The search for missing resonances: the neutron anomaly

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- **motivations**
- **setups**
- **results**
- **conclusions**

CBELSA/TAPS Collaboration

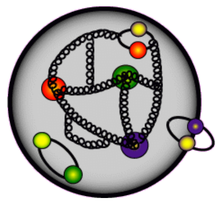
Basel Uni., CH
Bochum Uni., DE
Bonn Uni., DE
Dresden Uni., DE
Erlangen Uni., DE
Petersburg NPI Gatchina, RUS
Giessen Uni., DE
KVI Groningen, NL
Tallahasse Uni., USA

A2 Collaboration

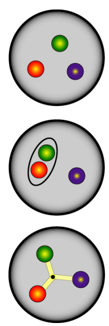
Basel Uni., CH
Bochum Uni., DE
Bonn Uni., DE
Cambridge MIT, USA
Dubna JINR, RUS
Edinburgh Uni., UK
Petersburg NPI Gatchina, RUS
Glasgow Uni., UK
Halifax SM Uni, CA
Kent Uni, USA
Los Angeles UCL, USA
Lund Uni. MAX-lab, SWE
Mainz Uni., DE
Moscow INR, RUS
Moscow LPI, RUS
Pavia INFN, IT
Sackville MA Uni,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

Nucleon structure

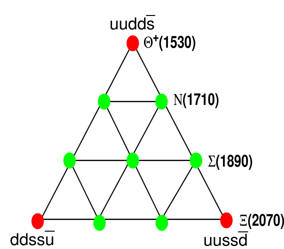
complex system
- valence quarks
- sea quarks
- gluons



degrees of freedom ?
- 3 constituent quarks
- quark-diquark
- quark flux-tube

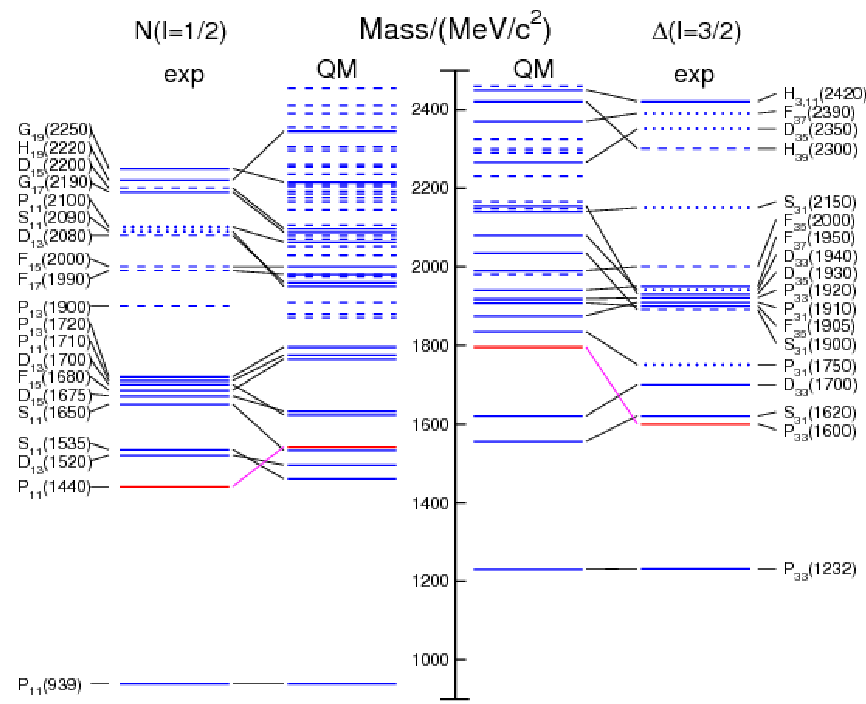


more complicated structure
- couple channel
- chiral soliton



comparison: known excited states – constituent quark model

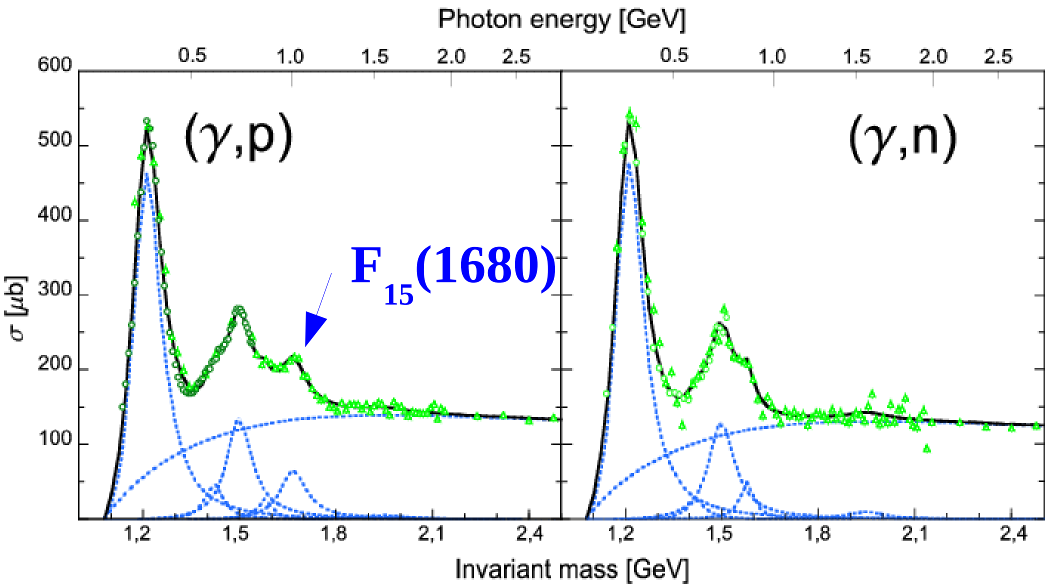
(Capstick & Roberts)



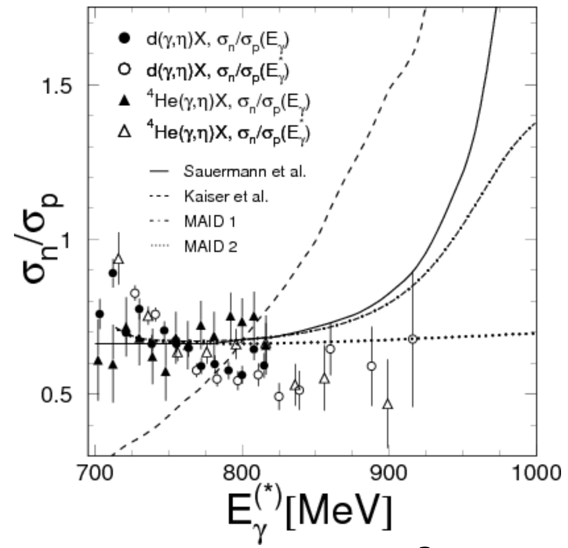
ordering of low lying states ?
missing resonances ?

proton resonances versus neutron resonances

photoabsorption on the nucleon (Bianchi et al)



photoproduction of η-meson from light nuclei (TAPS – MAMI collaboration)



- **Δ*: n and p electromagnetic coupling are the same**
- **N*: n and p have different electromagnetic coupling**
- **no neutron target**
- **light nuclei: LD$_2$, L^{3}He => nuclear effects**

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

M(n**) directly**

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

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

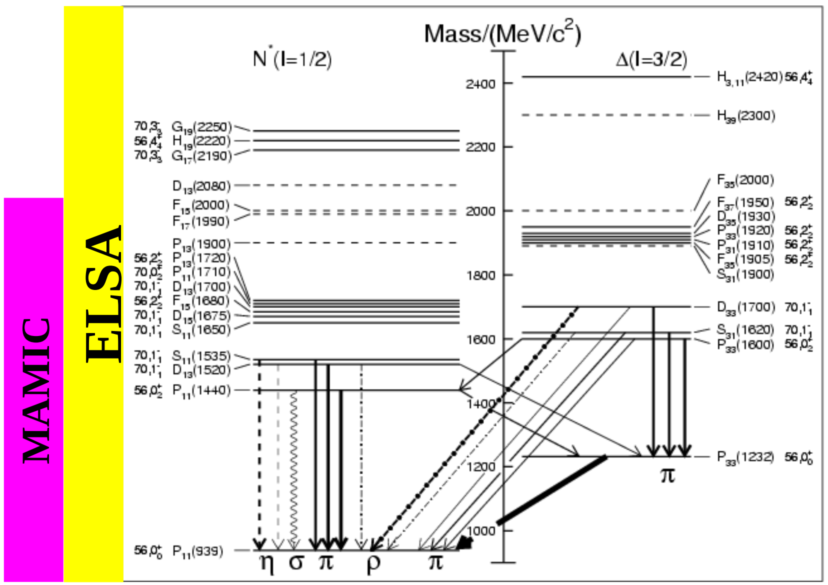
$$\sigma_n \approx \left|A^{IS}_{1/2} - A^{IV}_{1/2}\right|^2 = \left|A^{n}_{1/2}\right|^2$$

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

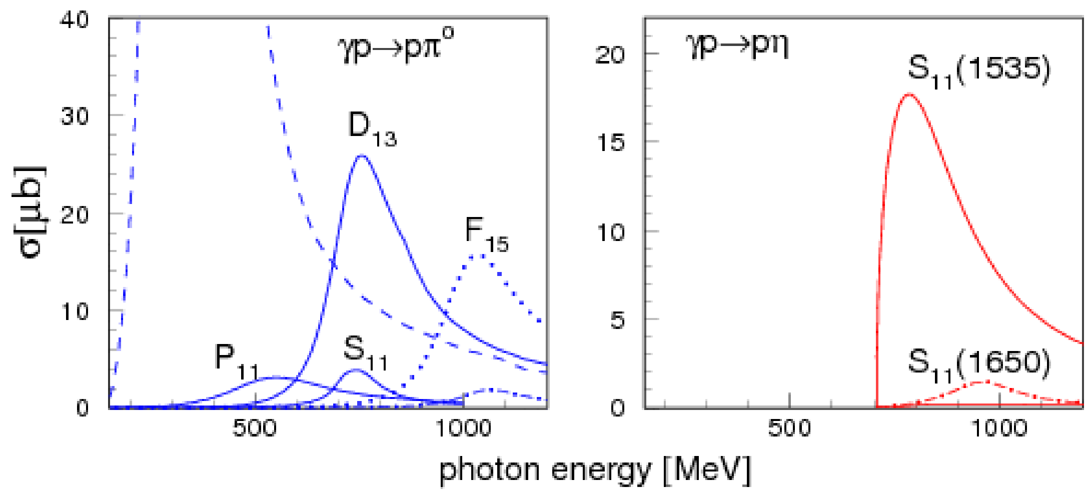
find the iso-spin composition of the resonances

