Mesons photoproduction off light nuclei

Igal Jaeglé for the **CBELSA/TAPS** and **A2** Collaborations
University of Hawaii *

- **introduction**
- **setups**
- **results**
- **conclusions**
- **bibliography**

CBELSA/TAPS Collaboration

Basel Uni., CH
Bochum Uni., DE
Bonn Uni., DE
Dresden Uni., DE
Erlangen Uni., DE
Petersburg NPI Gatchina, RUS
Giessen Uni., DE
KVI Groningen, NL
Tallahasse Uni., USA

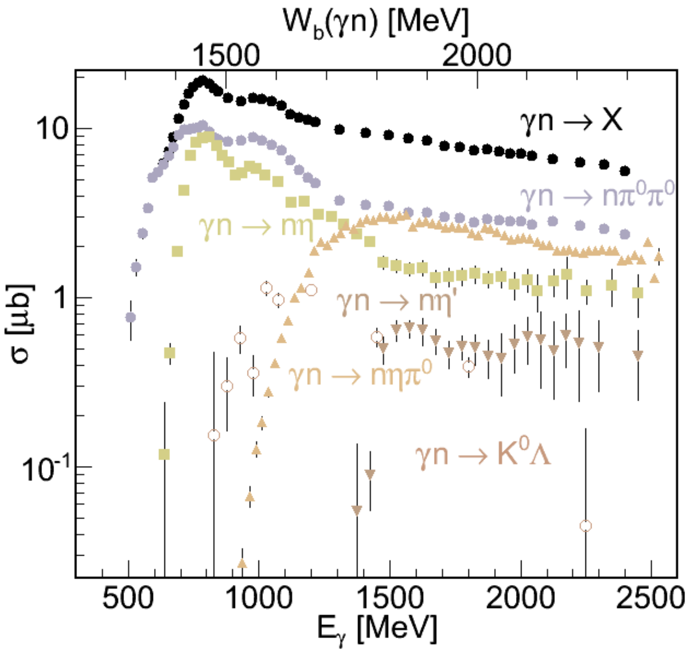
A2 Collaboration

Basel Uni., CH
Bochum Uni., DE
Bonn Uni., DE
Cambridge MIT, USA
Dubna JINR, RUS
Edinburgh Uni., UK
Petersburg NPI Gatchina, RUS
Glasgow Uni., UK
Halifax SM Uni, CA
Kent Uni, USA
Los Angeles UCL, USA
Lund Uni. MAX-lab, SWE
Mainz Uni., DE
Moscow INR, RUS
Moscow LPI, RUS
Pavia INFN, IT
Sackville MA Uni, CA
Monsk TP Uni., RUS
Tubingen Uni., DE
Washington GW Uni,, USA
Washington C Uni., USA
Zagreb RBI, CRO

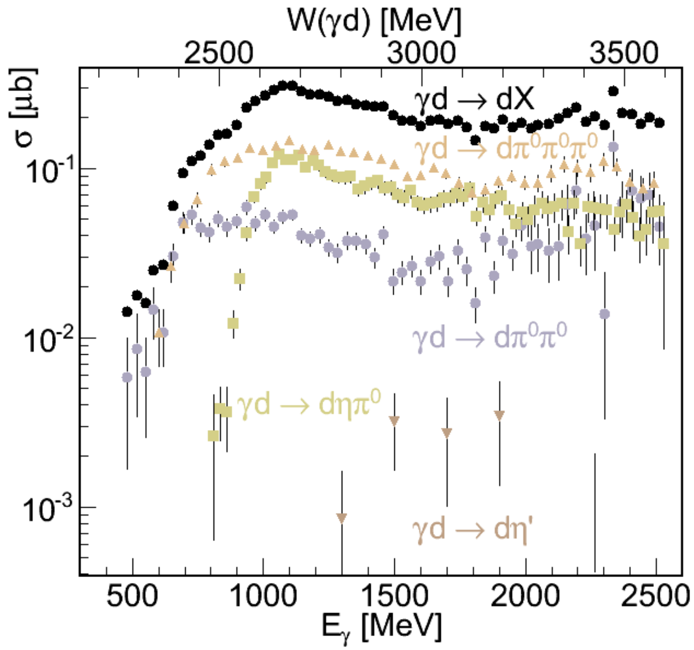
*** UH is not a member of the CBESLA/TAPS and A2 Collaborations, the results reported here are from my previous appointment (as a PhD and PostDoc in the group of Prof. Krusche at the University of Basel) and also currently obtained off the record**

Mesons photoproduction off light nuclei

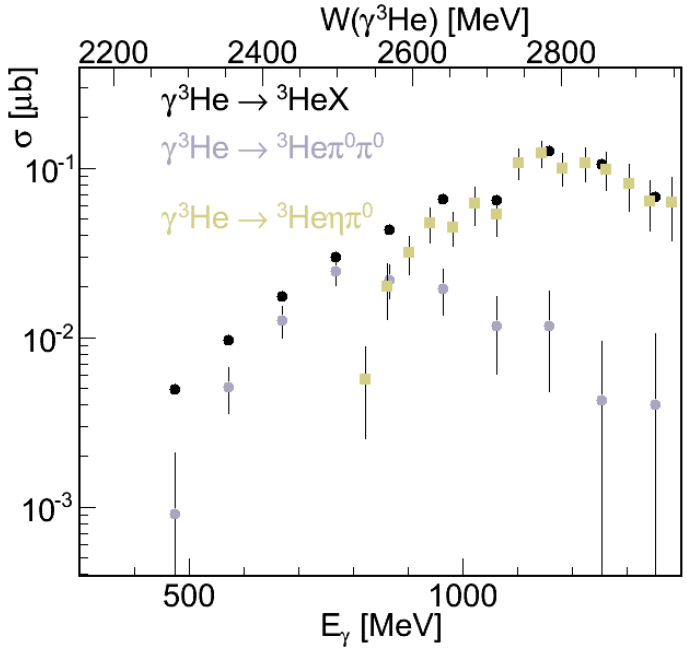
- mesons photoproduction off the neutron



- coherent photoproduction of mesons off the deuteron



- coherent photoproduction of mesons off ^{3}He



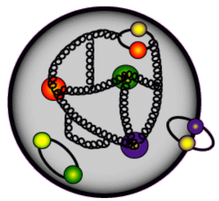
- isospin composition of the resonances
- search for missing resonances
- resonances coupling strongly to γn

- isospin filter
- eg $\gamma d \to N^* \to d\pi^0\pi^0$
- map spin structure of the elementary amplitude
- isotope dependence
- search for meson bound states

Nucleon structure

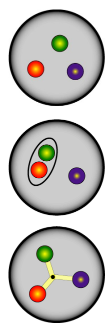
complex system

- valence quarks
- sea quarks
- gluons



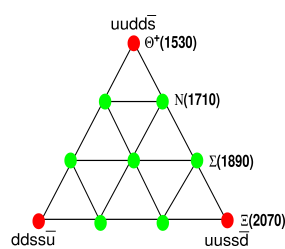
degrees of freedom ?

- 3 constituent quarks
- quark-diquark
- quark flux-tube

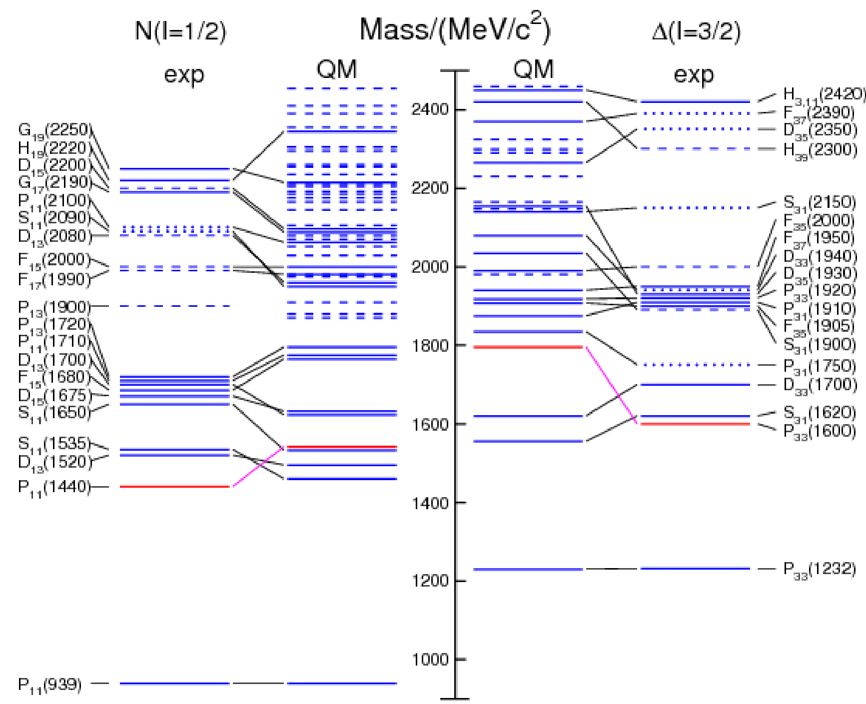


more complicated structure

- couple channel
- chiral soliton



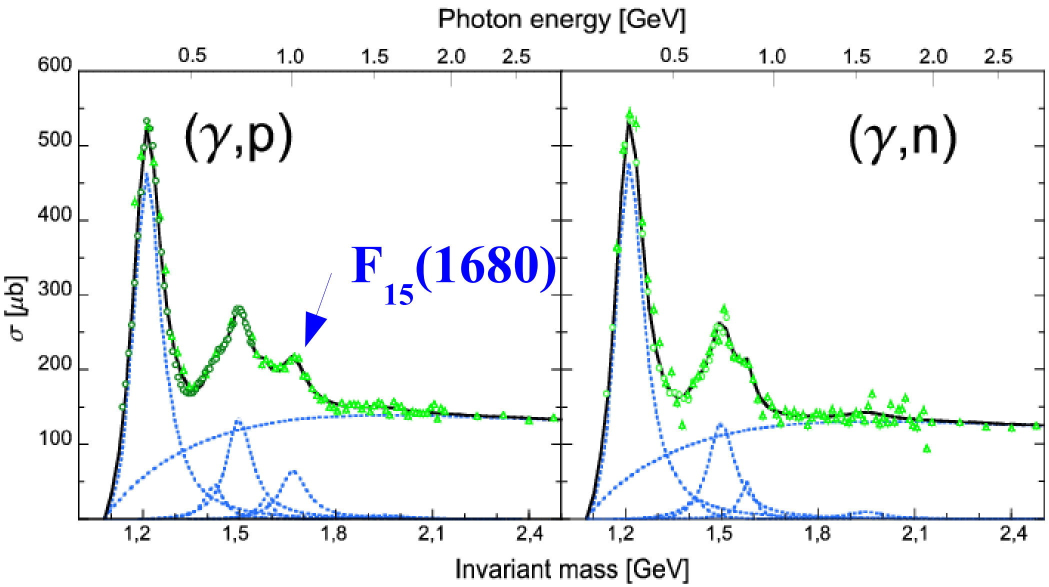
comparison: known excited states – constituent quark model (Capstick & Roberts)



