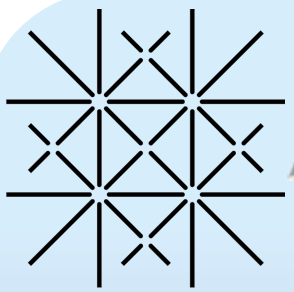
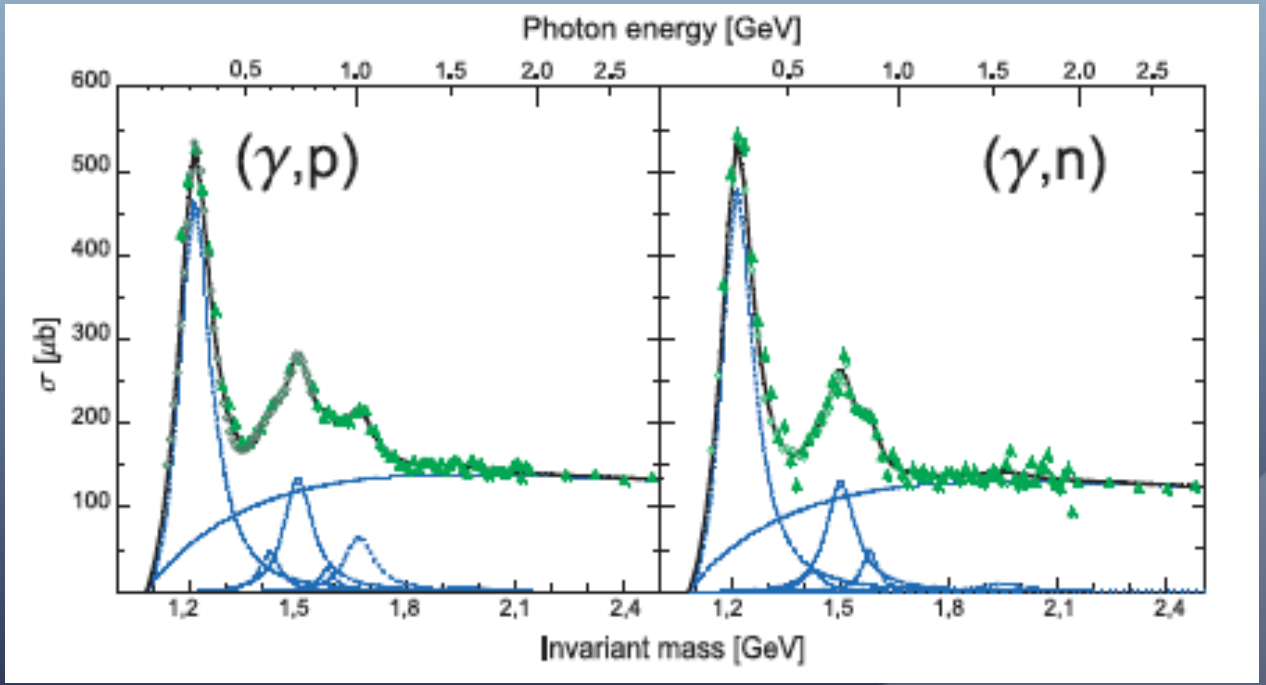


Recent Results from Photoproduction off Mesons at A2

Natalie K. Walford
University of Basel

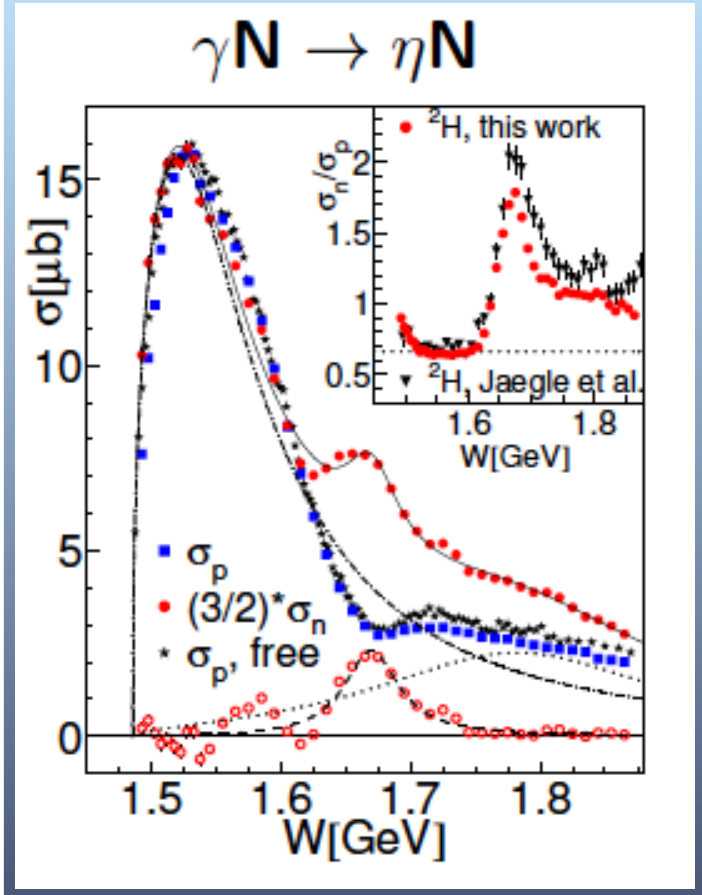
Total Cross Section

- Different structures observed on proton and neutron data
- Neutron has different resonance contributions
- Neutron targets more difficult to deal with due to Fermi motion, FSI
- Sparse database requires more data
- Isospin decomposition of el. mag. transition amplitudes needs neutron measurements

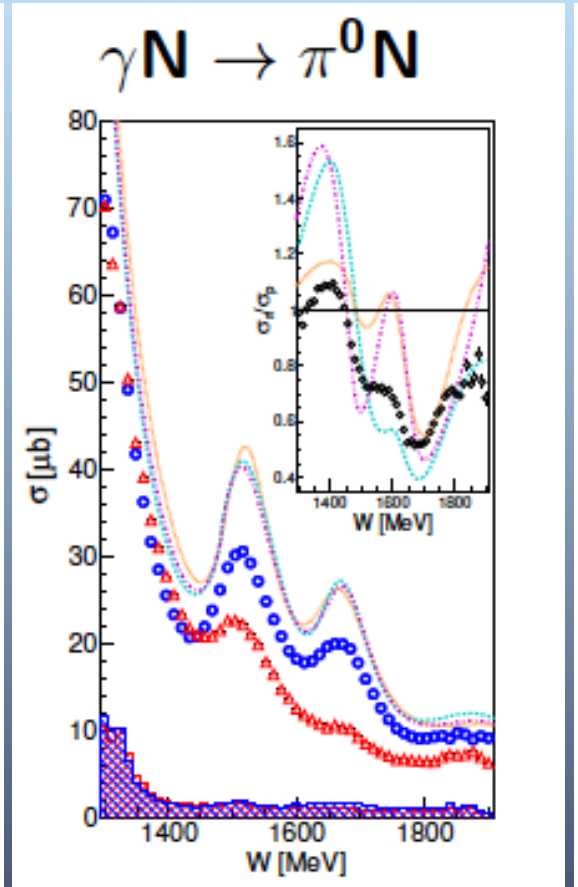


Resonance Contributions

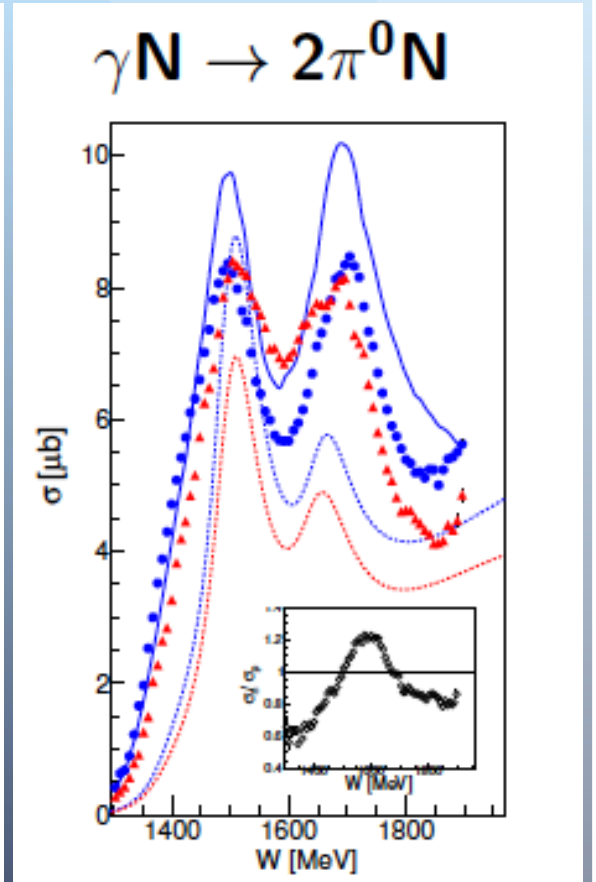
Different contributions for proton and neutron!!!!



Werthmüller *et al.*, PRL111,232001 (2013)



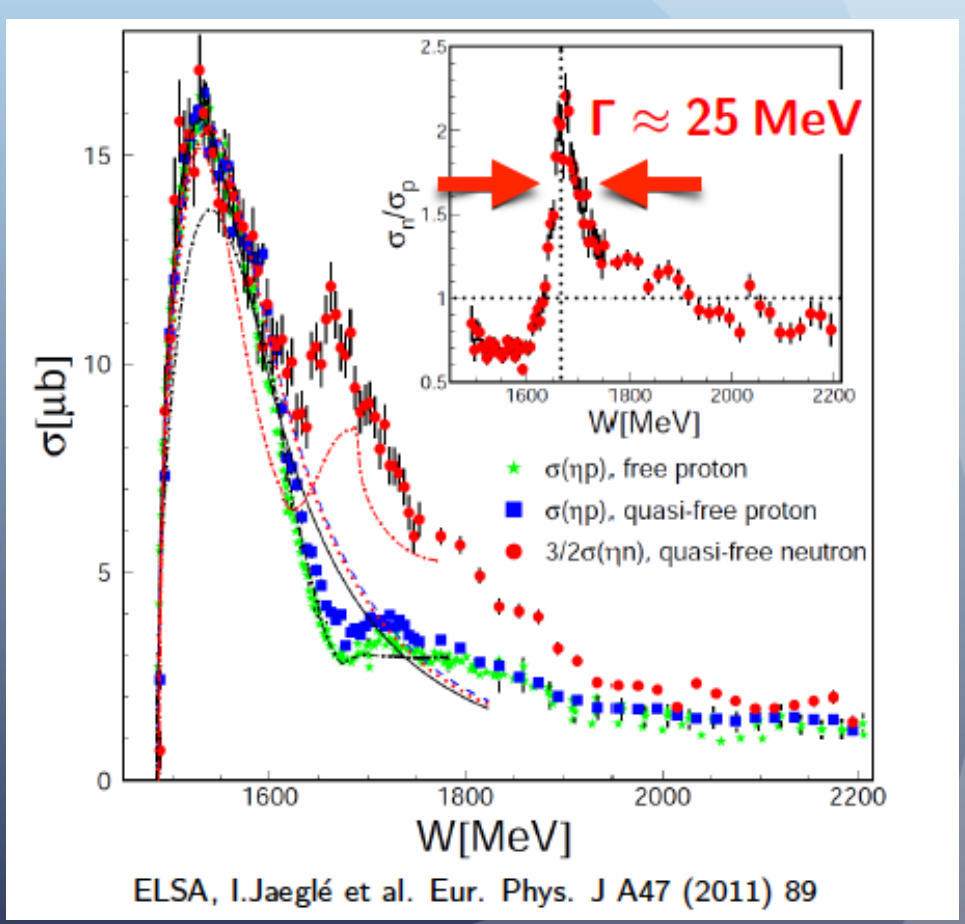
Dieterle *et al.*, PRL112,142001 (2014)



Dieterle *et al.*, EPJ A51 142 (2015)

η Photoproduction

- Narrow structure visible around W=1.66 GeV
- Seen by A2, GRAAL, CBELSA/TAPS, and Sendai collaborations
- Different properties compared to other nucleon resonances (Γ~150 MeV)
- Input from polarization observables necessary to identify quantum numbers



