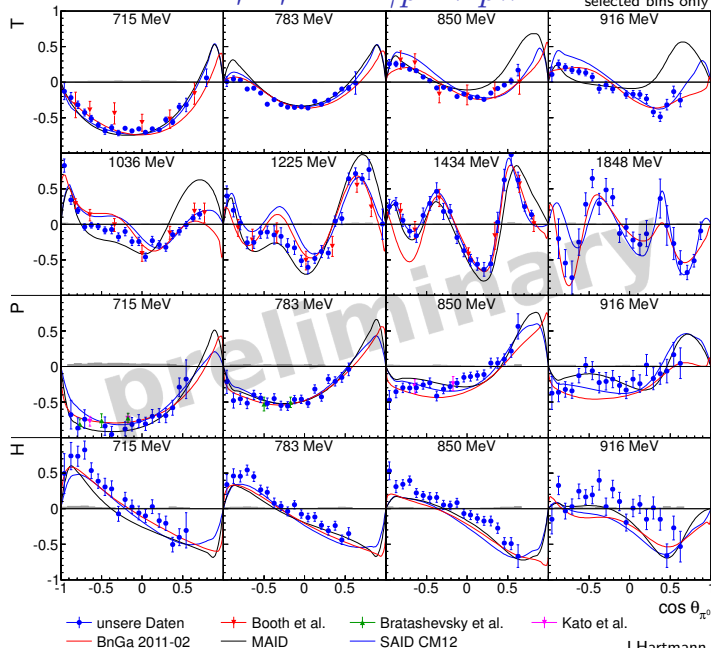


$\alpha$ : beam polarisation plane

$\beta$ : target polarisation plane

# T, P, H in $\gamma p \rightarrow p\pi^0$

selected bins only





# T, P, H in $\gamma p \rightarrow p\eta$

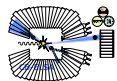
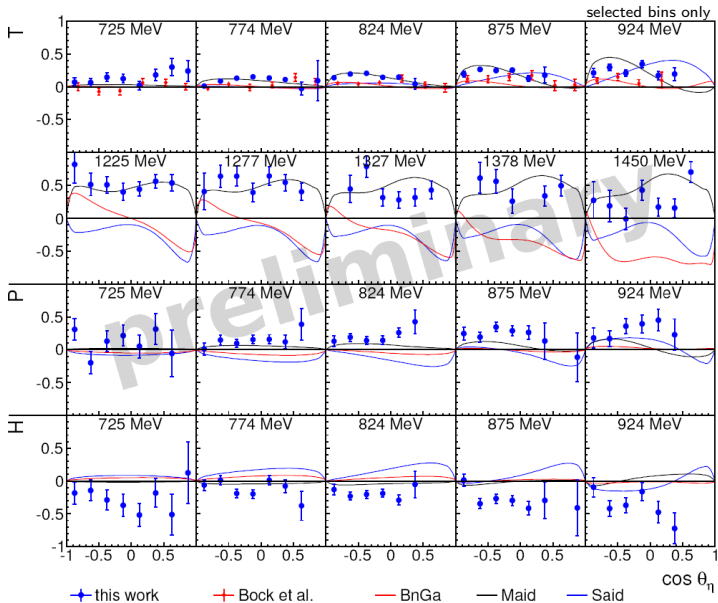
Motivation

Experiment

Results

Single Mesons

Double Mesons



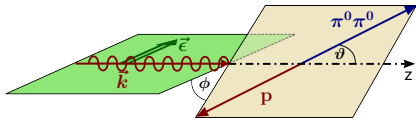
# Quasi 2-body approach

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

use quasi 2-body approach  $\Rightarrow$  single meson photoproduction

two choices for  
two particle system

- $p(\pi^0 \pi^0)$
- $(p \pi^0) \pi^0$



single meson:  $\mathcal{O}(E_\gamma, \cos \vartheta)$

double meson:  $\mathcal{O}(E_\gamma, \cos \vartheta, m_{12}, \phi^*, \theta^*)$

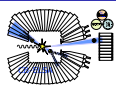
$$\frac{d\sigma}{d\Omega}(\theta, \phi) = \frac{d\sigma}{d\Omega}(\theta) \cdot \left[ 1 - \delta_\ell \Sigma(\theta) \cos(2\phi) \right.$$