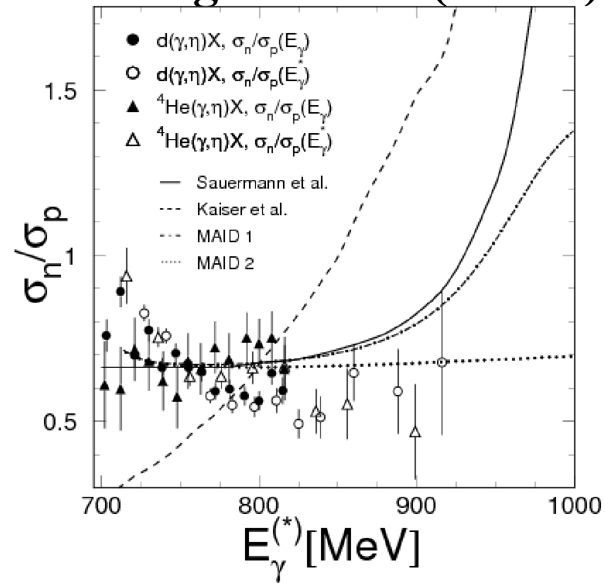
ordering of low lying states ?
missing resonances ?

proton resonances versus neutron resonances

photoabsorption on the nucleon (Bianchi et al)



photoproduction of η-meson from light nuclei (TAPS)



- **Δ*: n and p electromagnetic coupling are the same**
- **N*: n and p have different electromagnetic coupling**
- **no neutron target**
- **light nuclei: LD_2 => nuclear effects**

M(inclusive) = M(p) + M(n) + M(coherent)

M(n) directly

M(n) = M(inclusive) – M(p) if M(coherent) <<1

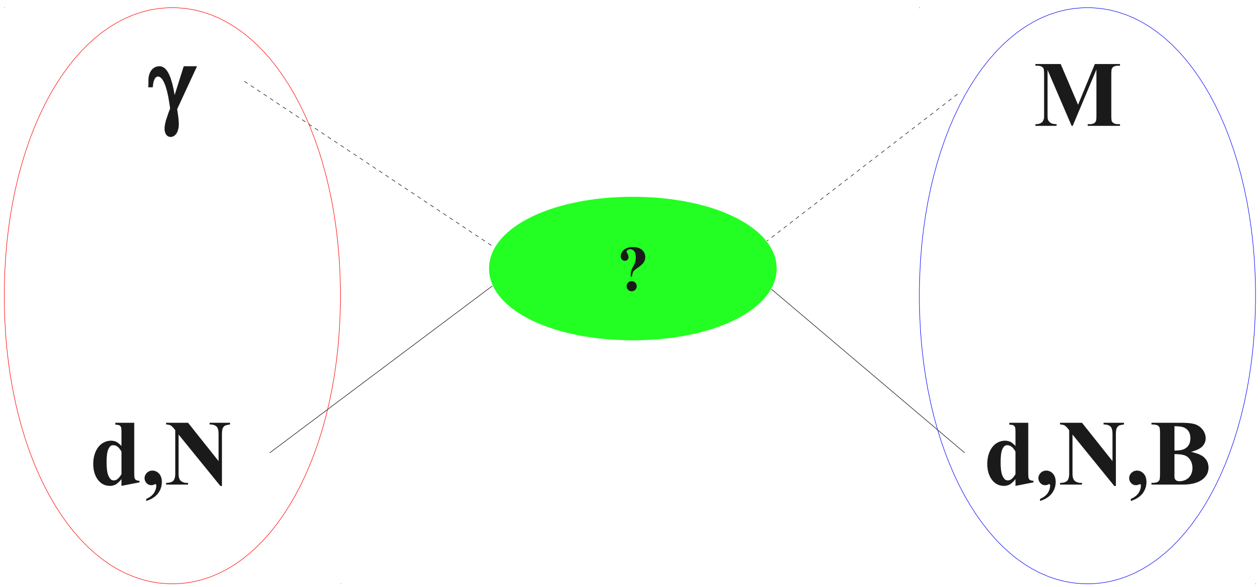
$$\sigma_p \approx \left|A_{1/2}^{IS} + A_{1/2}^{IV}\right|^2 = \left|A_{1/2}^{p}\right|^2$$

$$\sigma_n \approx \left|A_{1/2}^{IS} - A_{1/2}^{IV}\right|^2 = \left|A_{1/2}^{n}\right|^2$$

$$\sigma_d \approx \left|A_{1/2}^{IS}\right|^2$$

find the iso-spin composition of the resonances

Search for missing resonances by looking at resonances coupling strongly to γn



initial state interaction

final state interaction

N : n,p

B : Λ

M: $\eta, \eta', \pi^o\pi^o, \pi^o\eta, \pi^o\omega, \pi^o\pi^o\pi^o, K^o$

$\gamma + n \rightarrow \eta + n \rightarrow \pi^o\pi^o\pi^o + n \rightarrow 6\gamma + n$

$\gamma + n \rightarrow \eta' + n \rightarrow \pi^o\pi^o\eta + n \rightarrow 6\gamma + n$

$\gamma + n \rightarrow \pi^o\pi^o + n \rightarrow 4\gamma + n$

$\gamma + n \rightarrow \pi^o\eta + n \rightarrow 4\gamma + n$

$\gamma + n \rightarrow K^o\Lambda(1115) \rightarrow 6\gamma + n$

$\gamma + d \rightarrow \pi^o\eta + d \rightarrow 4\gamma + d$

$\gamma + d \rightarrow \pi^o\pi^o + d \rightarrow 4\gamma + d$

$\gamma + d \rightarrow \pi^o\omega + d \rightarrow 4\gamma + d$

$\gamma + d \rightarrow \pi^o\pi^o\pi^o + d \rightarrow 6\gamma + d$

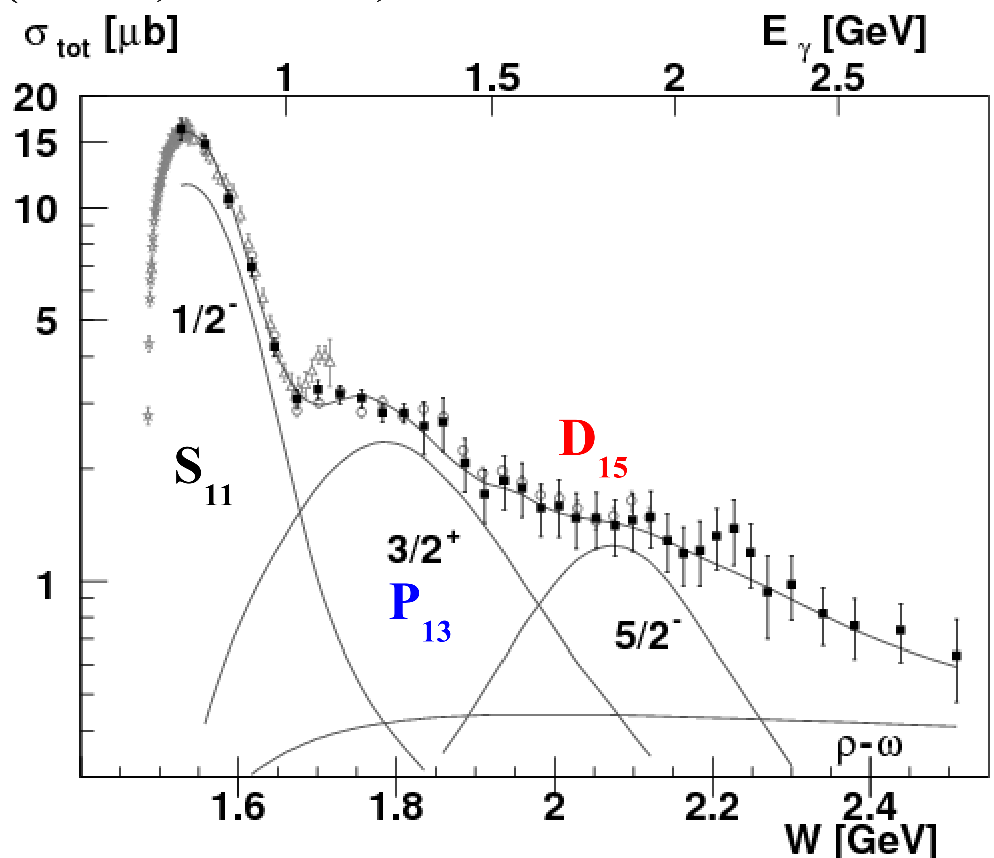
$\gamma + d \rightarrow \pi^o\pi^o\eta + d \rightarrow 6\gamma + d$

$\gamma + d \rightarrow \eta' + d \rightarrow 6\gamma + d$

- initial state interaction to produce resonances
- final state interaction to produce
  - short live mesons that interact with other mesons
  - short live mesons that interact with nucleons
  - short live mesons that interact with nuclei

Resonances coupling to η photoproduction

Photoproduction of η-meson off the proton
(TAPS, GRAAL, CLAS and CB–ELSA collaborations)



Bonn-Gatchina PWA
(A.V. Anisovich et al.)
Result : S_{11}, P_{13} and
new resonance $D_{15}(2070)$

- **η works as an isospin filter**

=> only N* are tagged

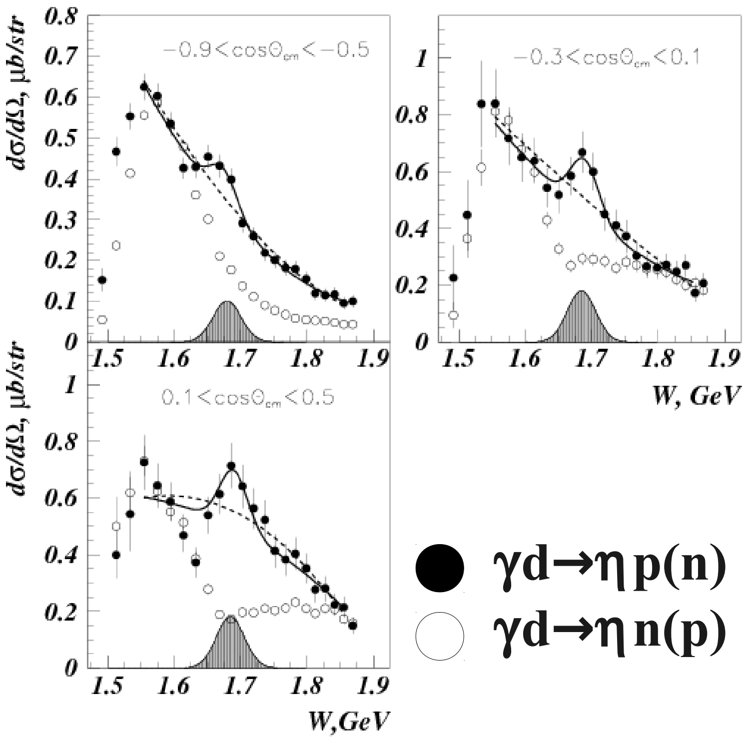
Involve less than 12 resonances

$D_{13}(1520)$
$S_{11}(1535)$
$S_{11}(1650)$
$D_{15}(1675)$ **couples strongly to the n**
$F_{15}(1680)$ **couples strongly to the p**
$P_{11}(1710)$
$P_{13}(1720)$ **ambiguity**
...
$D_{15}(2070)$ **couples strongly to the ?**

The neutron anomaly: $\gamma n(p) \rightarrow \eta\, n(p)$

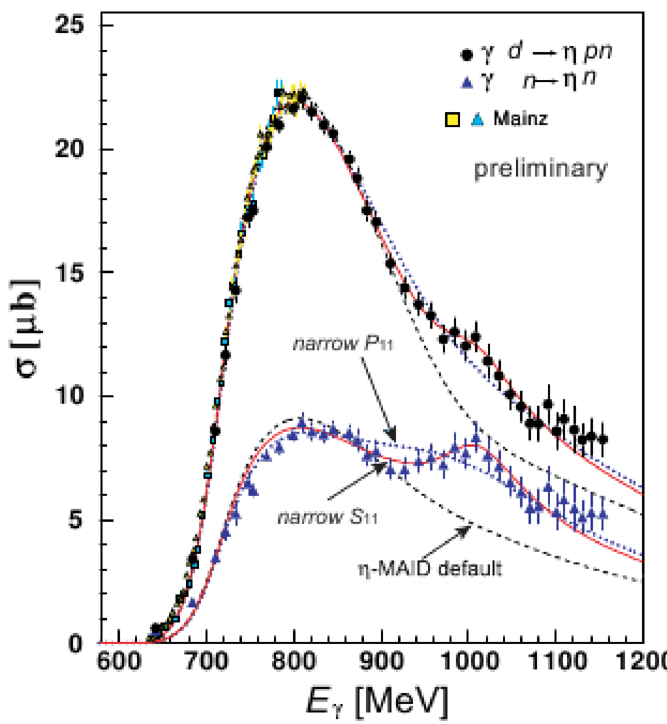
- GRAAL, Tohoku-LNS **show a bump on the neutron which is not seen on the proton**
- **the bump is getting narrower if the Fermi motion is removed**

GRAAL (V. Kuznetsov et al.)



