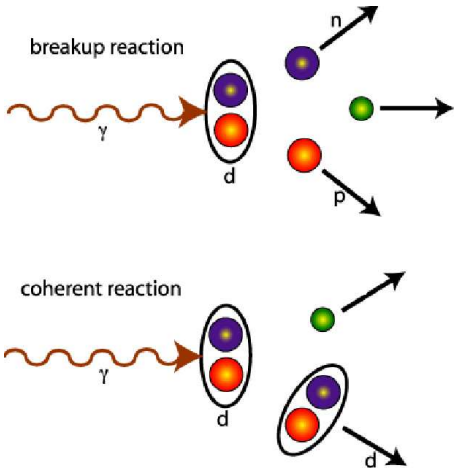
Photoproduction of mesons off light nuclei

B. Krusche, U. Basel



Introduction

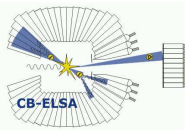
Experimental setups

- Crystal Ball & TAPS @ MAMI
- Crystal Barrel & TAPS @ ELSA

Experimental results

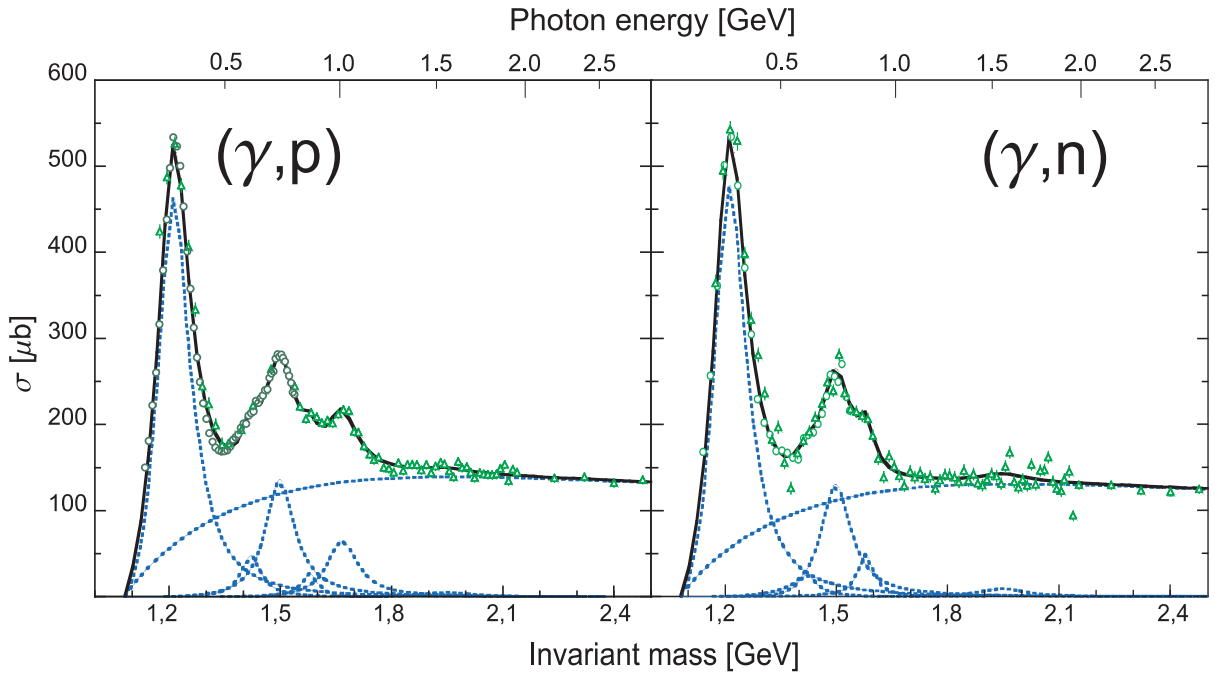
- photoproduction off quasi-free nucleons: η, π^o, $\pi^o\pi^o$, η', $\pi^o\eta$, $\pi^\pm\eta$, $\pi^o\pi^\pm$,...
- coherent photoproduction of mesons off light nuclei: η, $\pi^o\eta$, $\pi^o\pi^o$, $\pi^o\pi^o\pi^o$

Conclusions



electromagnetic excitations of the neutron

- **importance of measurements off the neutron:**
  - different resonance contributions
  - needed for extraction of iso-spin composition of elm. couplings



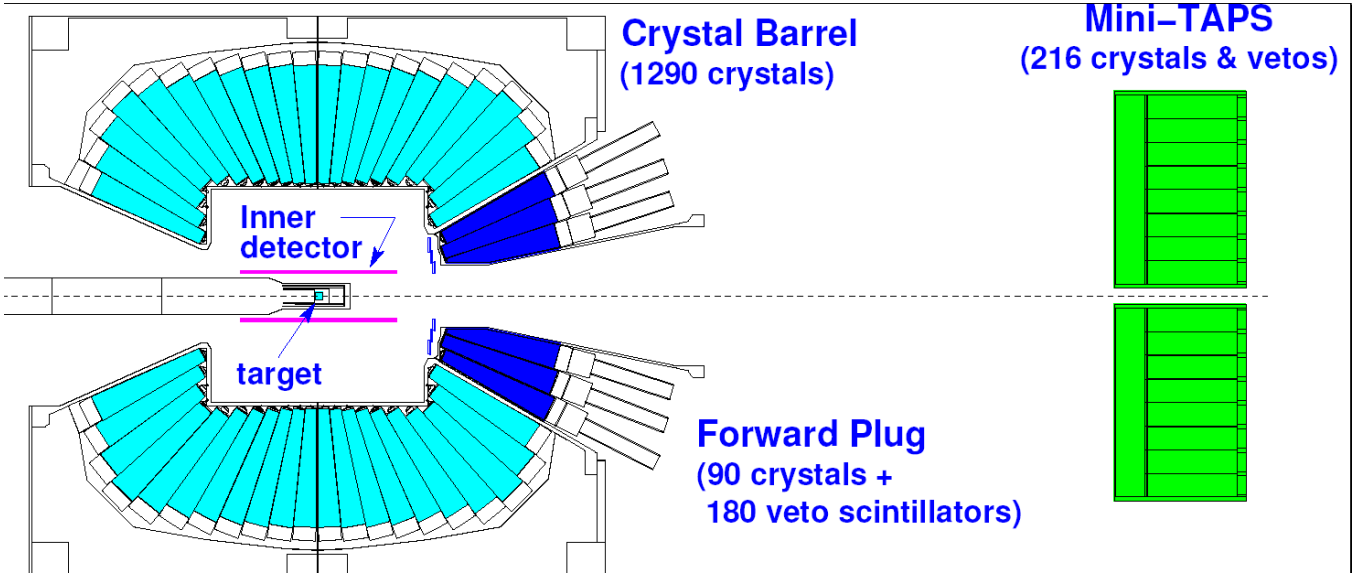
- **complications due to use of nuclear targets (deuteron):**
  - coincident detection of recoil nucleons
  - Fermi motion, nuclear effects like FSI, coherent contributions

Experiments: Crystal Ball & Crystal Barrel with TAPS

- **Bonn ELSA accelerator:**

  Crystal Barrel (CsI),
  TAPS (BaF_2) forward wall,
  inner detectors

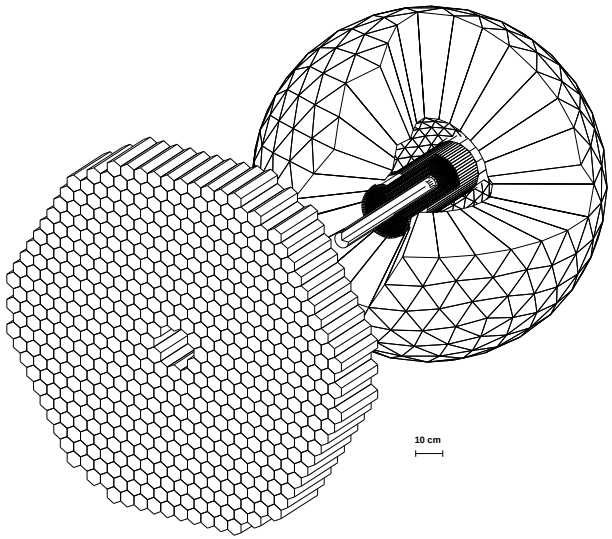
  $E_\gamma \leq$ 3.5 GeV,
  lin. pol.: available,
  circ. pol.: available