Polarization Observables

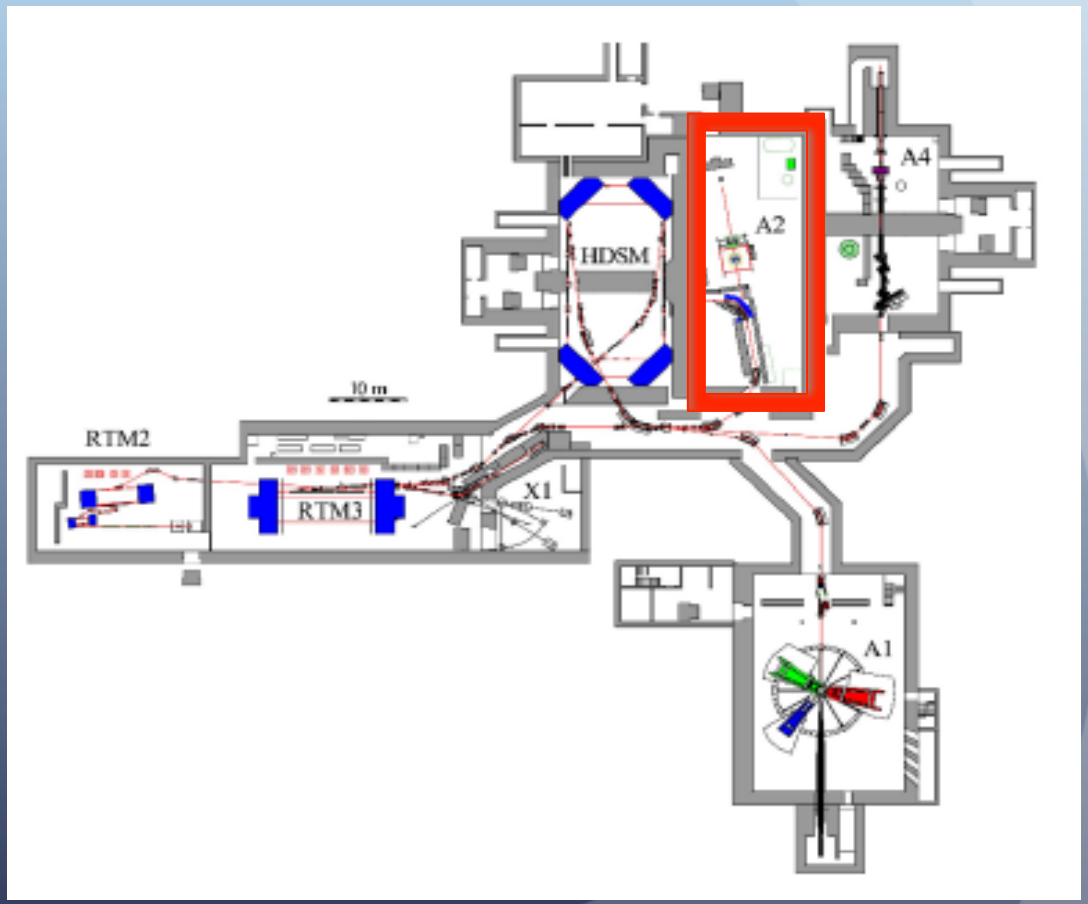
- Photoproduction described by four complex amplitudes
- 16 independent measurables calculated
- Extracted based on beam, target, and recoil polarization
- Not all observables are independent from each other

Photon	Target				Recoil			Target + Recoil			
	–	–	–	–	x'	y'	z'	x'	x'	z'	z'
	–	x	y	z	–	–	–	x	z	x	z
unpolarized	σ_0	0	T	0	0	P	0	$T_{x'}$	-$L_{x'}$	$T_{z'}$	$L_{z'}$
linear pol.	$-\Sigma$	H	(-P)	$-G$	$O_{x'}$	(-T)	$O_{z'}$	(-$L_{z'}$)	($T_{z'}$)	(-$L_{x'}$)	(-$T_{x'}$)
circular pol.	0	F	0	$-E$	$-C_{x'}$	0	$-C_{z'}$	0	0	0	0

Spin observable	Helicity representation
$\check{\Omega}^1 \equiv \mathcal{I}(\theta)$	$\frac{1}{2}(\lvert H_1\rvert^2+\lvert H_2\rvert^2+\lvert H_3\rvert^2+\lvert H_4\rvert^2)$
$\check{\Omega}^4 \equiv \check{\Sigma}$	$\mathrm{Re}(-H_1H_4^*+H_2H_3^*)$
$\check{\Omega}^{10} \equiv -\check{T}$	$\mathrm{Im}(H_1H_2^*+H_3H_4^*)$
$\check{\Omega}^{12} \equiv \check{P}$	$\mathrm{Im}(-H_1H_3^*-H_2H_4^*)$
$\check{\Omega}^3 \equiv \check{G}$	$\mathrm{Im}(H_1H_4^*-H_3H_2^*)$
$\check{\Omega}^5 \equiv \check{H}$	$\mathrm{Im}(-H_2H_4^*+H_1H_3^*)$
$\check{\Omega}^9 \equiv \check{E}$	$\frac{1}{2}(\lvert H_1\rvert^2-\lvert H_2\rvert^2+\lvert H_3\rvert^2-\lvert H_4\rvert^2)$
$\check{\Omega}^{11} \equiv \check{F}$	$\mathrm{Re}(-H_2H_1^*-H_4H_3^*)$
$\check{\Omega}^{14} \equiv \check{O}_x$	$\mathrm{Im}(-H_2H_1^*+H_4H_3^*)$
$\check{\Omega}^7 \equiv -\check{O}_z$	$\mathrm{Im}(H_1H_4^*-H_2H_3^*)$
$\check{\Omega}^{16} \equiv -\check{C}_x$	$\mathrm{Re}(H_2H_4^*+H_1H_3^*)$
$\check{\Omega}^2 \equiv -\check{C}_z$	$\frac{1}{2}(\lvert H_1\rvert^2+\lvert H_2\rvert^2-\lvert H_3\rvert^2-\lvert H_4\rvert^2)$
$\check{\Omega}^6 \equiv -\check{T}_x$	$\mathrm{Re}(-H_1H_4^*-H_2H_3^*)$
$\check{\Omega}^{13} \equiv -\check{T}_z$	$\mathrm{Re}(-H_1H_2^*+H_4H_3^*)$
$\check{\Omega}^8 \equiv \check{L}_x$	$\mathrm{Re}(H_2H_4^*-H_1H_3^*)$
$\check{\Omega}^{15} \equiv \check{L}_z$	$\frac{1}{2}(-\lvert H_1\rvert^2+\lvert H_2\rvert^2+\lvert H_3\rvert^2-\lvert H_4\rvert^2)$

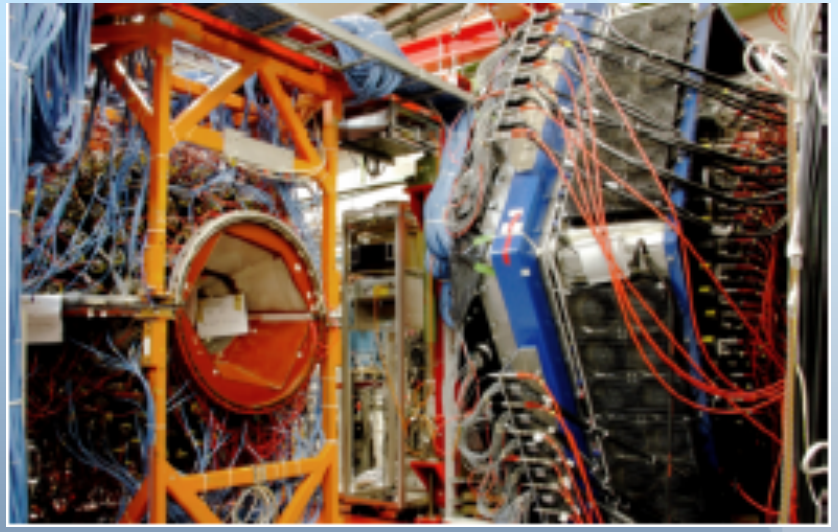
Mainz Microtron-MAMI

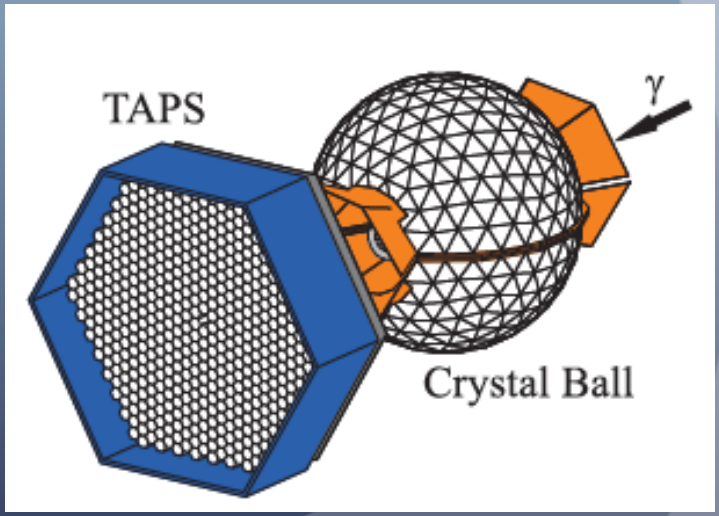
- LINAC (3.97 MeV)
- Racetrack microtrons (855 MeV)
- Harmonic double sided microtron (up to 1.6 GeV)
  - Linear and circular beam available
- Glasgow Tagging Spectrometer used



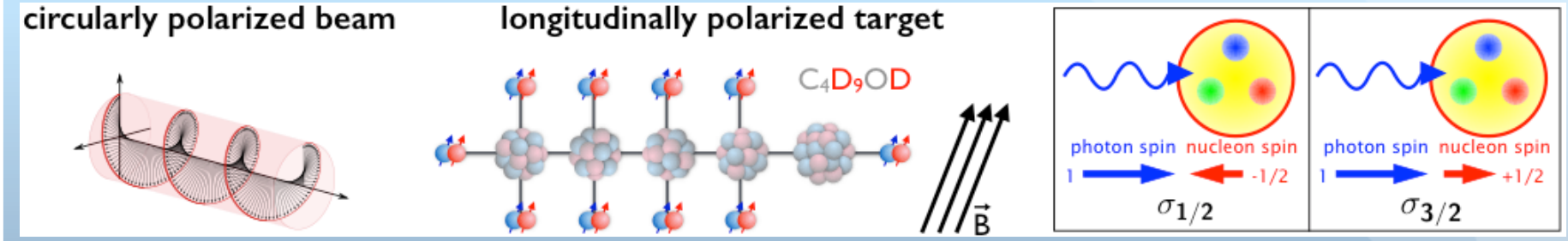
Crystal Ball/TAPS Setup

- Crystal Ball:
  - 672 NaI crystals
  - $20^\circ < \theta < 160^\circ$
- TAPS:
  - 366 BaF_2 crystals and 72 $PbWO_4$ crystals
    $2^\circ < \theta < 20^\circ$
- PID done using ΔE – E with a plastic scintillator barrel
- Charged particles accessible with MWPC, no magnetic field
- Frozen D-Butanol and H-Butanol targets available (transverse and longitudinally polarized)





Extraction of E, $\sigma_{1/2}$, and $\sigma_{3/2}$



2 extraction methods for E:

$$E^{vers1} = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} = \frac{\sigma_{diff}}{\sigma_{sum}}$$

$$E^{vers2} = \frac{\sigma_{diff}}{2\sigma_{unpol}}$$

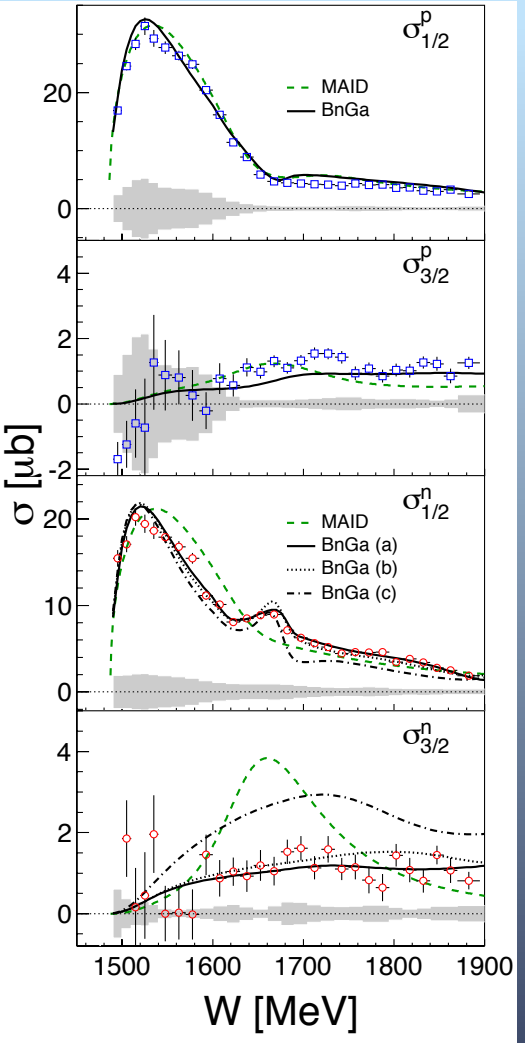
3 extraction methods for $\sigma_{N/2}$:

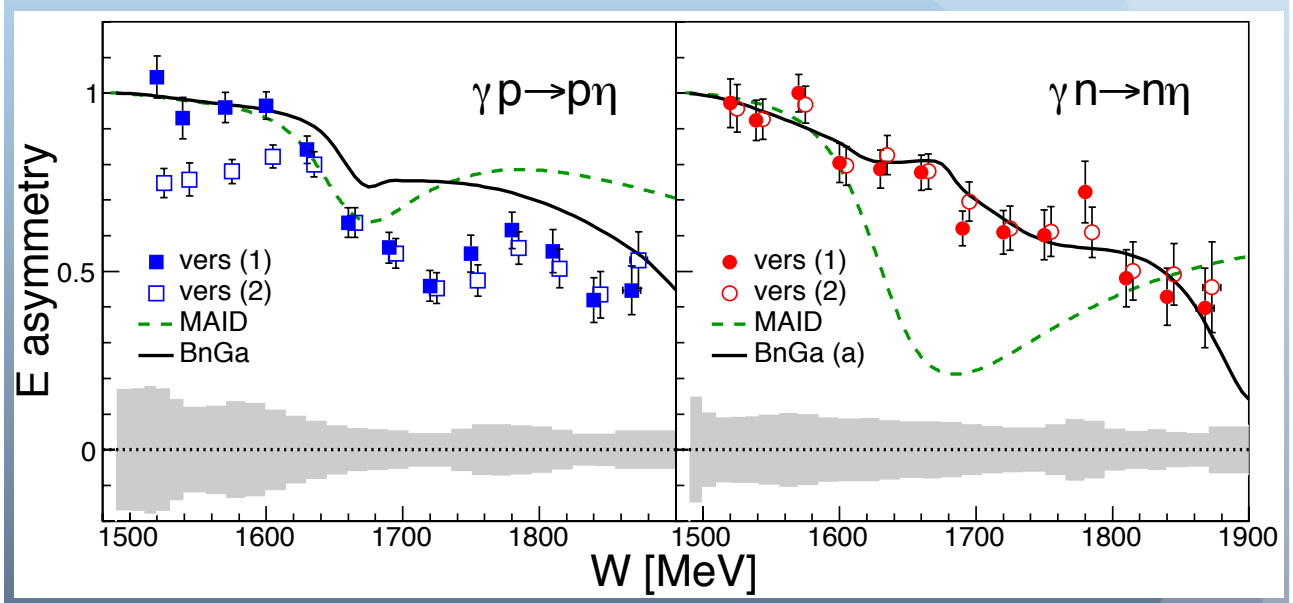
$$\sigma_{1/2}^{vers1} = \sigma_{unpol}(1 + E^{vers1})$$
$$\sigma_{3/2}^{vers1} = \sigma_{unpol}(1 - E^{vers1})$$

$$\sigma_{1/2}^{vers2} = \sigma_{unpol}(1 + E^{vers2}) = \frac{2\sigma_{unpol} + \sigma_{diff}}{2}$$
$$\sigma_{3/2}^{vers2} = \sigma_{unpol}(1 - E^{vers2}) = \frac{2\sigma_{unpol} - \sigma_{diff}}{2}$$

$$\sigma_{1/2}^{vers3} = \frac{\sigma_{sum} + \sigma_{diff}}{2}$$
$$\sigma_{3/2}^{vers3} = \frac{\sigma_{sum} - \sigma_{diff}}{2}$$

E and $\sigma_{N/2}$ for ηN

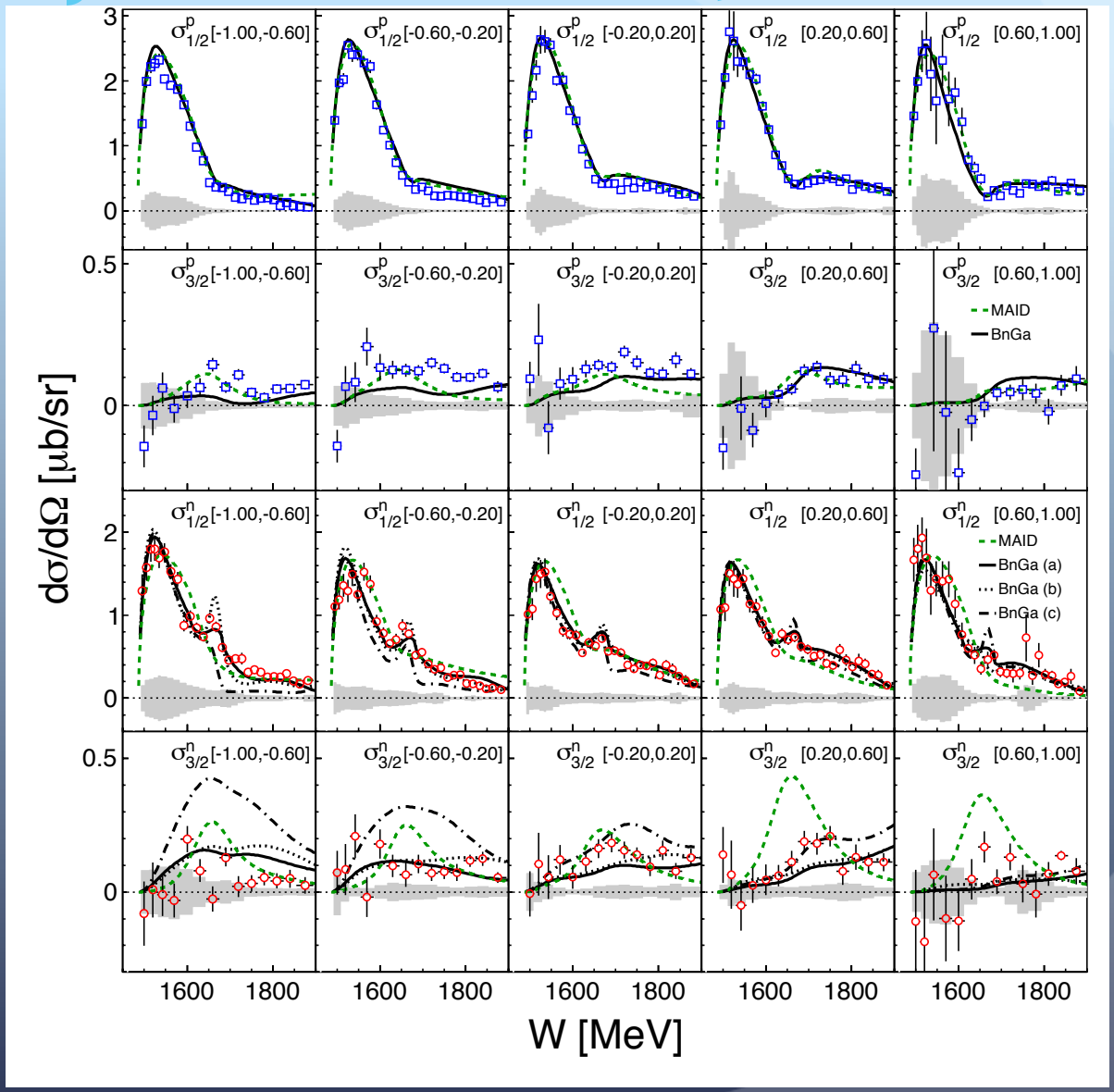




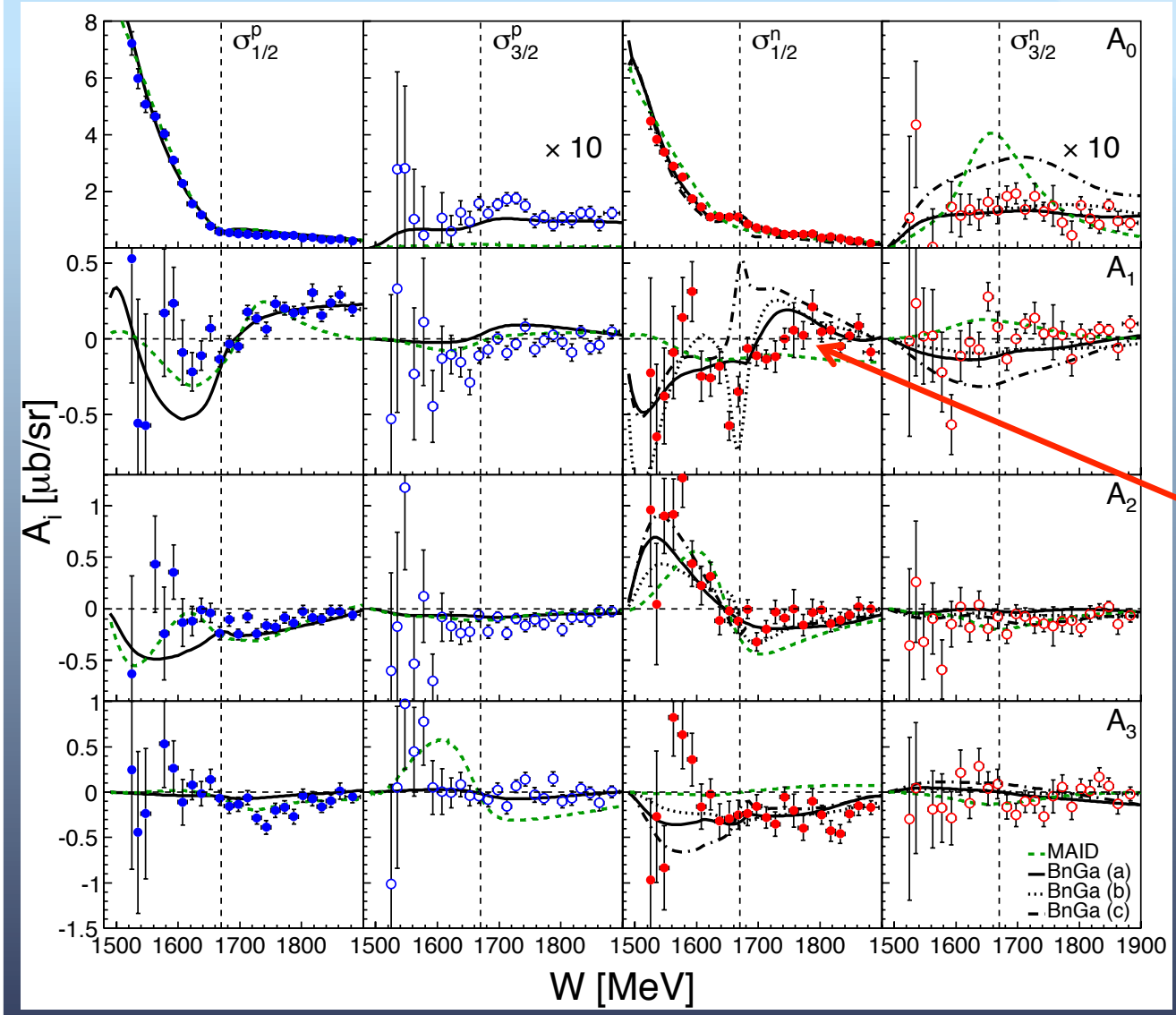
Witthauer *et al.*, PRL **117** 132502 (2016)

Angular Asymmetries for ηN

Witthauer *et al.*, PRL **117** 132502 (2016)



Legendre Coefficients for ηN

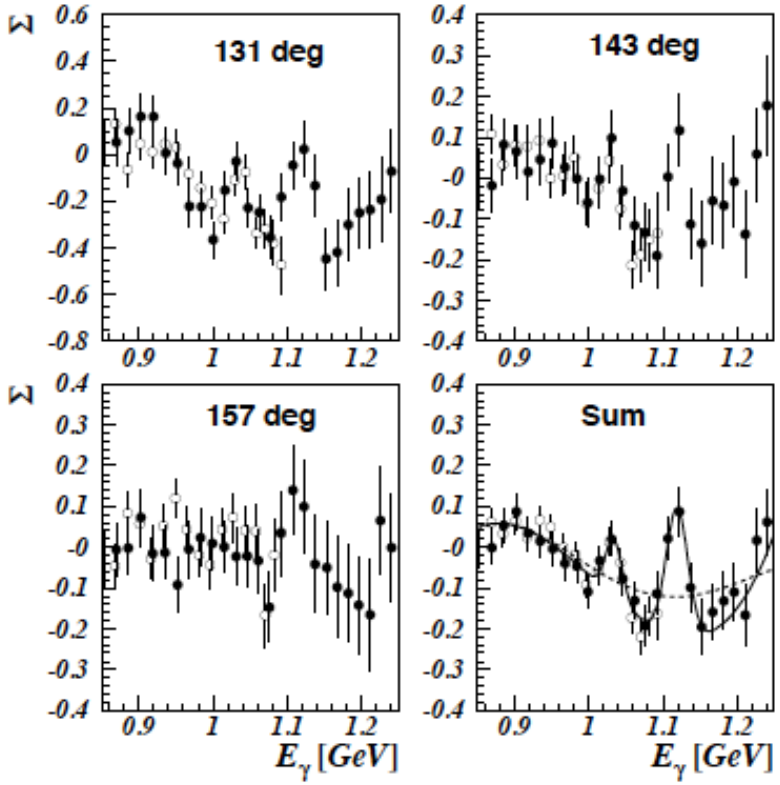


Model results with a positive interference sign of P_{11} and S_{11} are more similar to the measured data than the predictions without the addition of a narrow P_{11} state

