Effect of Sigma-beam Asymmetry data on the Neutron in fits to Single Pion Photoproduction

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- Pion Photoproduction
- Recent GRAAL $\gamma n \rightarrow \pi N$ data and Multipole fits
- Sum Rules
- FSI effect
- Summary and Prospects

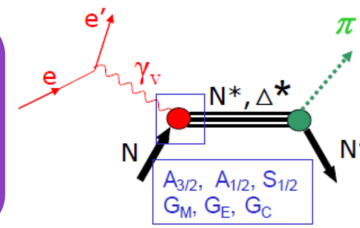
N* and Δ* States coupled to πN

[SAID: http://gwdac.phys.gwu.edu/]

- GW SAID N* program consists of $\pi N \rightarrow \pi N$ ⟹ $\gamma N \rightarrow \pi N$ ⟹ $\gamma^* N \rightarrow \pi N$

  As was established by Dick Arndt on 1997

- Assuming dominance of 2-hadronic channels [πN elastic & $\pi^- p \rightarrow \eta n$], we parameterize $\gamma^* N \rightarrow \pi N$ in terms of $\pi N \rightarrow \pi N$ amplitudes



- That is **One** of the most convincing ways to study **Spectroscopy** of N* & Δ* is πN PWA

- Non-strange objects in the PDG Listings come mainly from: Karlsruhe-Helsinki, Carnegie-Mellon-Berkeley, and GW/VPI
- The main source of EM couplings is the GW/VPI analysis

CNS
Center for Nuclear Studies
Data Analysis Center

Partial-Wave Analyses at GW
[See Instructions]
Pion-Nucleon
Pion-Pion-Nucleon
Kaon-Nucleon
Nucleon-Nucleon
Pion Photoproduction
Pion Electroproduction
Kaon Photoproduction
Eta Photoproduction
Eta-Prime Photoproduction
Pion-Deuteron (elastic)
Pion-Deuteron to Proton+Proton

Analyses From Other Sites
Mainz (MAID – Analyses)
Nijmegen (Nucleon-Nucleon OnLine)

Contact

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Single Pion Photoproduction

- Only with good data on both **proton** and **neutron** targets one can hope to disentangle the **isoscalar** and **isovector** EM couplings of the various **N^*** and **Δ^*** resonances,

  as well as the isospin properties of the non-resonant **background amplitudes**

- The lack of **$\gamma n \rightarrow \pi^- p$** and **$\pi^0 n$** data does not allow us to be as confident about the determination of **neutron** couplings relative to those of the **proton**

Where we Are now

- Some of the N* baryons [N(1675)5/2⁻, for instance] have stronger EM couplings to the **neutron** than to the **proton** but parameters are very uncertain

PDG10: N(1675)5/2⁻→pγ , helicity-1/2 ampl A1/2: +0.019±0.008
N(1675)5/2⁻→nγ , helicity-1/2 ampl A1/2: −0.043±0.012

N(1675)5/2⁻→pγ , helicity-3/2 ampl A3/2: +0.015±0.009
N(1675)5/2⁻→nγ , helicity-3/2 ampl A3/2: −0.058±0.013

- PDG estimate for the ***A1/2*** & ***A3/2*** decay amplitudes of the **N(1720)3/2+** state are consistent with zero, while the recent SAID determination gives small but non-vanishing values

	PDG10	SAID-SP09
N(1720)3/2⁺→pγ , helicity-1/2 ampl A1/2:	+0.018±0.030	+0.0905±0.0033
N(1720)3/2⁺→pγ , helicity-3/2 ampl A3/2:	−0.019±0.020	−0.0360±0.0039

- Other unresolved issues relate to the second P_{11}, **N(1710)1/2+**, that are not seen in the recent πN PWA, contrary to other PWAs used by the PDG10

Citation: K. Nakamura *et al.* (Particle Data Group), JPG **37**, 075021 (2010) (URL: http://pdg.lbl.gov)

$N(1710)\ P_{11}$ $I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$ Status: ***

Most of the results published before 1975 were last included in our 1982 edition, Physics Letters **111B** 1 (1982). Some further obsolete results published before 1984 were last included in our 2006 edition, Journal of Physics, G **33** 1 (2006).