I. S. Barker, A. Donnachie, J. K. Storrow,  
Nucl. Phys. B95, 347 (1975)

$$+ \Lambda_x \cdot (-\delta_\ell H(\theta) \sin(2\phi) + \delta^\odot F(\theta))$$

$$+ \Lambda_y \cdot (-\delta_\ell P(\theta) \cos(2\phi) + T(\theta))$$

$$- \Lambda_z \cdot (-\delta_\ell G(\theta) \sin(2\phi) + \delta^\odot E(\theta)) \Big]$$



Motivation

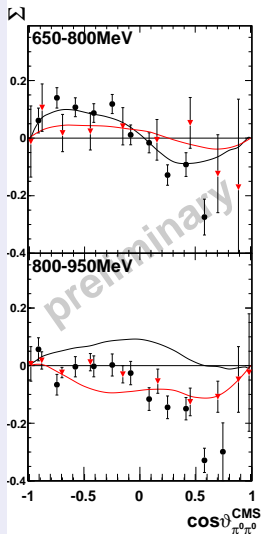
Experiment

Results

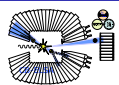
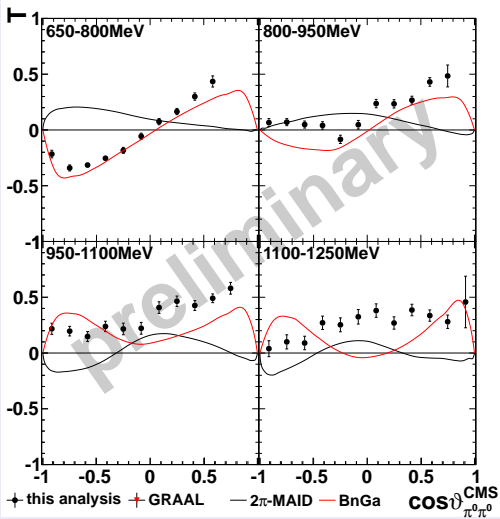
Single Mesons

Double Mesons

## Beam asymmetry



## Target asymmetry



Motivation

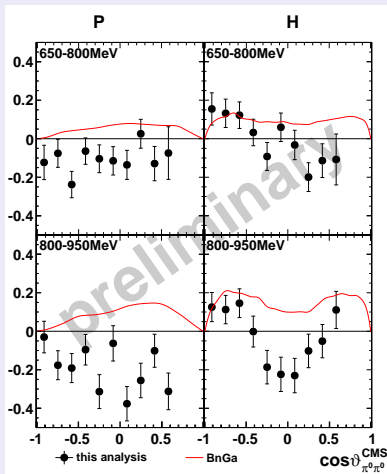
Experiment

Results

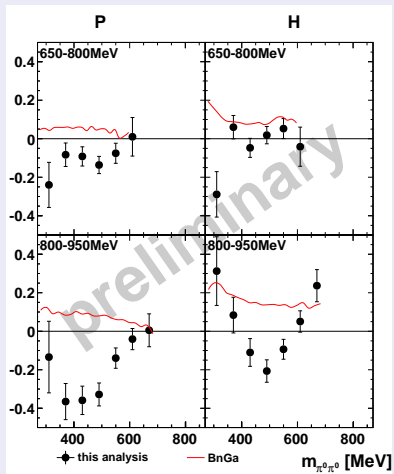
Single Mesons

Double Mesons

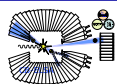
$P, H(E_\gamma, \cos\vartheta)$



$P, H(E_\gamma, m_{\pi^0\pi^0})$

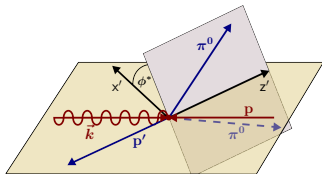


T.Seifen



# 3-body approach

- Motivation
- Experiment
- Results
- Single Mesons
- Double Mesons

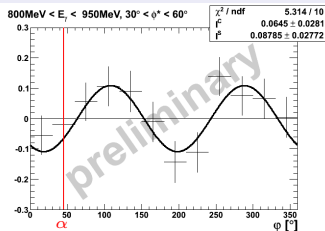


Photon Pol.		Target Pol. Axis		
		<i>x</i>	<i>y</i>	<i>z</i>
unpolarised	$\sigma$	$P_x$	$P_y$	$P_z$
linear $\sin(2\phi)$	$I^s$	$P_x^s$	$P_y^s$	$P_z^s$
linear $\cos(2\phi)$	$I^c$	$P_x^c$	$P_y^c$	$P_z^c$
circular	$I^\odot$	$P_x^\odot$	$P_y^\odot$	$P_z^\odot$