Witthauer *et al.*, PRL 117 132502 (2016)

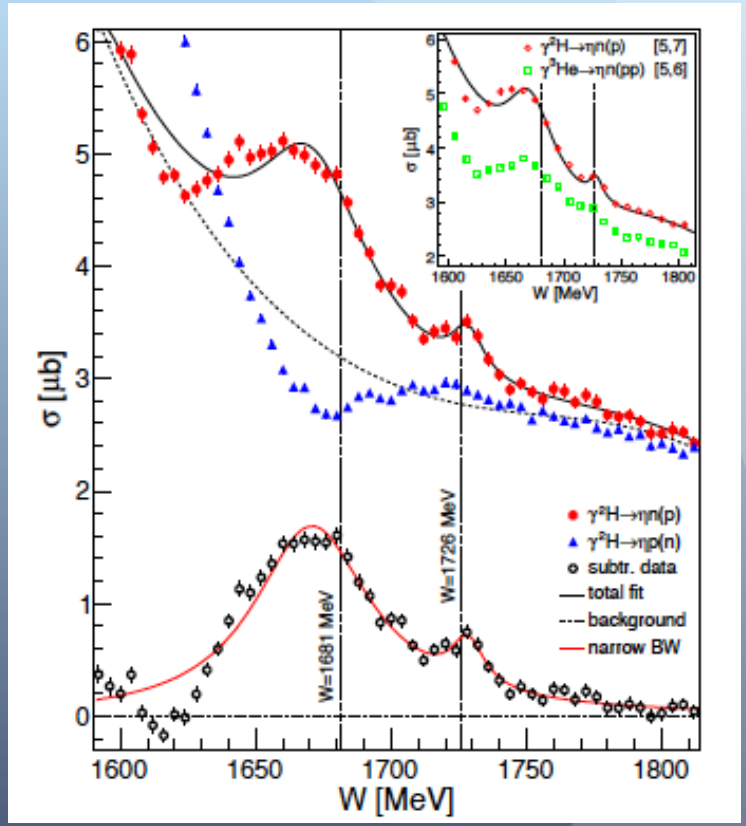
Another look at ηn

Narrow structure seen in **Compton scattering** off proton:



GRAAL experiment: Kuznetsov *et al.*, PRC 91 042201 (2015)

Peak at same *W* significant in relation to ηn in **total cross section**:

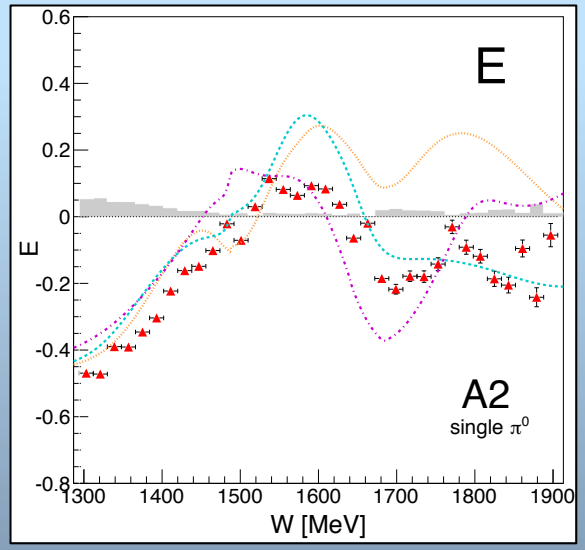


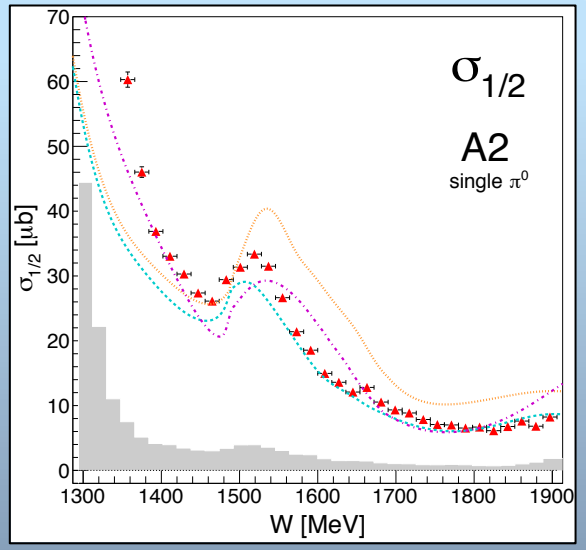
A2 experiment: Werthmüller *et al.*, PRC 92 069801 (2015)