The latest GWU analysis (ARNDT 06) finds no evidence for this resonance.

SAID for Pion Photoproduction

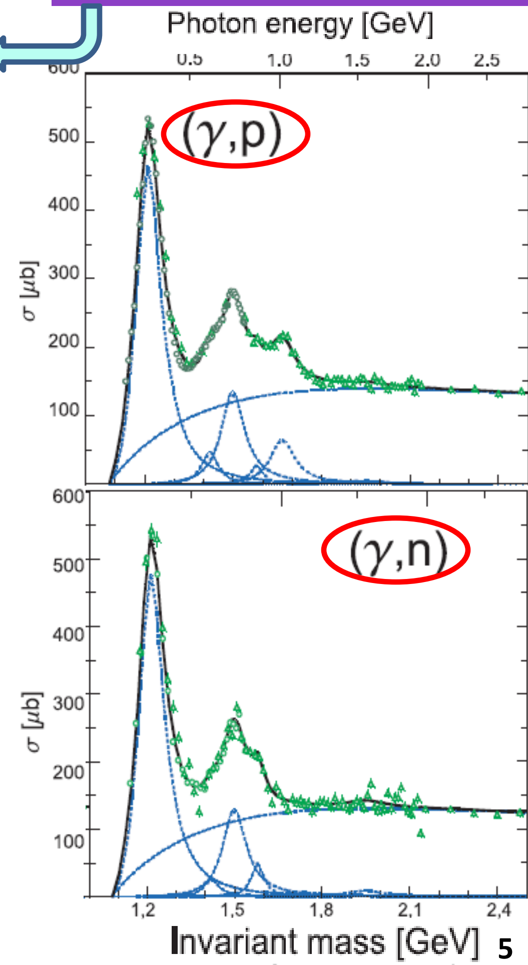
[M. Dugger *et al* Phys Rev C **79**, 065206 (2009) G. Mandaglio *et al* Phys Rev C **82**, 045209 (2010)]
[R. Arndt, W. Briscoe, IS, R. Workman, Phys Rev C **66**, 055213 (2002)]

- Energy dependent SP09/MA09 and associated SES
- E = 145 – 2700 MeV [W = 1080 – 2460 MeV]
- PWs = 60 [E & M multipoles] [J < 6]
- Prms = 210
- Constraint: $M = (\text{Born} + \alpha_R)(1 + iT_{\pi N}) + \alpha RT_{\pi N}$ + higher terms

Born: no free parameters to fit

πN PWA [no theoretical input]

Reaction	Data (Dpol)	χ^2
$\gamma p \to \pi^0 p$	14,052 (3 %)	30,949
$\gamma p \to \pi^+ n$	8,510 (5 %)	16,240
$\gamma n \to \pi^- p$	2,432 (0 %)	5,248
$\gamma n \to \pi^0 n$	364 (0 %)	1,021
Total	25,358	53,458



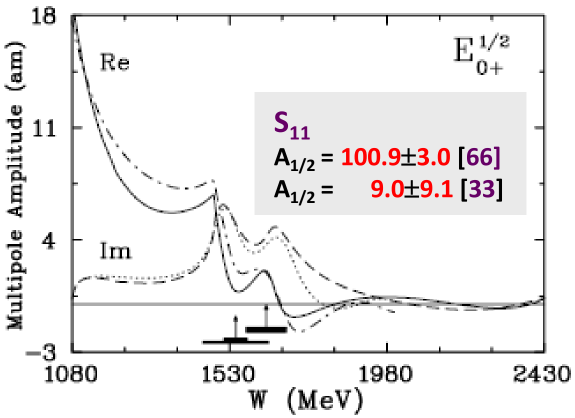
- **1st generation** - ('60–'90)
  10k data [85% bremsstrahlung data]
  30% data is polarized
  [limited coverage, broad energy binning]
- **2nd generation** ('90–'10) → SAID fits
  25k data [60% tagged data]
  30% data is polarized
  Dearth of neutron data
- **3rd generation** ('10+)
  New data will come from JLab, MAMI-C, Spring-8, CB-ELSA, MAX-lab, *etc*