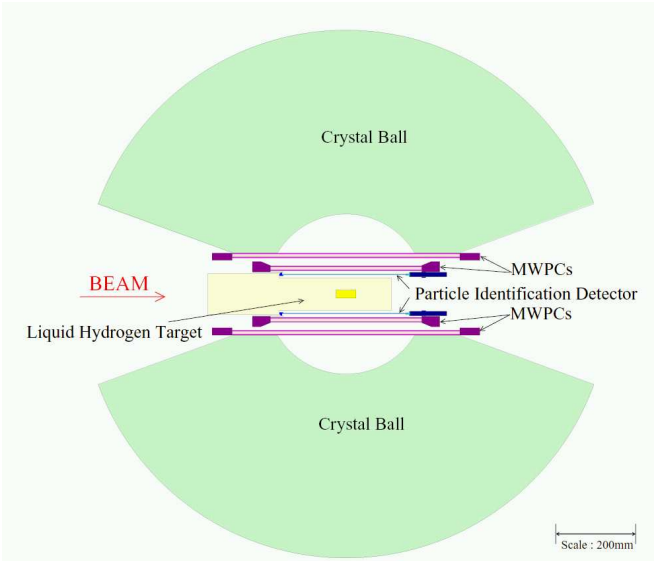


- **Mainz MAMI accelerator:**

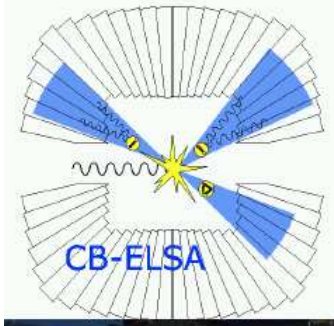
  Crystal Ball (NaJ),
  TAPS (BaF_2) forward wall,
  inner detectors

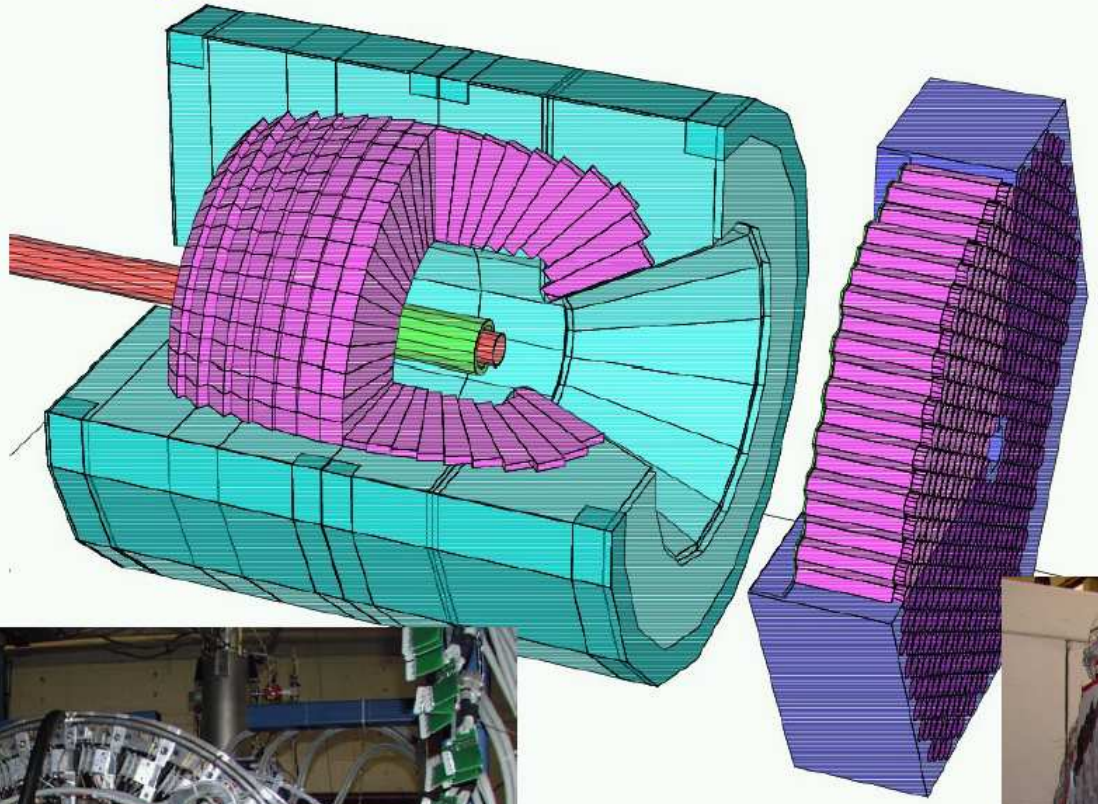
  $E_\gamma \leq$ 1.5 GeV,
  lin. pol.: available,
  circ. pol.: available