Nature and properties of known resonances

excited states of the nucleon



broad overlapping resonances



η iso-spin filter

N*/Δ* → πN	**N* → ηN**
N*/Δ* → Δπ	**N* → N*η/π**
N*/Δ* → N*π	**Δ* → Δη**

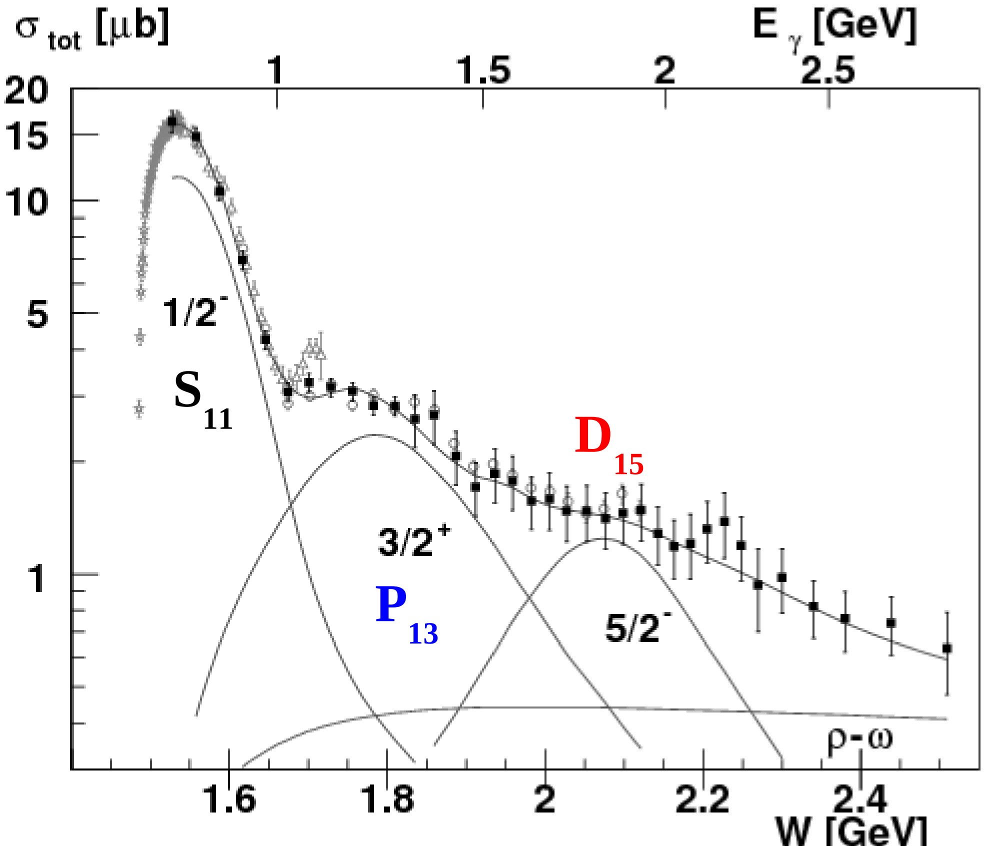
characteristic meson decays can tag specific resonances

e.g. $S_{11}(1535) \rightarrow \eta N$ $b_{\eta} = 50\%$

▶ **study of resonances that couple strongly to the neutron**

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)

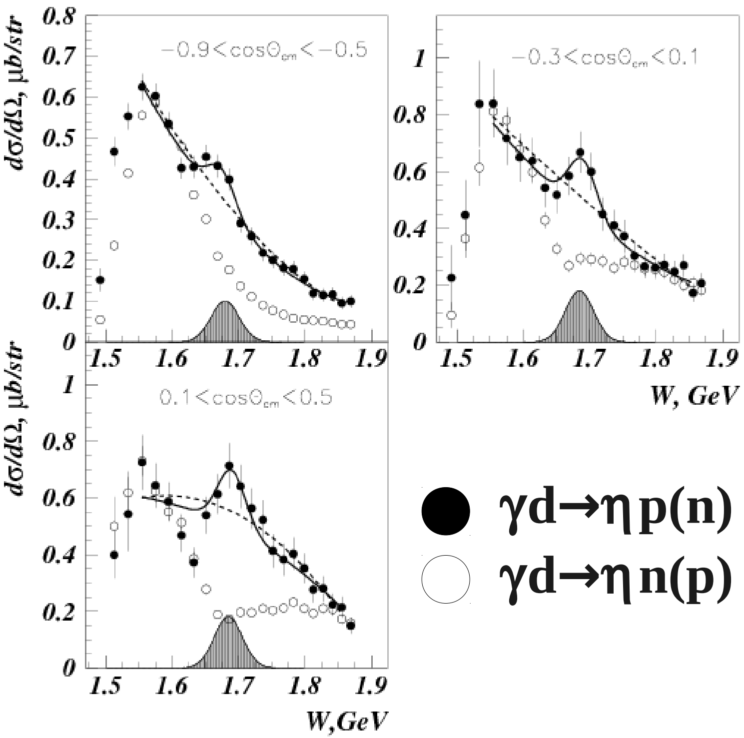
Involve less than 12 resonances

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) **ambiguity**
P_{13}(1720)
...
D_{15}(2070) couples strongly to the ?

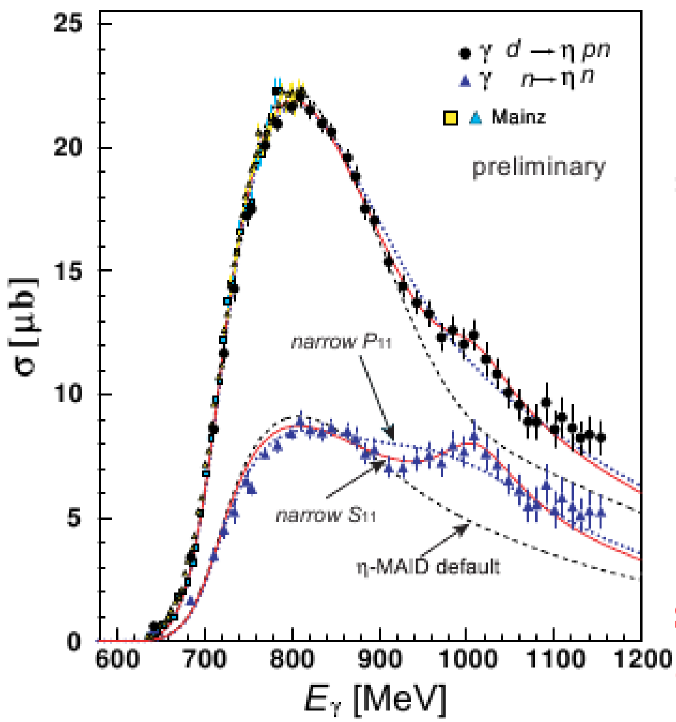
The neutron anomaly
$\gamma d \rightarrow \eta\, n(p)$

- **GRAAL, Tohoku-LNS, CBELSA-TAPS and the preliminary A2 results 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.)



Tohoku-LNS (F. Miyahara et al.)



- **GRAAL**

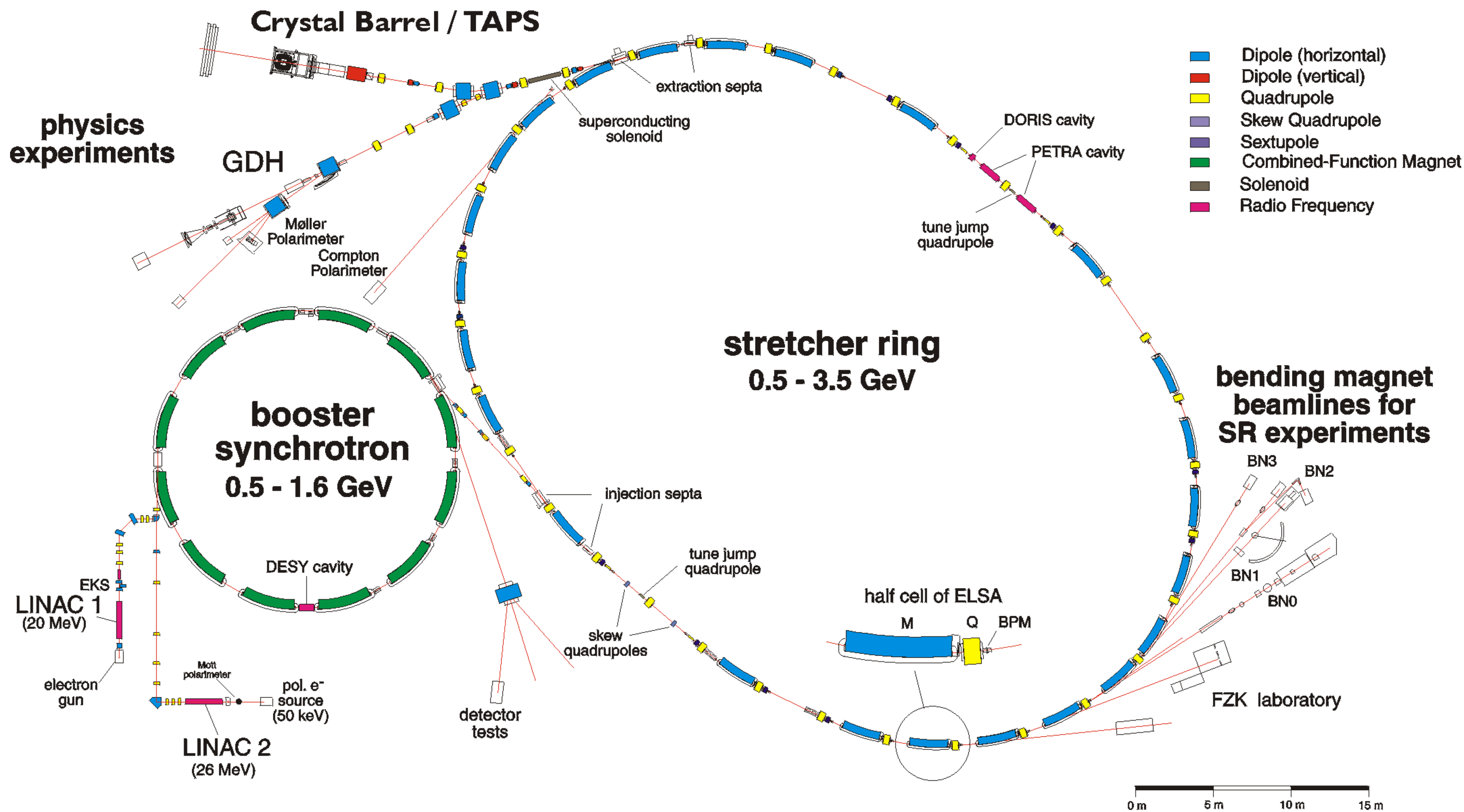
W ~ 1680 MeV, Γ < 30 MeV

- **Tohoku-LNS**

W ~ 1666 MeV, Γ < 40 MeV

so far no informations about quantum numbers of possible resonance or whatever nature of the sturcture