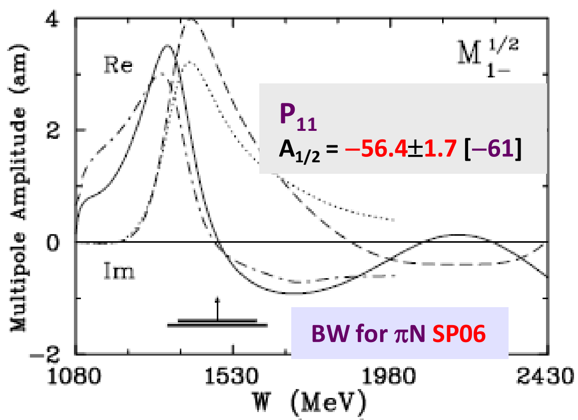
Much less known

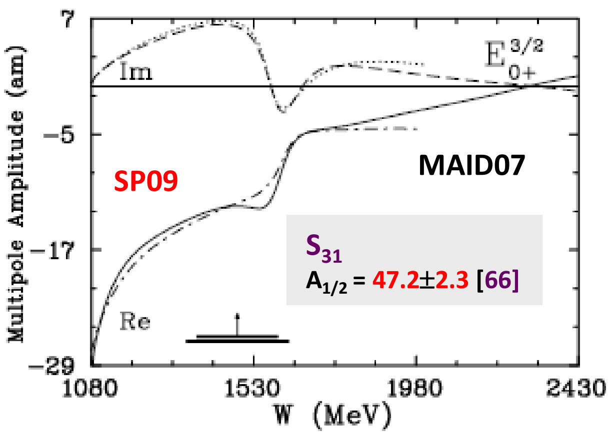
Proton Multipoles for SP09 [CLAS $\pi^0 p$ & $\pi^+ n$ data included]

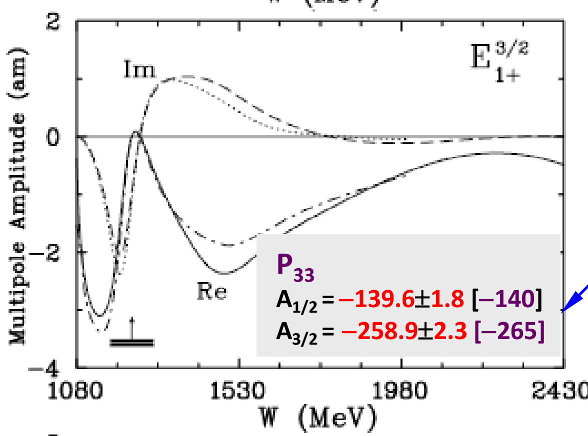
[M. Dugger *et al* Phys Rev C **79**, 065206 (2009)]

- **Overall**: the difference between **MAID07** and **SAID SP09** is rather small but… Resonances may be essentially different









- MAID **Ansatz** has been used to determine **EM** couplings

- Significant changes have occurred at **high energies**
- Comparisons to earlier **SAID** fits and fit from the **Mainz** group show that the new **SP09** solution is much more satisfactory at **higher energies**

- The **statistical significance** of any inconsistencies with the **MAID** analysis cannot be determined, as no uncertainties for **photon helicity amplitudes** estimation have been presented

- MAID07 does not include recent **CLAS** $\pi^0 p$ & $\pi^+ n$ and **LEPS** $\pi^0 p$ data

MAID07: D. Drechsel *et al* Eur Phys J A 34, 69 (2007)