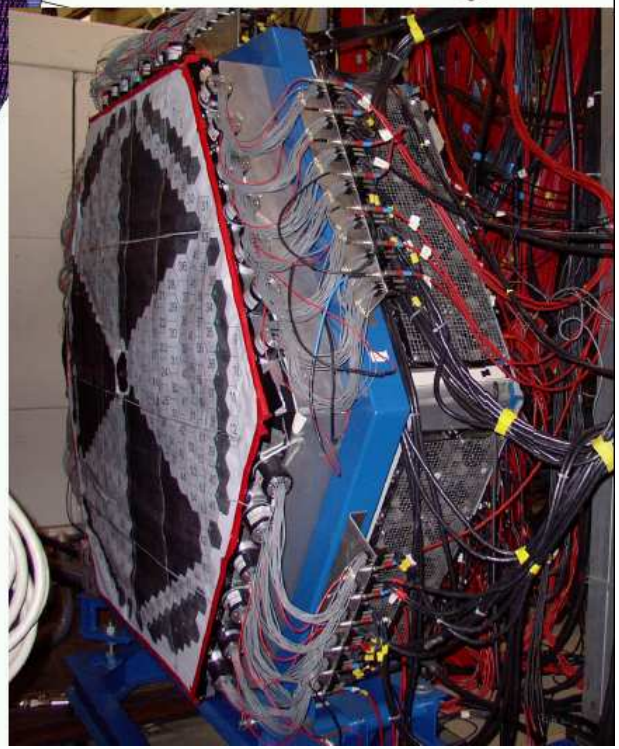


Crystal Barrel and TAPS

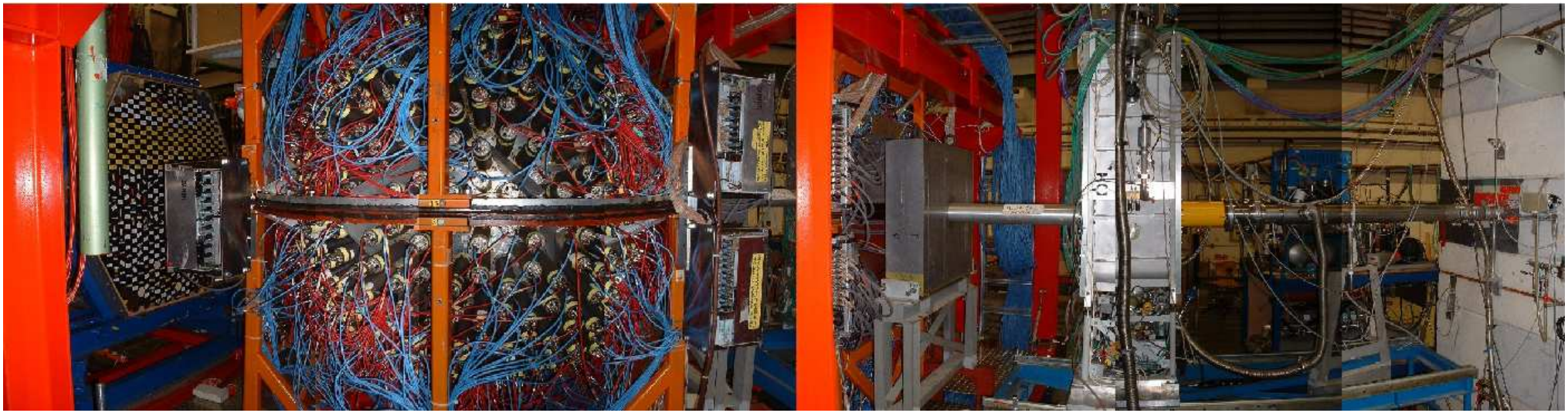




TAPS



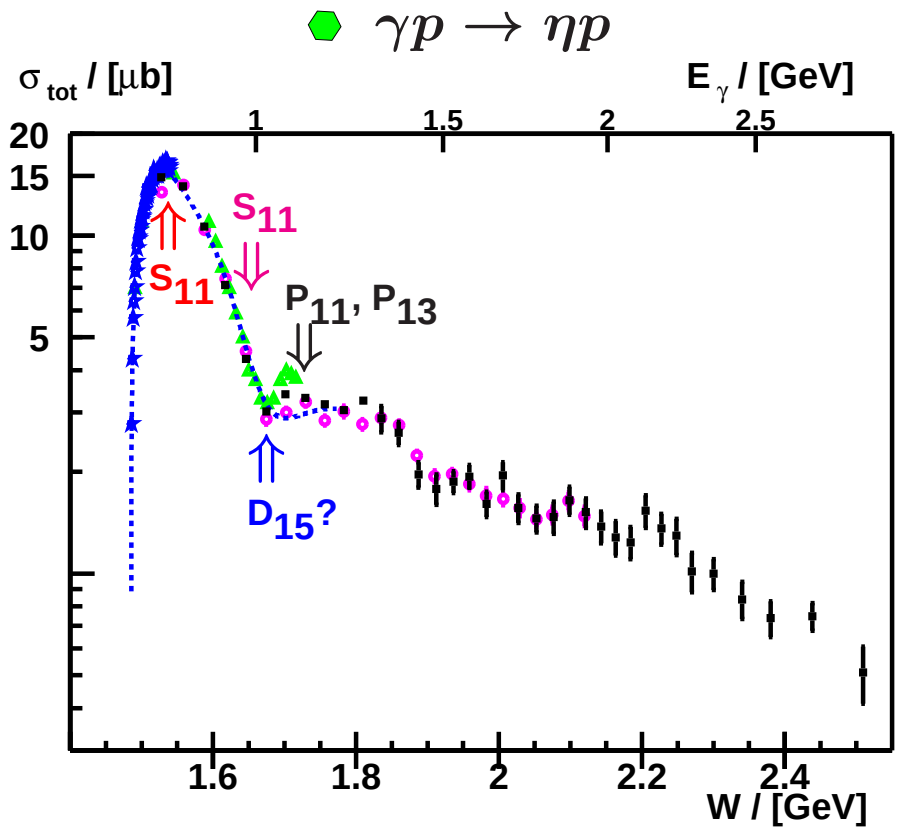
TAPS Crystal Ball - at MAMI



η-photoproduction off the proton: resonance contributions?

branching ratios and elm. couplings (PDG):

state	b_η [%]	$A^p_{1/2}$	$A^p_{3/2}$	$A^n_{1/2}$	$A^n_{3/2}$
• $D_{13}(1520)$:	0.23±0.04	-24	166	59	139
• $S_{11}(1535)$:	30 - 55	90		-46	
• $S_{11}(1650)$:	3 - 10	53		-15	
• $D_{15}(1675)$:	0±1	19	15	-43	-58
• $F_{15}(1680)$:	0±1	-15	133	29	-33
• $D_{13}(1700)$:	0±1				
• $P_{11}(1710)$:	6.2±1.0				
• $P_{13}(1720)$:	4±1				



- **$D_{15}(1675)$ has stronger electromagnetic coupling to neutron than to proton**

  but parameters quite uncertain:

  $A^n_{1/2}$=-(21-57), $A^n_{3/2}$=-(30-77)

  b_η=0-1% (PDG), b_η=17% (ETA-MAID, Chiang et al.)

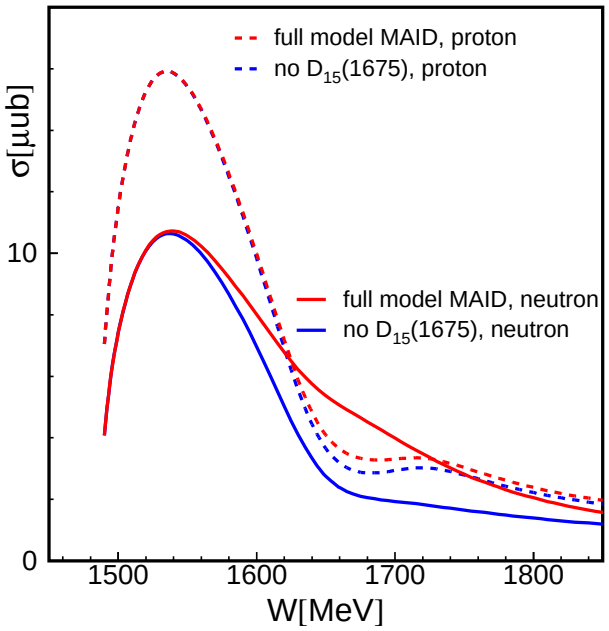
- **interference structure in S_{11}-sector?**

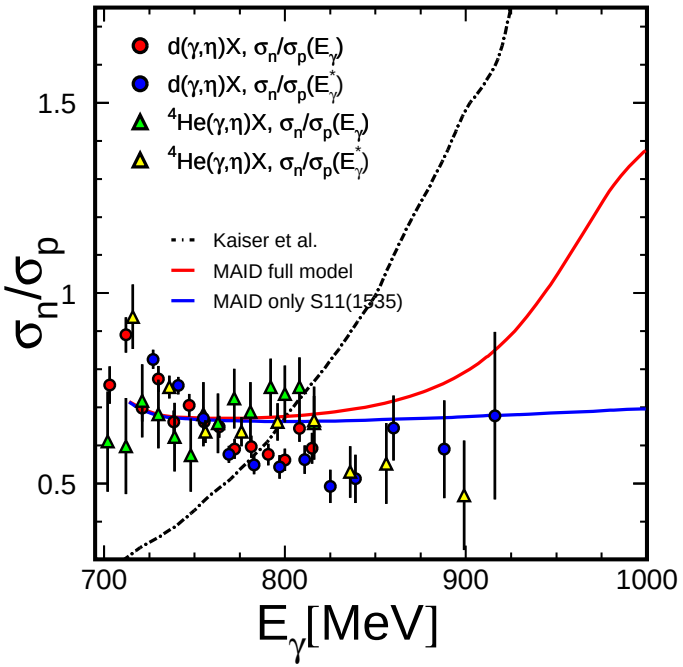
Data:

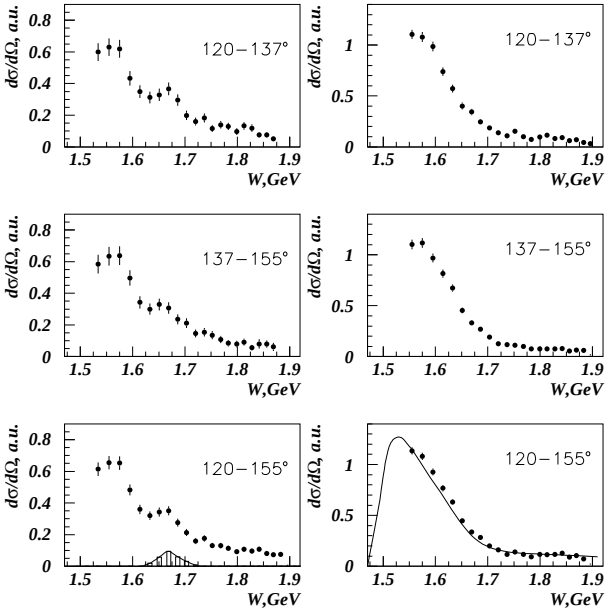
- TAPS: B. Krusche et al., PRL74 (1995) 3736
- GRAAL: F. Renard et al., PLB528 (2002) 215
- CLAS: M. Dugger et al., PRL89 (2002) 222002
- Crystal Barrel: V. Crede et al., PRL94 (2005) 012004

what is expected for $n(\gamma,\eta)n$ - why is it interesting?