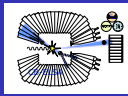
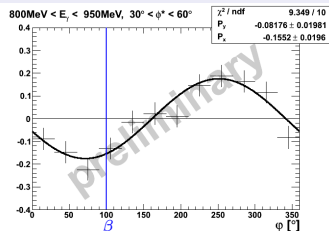
$$\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega} \cdot \left\{ (1 + \Lambda_x P_x + \Lambda_y P_y) + \delta_\ell \cdot \left[ \sin(2\phi) \cdot (I^s + \Lambda_x P_x^s + \Lambda_y P_y^s) + \cos(2\phi) \cdot (I^c + \Lambda_x P_x^c + \Lambda_y P_y^c) \right] \right\}$$

W. Roberts, T. Oed, Phys. Rev. C 71 (2005)

$\gamma p \rightarrow p(\pi^0 \pi^0)$



$\gamma p \rightarrow p(\pi^0 \pi^0)$



Motivation

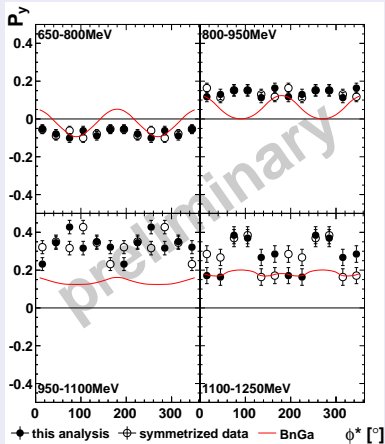
Experiment

Results

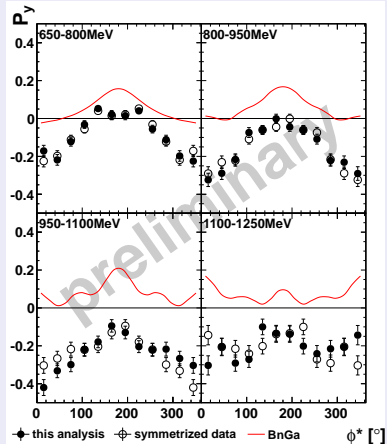
Single Mesons

Double Mesons

$$\gamma p \rightarrow p(\pi^0 \pi^0)$$



$$\gamma p \rightarrow (p\pi^0)\pi^0$$



T.Seifen

# Target asymmetry $P_x$

Motivation

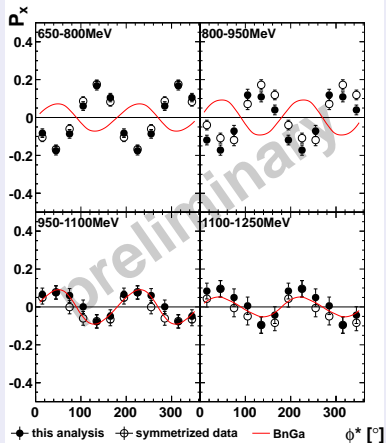
Experiment

Results

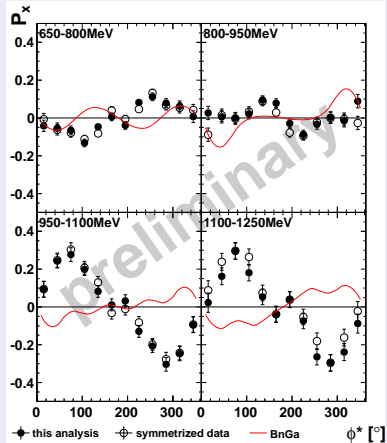
Single Mesons

Double Mesons

$$\gamma p \rightarrow p(\pi^0 \pi^0)$$

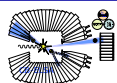


$$\gamma p \rightarrow (p\pi^0)\pi^0$$

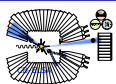


$\Rightarrow 2\pi^0$  photoproduction not yet understood

T.Seifen



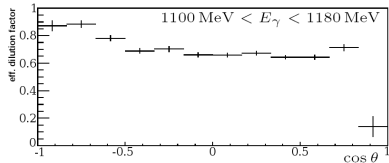
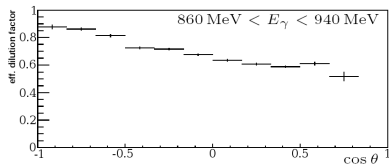
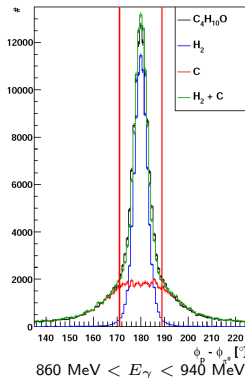
- Our experimental knowledge of the spectrum and properties of baryon resonances is steadily increasing!
  - ↔ Important contribution from photoproduction experiments
    - CBELSA/TAPS:
      - New high quality double polarisation data
      - Various final states
    - Existing PWA predictions:
      - Large discrepancies in comparison to new data
    - → New data provides important constraints for extraction of baryon resonances
  - New experimental information = detailed testing ground for quark models, lattice QCD, dynamically generated resonances, ... other theoretical approaches
  - ⇒ Significant contribution to a better understanding of QCD in the non-perturbative regime