ELSA: electron accelerator @Bonn

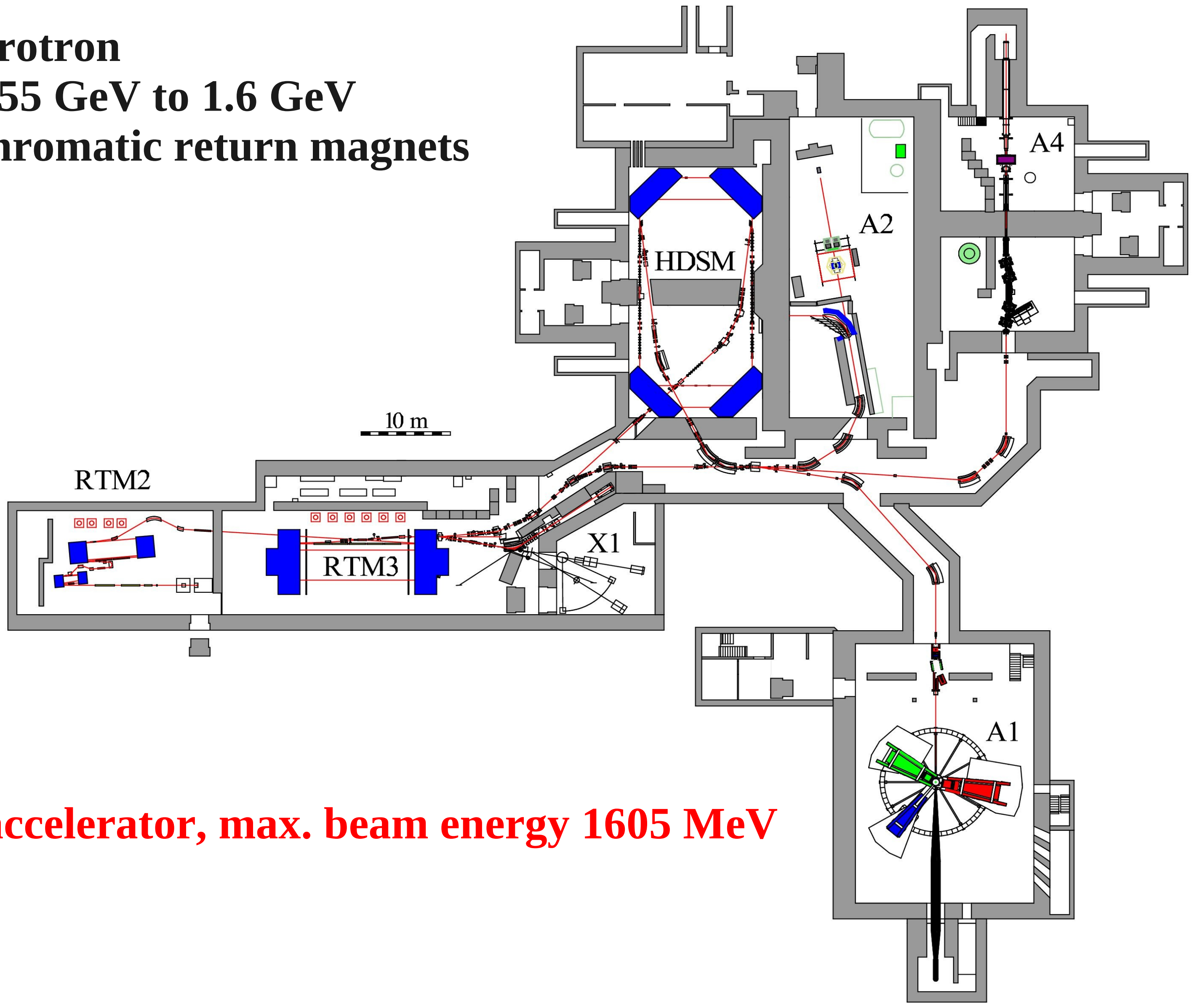


quasi-monochromatic photon beam via bremsstrahlungs tagging 0.3 GeV ≤ E_γ ≤ 2.6 GeV

MAMI-C: electron accelerator @Mayence

harmonic double sided microtron

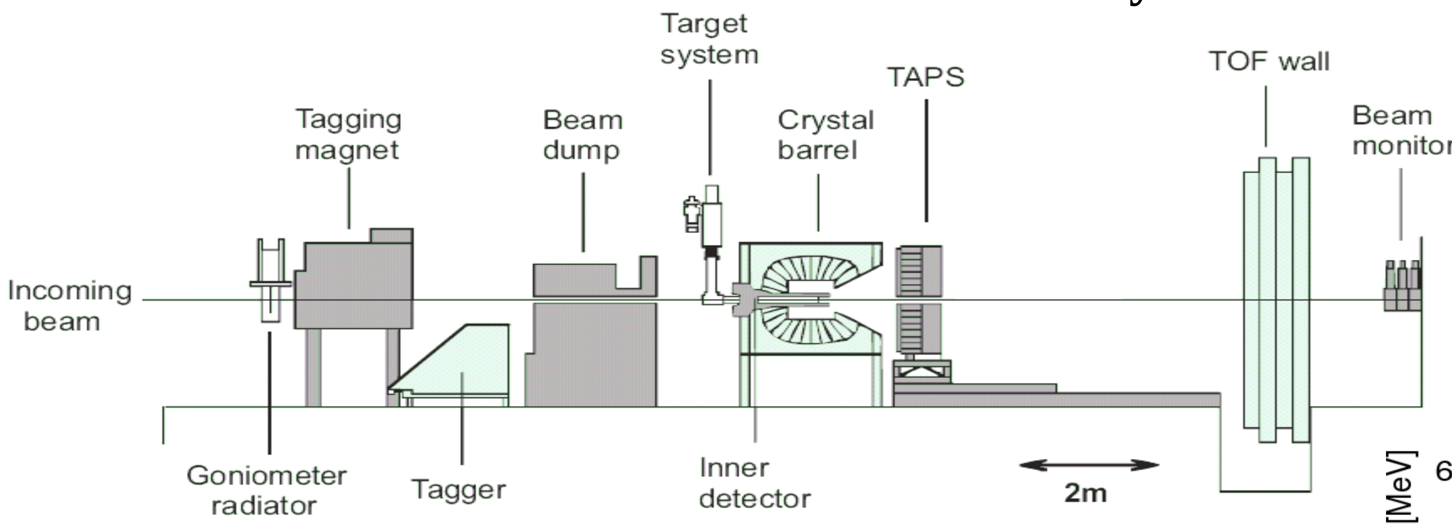
- **energy increase from 0.855 GeV to 1.6 GeV**
- **2HF structures and 2 achromatic return magnets**



continuous wave electron accelerator, max. beam energy 1605 MeV

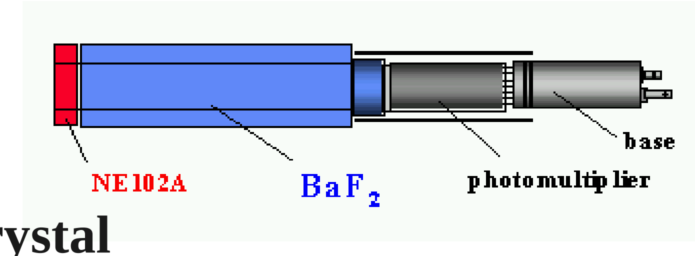
Crystal Barrel and TAPS detectors

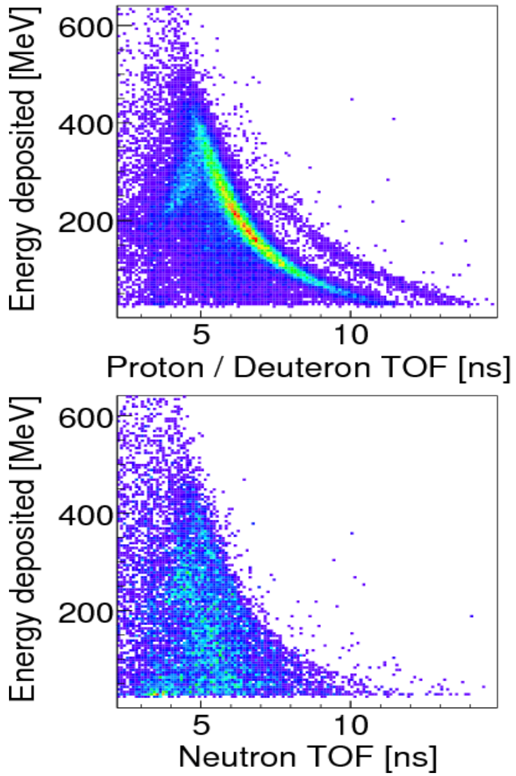
4π detectors: **1818 crystals + CPCs**



measure:
- incident photon beam
- γ
- proton
- neutron
- deuteron

particle identification TAPS
TAPS veto detector
- 5 mm plastic scintillator
- individual for each BaF_2 crystal

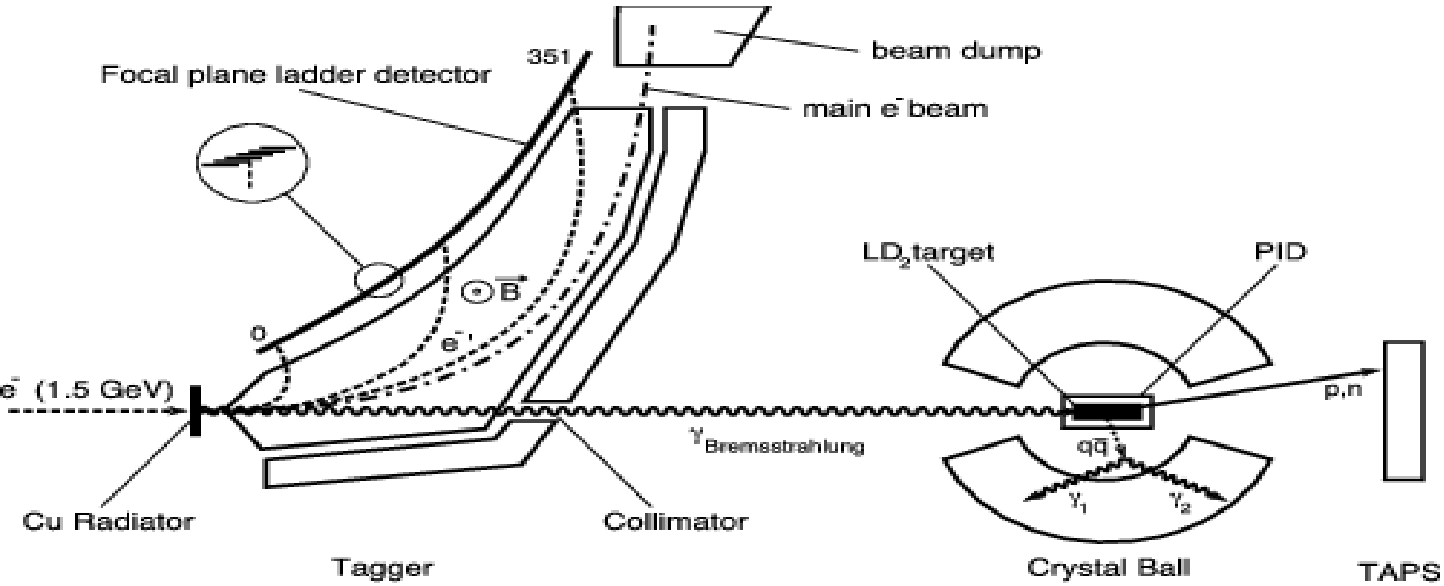




proton
veto hit in front of BaF2 crystal + E vs TOF
neutron
no veto hit + E vs TOF

Crystal Ball and TAPS detectors

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



measure:

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

particle identification CB

PID detector

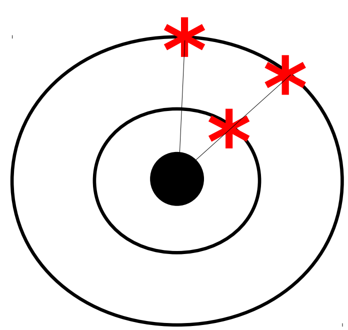
- 24 scintillators
- cylindrical shape

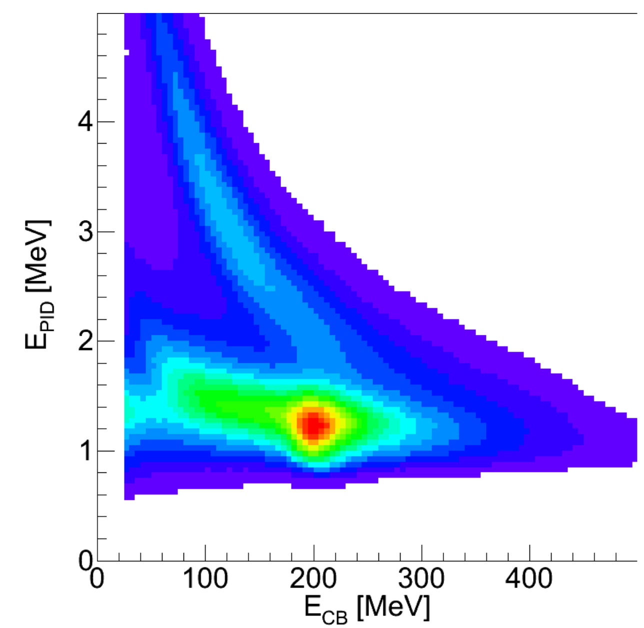
proton

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

neutron

no scintillator has fired

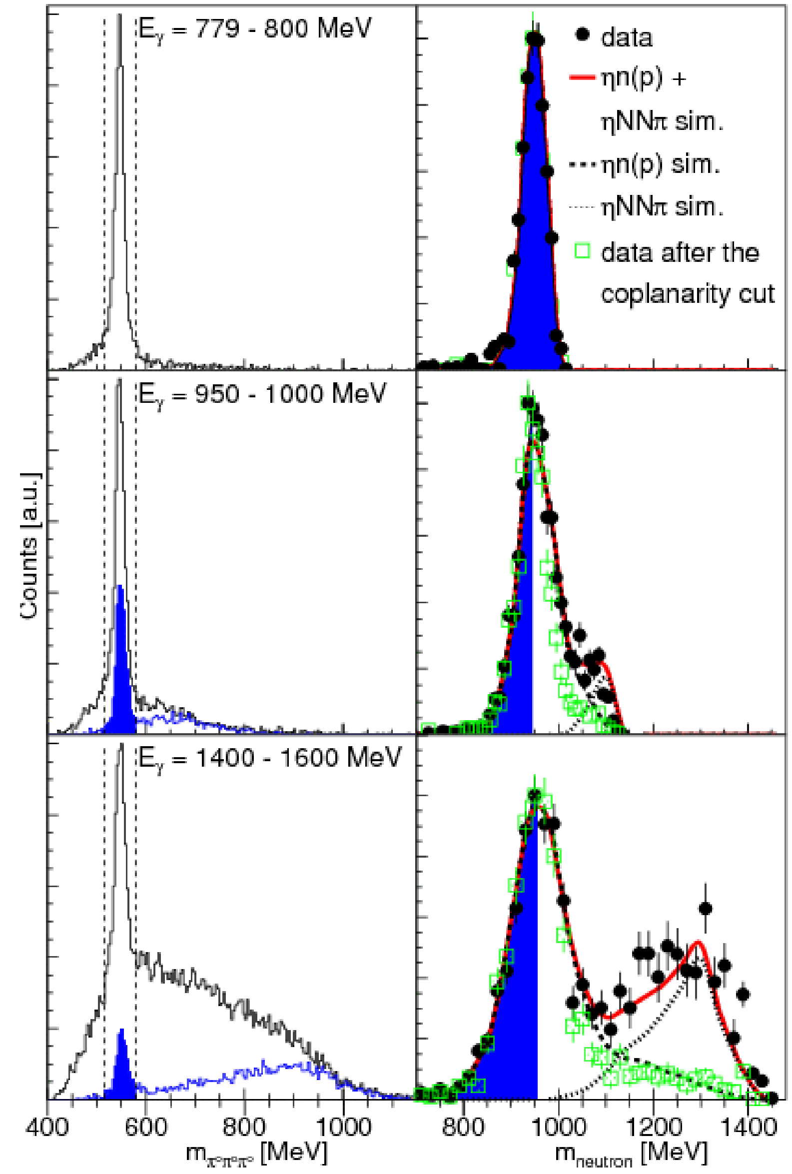




Reaction identification γ+n(p)$\rightarrow\eta$+n(p) with Crystal Barrel and TAPS

- decay channel $\eta\rightarrow\pi^o\pi^o\pi^o\rightarrow 6\gamma$
- select events with 7 hits
- invariant mass of all photon pairs
- cut on π^o mass
- select best combination of 6γ to 3π^o by χ^2-test
- use π^o mass as constrain, construct 3π^o invariant mass
- missing mass analysis to remove $\eta\pi$ final state; treat recoil nucleon as missing particle

$$m^2 = (P_\gamma + P_N - P_\eta)^2$$

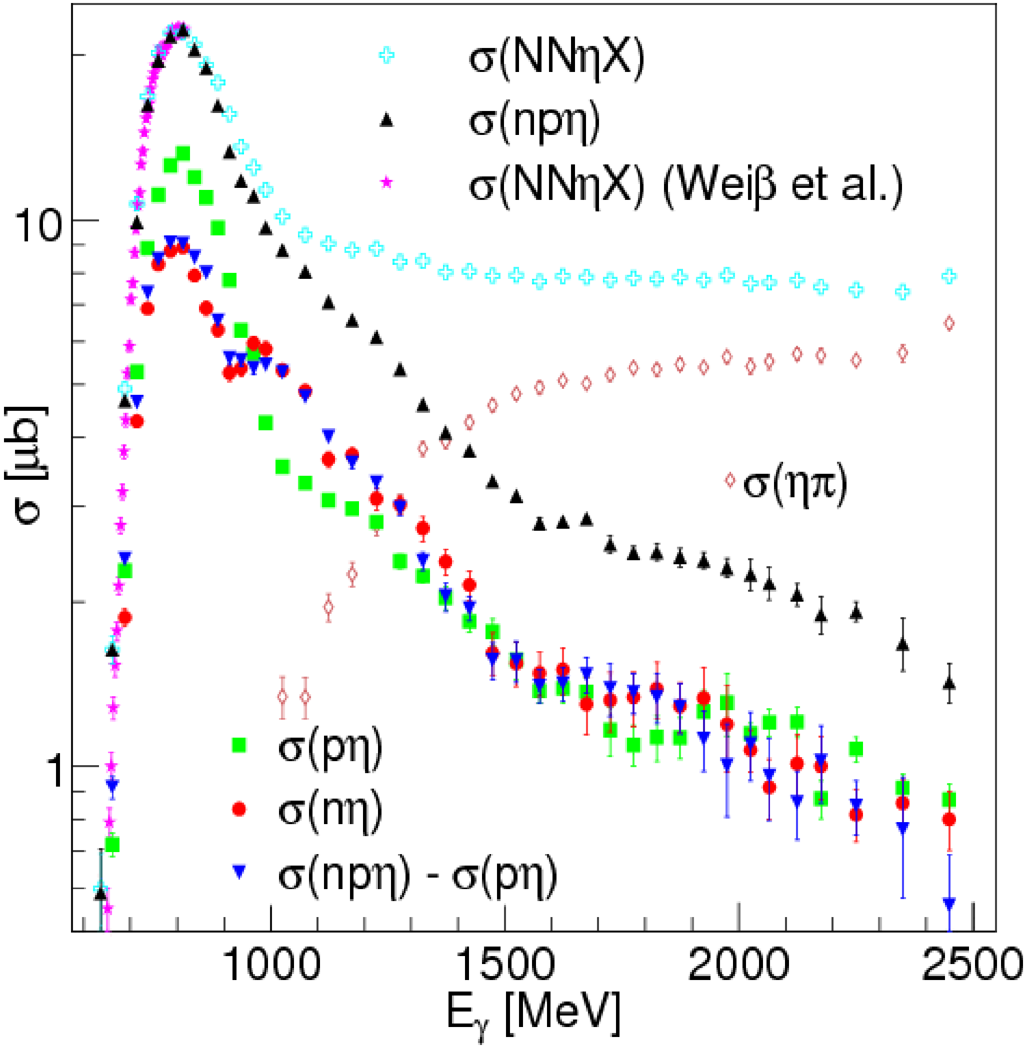


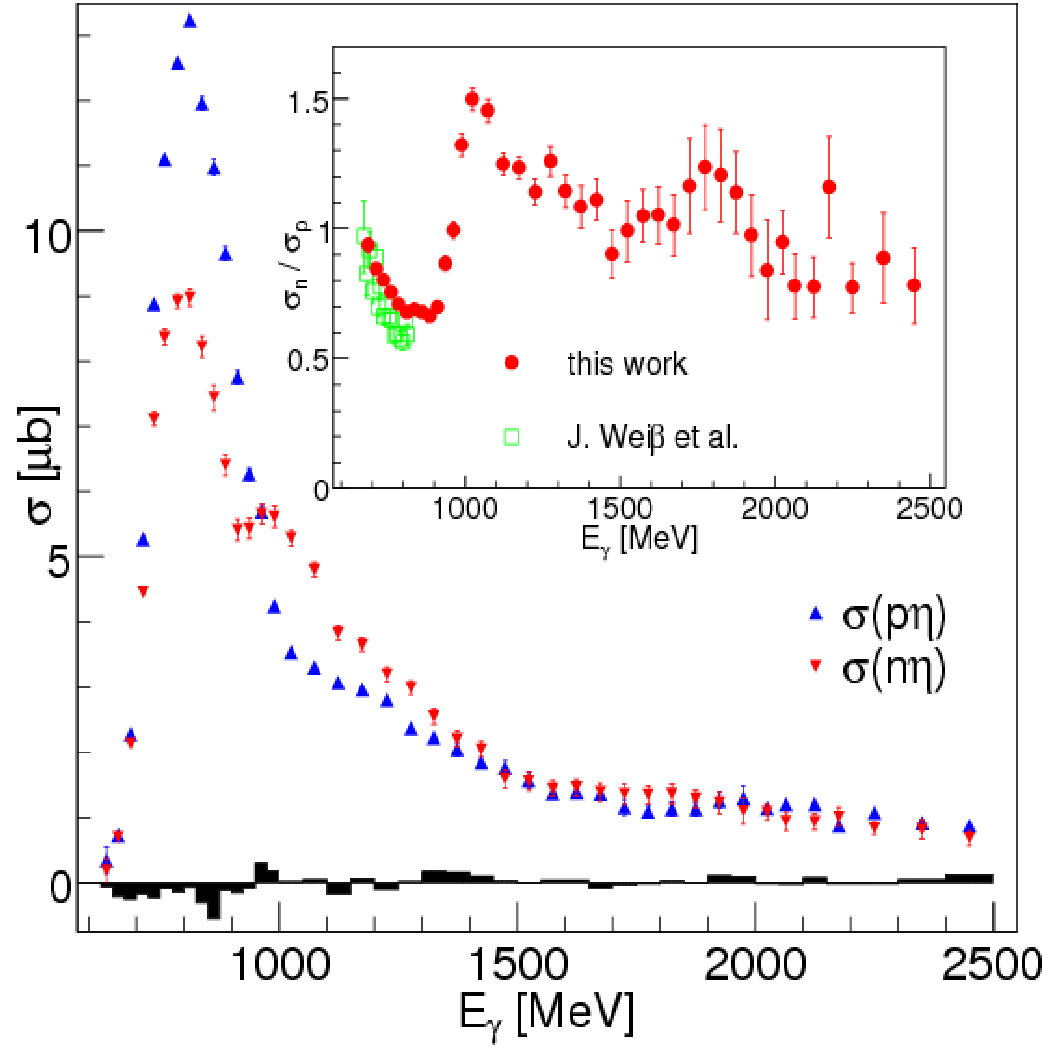
quasifree η-photoproduction off the deuteron