- **total cross sections for proton and neutron from MAID model with and without $D_{15}(1675)$)**
- **previous data from MAMI only at lower incident photon energies**
- **GRAAL experiment reported narrow structure in neutron excitation function**





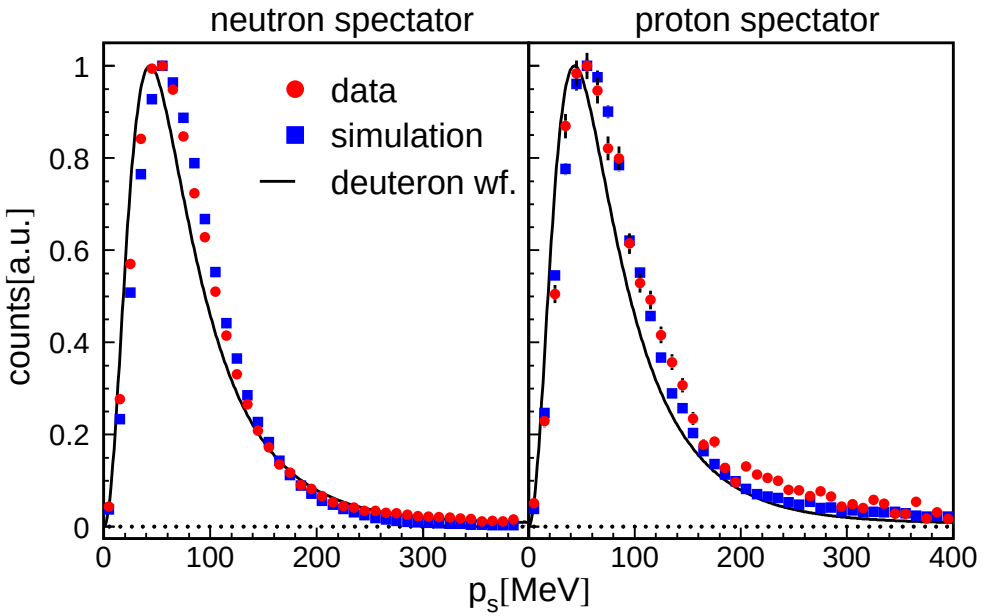


- **predictions from chiral soliton models: P_{11}-like state of the anti-decuplet has strong photon-coupling to the neutron and large ηN decay branching ratio**

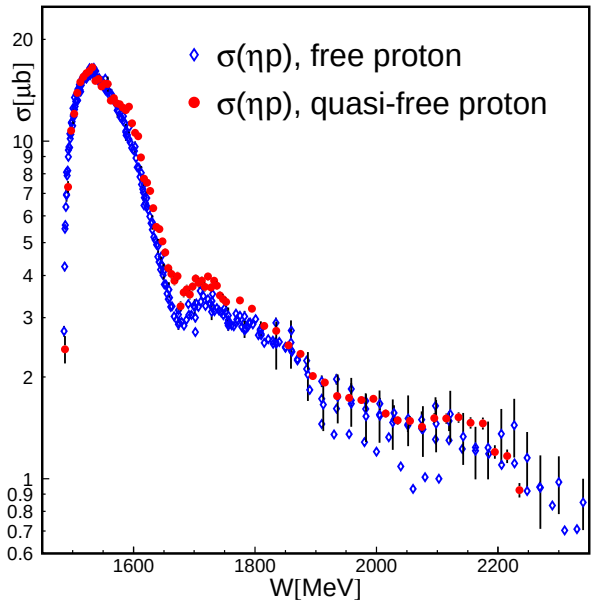
control over Fermi motion and FSI effects

- test with help of proton data:
- most simple test: comparison of quasi-free proton cross section with Fermi folded free proton cross section - perfect agreement
- more detailed: final state kinematically completely determined, four-momenta of meson, participant-, and spectator-nucleon known
  $\Longrightarrow W$ follows from invariant mass of meson and participant nucleon

- momenta of spectator nucleons



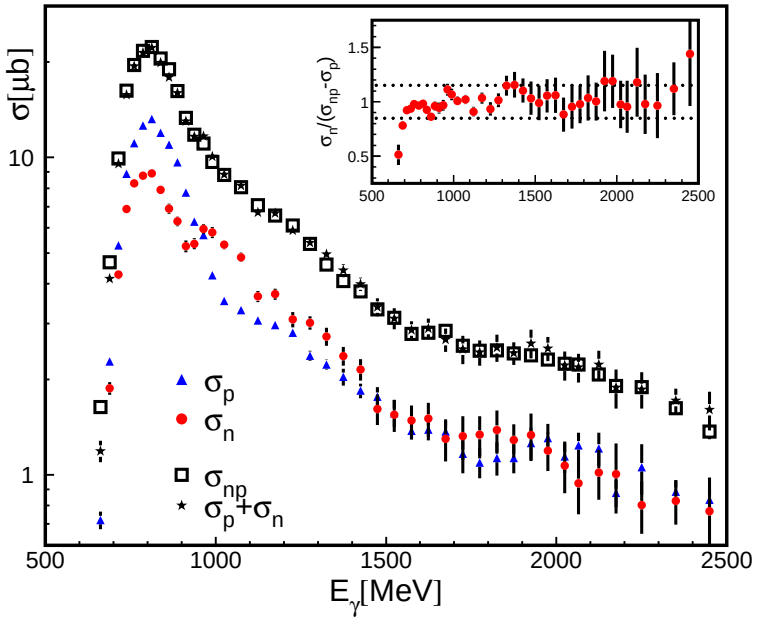
- proton excitation functions $\sigma(W)$

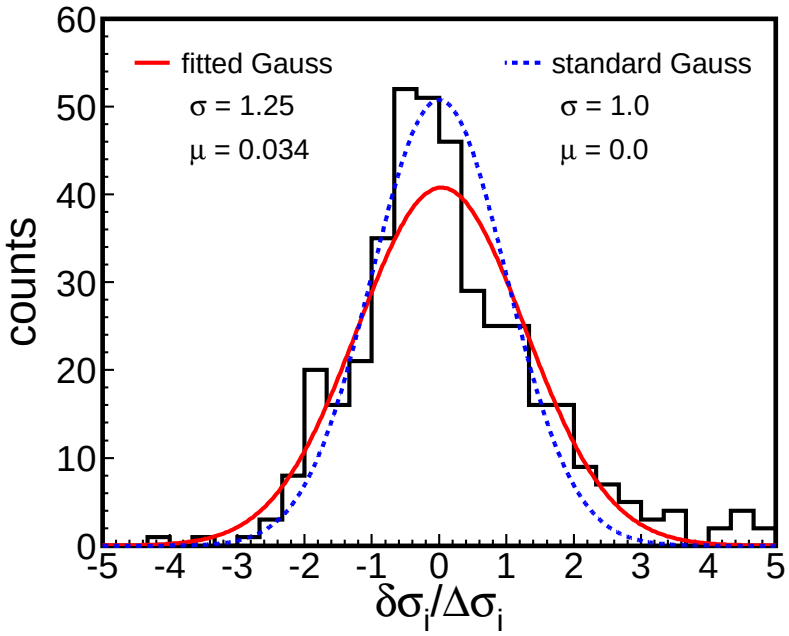


control over detection efficiency of recoil nucleons

- η-photoproduction
- internal consistency: $\sigma_{incl} = \sigma_p + \sigma_n + (\sigma_d)$
- coherent part σ_d negligible: $\sigma_n \approx \sigma_{incl} - \sigma_p$

- excitation functions σ
- distribution of differences of $\frac{d\sigma}{d\Omega}(n), \frac{d\sigma}{d\Omega}(incl-p)$