M(n) directly

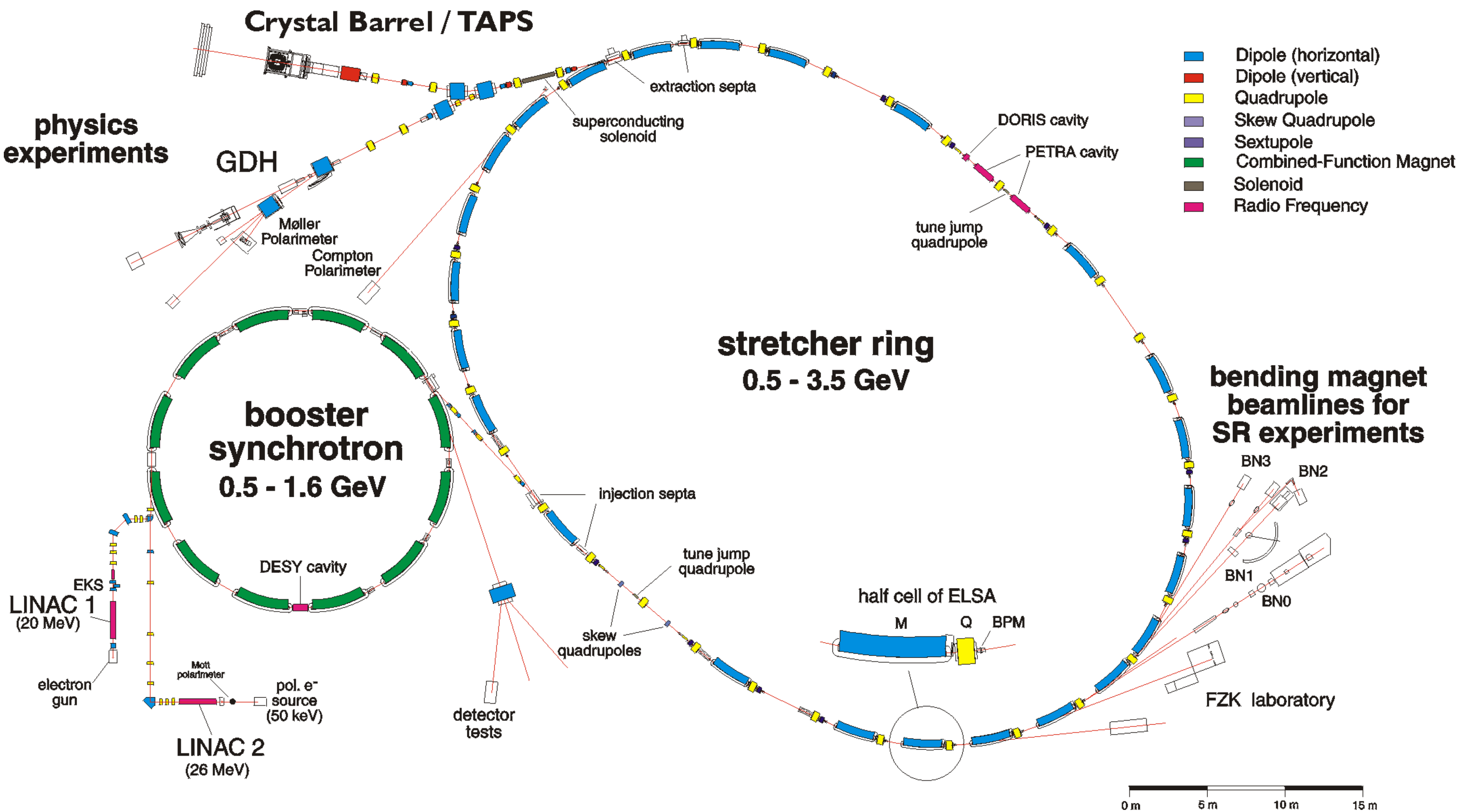
Tohoku-LNS (F. Miyahara et al.)



M(n) = M(inclusive) – M(p)

- **GRAAL**
  W ~ 1680 MeV, Γ < 30 MeV
- **Tohoku-LNS**
  W ~ 1666 MeV, Γ < 40 MeV

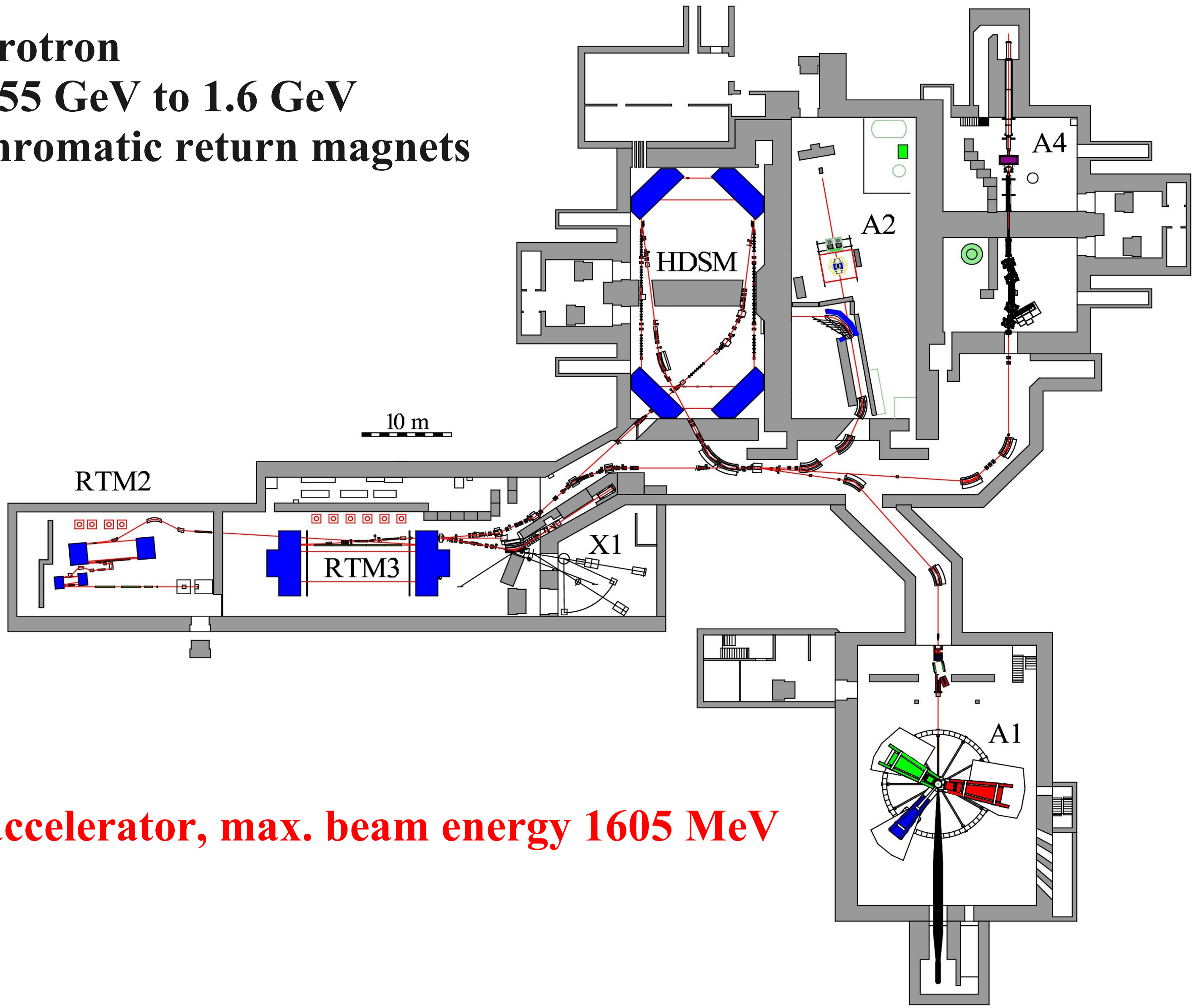
ELSA: electron accelerator @Bonn



quasi-monochromatic photon beam via bremsstrahlungs tagging 0.3 GeV $\leq E_\gamma \leq$ 2.6 GeV

MAMI-C: electron accelerator @Mayence

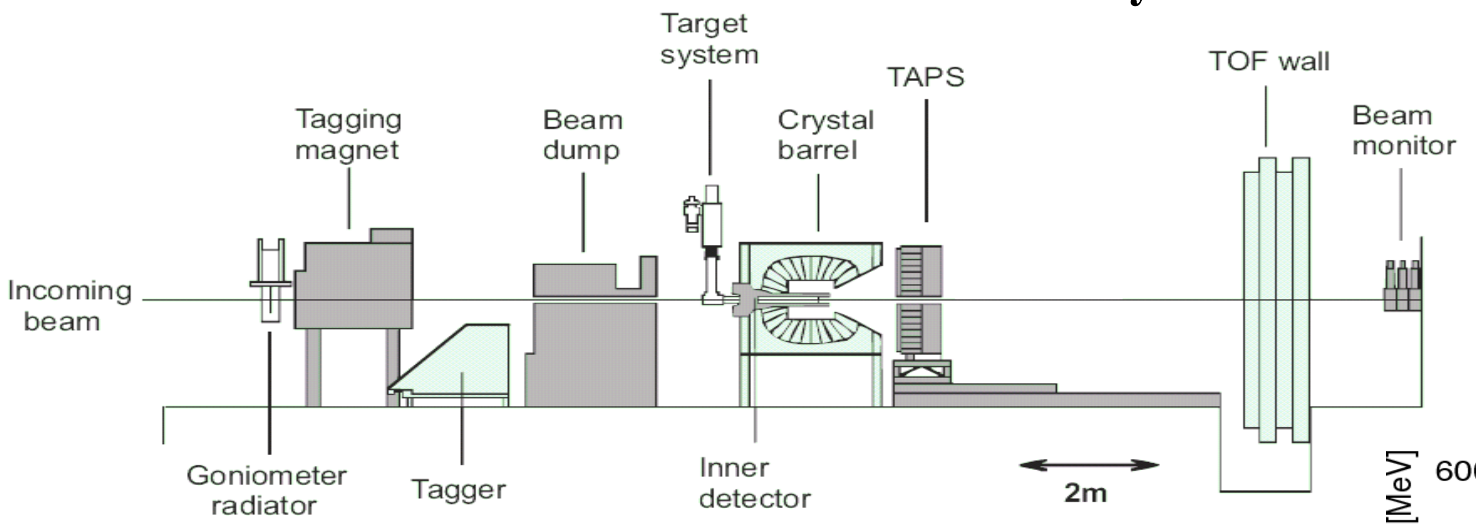
harmonic double sided microtron
- **energy increase from 0.855 GeV to 1.6 GeV**
- **2HF structures and 2 achromatic return magnets**