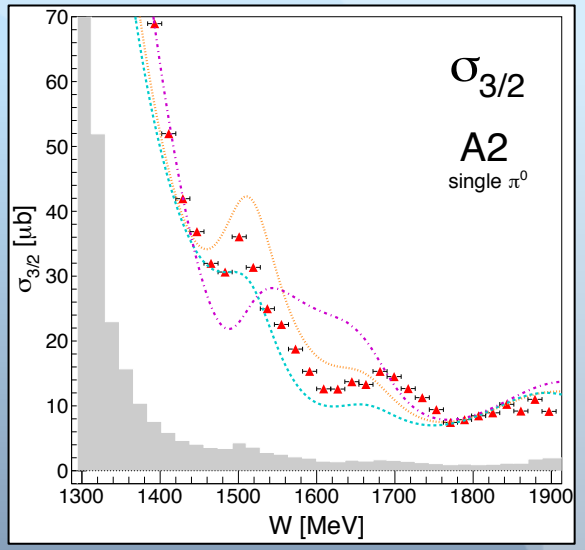
MAID
SAID
BnGA

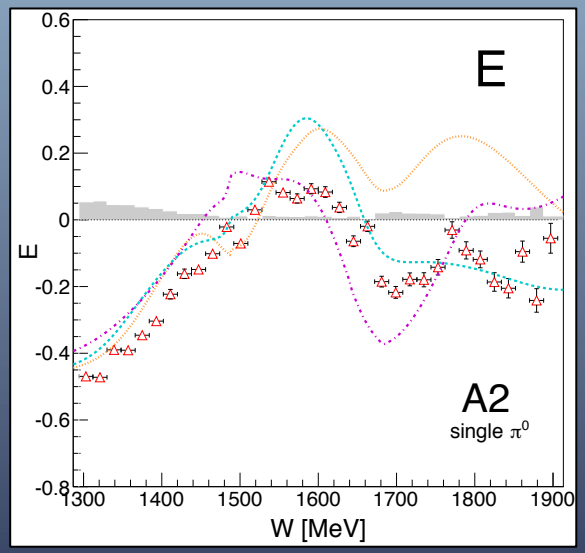
E for $\pi^0 n$

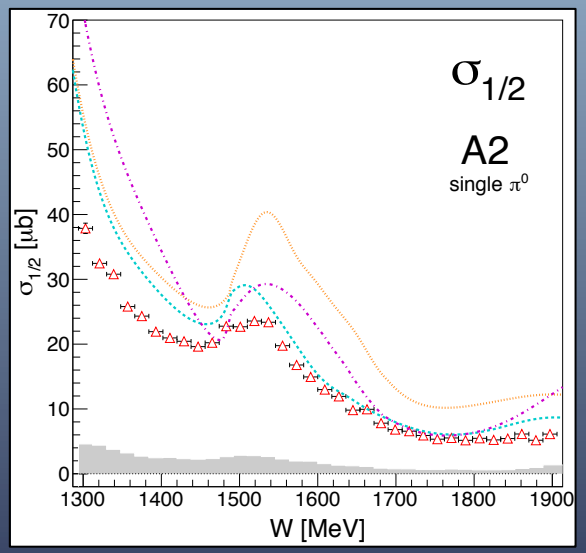
Full-free
Open-quasifree

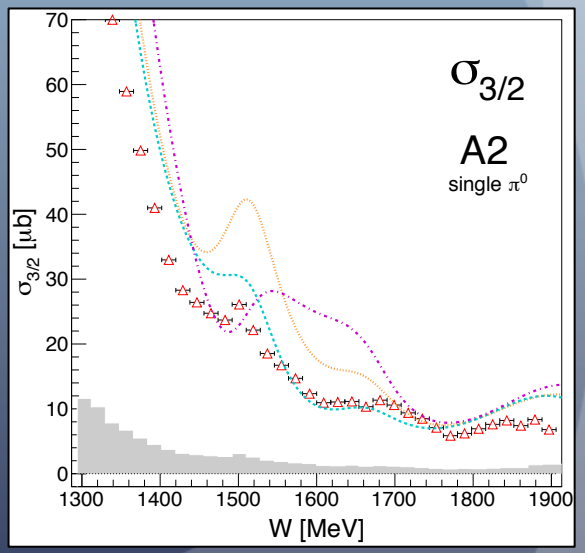












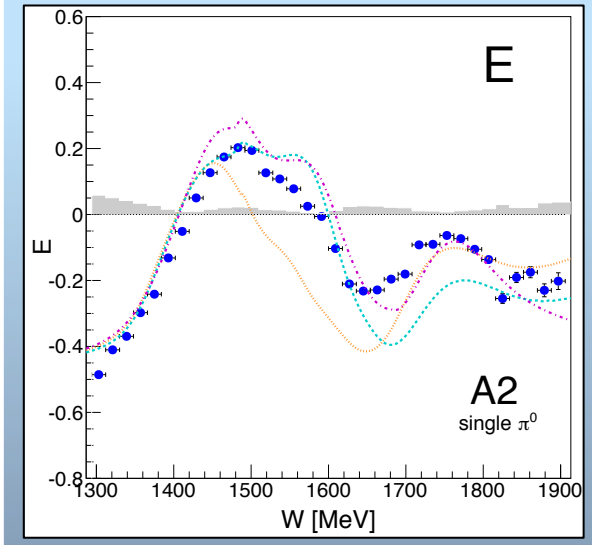
Walford, SPIN2016

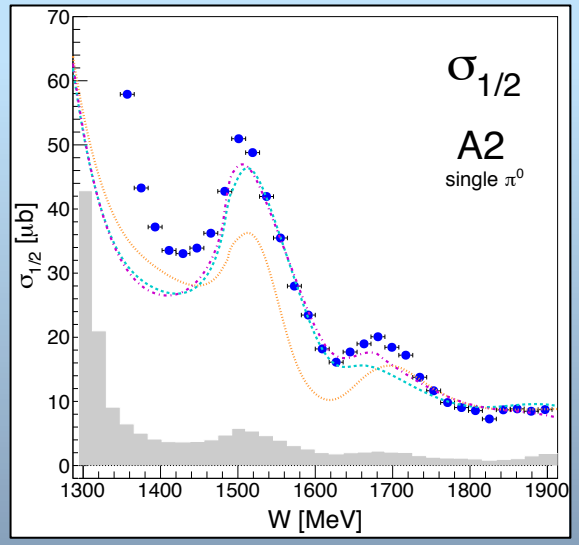
Dieterle *et al.*, in preparation

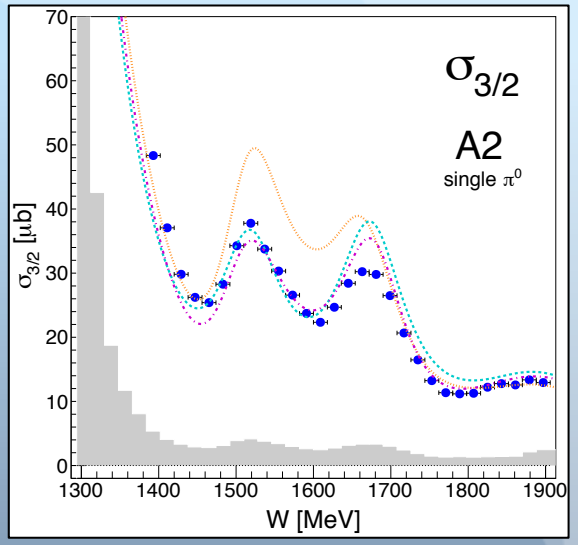
MAID
SAID
BnGA

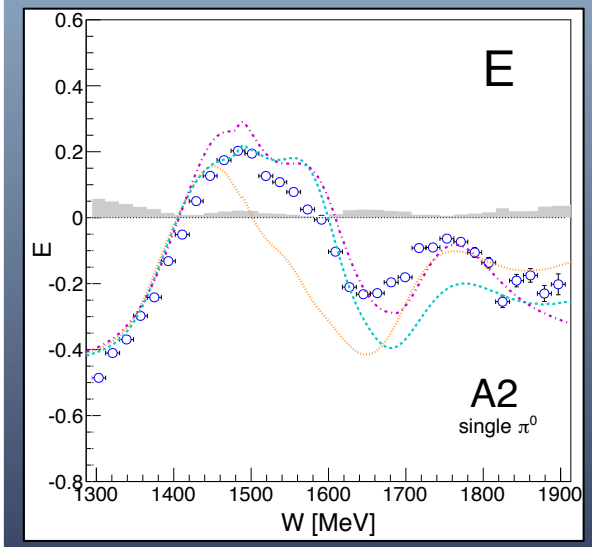
E for $\pi^0 p$

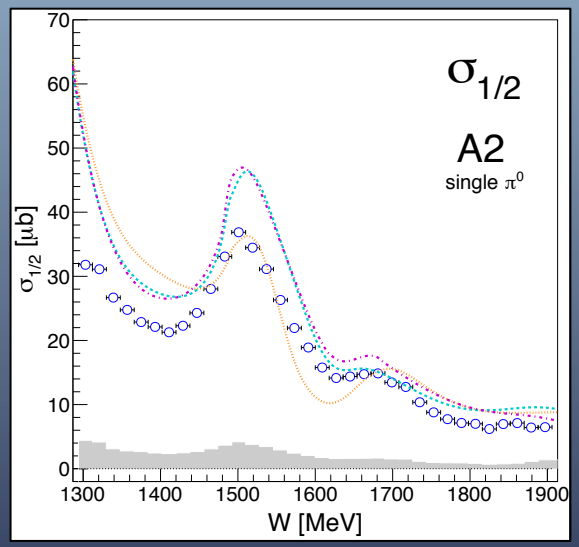
Full-free
Open-quasifree

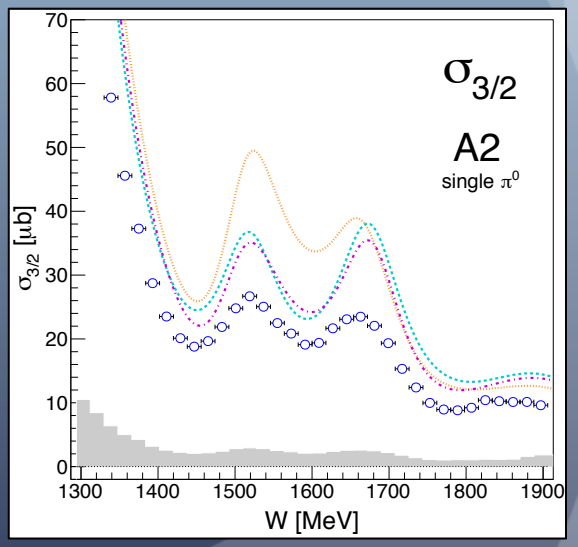












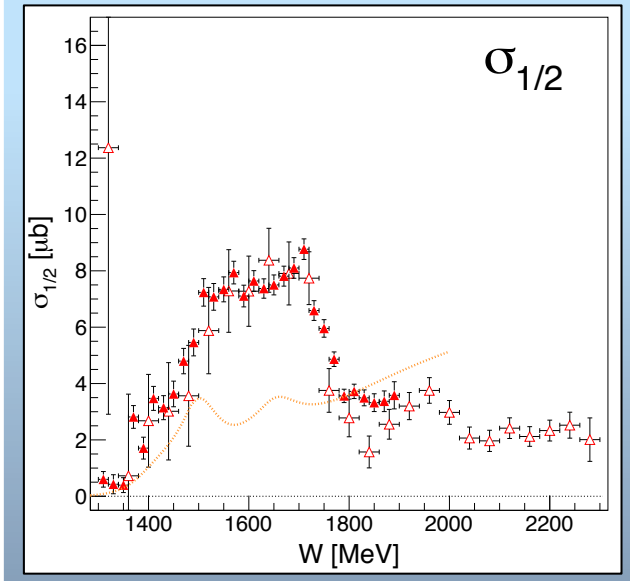
Walford, SPIN2016

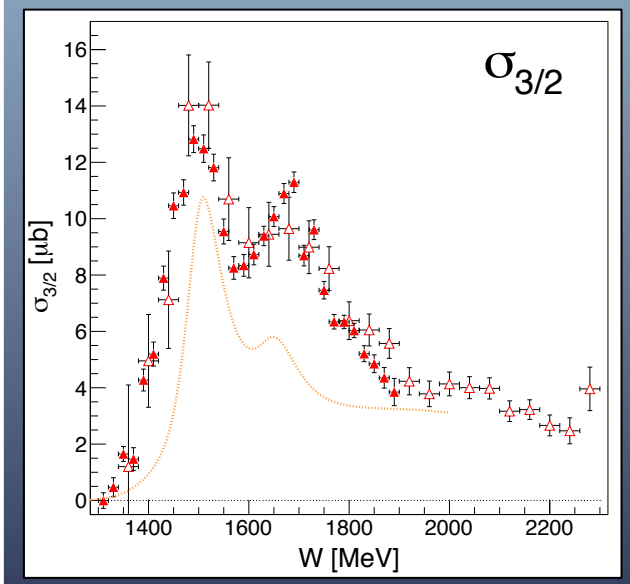
Dieterle *et al.*, in preparation

MAID

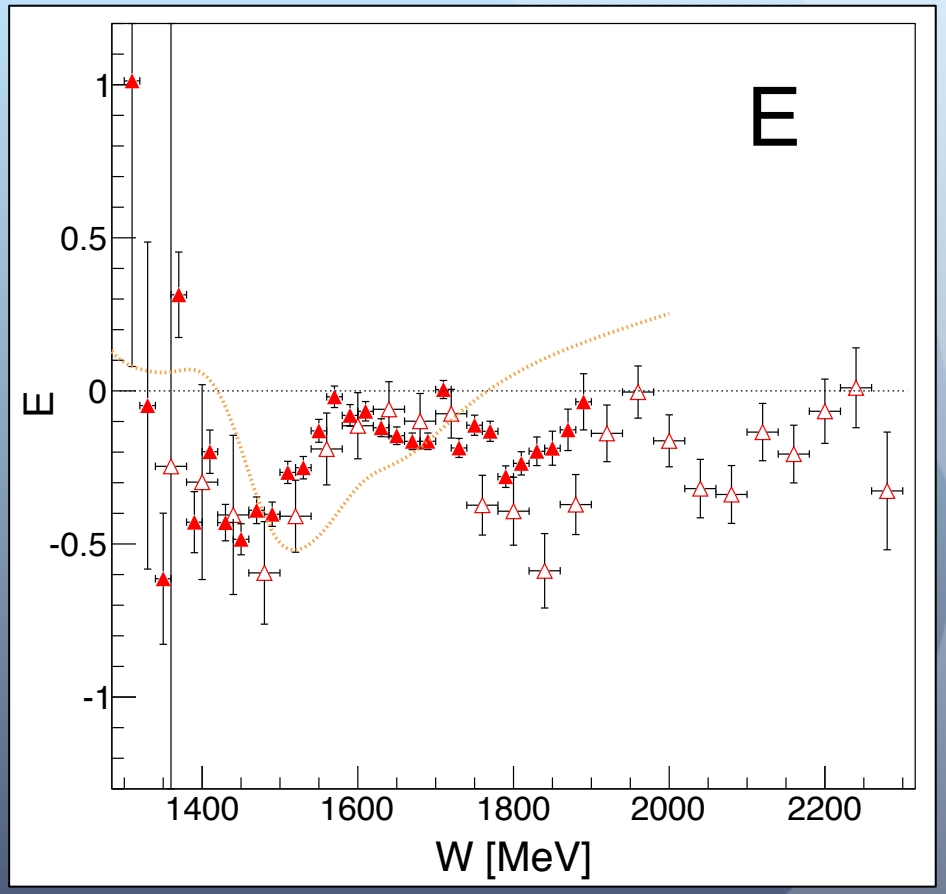
E for $\pi^0\pi^0 n$

Full-Crystal Ball
Open-CBELSA





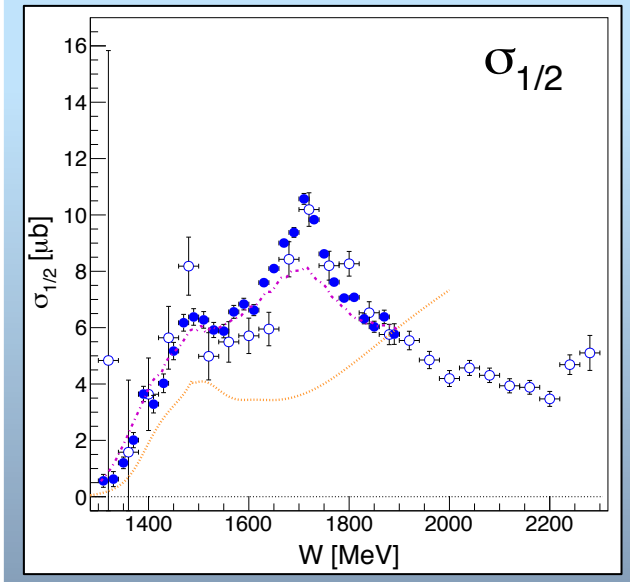
Walford, SPIN2016

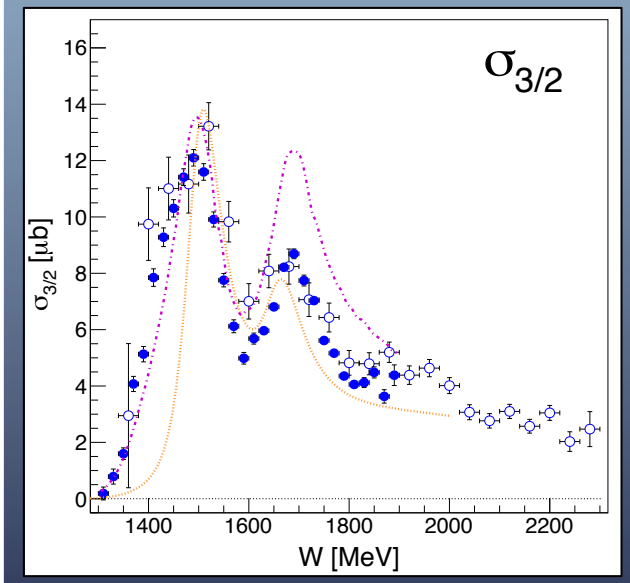


Dieterle *et al.*, in preparation

MAID
BnGA

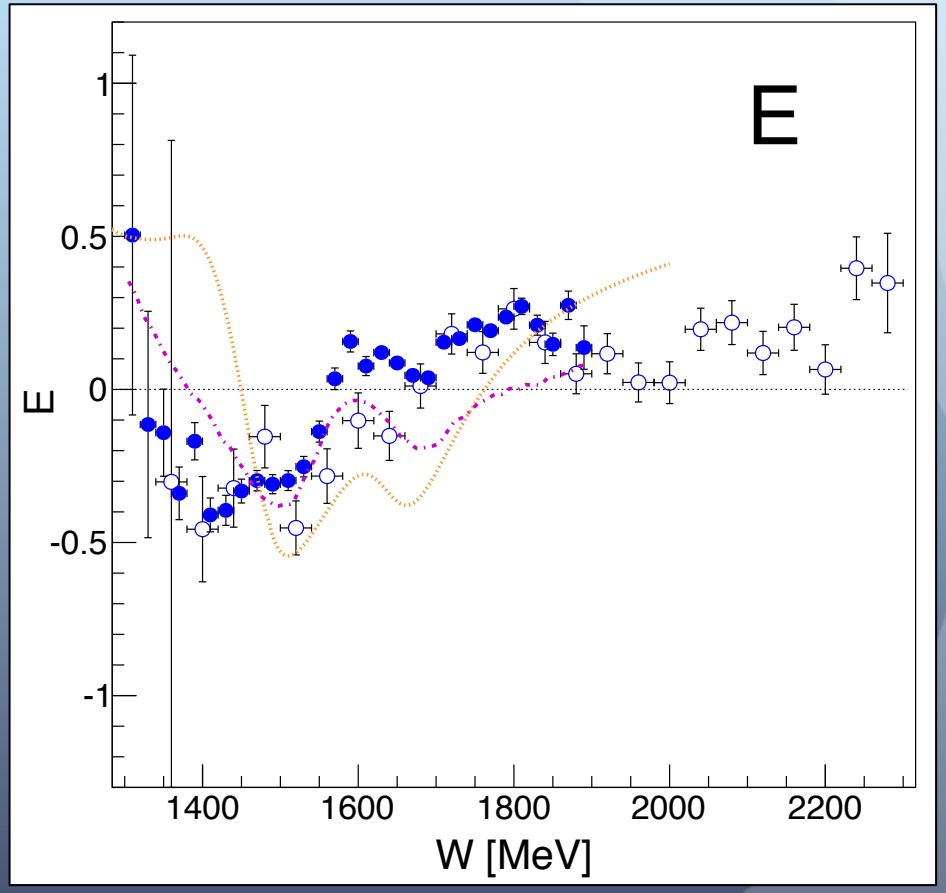
E for $\pi^0\pi^0 p$





Walford, SPIN2016

Full-Crystal Ball
Open-CBELSA



Dieterle *et al.*, in preparation

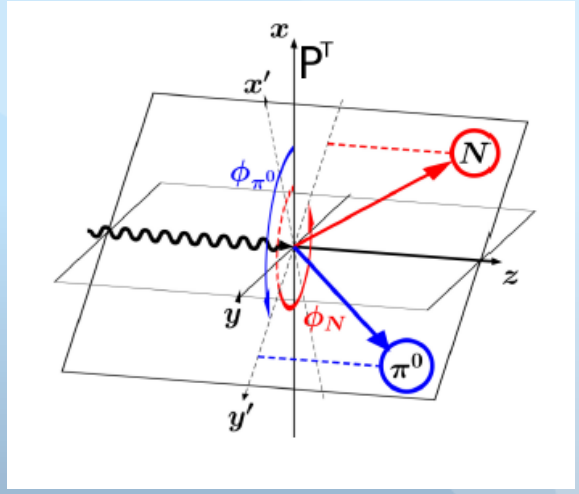
Extraction of *T* and *F*

$$T cos\phi' = \frac{1}{P_T} \frac{d\sigma^{\uparrow}\phi' - d\sigma^{\downarrow}\phi'}{d\sigma^{\uparrow}\phi' + d\sigma^{\downarrow}\phi'}$$