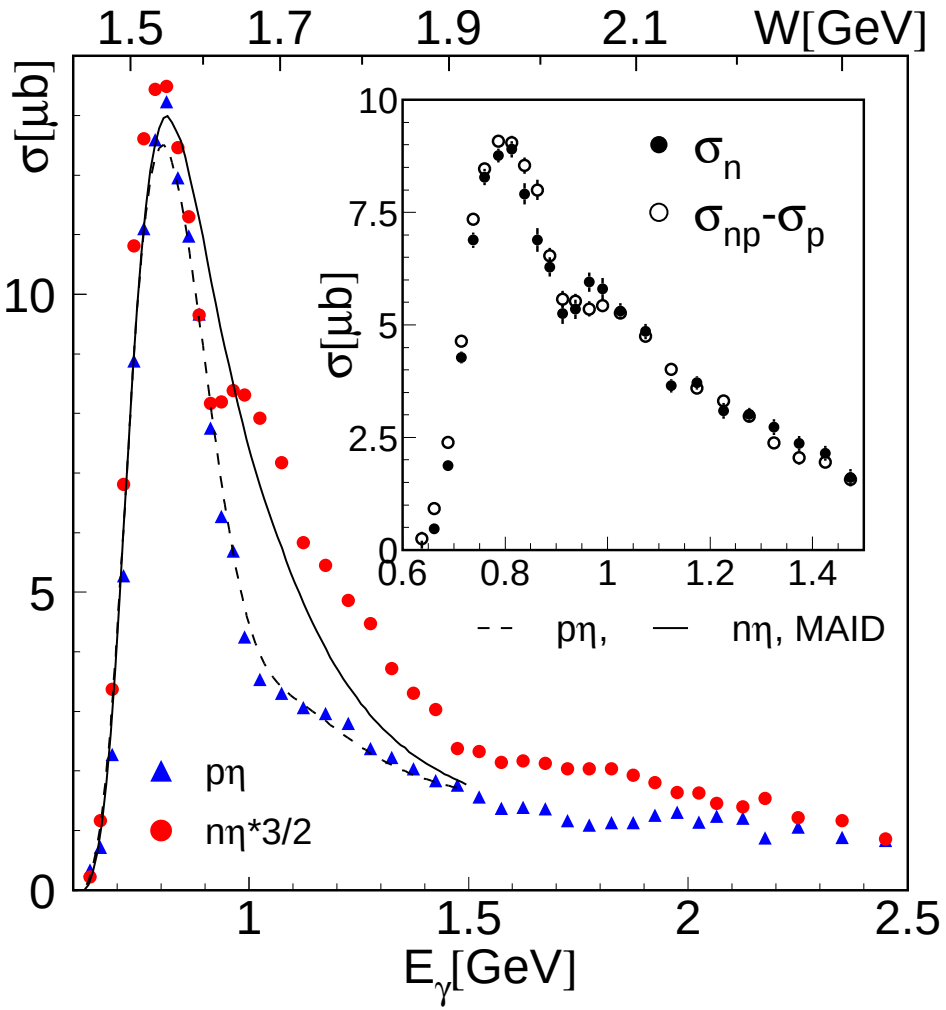


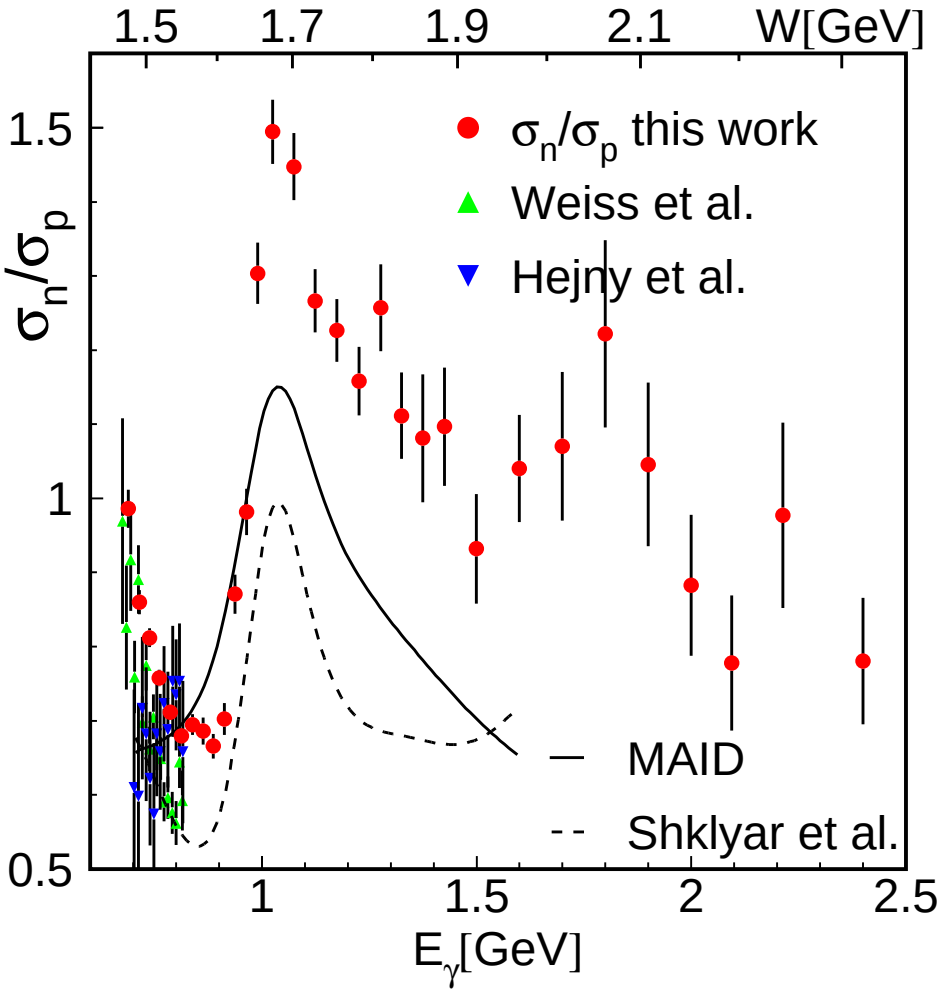


- no indication of systematic effects from neutron detection efficiency!

quasifree η-photoproduction off the deuteron

- **total cross section for $\gamma n \rightarrow \eta n$ from as function of incident photon energy:**
  pronounced structure around $E_\gamma \approx$1 GeV

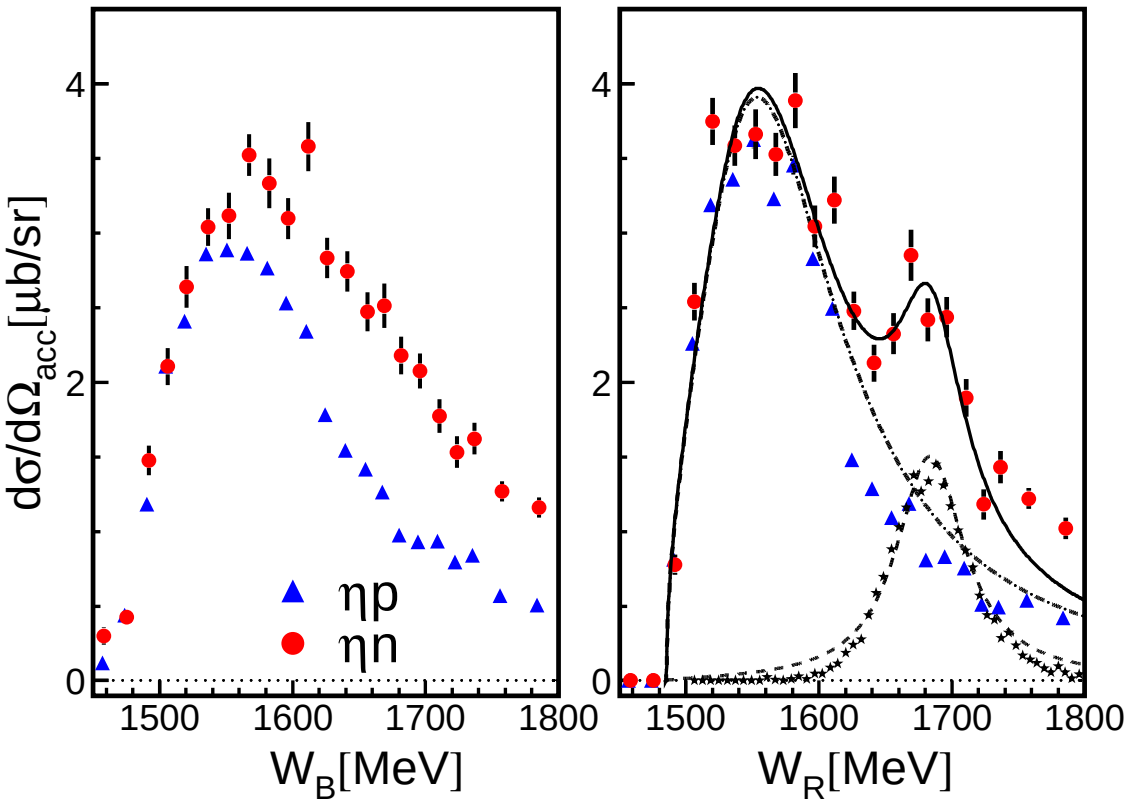




‘de-folding’ of Fermi motion

- for events with neutron in TAPS
  ($\cos(\Theta_\eta^\star) < -0.1$)
  neutron energy from time-of-flight
- comparsion: W from photon energy (Fermi smeared) - W from nucleon - meson 4-vectors (resolution smeared)
- de-folded proton cross section similar to free proton,
  de-folded neutron cross section shows structure around 1.7 GeV:

I. Jaegle et al.,
Phys. Rev. Lett. 100 (2008) 252002



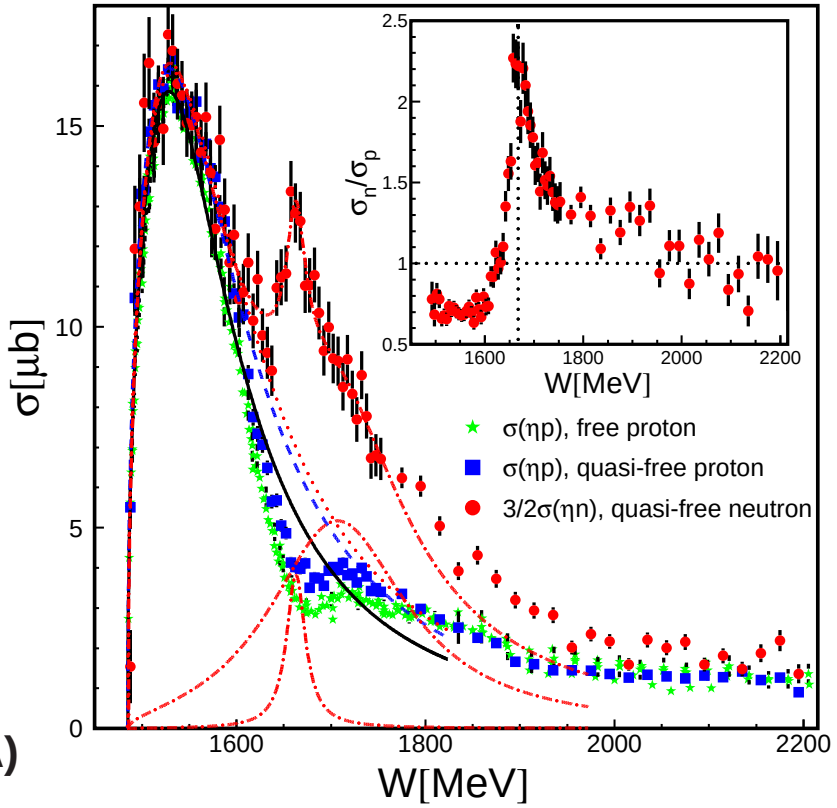
position: W=1683 MeV
width: Γ=60±10 MeV
(resolution dominated)

‘de-folding’ of Fermi motion - kinematical reconstruction

- **reaction kinematics completely determined even without neutron ToF:**

  - **initial state:**
    incident photon and deuteron at rest
    known/measured: $E_\gamma, m_d, \vec{p}_d = 0$
  - **final state:**
    η**, participant, and spectator nucleon**
    known/measured: $m_s, m_p, \Theta_p, \Phi_p, m_\eta, \vec{p}_\eta$
    not measured: $T_p, \vec{p}_s$ **(four variables)**
  - **four constraints**
    from energy/momentum conservation
    $\rightarrow$**four-vectors of**
    participant and spectator determined

- **structure in n excitation function**
  width ≈(25±10) MeV
  (resolution dominated)