continuous wave electron accelerator, max. beam energy 1605 MeV

Crystal Barrel and TAPS detectors

4π detectors: 1818 crystals + CPCs

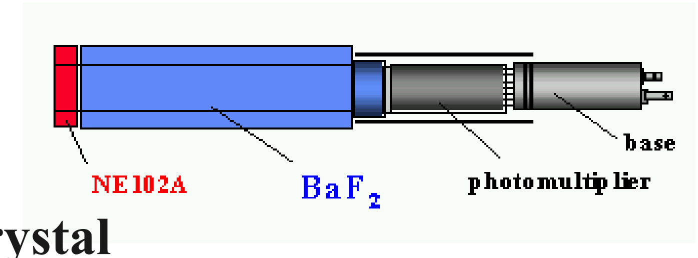


measure: $E_\gamma = E^o_{e^-} - E_{e^-}$

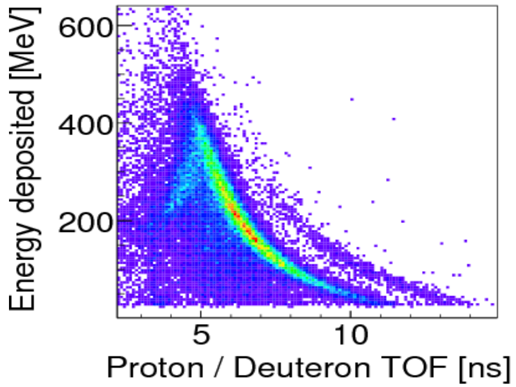
- **incident photon beam**
- **γ**
- **proton**
- **neutron**
- **deuteron**

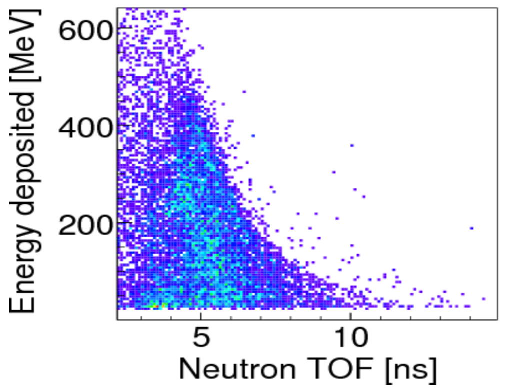
particle identification TAPS
TAPS veto detector

- **5 mm plastic scintillator**
- **individual for each BaF_2 crystal**



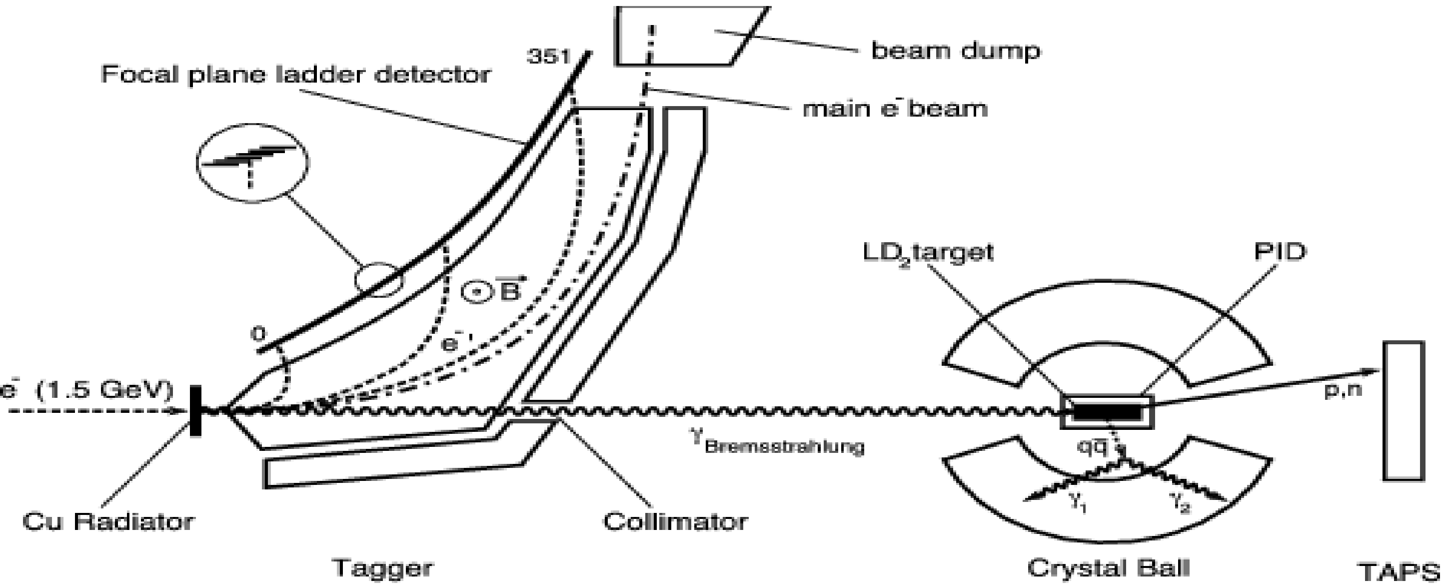
proton
veto hit in front of BaF2 crystal + E vs TOF
neutron
no veto hit + E vs TOF





Crystal Ball and TAPS detectors

4π detectors and 4π trigger : ~ 1000 crystals + CPCs



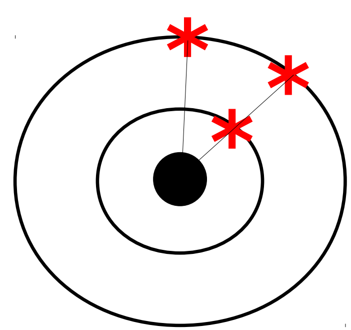
measure: $E_\gamma = E^o_{e^-} - E_{e^-}$

- **incident photon beam**
- **γ**
- **$\pi^{+/-}$**
- **proton**
- **neutron**
- **deuteron**

particle identification CB

PID detector

- **24 scintillators**
- **cylindrical shape**

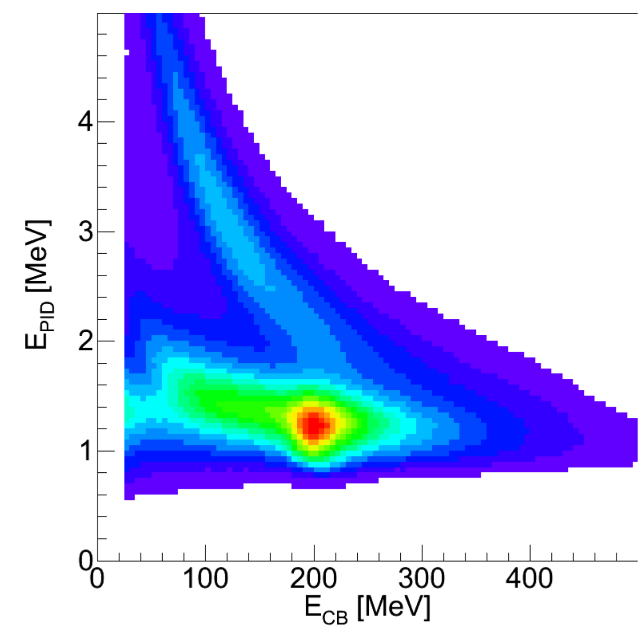


proton

a scintillator matches a hit in the CB + E_{PID} v E_{CB}

neutron

no scintillator has fired



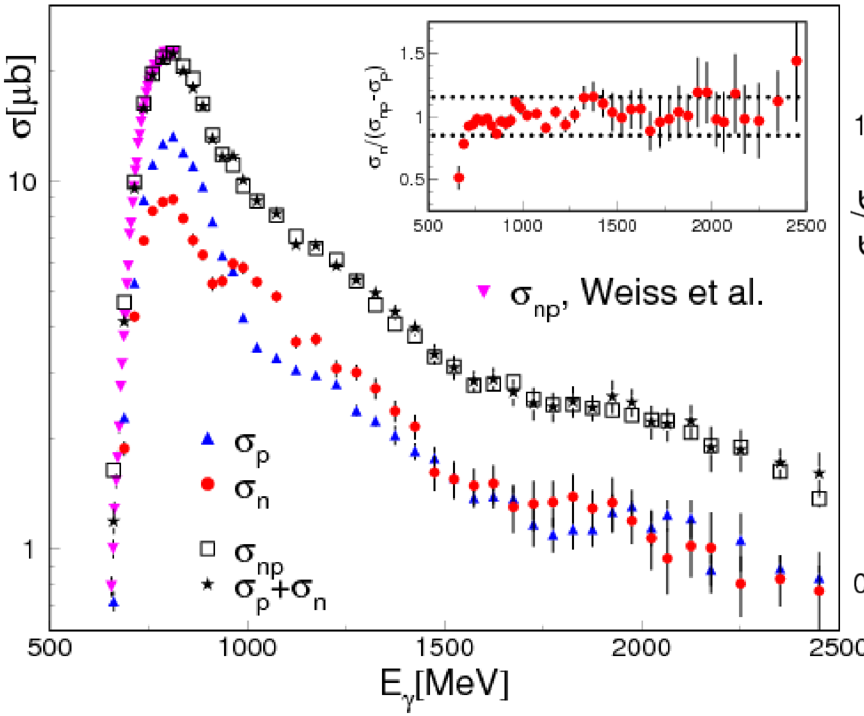
η photoproduction off the deuteron

CBELSA/TAPS,
PRL 100 (2008) 252002

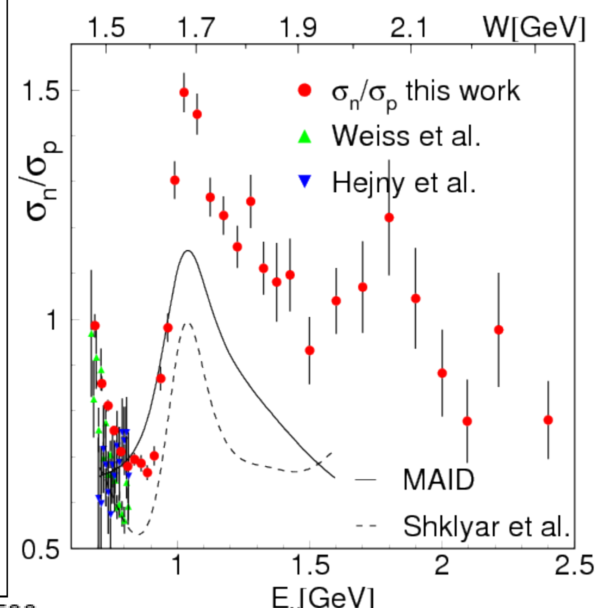
γn→ηn measured in 2 different ways :