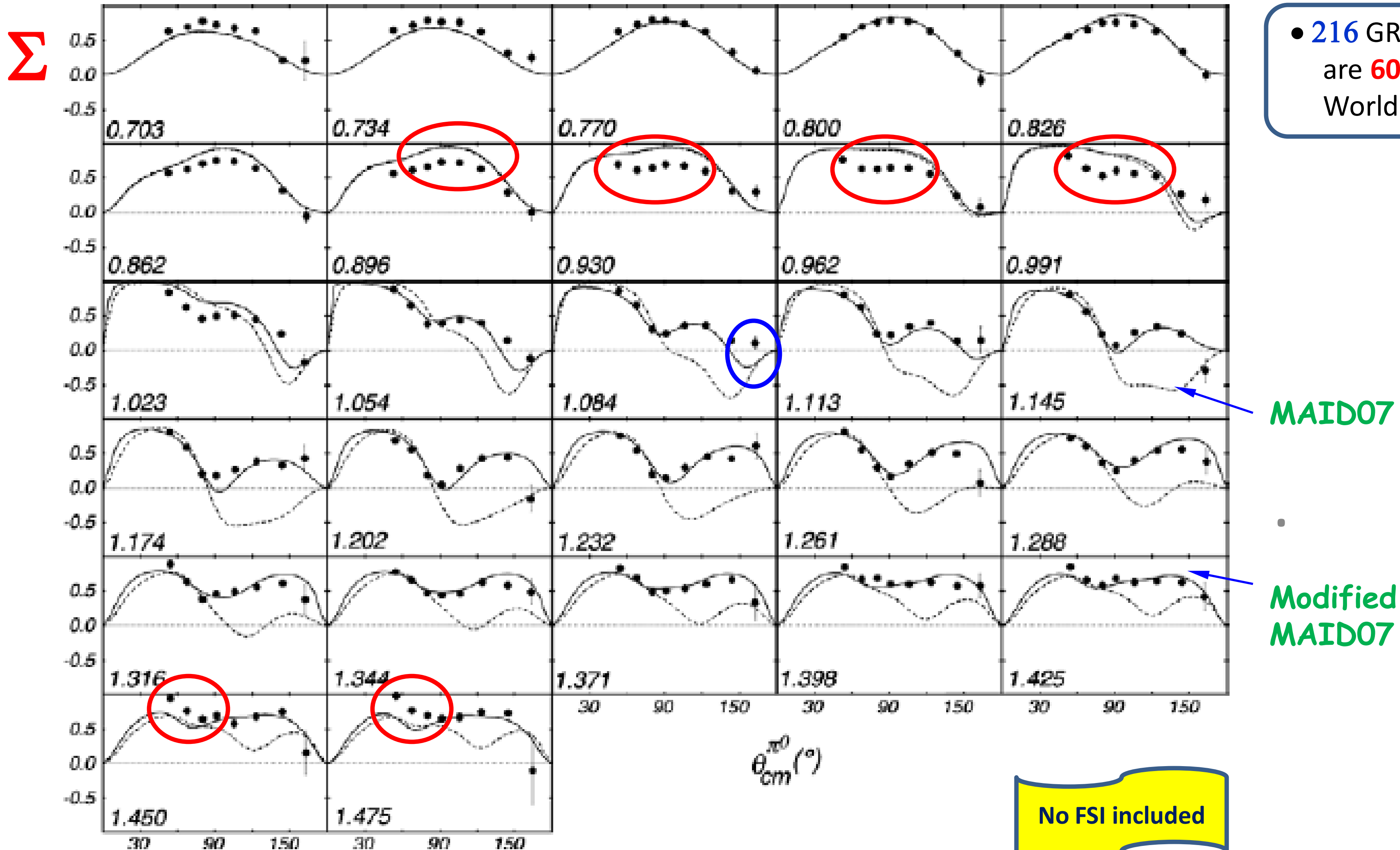
GRAAL Σ Measurements

- First tagged measurements of the $\vec{\gamma}n \rightarrow \pi^0 n$ & $\pi^- p$ reactions by the GRAAL Collaboration

Reac	Nexp	Ndta	Emn (MeV)	Emx (MeV)	Θmn (deg)	Θmx (deg)
$\pi^0 n$	27	216	703	1475	53	164
$\pi^- p$	11	99	753	1439	33	163

New GRAAL Σ for $\vec{\gamma}n \to \pi^0 n$ vs. MAID07

[R. Di Salvo et al Eur J Phys A **42**, 151 (2009)]