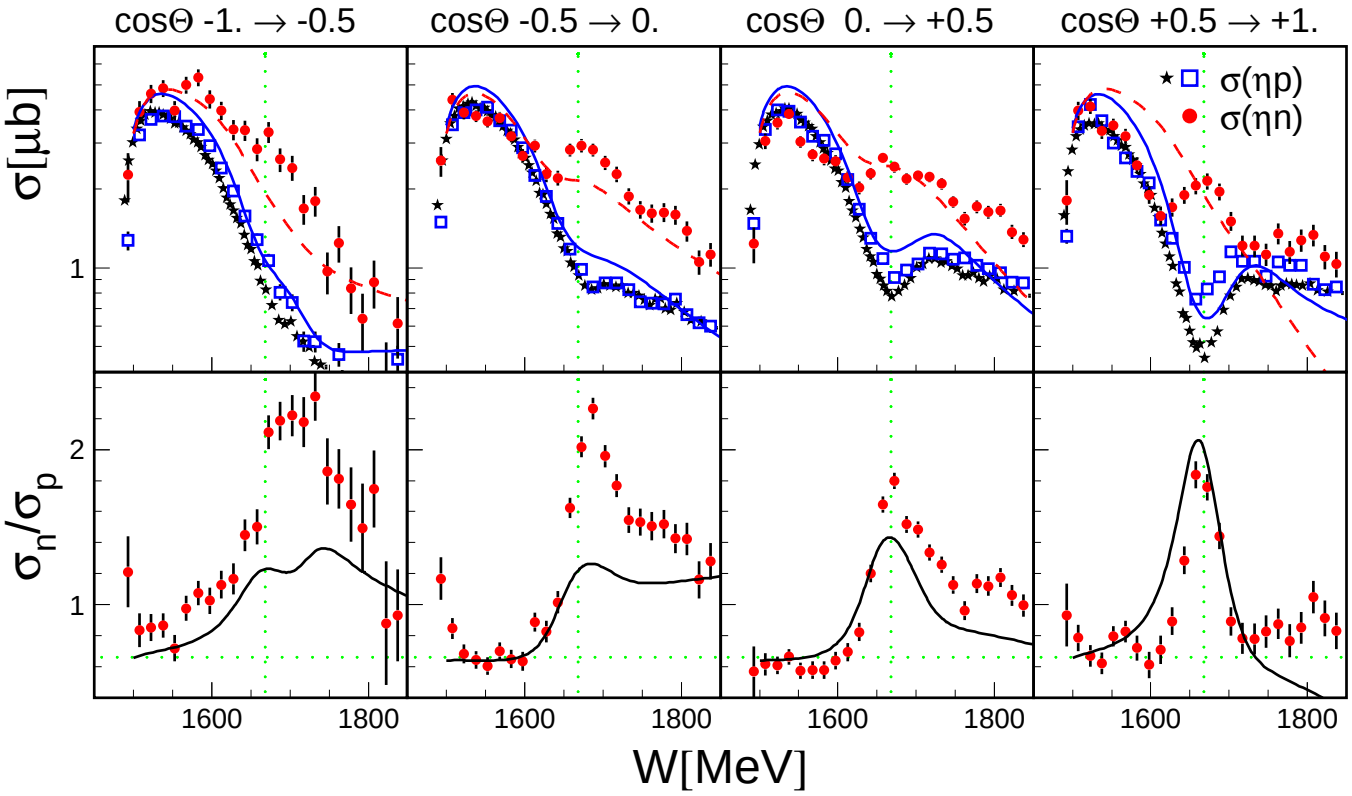


I. Jaegle et al., arXiv:1107.2046 (published in Eur. Phys. J. A)

Fermi de-folded proton and neutron data

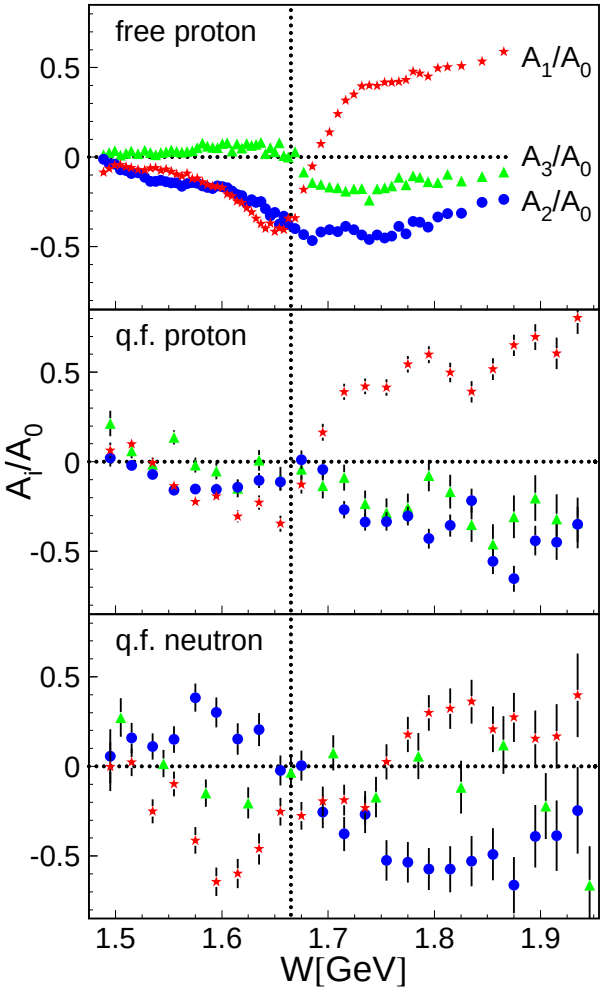
- **excitation functions for different bins of polar angle**

free proton data (⋆): McNicoll et al. PRC 82 (2010); curves: MAID model



- **fit with:**

$$\frac{d\sigma}{d\Omega} = \frac{q^\star}{k^\star} \times \sum A_i P_i(\cos(\Theta^\star))$$

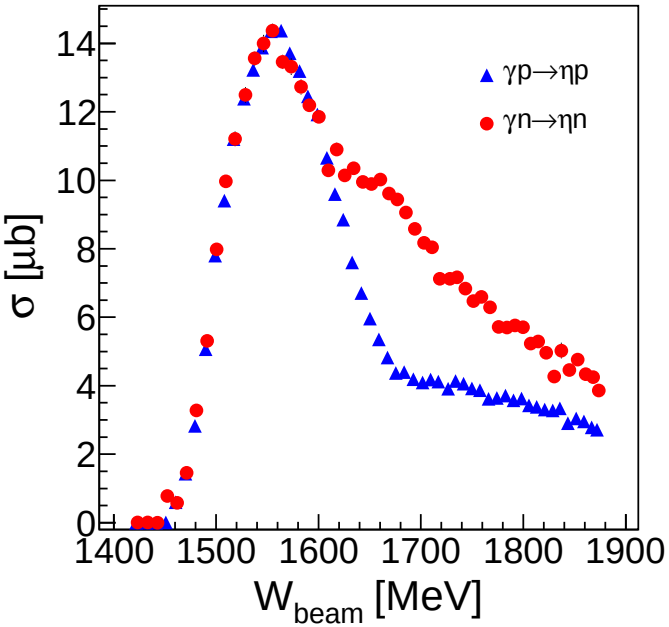


- **'peak' in neutron cross section related to 'dip' in proton cross sections (?)**
- **only 'dip' reproduced by MAID!**

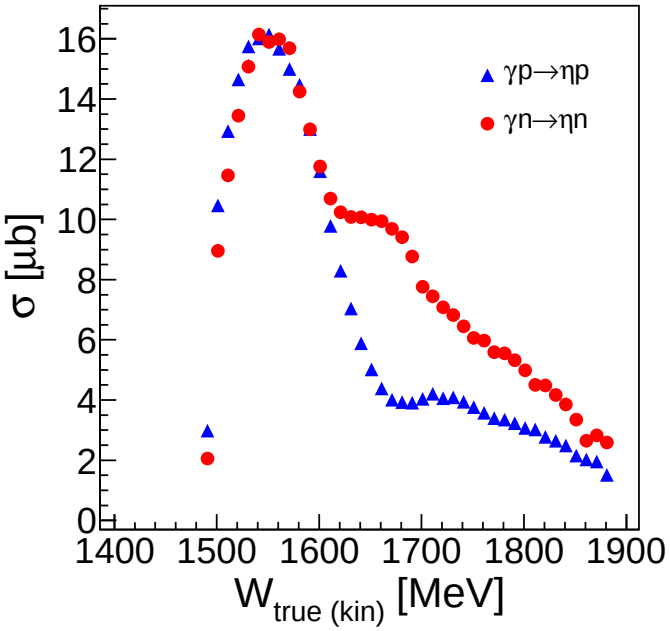
preliminary excitation functions from MAMI

D. Werthmüller et al.

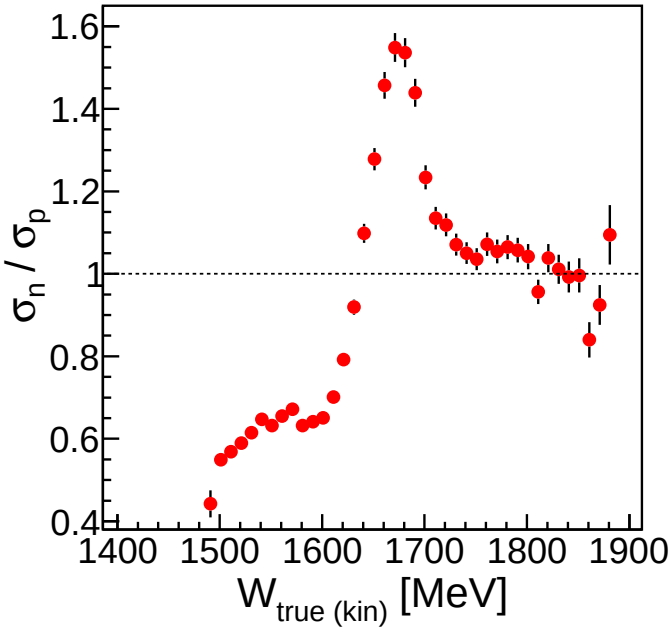
- $W = f(E_\gamma)$



- $W = f(n, \eta)$



- ratio σ_n/σ_p

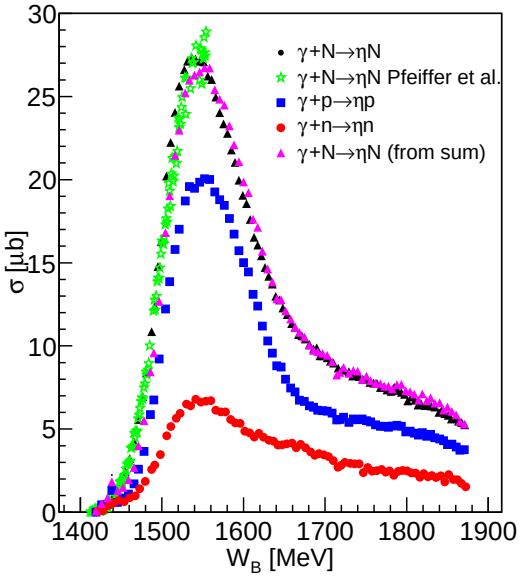


- new MAMI data confirm statistical significance of structure beyond any doubts
- correspond to ≈30% of data taken
- will allow detailed analysis of angular distributions
- width of structures still resolution dominated