- η in coincidence with the recoil neutron
- difference of inclusive cross section and in coincidence with the recoil proton

total cross section

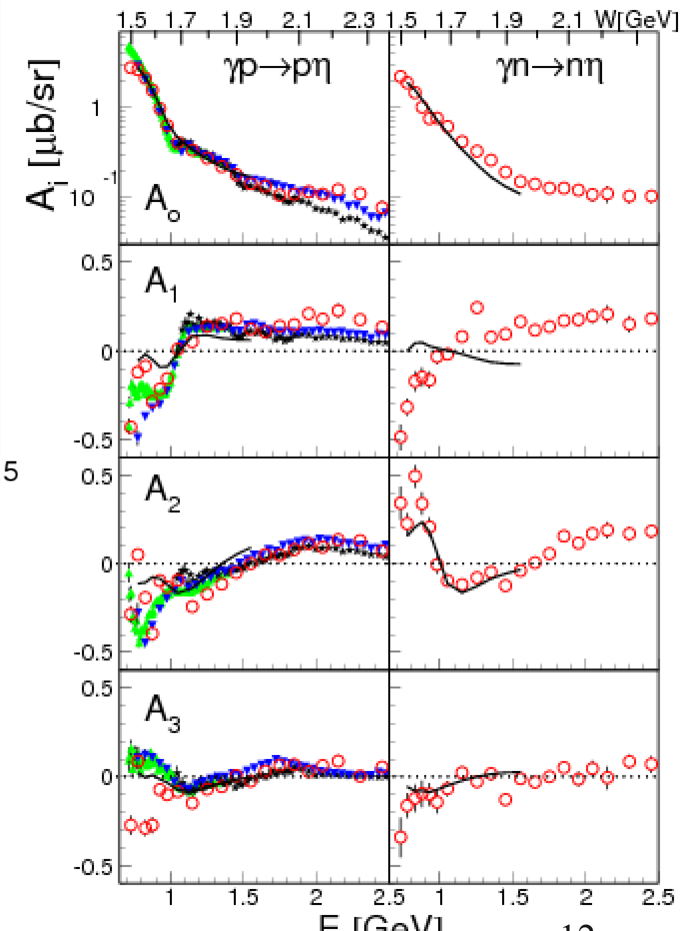


cross section ratio

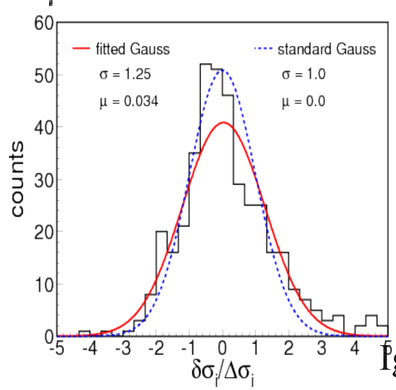


fit with

$$\frac{d\sigma}{d\Omega} = \sum_{l=0}^{3} A_l P_l^0(\cos(\theta_{cm}))$$

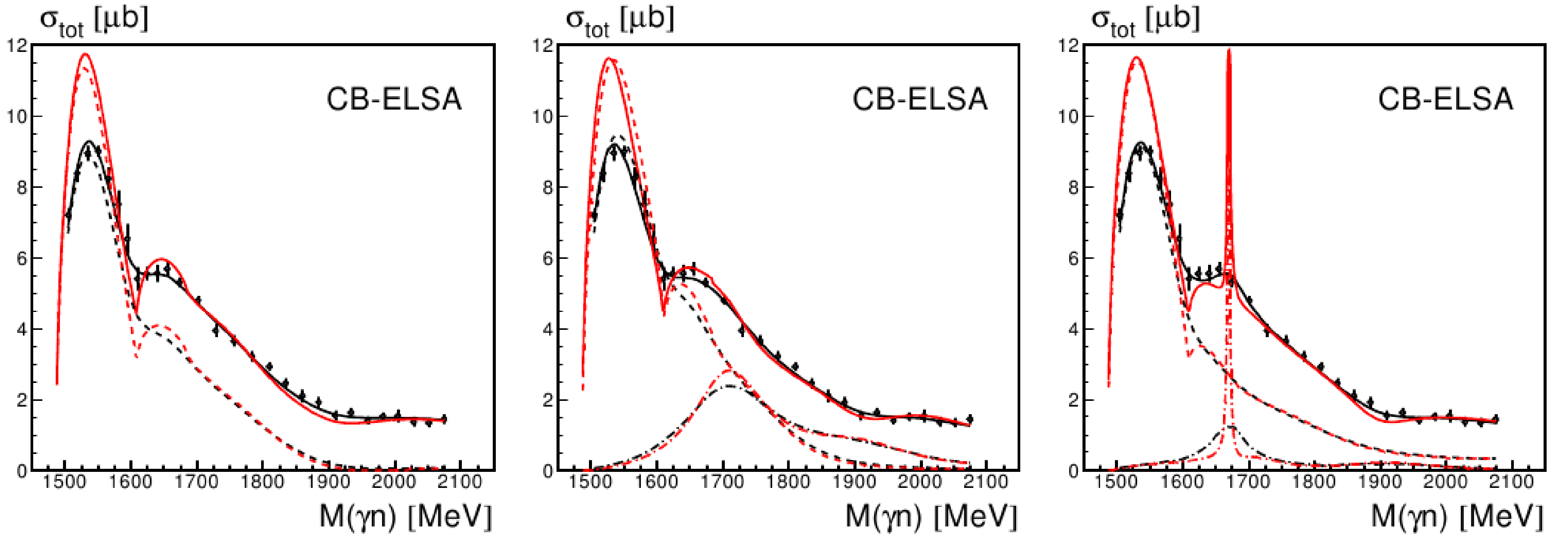


distribution difference of dσ/dΩ(n) and dσ/dΩ(np)



Bonn-Gatchina-Model analysis

A. Anisovich et al.



- **different scenarios are possible**
- **left: interference in S_{11}- sector**
- **center: introduction of a conventional (broad) P_{11} resonance**
- **right: introduction of a very narrow P_{11}**

De-folding the Fermi motion w/o TOF

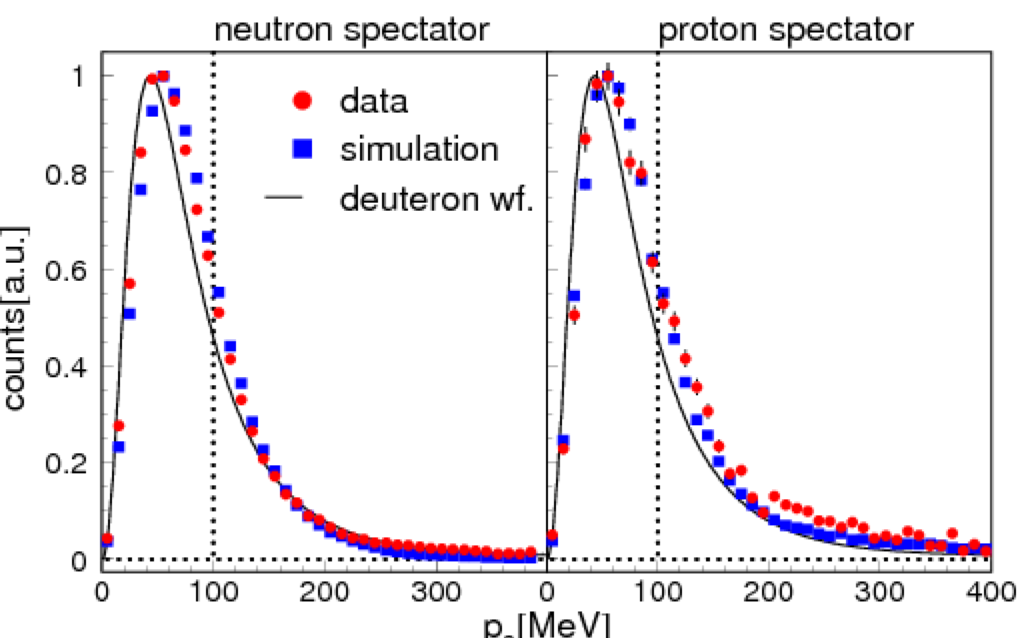
CBELSA/TAPS submitted to EPJA

- **using the reaction, $\gamma d \rightarrow \eta pn$, kinematics:**

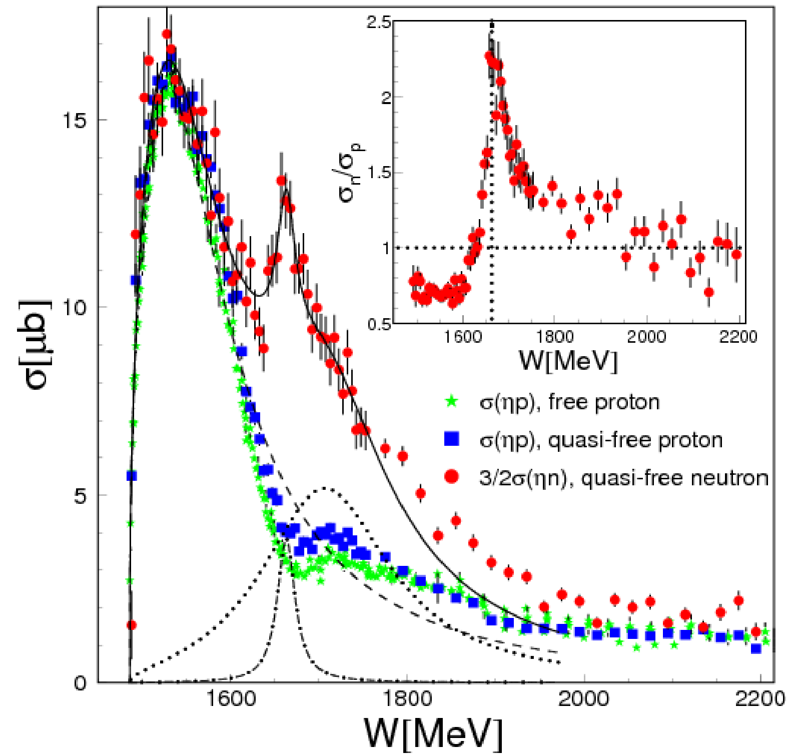
3 particles * 4-vec = 12 dof
- 3 identified masses = 9 dof
- energy & momentum conservations
= 5 dof

=> θ_η, φ_η, T_η, θ_n, φ_n are measured

=> T_n (as well as spectator momentum and energy) can be calculated



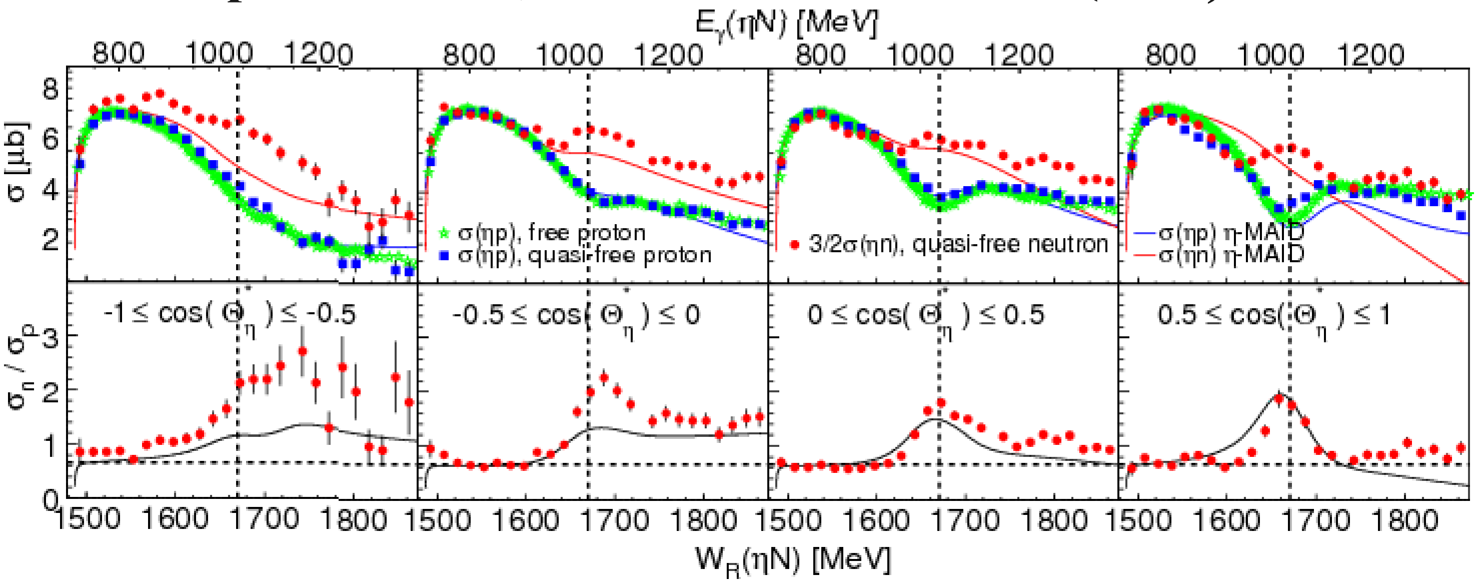
- **η-nucleon pair final state invariant mass compared with free p (TAPS, GRAAL, CB, A2 and CLAS) => width 25 MeV ± 10 MeV**