CBELSA/TAPS

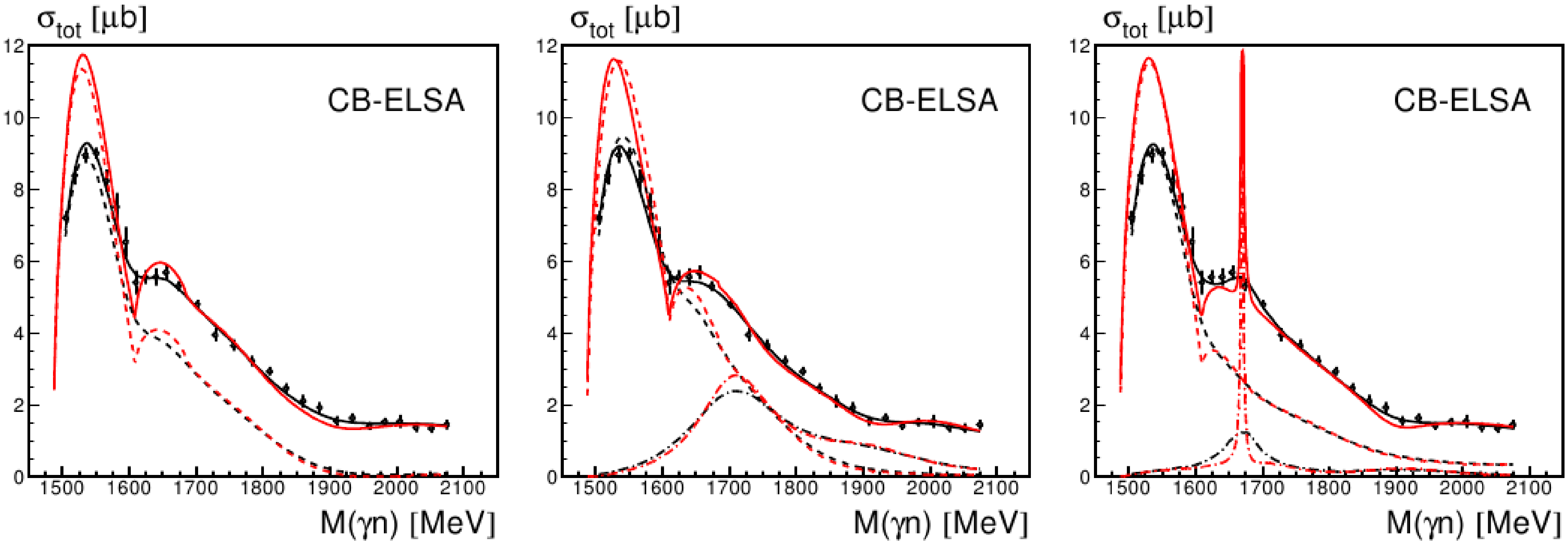
γn → ηn measured in 2 different ways :

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





Bonn-Gatchina-Model analysis



- **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}**

A. Anisovich et al.
A. Sarantsev talk

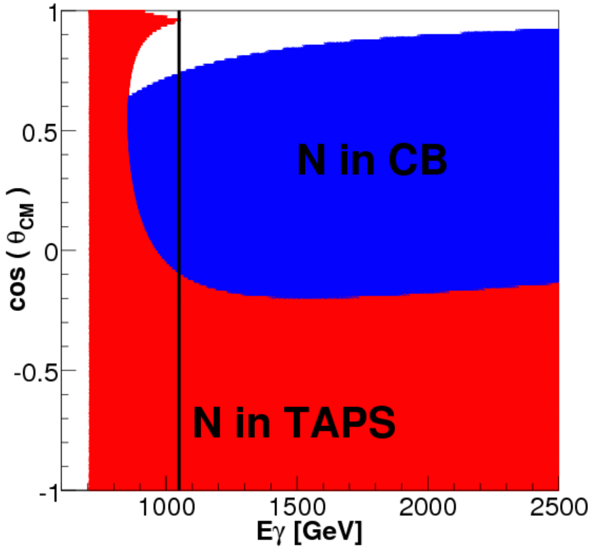
De-folding the fermi motion

CBELSA/TAPS

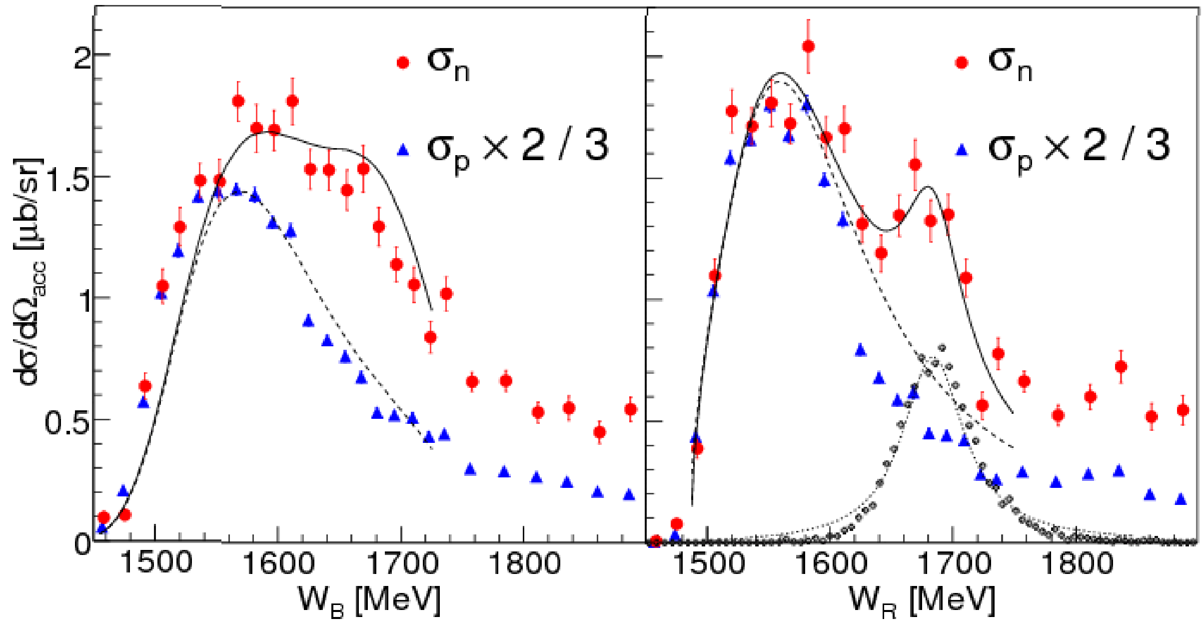
- Find the true cm energy from

$$s = (E_\eta + E_N)^2 - (p_\eta + p_N)^2$$

- Possible when the recoil nucleon is going into the forward wall, use of the time-of-flight (cos (θ_{cm}) < -0.1)



- Result
  - de-folded proton cross section similar to free proton
  - de-folded neutron cross section shows narrow structure around 1 GeV



W = 1684 MeV ± 2 MeV
Γ = 60 MeV ± 10 MeV
experimental resolution 60 MeV

De-folding the fermi motion w/o TOF: $\gamma d \to \eta pn$

Preliminary

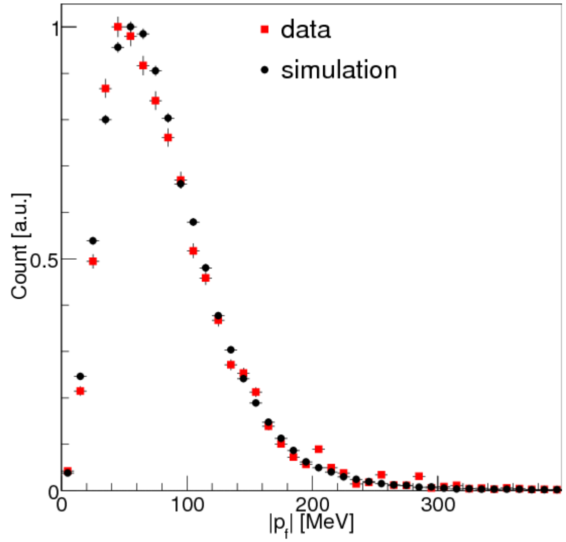
CBELSA/TAPS

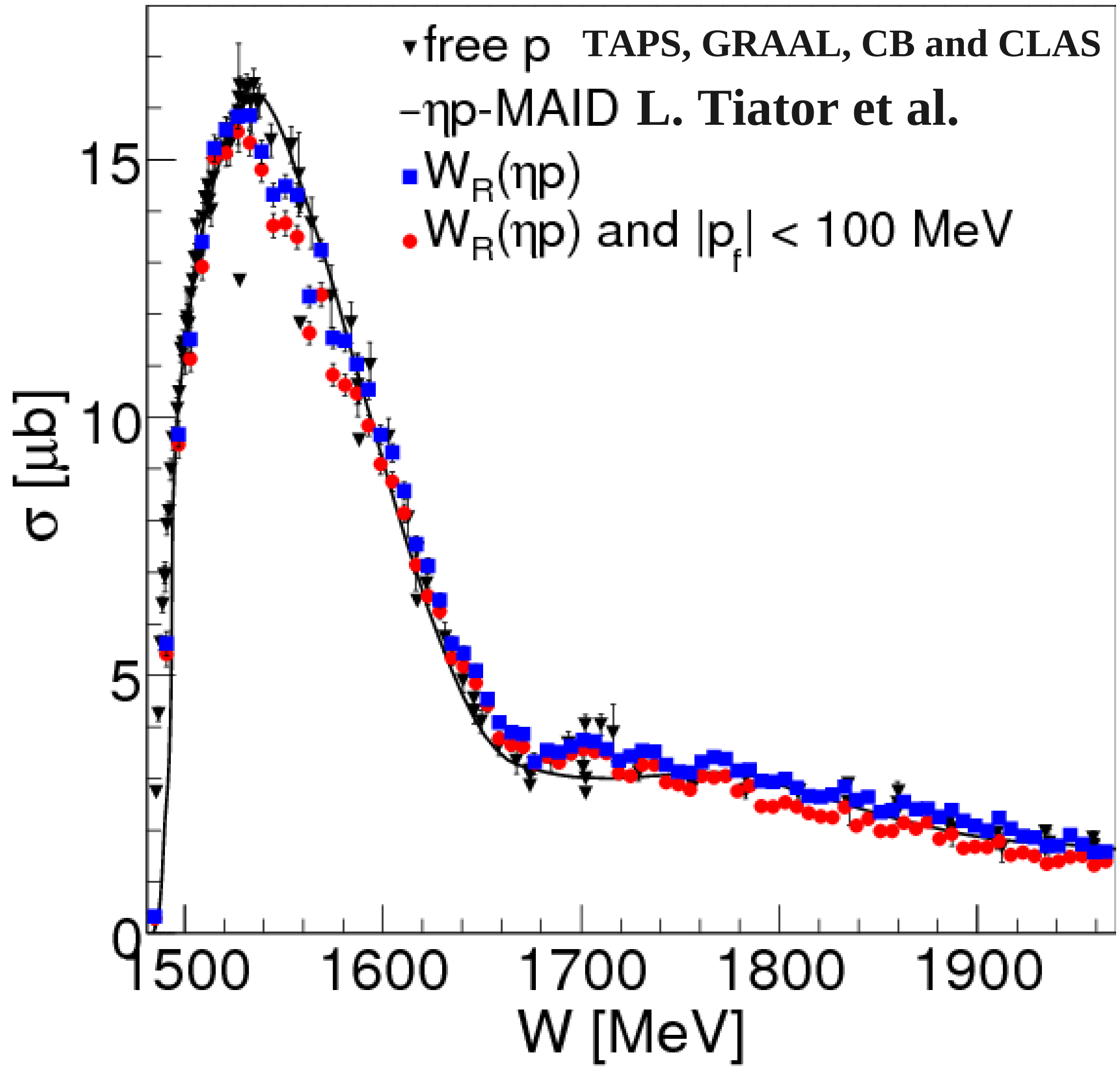
- a three body decays, for a given incident photon beam, has:

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

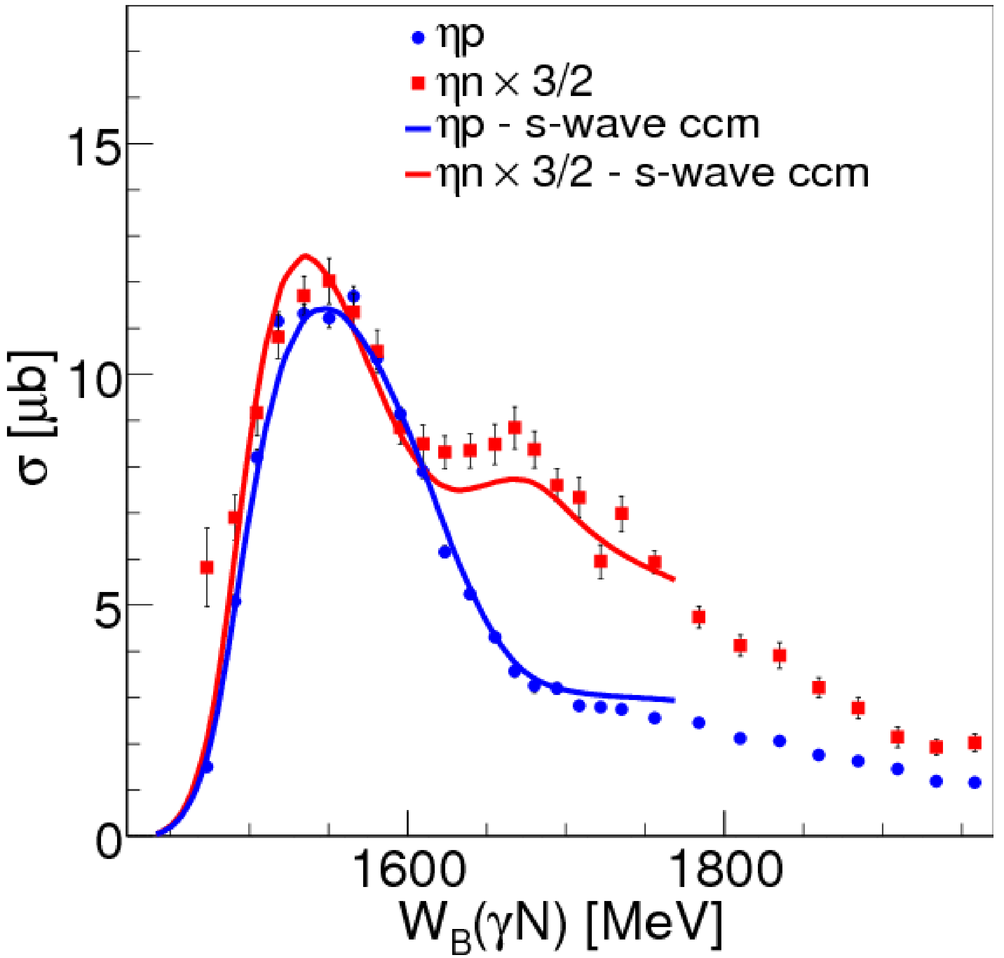




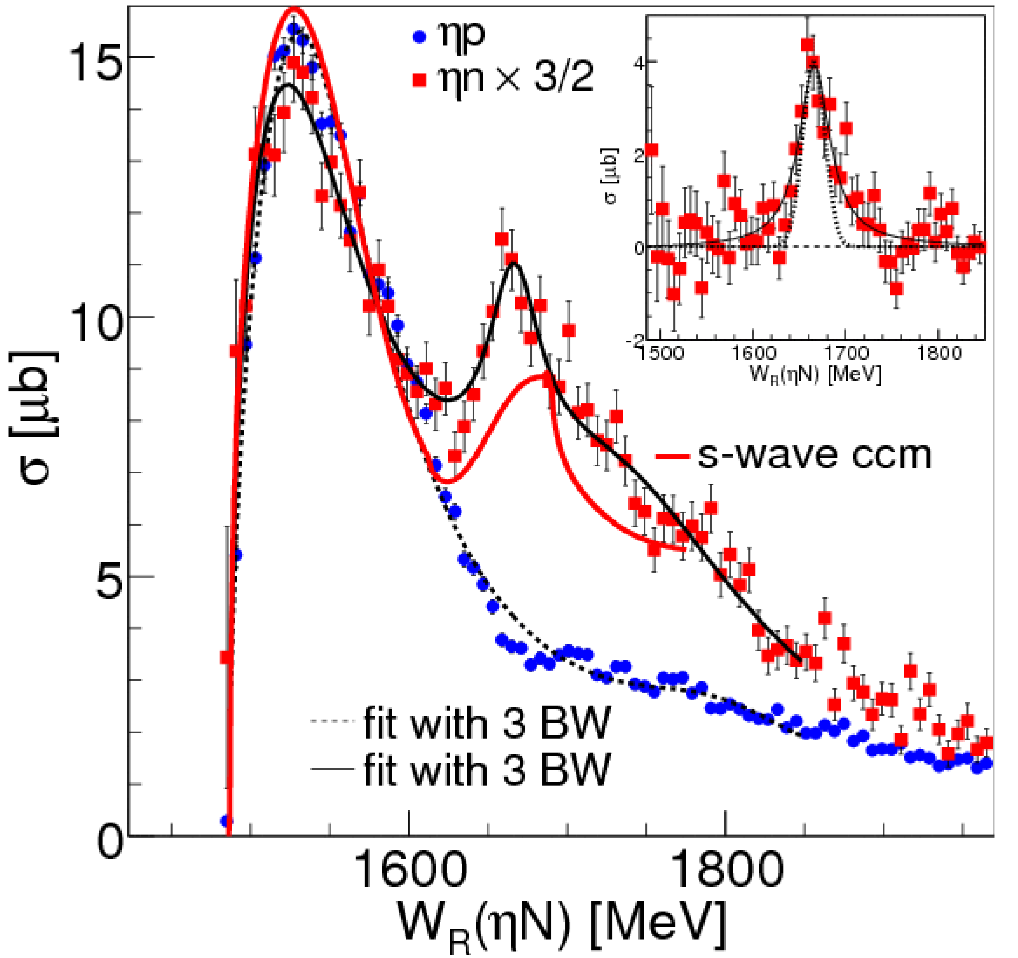
New analysis of the old Bonn data

Preliminary

with Fermi motion



with out Fermi motion



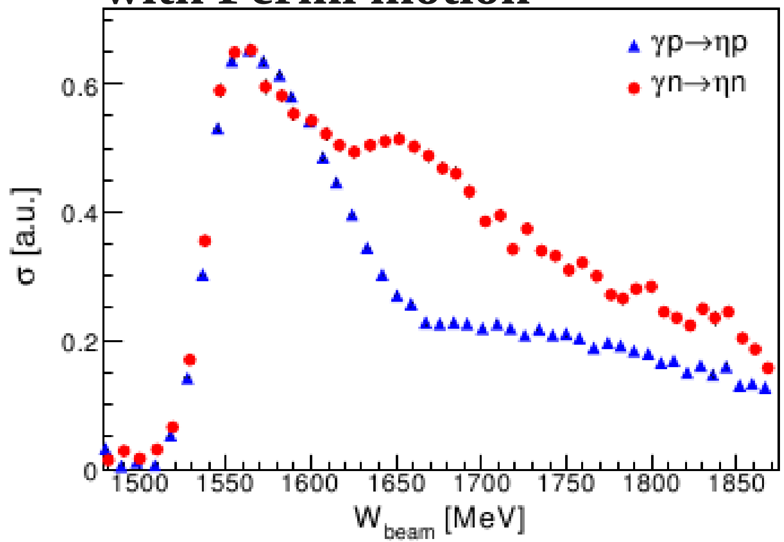
- co-planarity and p_f cuts applied
- data compared to s-wave coupled channel model with dynamical generation of S_{11}(1535) pole (M. Doering et al. - K. Nakayama talk)

W = 1664 MeV ± 1 MeV
Γ = 28 MeV ± 3 MeV
experimental resolution 25 MeV

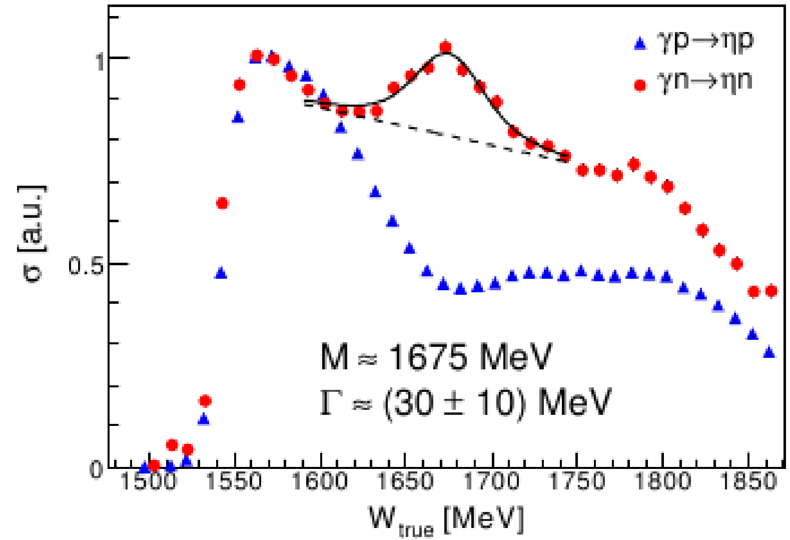
New high statistics measurement at MAMI-C