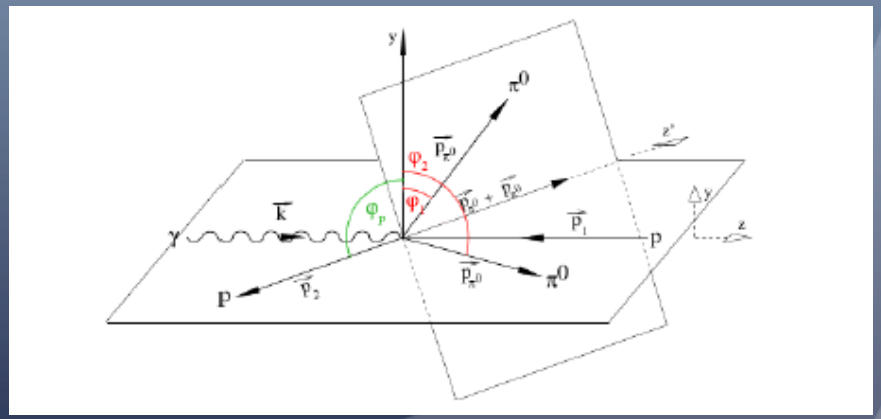
↑, ↓ denote target polarization state

$$F cos\phi = \frac{1}{P_T P_{circ}} \frac{d\sigma^{-}\phi - d\sigma^{+}\phi}{d\sigma^{-}\phi + d\sigma^{+}\phi}$$

+, - denote photon helicity state



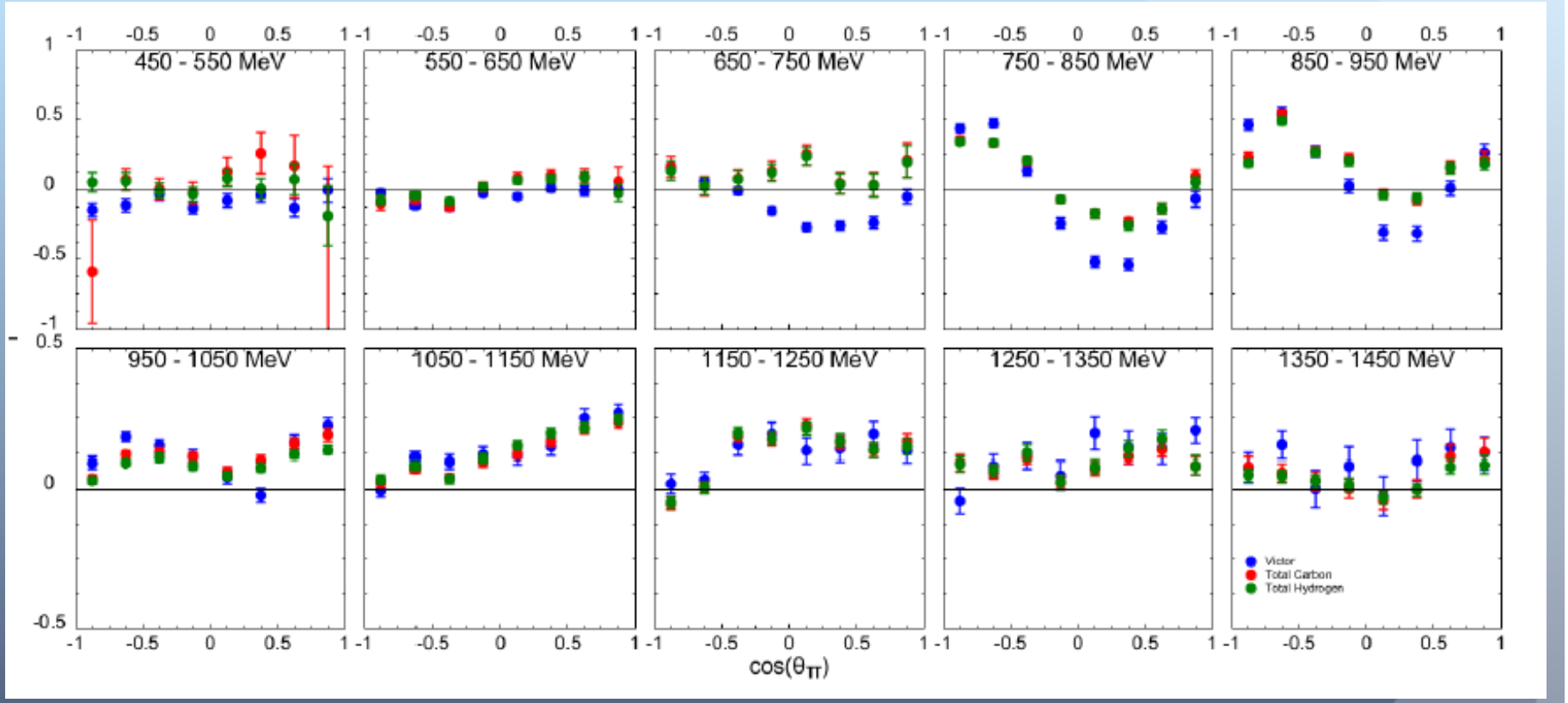
- Φ is the angle between target polarization plane and production plane
- Φ' is the angle between target polarization plane and normal to production plane



2 methods to extract:

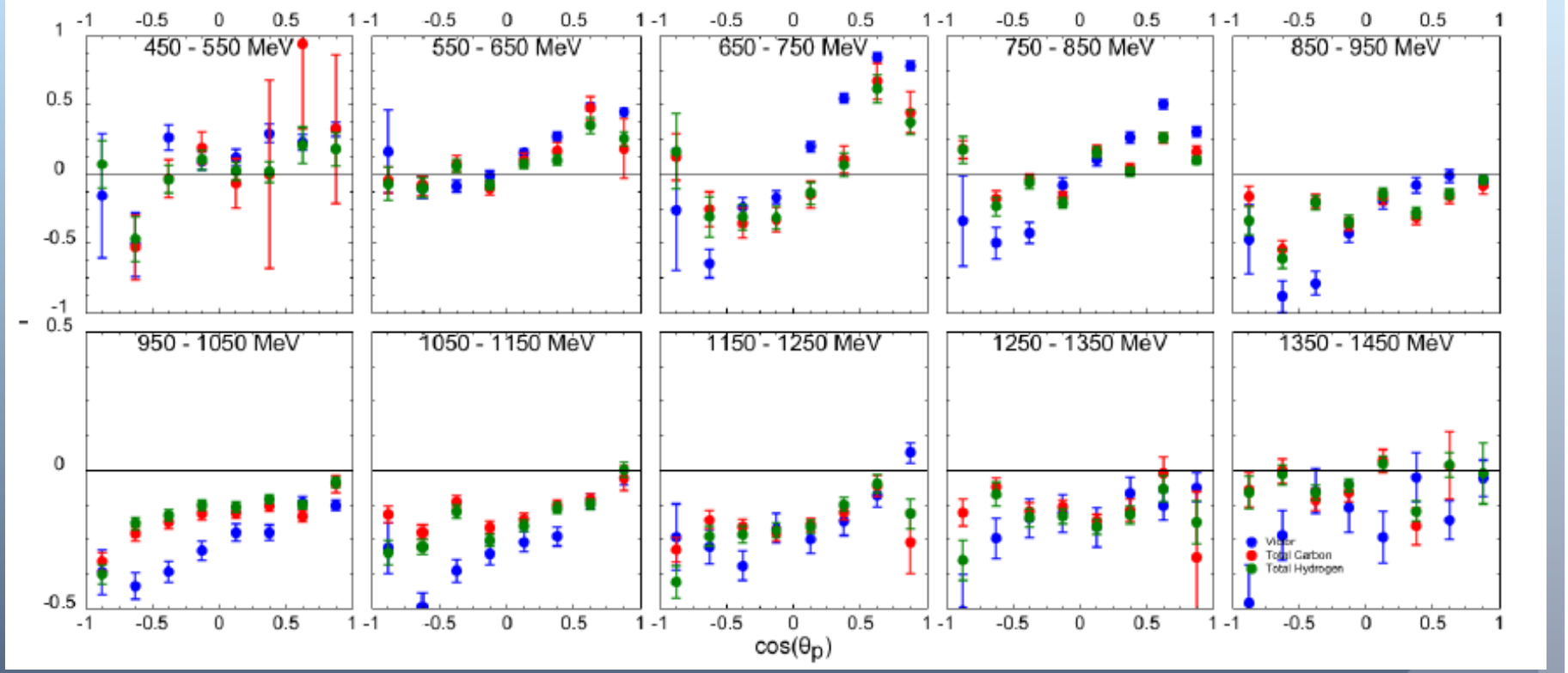
- Normalize with deuterium target (needs flux and efficiency correction)
- Normalize with D-Butanol/H-Butanol target (no flux or efficiency correction, but uses dilution factor)