- **Fermi motion effect is handled**
- **other nuclear effects are negligible**

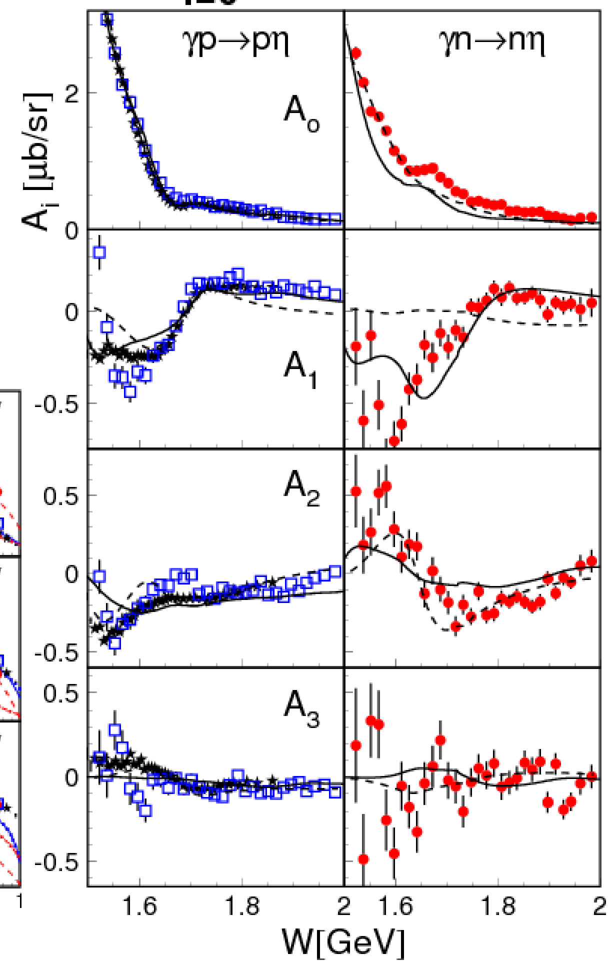
Fermi de-folded proton and neutron data of CBELSA/TAPS

- & free proton of A2, McNicoll et al. PRC 82 (2010)



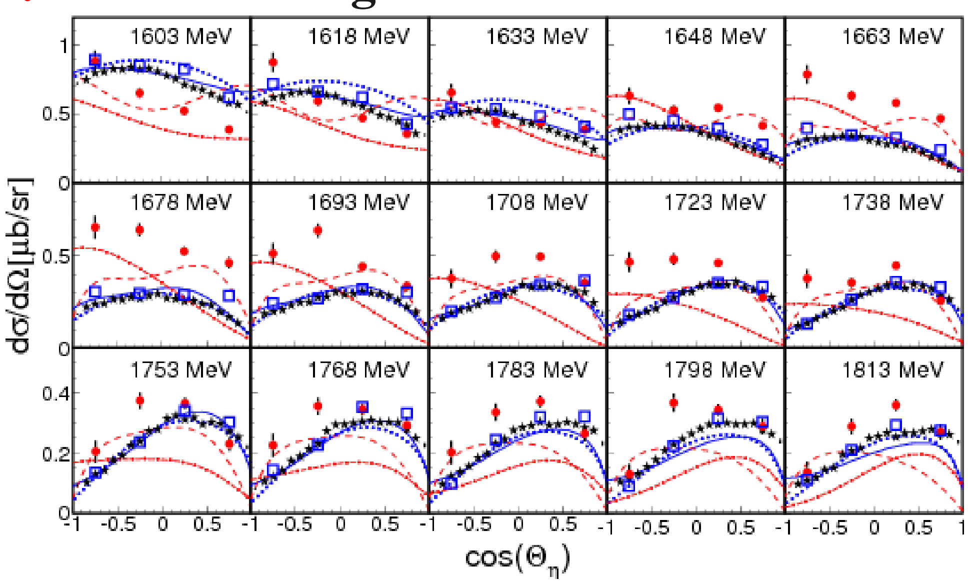
- fit with

$$\frac{d\sigma}{d\Omega} = \sum_{l=0}^{3} A_l P_l^0(\cos(\theta_{cm}))$$



- peak and dip related ?

- angular distributions

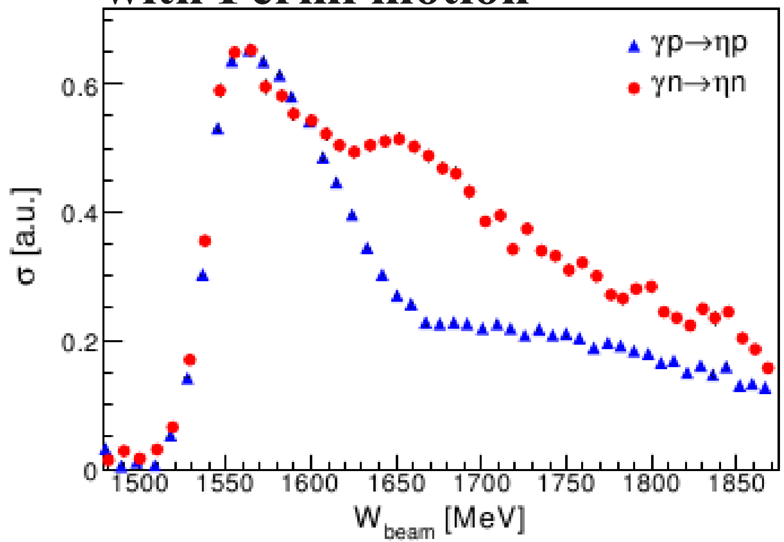


dashed line η-MAID
full line Shklyar et al.

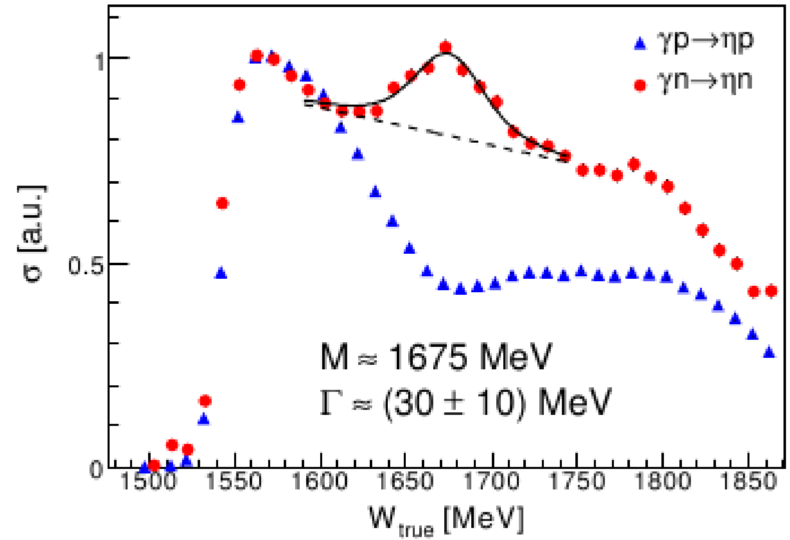
New high statistics measurement at MAMI-C

PhD of L. Witthauer **Preliminary** **PhD of D. Werthmueller**

with Fermi motion

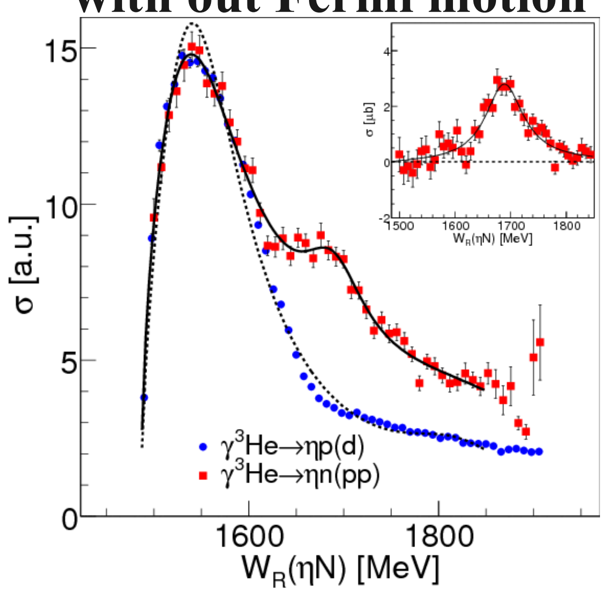


with out Fermi motion



A2

with out Fermi motion



- **very preliminary analysis on**
  - **LD_2 (no efficiency corrections)**

W ~ 1675 MeV, Γ ~ 30 MeV

  - **L^3He**

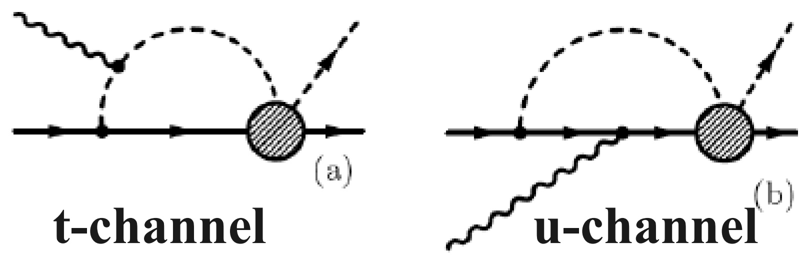
W ~ 1690 MeV, Γ ~ 83 MeV ± 18 MeV

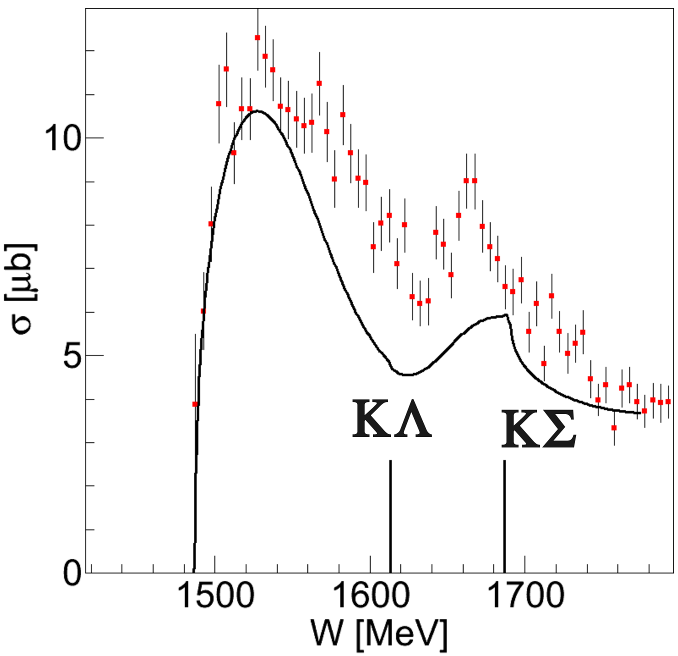
- **structure not due to a nucleus effect**