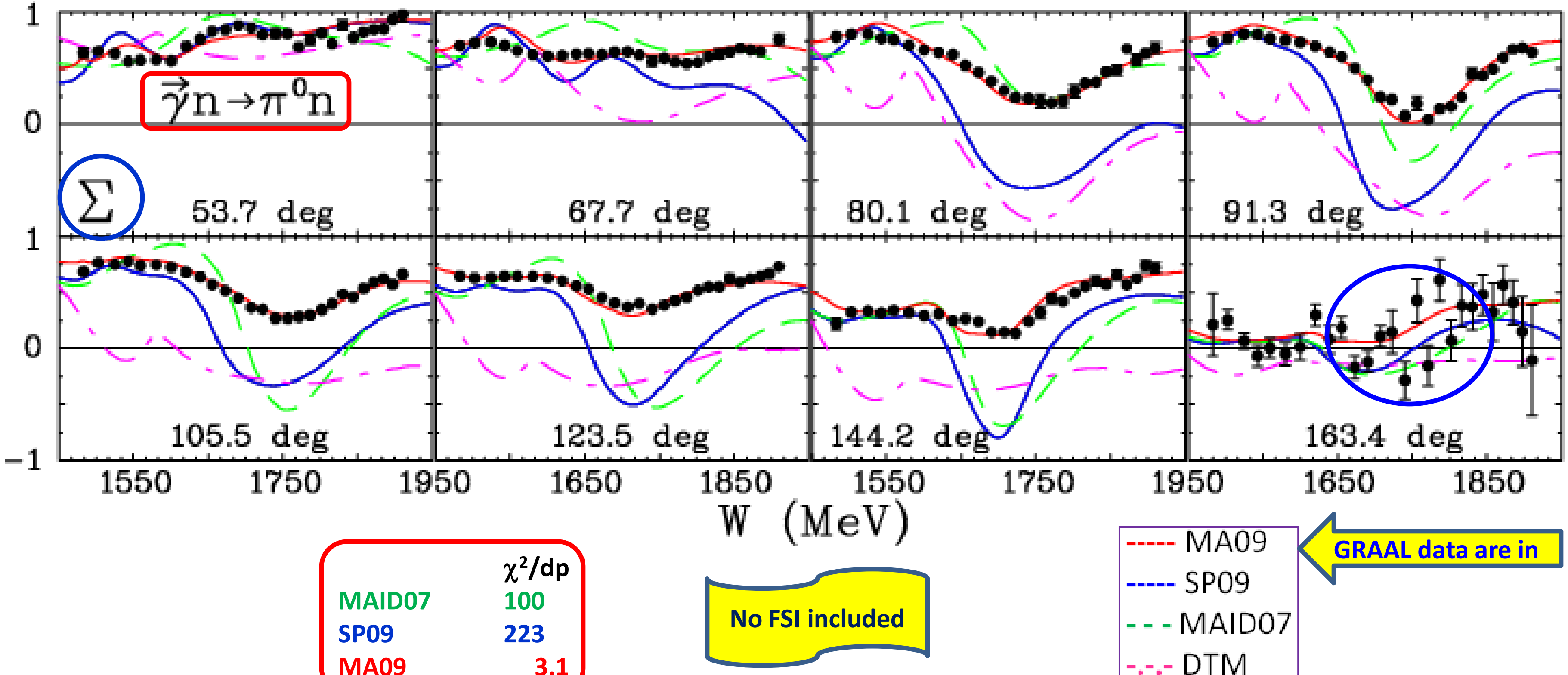
- 216 GRAAL Σs are 60% of the World $\pi^0 n$ data

New GRAAL Σ for $\vec{\gamma}n \rightarrow \pi^0 n$

[R. Di Salvo *et al* Eur Phys J A **42**, 151 (2009)]

- The difference between previous Pion Prod and new **GRAAL** measurements may result in significant changes in the **neutron** couplings