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

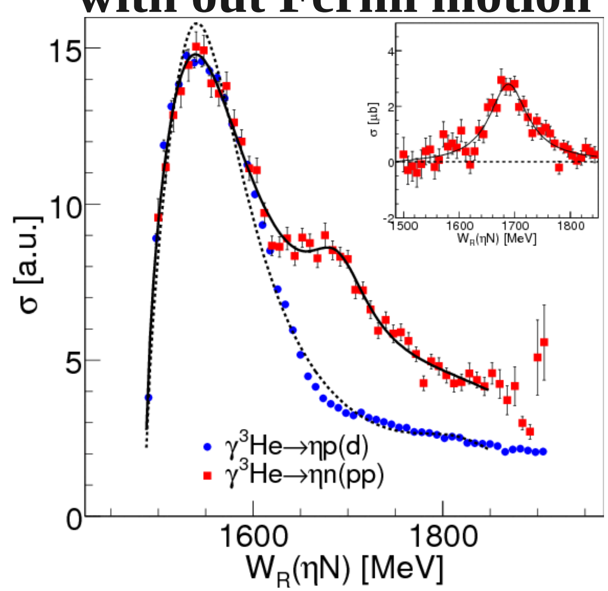
with Fermi motion



with out Fermi motion



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

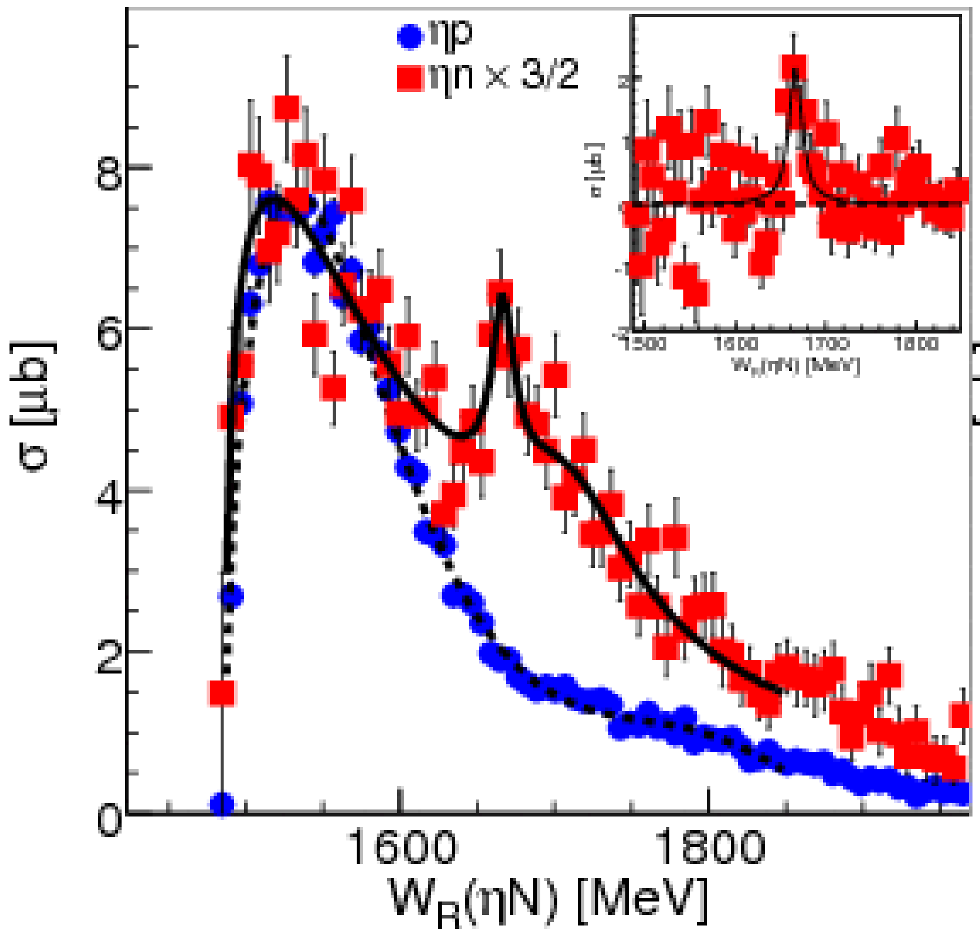
- **structure not due to a nucleus effect**

cos Θ^* behavior

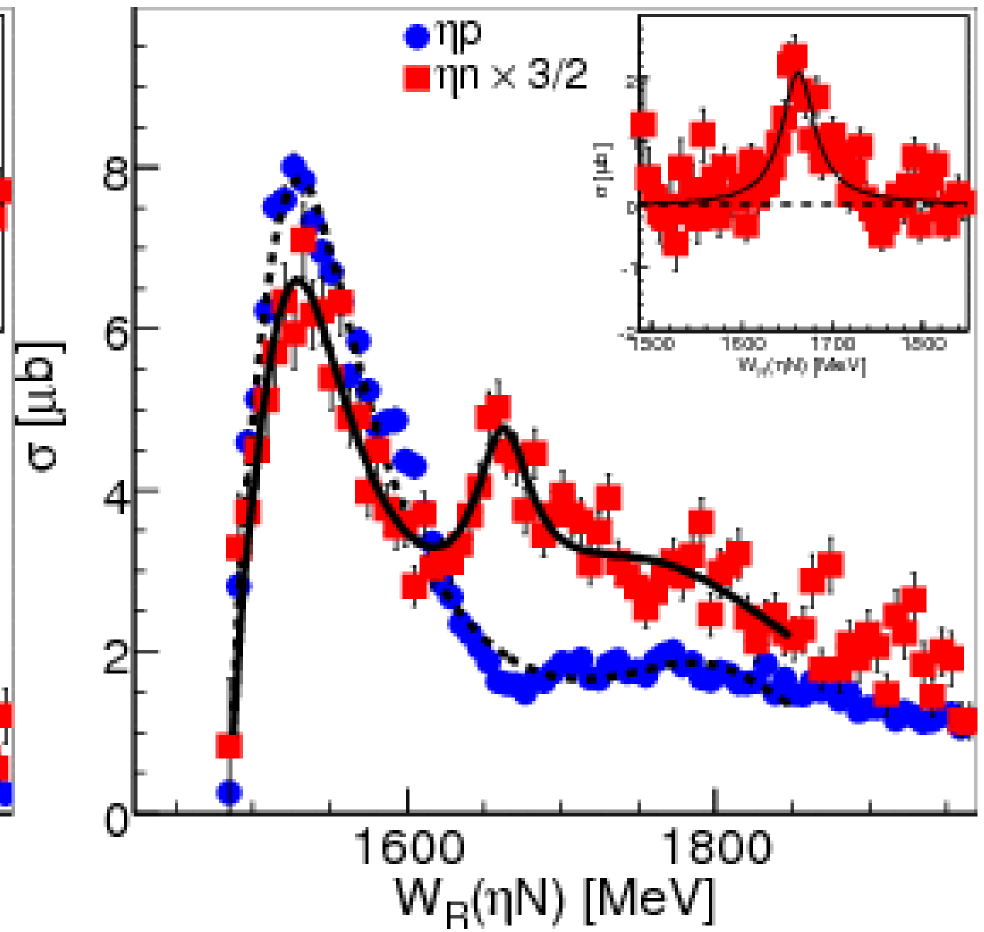
Preliminary

CBELSA/TAPS

cos Θ^* < 0



cos Θ^* > 0

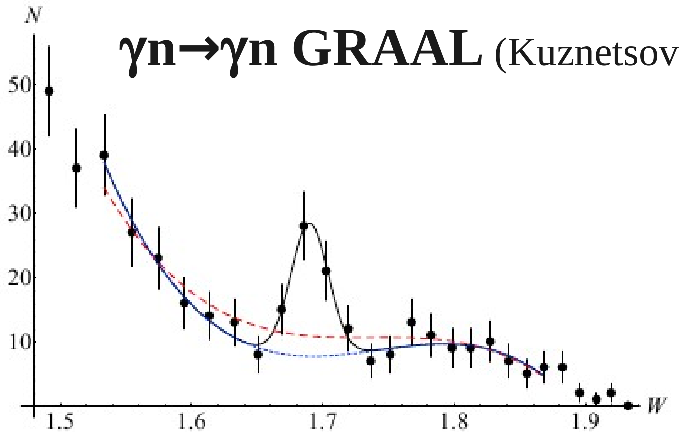


- **bump present in all cos Θ^***
- **mass and width are changing ?**

Decays of N(1710)P_{11}

new narrow resonance or know resonance with un-determined proprieties

N	Soliton	PDG 2007
Γ	>40 MeV	50 – 250 MeV
Br(Nπ)	13 %	10 – 20 %
Br(Nη)	28 %	.061 ± 1 %
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.)

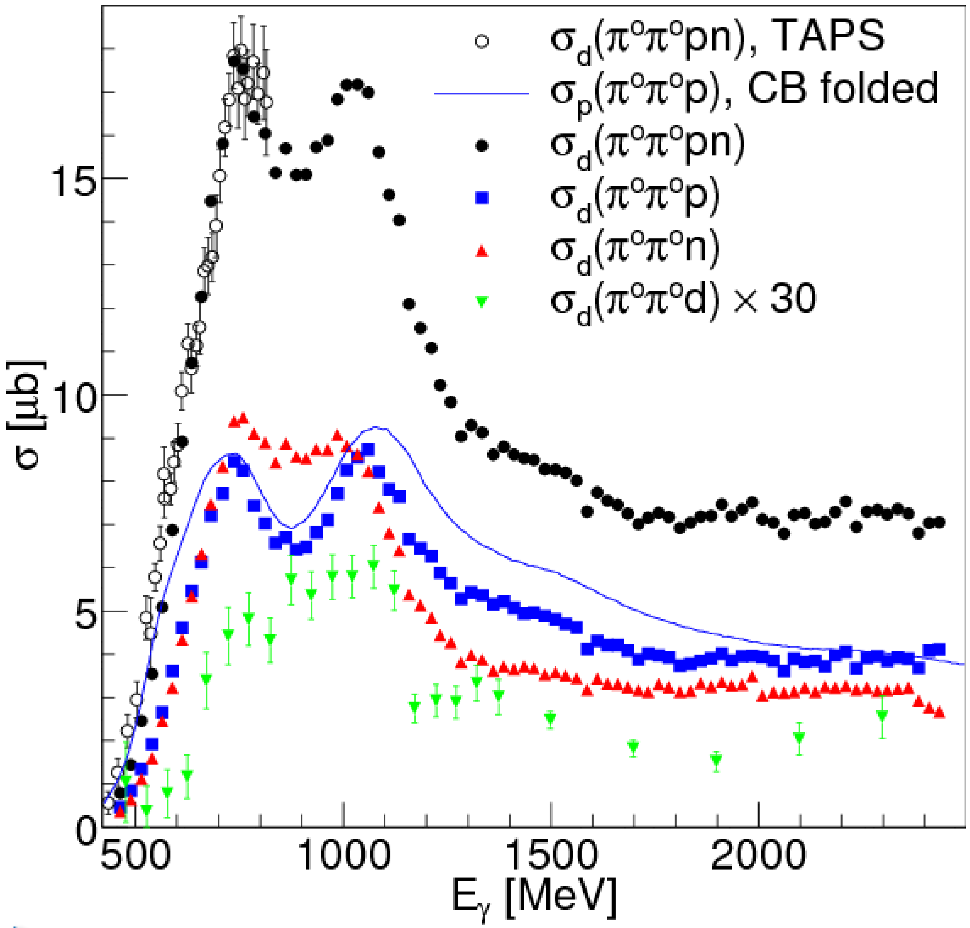
- **a bump is seen in γn→γn which is not seen in γp→γp**
- **not yet confirmed by another collaborations**