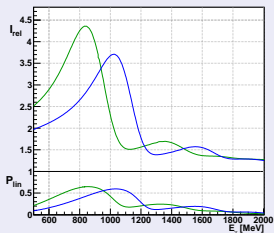


# Dilution factor

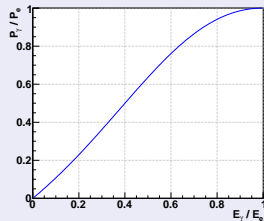
- Protons in  $H_2$ -Molecules are not polarisable
- Butanol as target material contains  $C$  and  $O$
- Dilution factor  $f = \frac{10}{10+32} = 0.24$
- Eff. dilution factor  $f = \frac{N_H}{N_{\text{Butanol}}} = \frac{N_{\text{Butanol}} - N_C}{N_{\text{Butanol}}}$  larger, because of
  - Fermi momentum
  - ...



## Beam polarisation

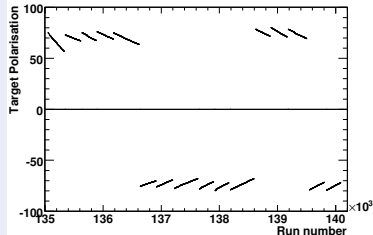
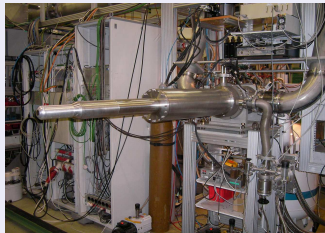


→  $P_\gamma \approx 68\%$  @ 950 MeV

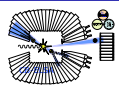


→  $P_\gamma \approx 68\%$  @ 2400 MeV

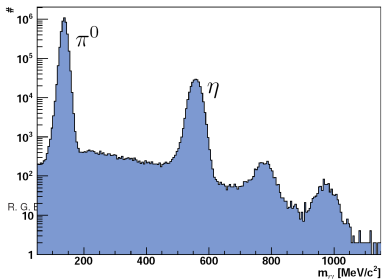
## Target polarisation



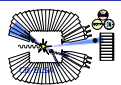
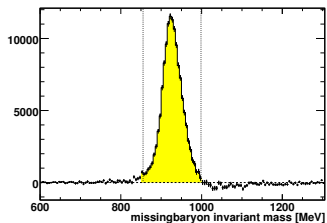
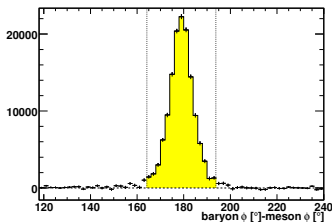
Target polarisation  $\phi(P_T) \approx 75\%$   
 Repolarisation every 2-3 days



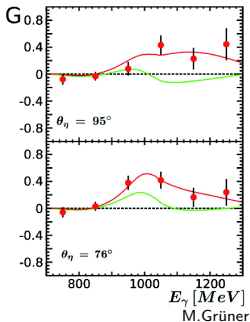
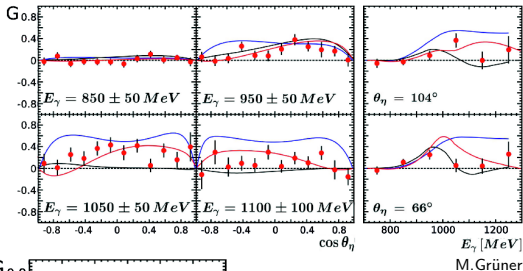
# Reconstruction



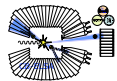
- Photons detected ( $E, \theta, \phi$ )
- Proton direction measured ( $\theta, \phi$ )



# G in $\gamma p \rightarrow p\eta$



- G klein an  $\eta$ -Schwelle
- Vorhersagen variieren stark bei höheren Energien
- Sensitiv auf Unterschiede verschiedener BnGa-PWA-Lösungen



# E in $\gamma p \rightarrow p\pi^0\pi^0$