T for $\pi^0\pi^0 p$



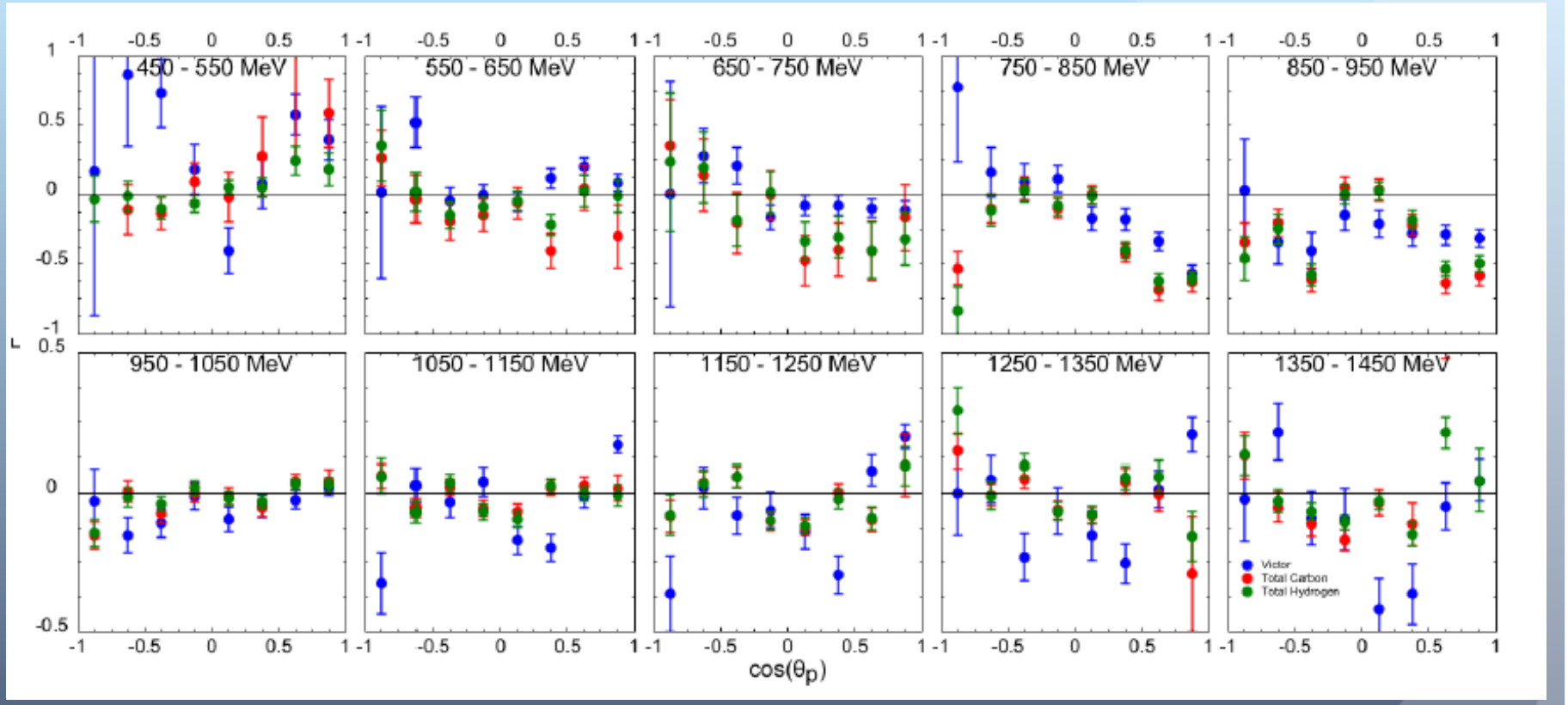
Garni *et al.*, preliminary

T for $\pi^0\pi^0 p$



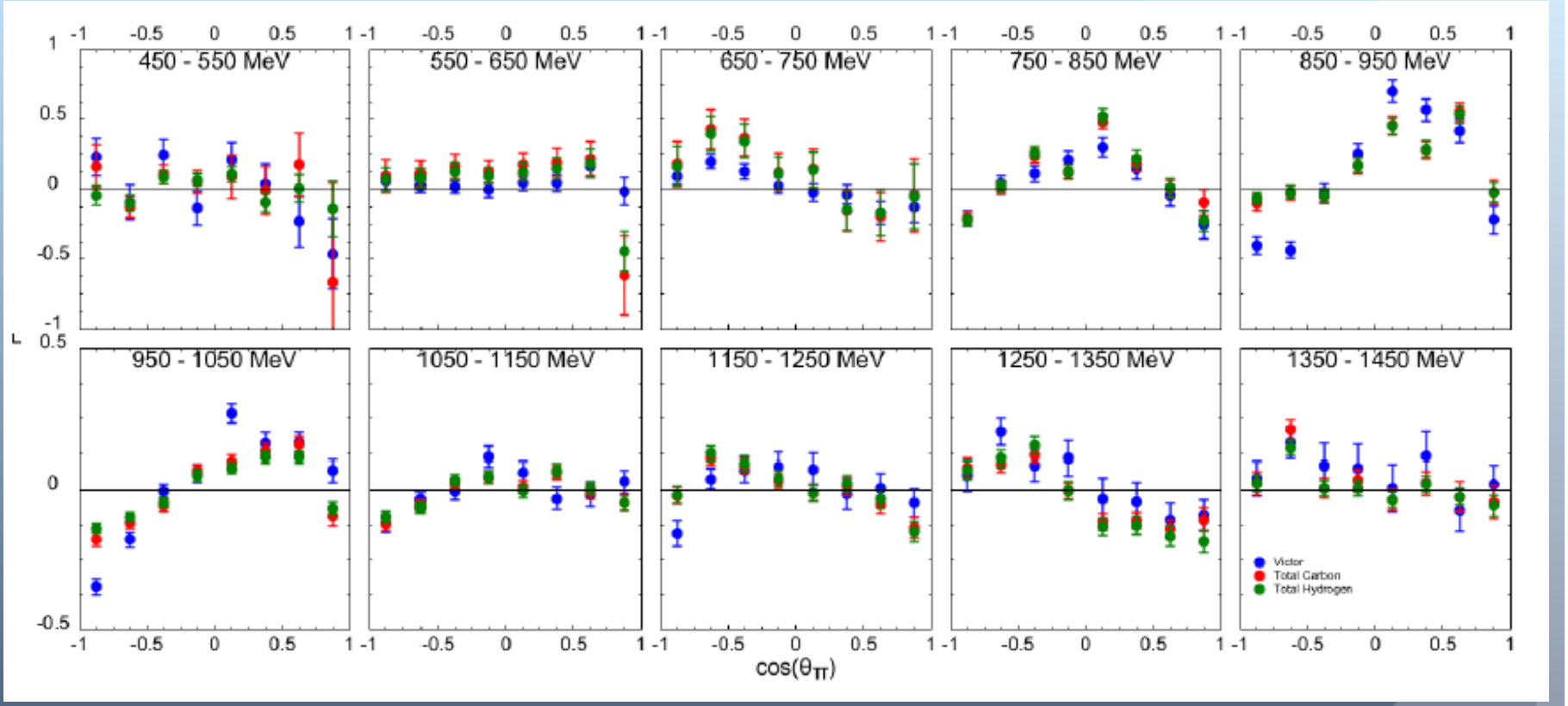
Garni *et al.*, preliminary

F for $\pi^0\pi^0 p$



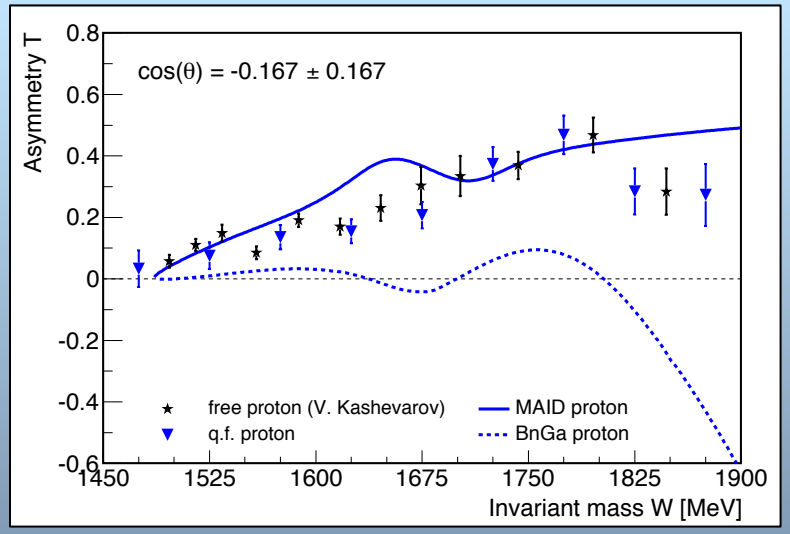
Garni *et al.*, preliminary

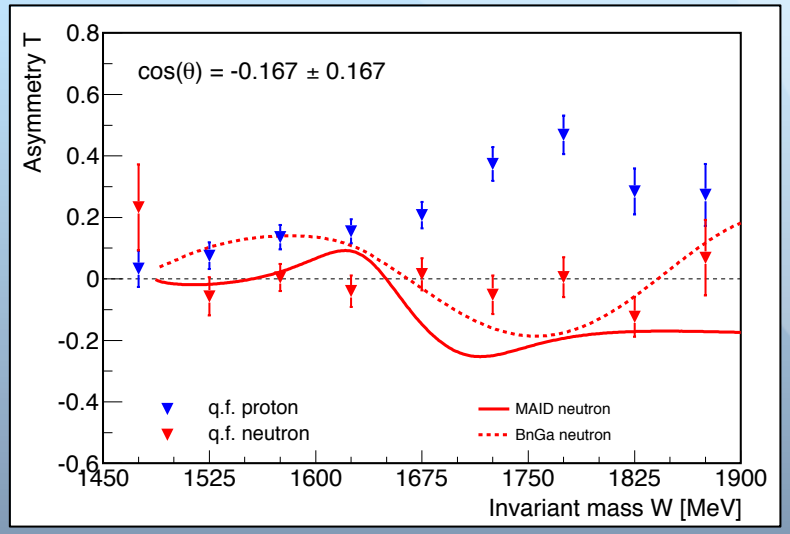
F for $\pi^0\pi^0 p$

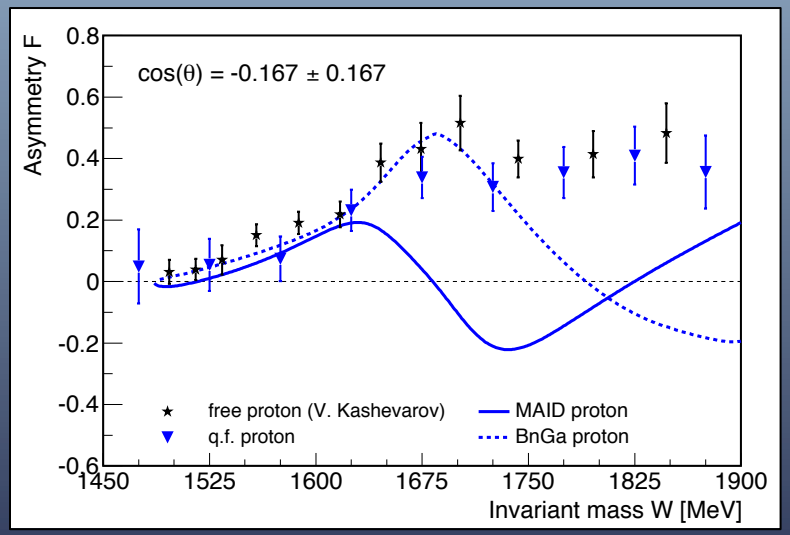


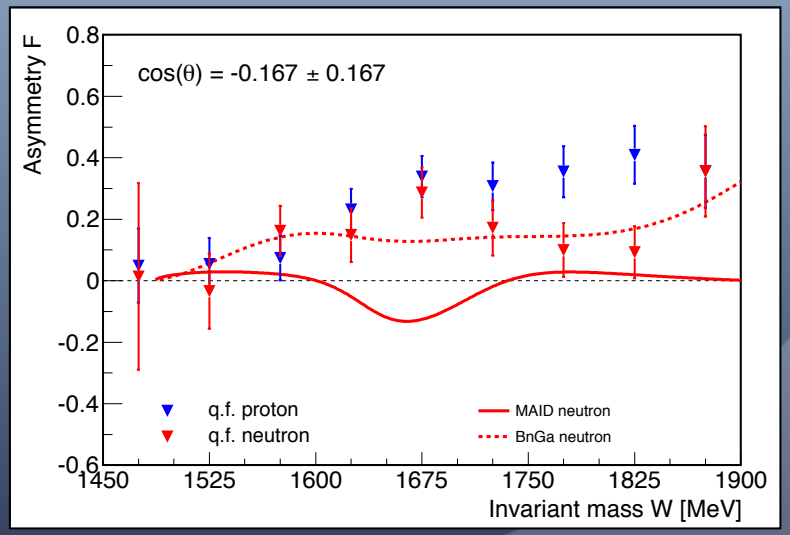
Garni *et al.*, preliminary

T, *F* for ηN









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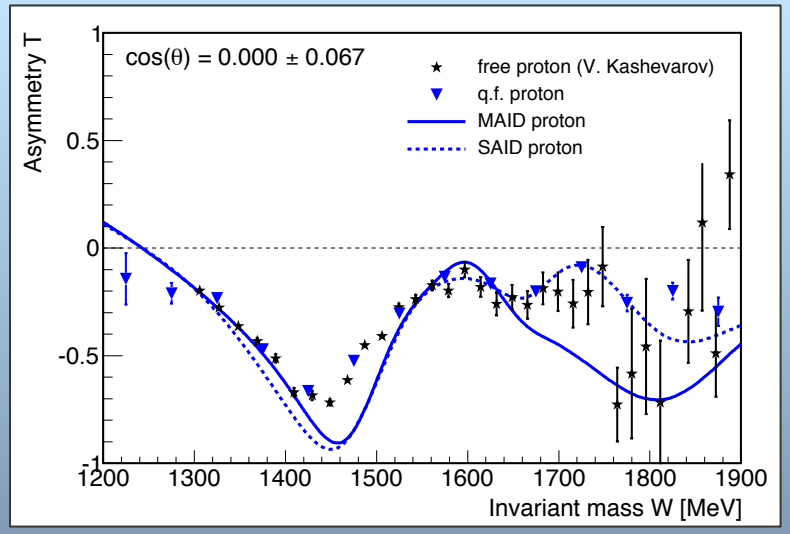
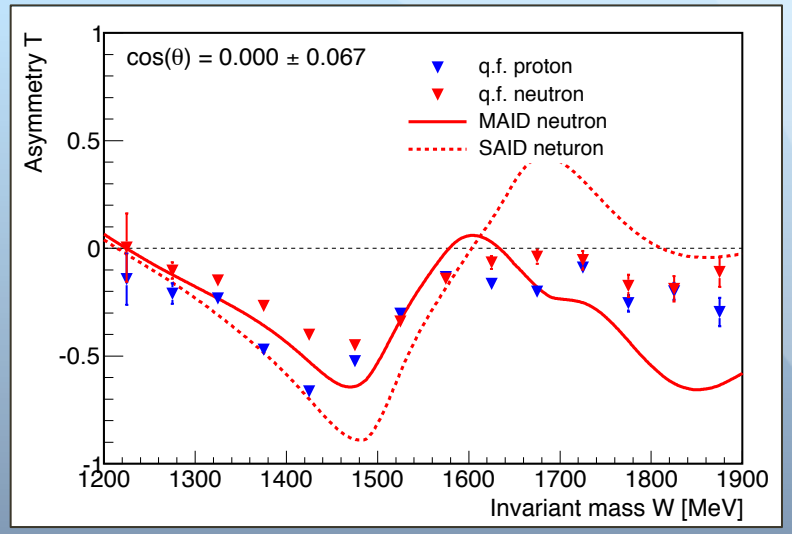
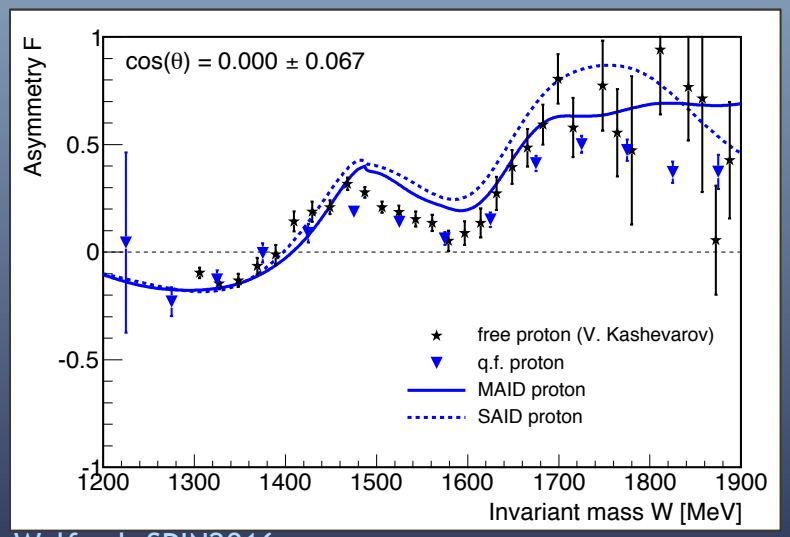
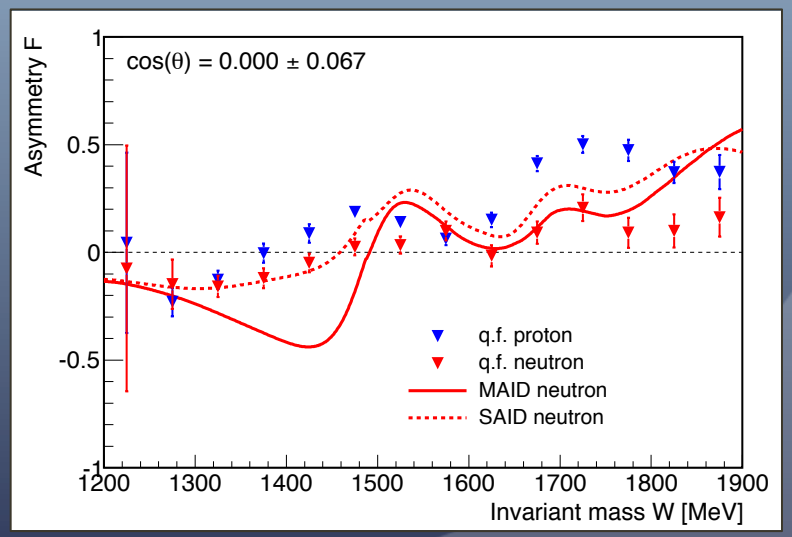
T, *F* for $\pi^0 N$









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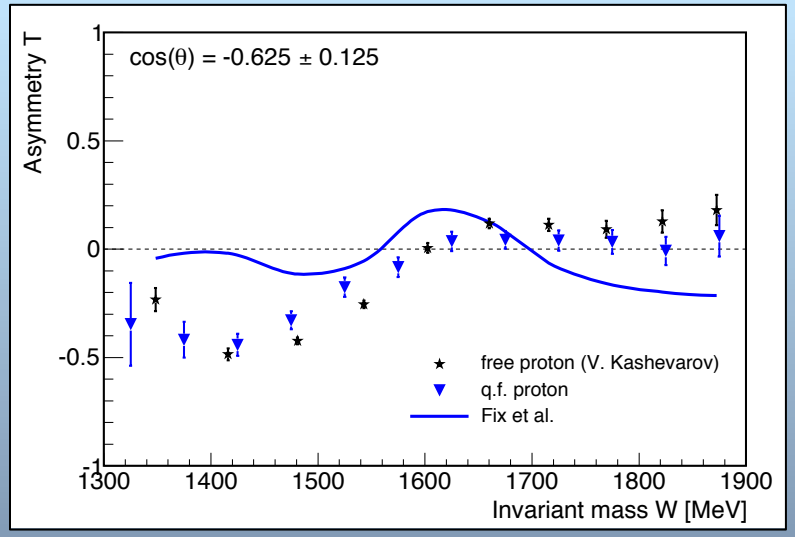
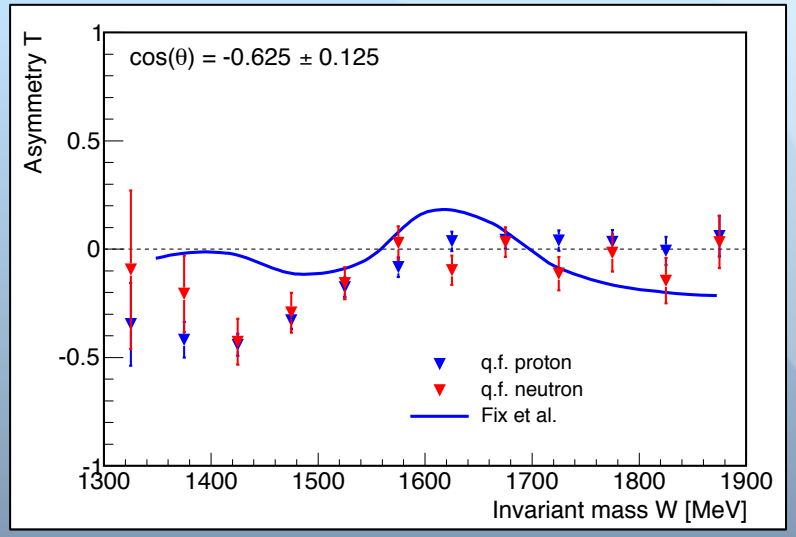
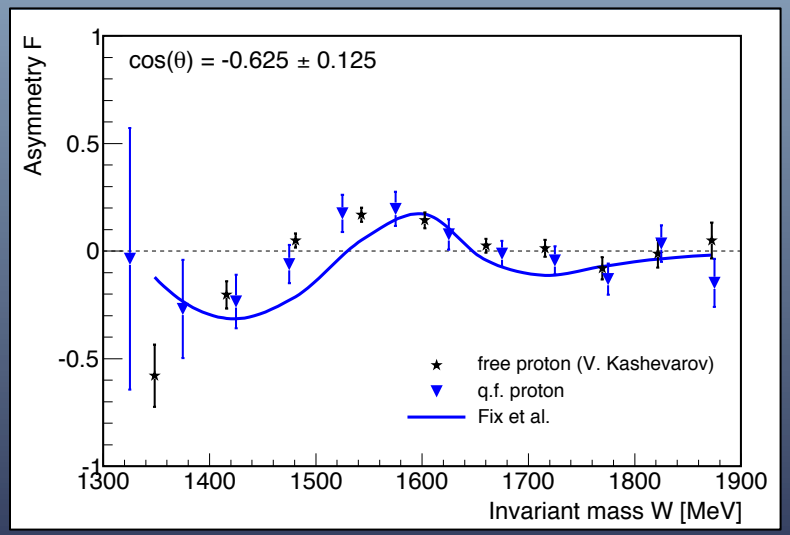
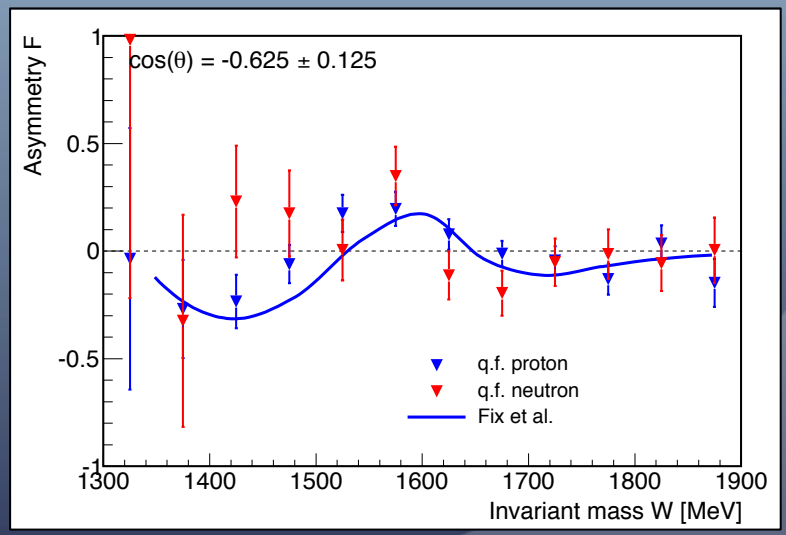
Strub *et al.*, very preliminary