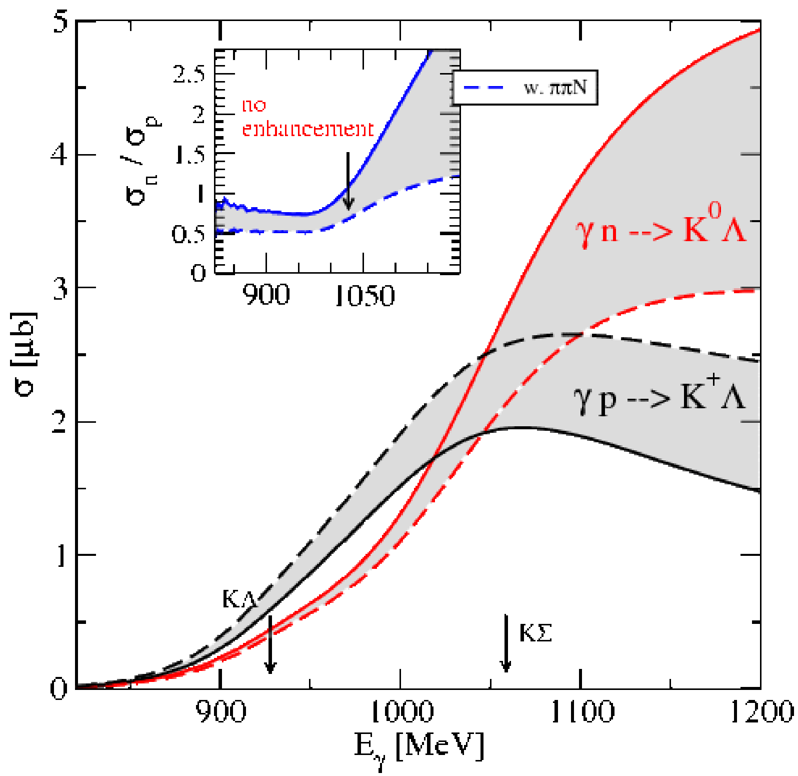
Couple mode channel

M. Doring et al

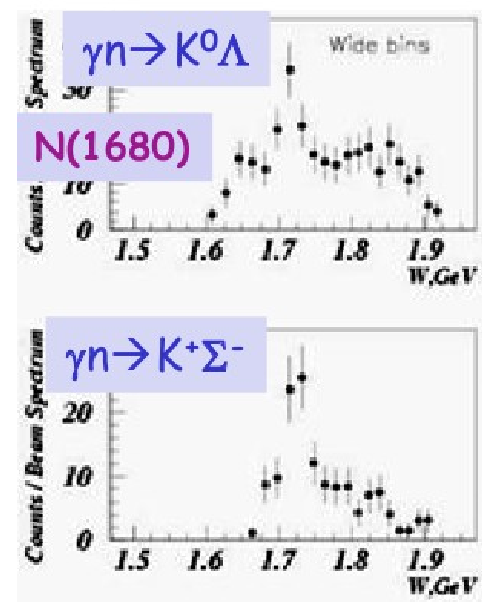
- **explains the neutron anomaly by intermediate state in the photon loops**
  - **neutron: $\pi^- p$, $\pi^0 n$, $\eta\, n$, $K^0\Lambda$, $K^+\Sigma^-$, $K^0\Sigma^0$**
  - **proton: $\pi^0 p$, $\pi^+ p$, $\eta\, p$, $K^+\Lambda$, $K^+\Sigma^0$, $K^0\Sigma^+$**





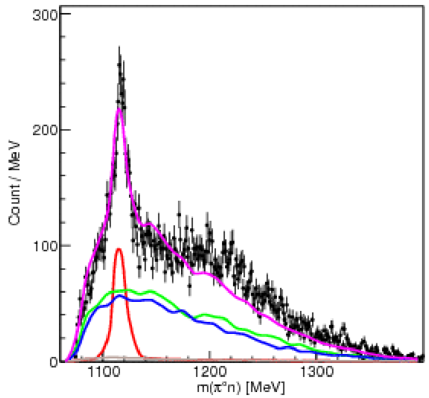


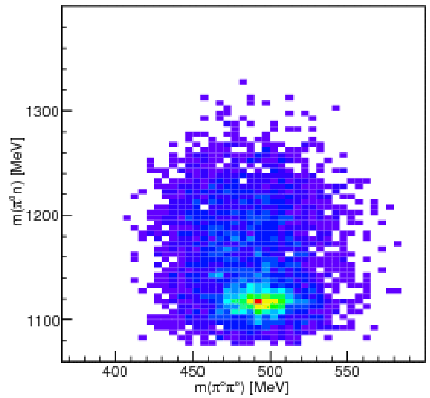
unpublished GRAAL results

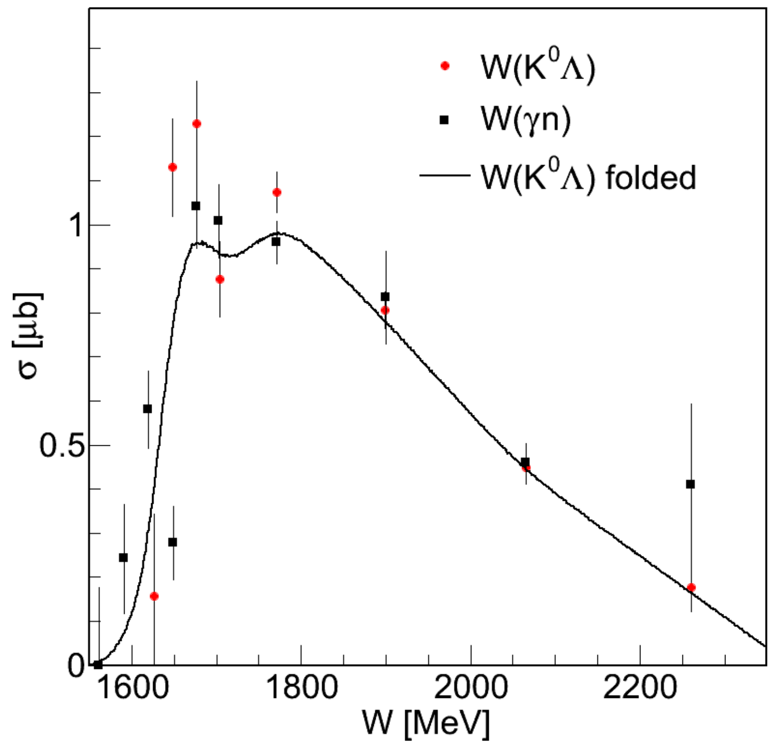


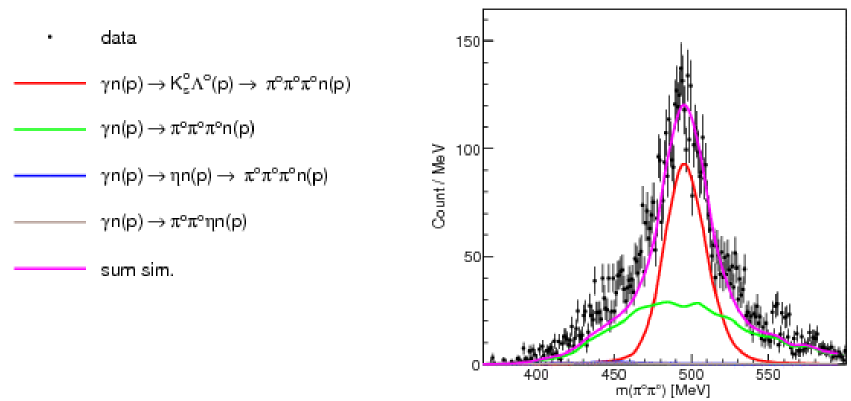
Strangeness: $\gamma n(p) \rightarrow K^{o}\Lambda^{o}(p) \rightarrow \pi^{o}\pi^{o}\pi^{o}n(p)$

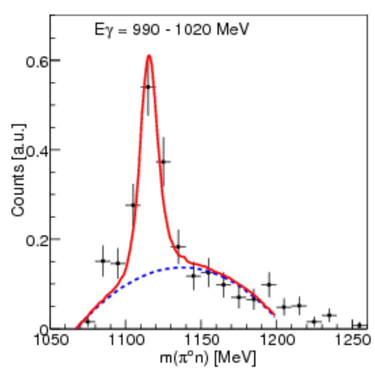
VERY PRELIMINARY

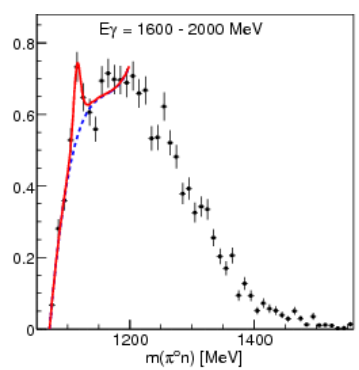












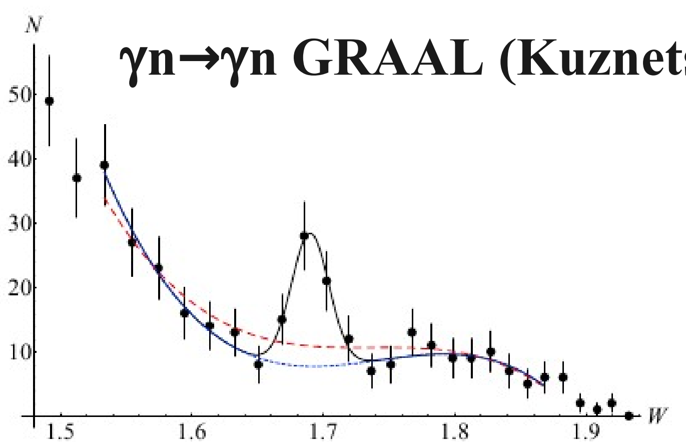
- **50 % of CBELSA/TAPS data**
- **much more statistics available at A2**
- **$\sigma \sim 5$ time smaller than expected => FSI ?**
- **seems to peak around 1650 GeV ?**

decays of N(1710)P_{11}

new narrow resonance or know resonance with un-determined proprieties

N	Soliton	PDG 2007
Γ	>40 MeV	<u>50 – 250 MeV</u>
Br(Nπ)	13 %	10 – 20 %
Br(Nη)	28 %	<u>.061 ± 1 %</u>
Br(Δπ)	13 %	15 – 40 %
Br(ΛK)	13 %	5 – 25 %
Br(ΣK)	1 %	
$(Br(N\pi)Br(N\eta))^{1/2}$	19 %	8 – 30 %
$(Br(N\pi)Br(\Lambda K))^{1/2}$	13 %	12 – 18 %
$(Br(N\pi)Br(\Delta\pi))^{1/2}$	12 %	16 – 22 %

γn→γn GRAAL (Kuznetsov et al.)