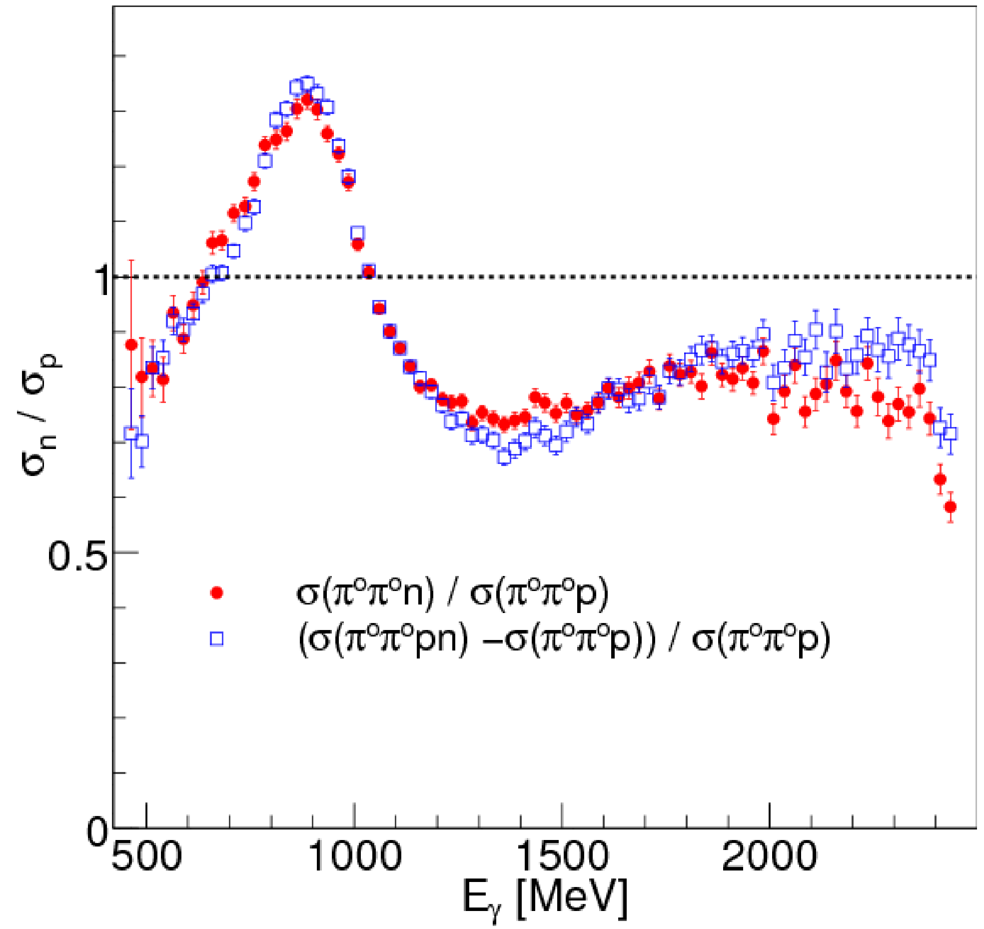
Photoproduction of $\pi^o\pi^o$-pairs off deuteron

Preliminary

CBELSA/TAPS

- **good agreement with TAPS**
- **good agreement between the two neutron measurements**





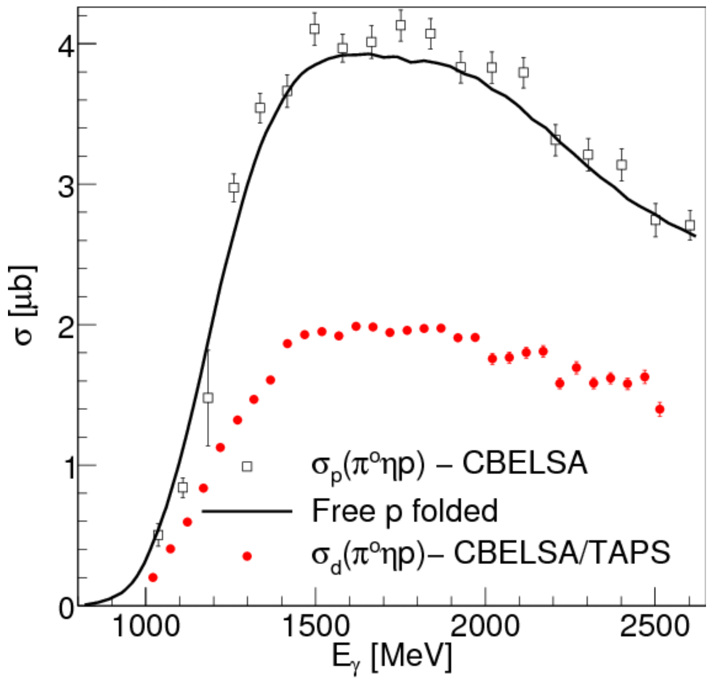
- **concerning the neutron anomaly nothing obvious is seen**

Photoproduction of $\pi^o\eta$-pairs off light nuclei

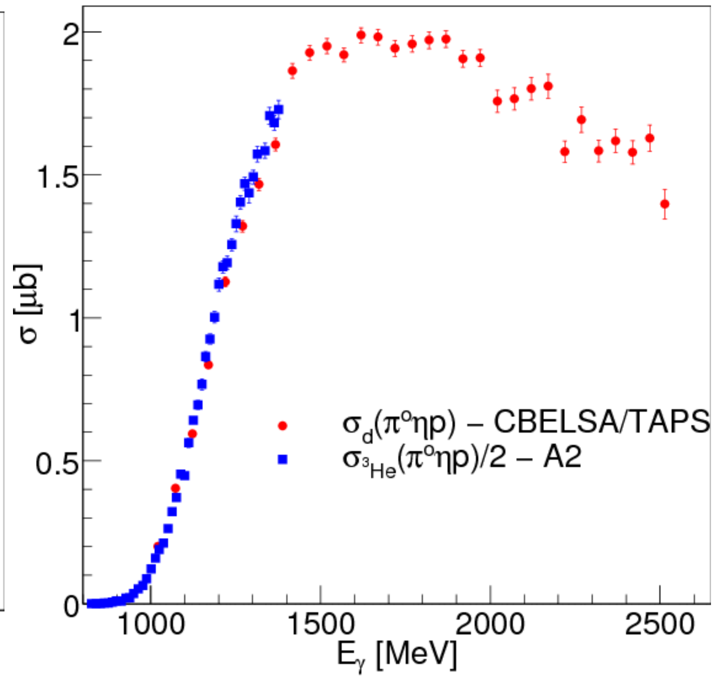
Preliminary

CBELSA/TAPS

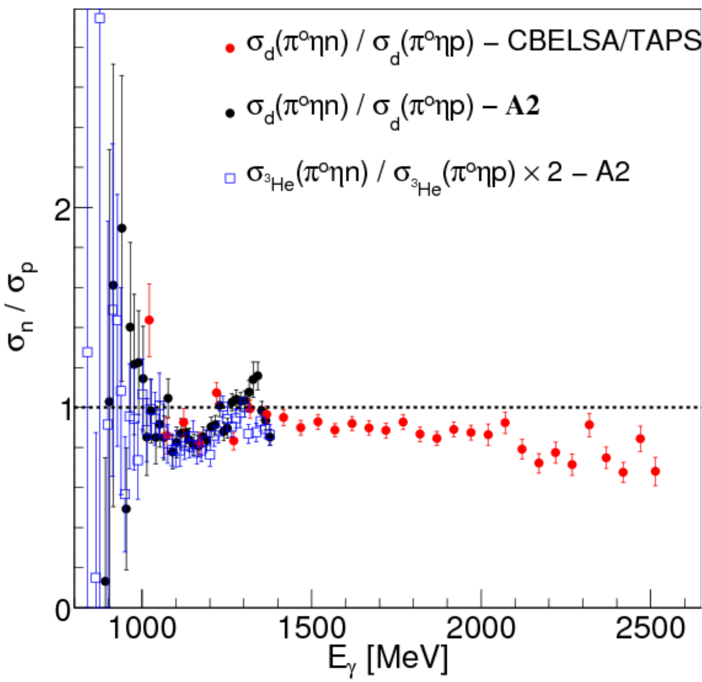
▶ **comparison between free p and quasi-free p**



▶ **comparison between p bound in the d and in the ^{3}He**



▶ **cross section ratios**



=> expected behavior

▶ **=> strong FSI ?**

▶ **$\sigma_n \sim \sigma_p$ - T = 3/2 resonances dominate with small T = 1/2 resonances contributions**

▶ **concerning the neutron anomaly nothing obvious is seen**

Conclusions

- **CBELSA/TAPS and A2 seem to show that the structure has W ~ 1670 MeV, Γ ~ 30 MeV**

- **high statistics measurement of $\gamma n \rightarrow \eta n$ at MAMI-C with precision "similar" to the one of $\gamma p \rightarrow \eta p$ at MAMI-C (I. Strakovsky talk)**

- **single (P,T and Σ) and double polarization (E,F,G and H) observables are needed and will be measured in the very near future in Mainz (J. Arends talk) and Bonn (R. Beck talk) to determine the nature of the structure and its quantum numbers**

- **the other possible candidate channels are being investigate with the high statistics measurement of Crystal Ball and TAPS at MAMI-C**
  - **$\gamma n \rightarrow \pi^o n$**
  - **$\gamma n \rightarrow \pi^o \pi^o n$**
  - **$\gamma n \rightarrow \pi^o \eta n$**
  - **$\gamma n \rightarrow \gamma n$**
  - **and maybe $\gamma n \rightarrow K^o \Lambda$**

Thanks for your attention

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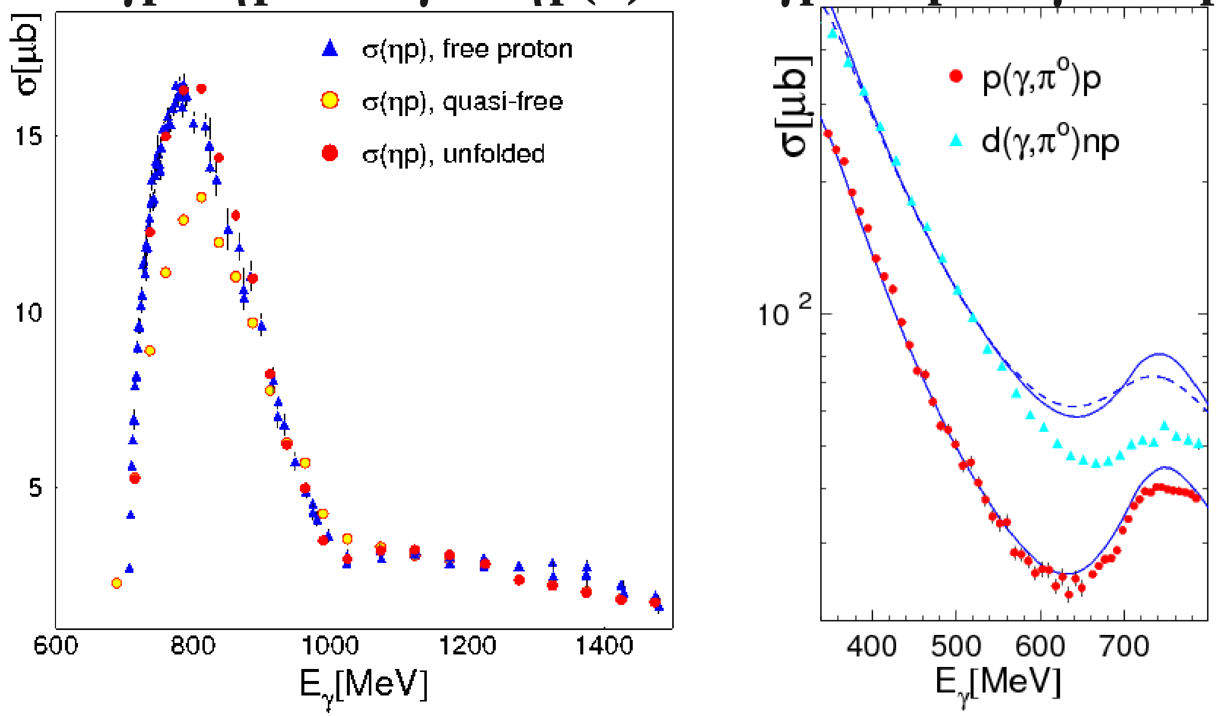
Nuclear effects

- Fermi motion => the nucleons are not at rest
- Final State Interactions (FSI)
- re-scattering
- coherent contributions

- comparison between free p and quasi-free p

$\gamma p \to \eta p$ vs. $\gamma d \to \eta p(n)$ $\gamma p \to \pi^o p$ vs. $\gamma d \to \pi^o pn$



- easy case
Fermi motion effect
=> is understood
- complicate case
Fermi motion + FSI + … effects
=> difficult to take into account