T, *F* for $\pi^0\pi^0 N$









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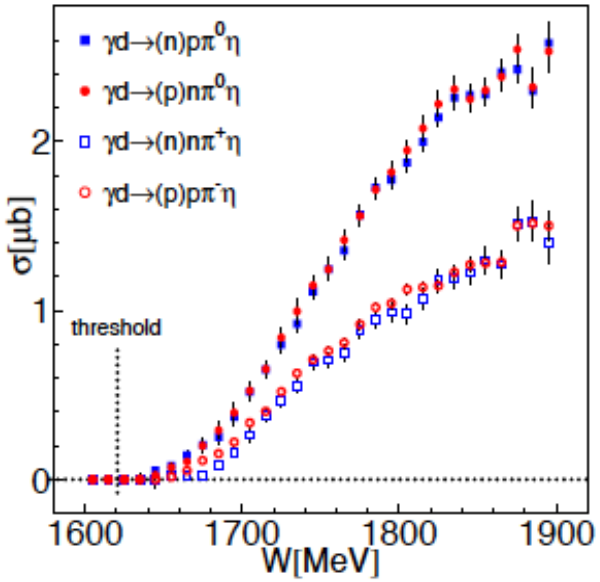
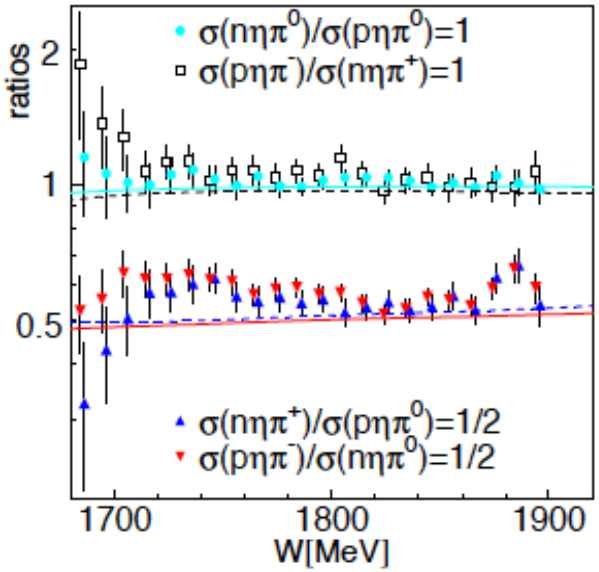
Isospin Decomposition of ηN

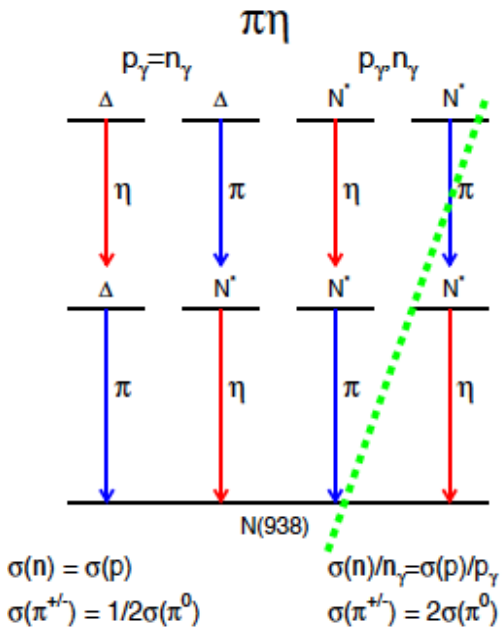
- Cross section ratios agree with γN-> Δ*-> ηΔ-> ηπN reaction chain
- Invariant mass and angular distributions very similar for protons and neutrons

Total Cross Sections



Cross Section Ratios





Käser *et al.*, Phys. Lett. B748 244 (2015)
Käser *et al.*, EPJ A **52** 272 (2016)

Conclusion

- Neutron database is sparse and the upcoming results will add to the database and help understand *N** properties
- Neutron measurements more difficult due to FSI and Fermi motion and require more time
- Channels investigated so far seem to have FSI effects less important for polarization observables than for cross sections
- Many results being prepared for publication
- For more A2 results, see Andreas Thomas' talk on Wednesday at 15:40 (Plenary III)