- **a bump is seen in γn→γn which is not seen in γp→γp**
- **not yet confirmed by another collaborations**

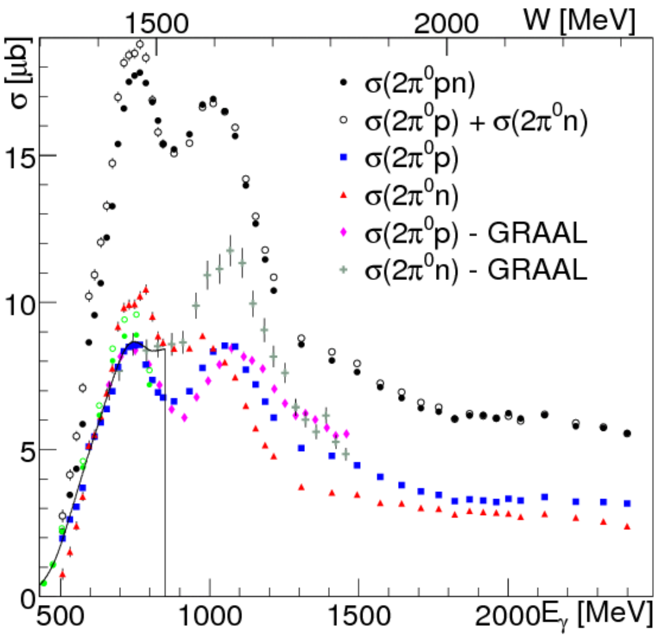
Photoproduction of $\pi^o\pi^o$-pairs off deuteron

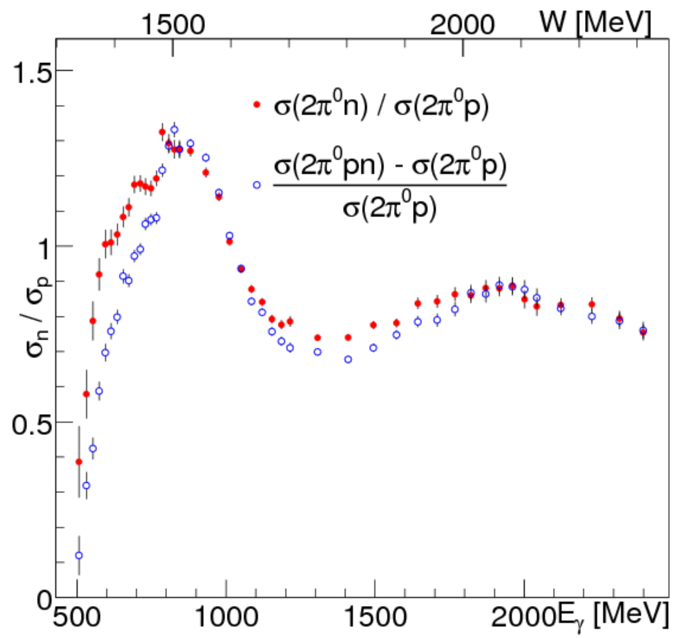
Preliminary

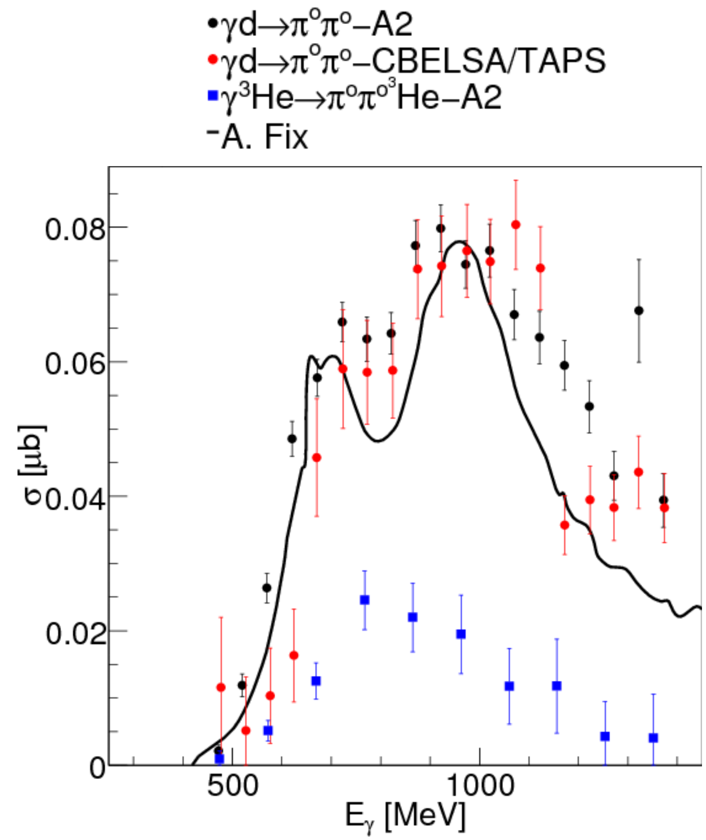
CBELSA/TAPS

- **good agreement between the two neutron measurements**
- **good agreement between the free p folded and quasi-free p**
- **disagreement with GRAAL around Eγ = 1 GeV**

- free p of A2 (Zehr et al.) folded



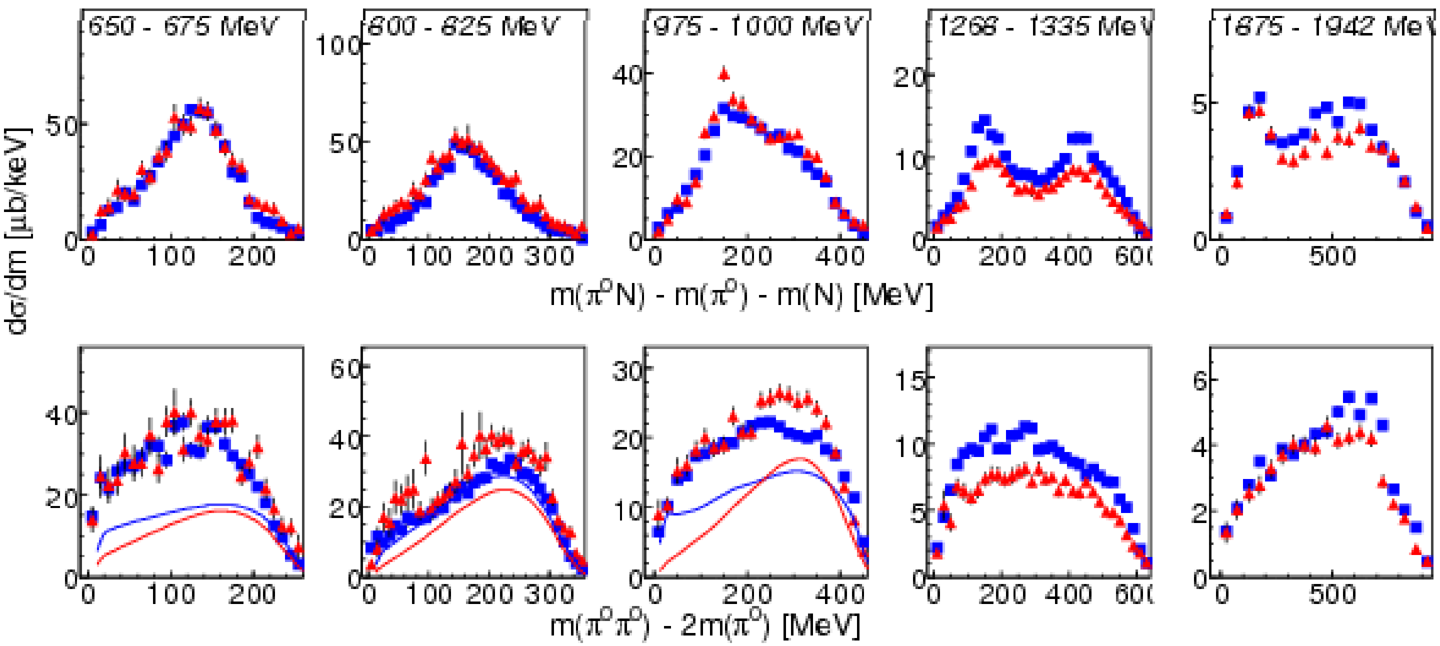




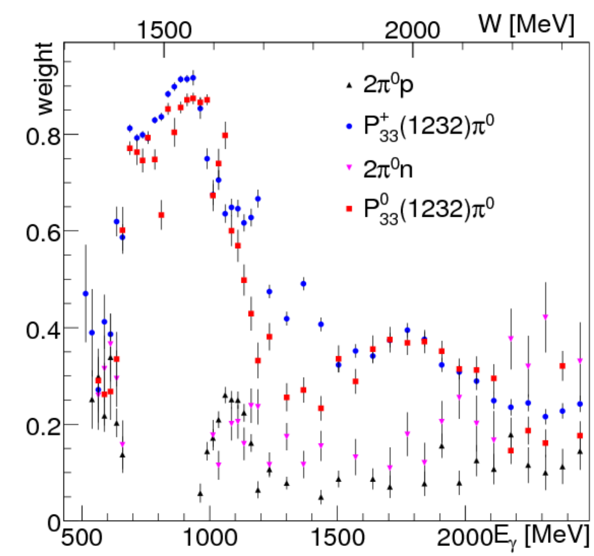
- **concerning the neutron anomaly nothing obvious is seen**
- **first measurement of coherent photoproduction of $\pi^0\pi^0$-pairs off light nuclei**

π^0N and $\pi^0\pi^0$ invariant mass

Preliminary



- **relative contribution of phase-space and Δ**



- **dσ/dm(n) and dσ/dm(p) compared to ππ-MAID (A. Fix et al.)**
- **invariant mass shape are similar up to Eγ = 1 GeV**
- **γN → N* or Δ* → Δ(1232)π^0 dominant mechanism from threshold to Eγ = 1 GeV**
- **interference between contributions from isoscalar γ and isovector γ**

=> isopsin ½ wave contribution

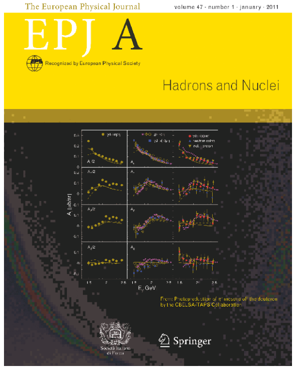
Conclusion

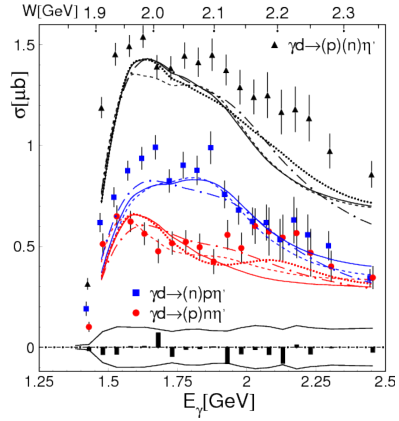
- narrow structure in excitation function of $\gamma n \rightarrow \eta n$

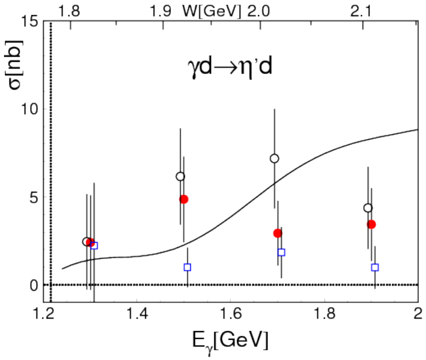
- GRAAL: W ~ 1680 MeV, Γ < 30 MeV
- Tohoku-LNS: W ~ 1666 MeV, Γ < 40 MeV
- CBELSA/TAPS: W ~ 1670 MeV, Γ < 30 MeV
- A2: W ~ 1675 MeV, Γ < 30 MeV

- single (P,T and Σ) and double polarization (E,F,G and H) observables are needed and are currently measured in Mainz and Bonn to determine the nature of the structure and its quantum numbers

- other channels have been and are being investigate







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Thanks for your attention

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