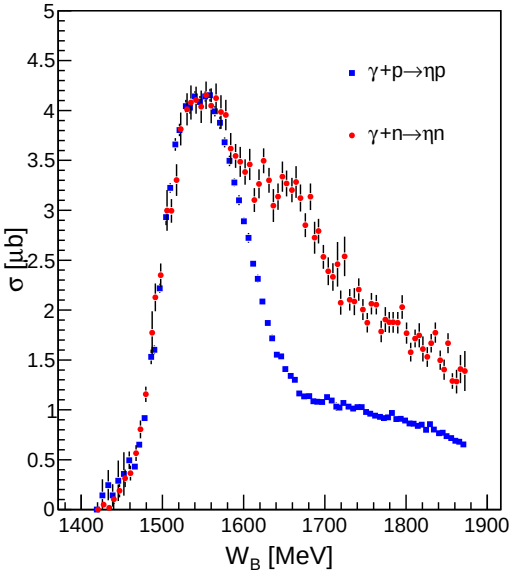
similar results for ^{3}He target

L. Witthauer et al.

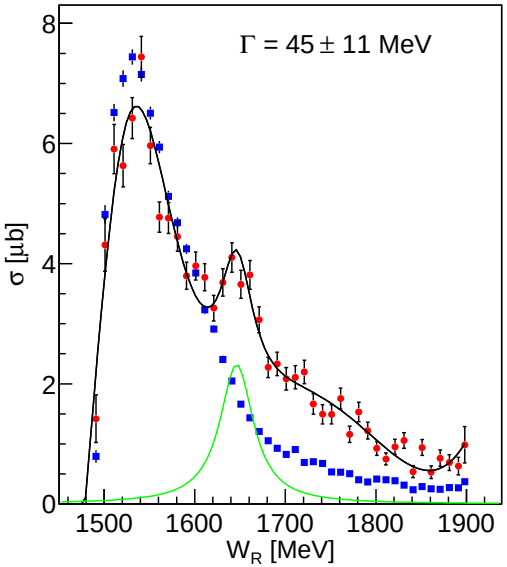
- inclusive and exclusive cross sections



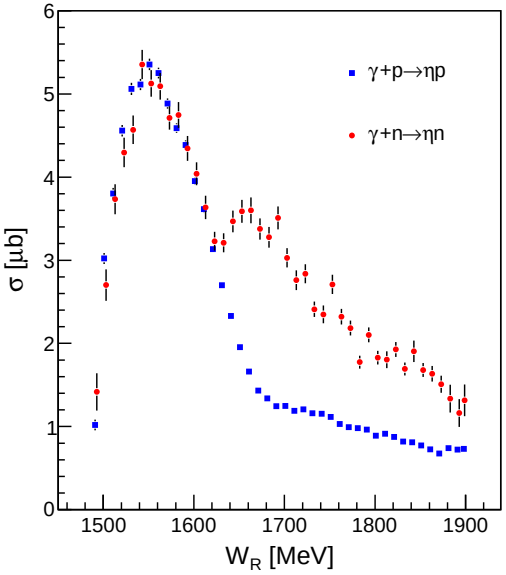
- quasi-free nucleon, W from incident photon energy



- quasi-free nucleons W from time-of-flight (only nucleons in TAPS)



- quasi-free nucleon, W from $N-\eta$ final state



Summary

- **narrow structure in excitation function of $\gamma n \to n\eta$:**

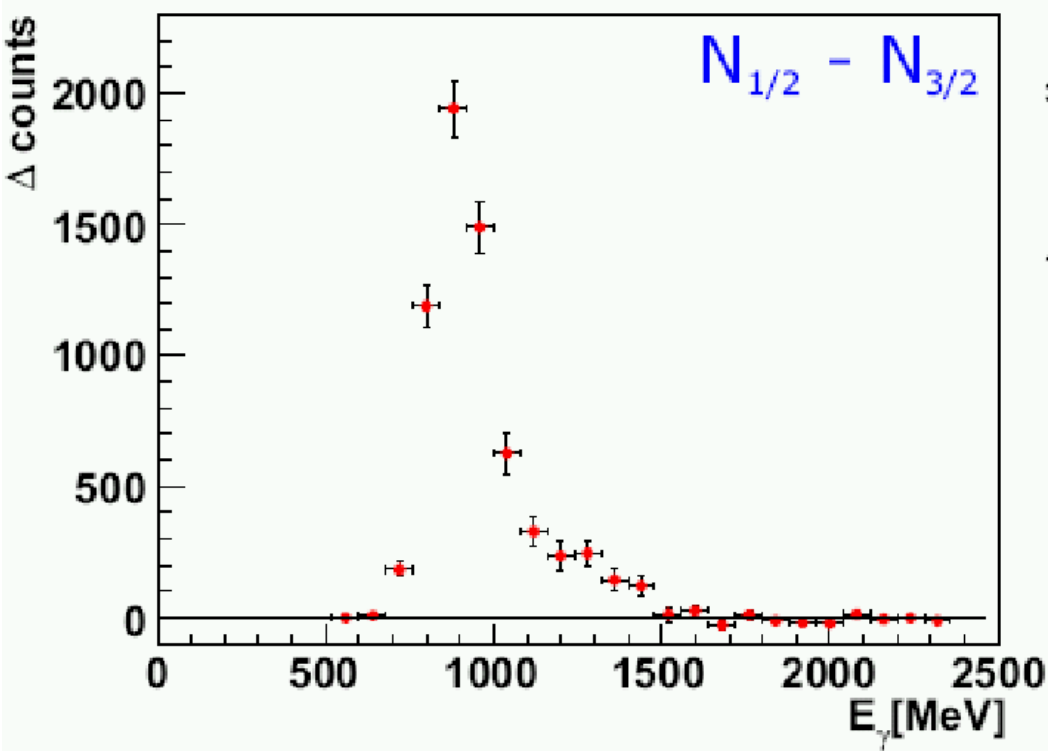
- **GRAAL:** $W \approx$ **1680 MeV,** $\Gamma <$**30 MeV**
- **Tohoku-LNS:** $W \approx$ **1670 MeV,** $\Gamma <$**40 MeV**
- **ELSA:** $W \approx$ **1665 MeV,** $\Gamma <$**40 MeV**
- **MAMI-C:** $W \approx$ **1675 MeV,** $\Gamma <$**50 MeV**
- **MAMI-C,** ^{3}**He:** $W \approx$ **1650 MeV,** $\Gamma <$**50 MeV**

- **so far no information about quantum numbers of possible resonance or whatever nature of the structure**

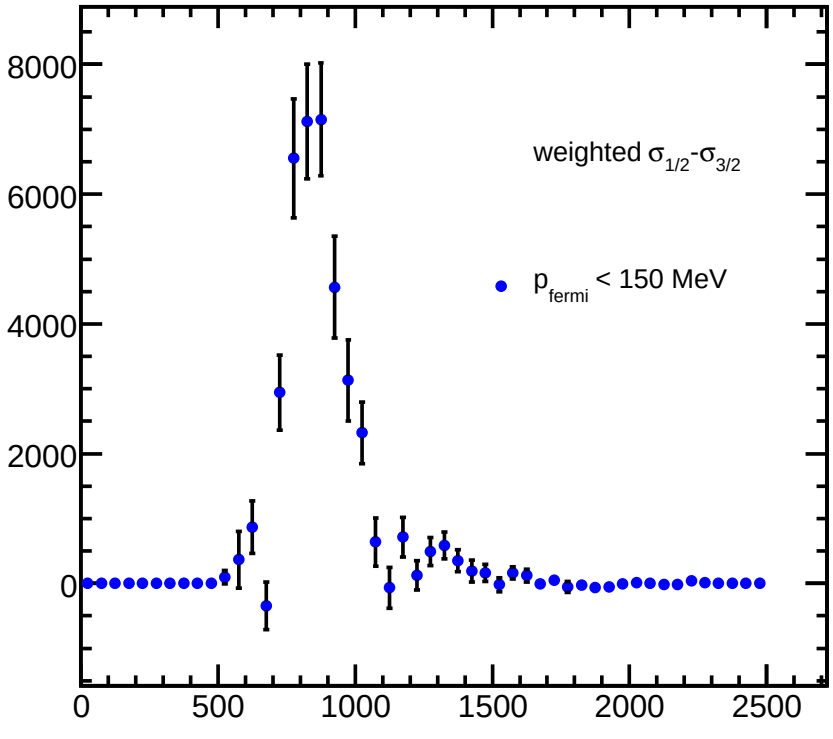
measrement of polarization observables under way

- at MAMI data taken for target asymetry T (transversely polarized target and double polarization observable F (tranversely polarized target, circularly polarized beam)
- at ELSA double polarization observable E ('GDH') (longitudinally polarized target, circularly polarized beam)

online results free proton



quasi-free proton



Conclusions

Systematic investigation of meson production off ^{2}H and ^{3}He

η-photoproduction off deuteron:

- large difference for resonance contributions to $p(\gamma,\eta)p$ and $n(\gamma,\eta)n$
- narrow structure in excitation function off neutron

other channels:

- iso-spin dependence of the elm. nucleon excitation

outlook:

- quasi-free (double) polarization observables

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