- 216 GRAAL Σs are **60**% of the World π^0**n** data



	χ^2/dp
MAID07	100
SP09	223
MA09	3.1

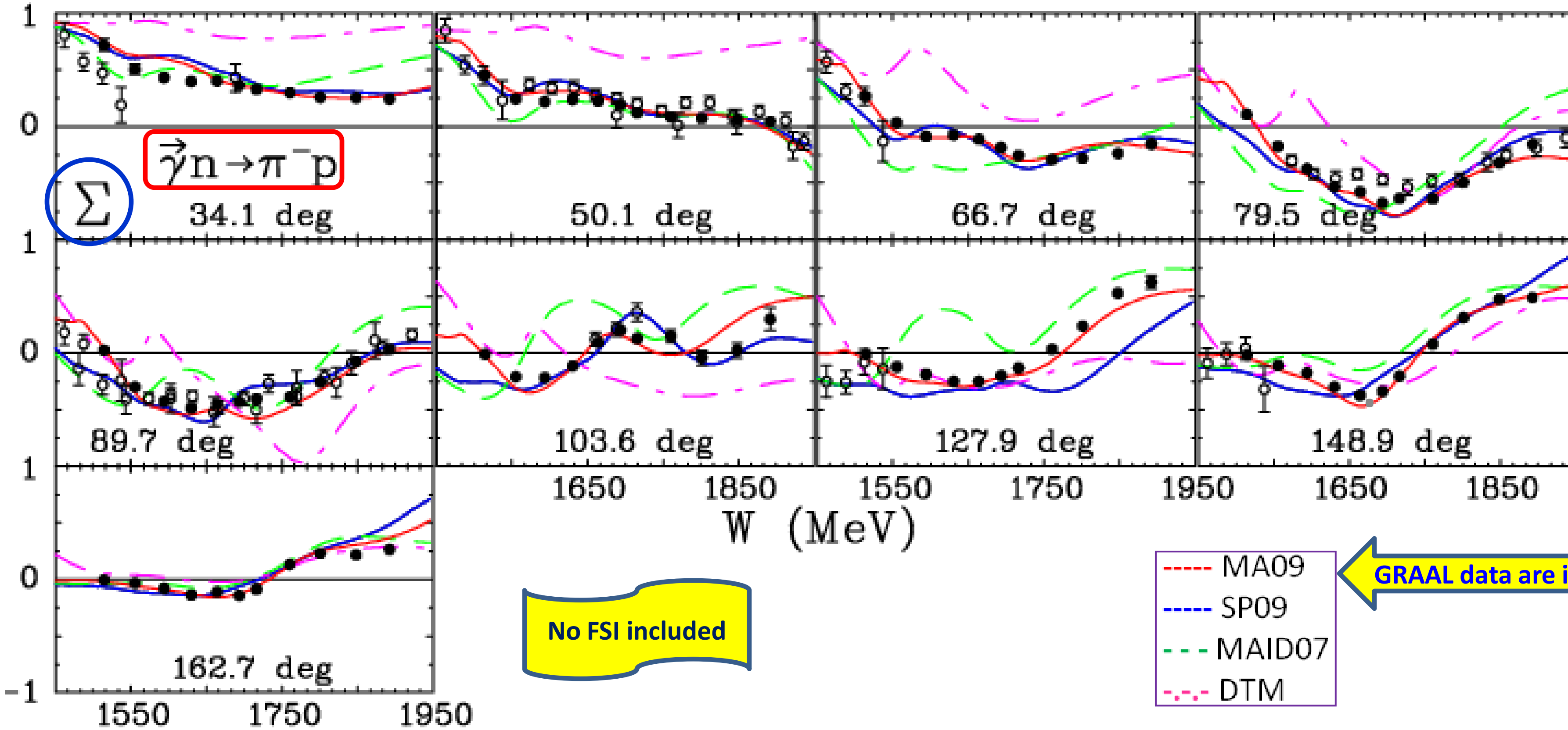
No FSI included

New GRAAL Σ for $\vec{\gamma}n \to \pi^- p$

[G. Mandaglio *et al* Phys Rev C **82**, 045209 (2010)]

- Previous $\gamma n \to \pi^- n$ measurements provided a better constraint vs $\gamma n \to \pi^0 n$ case

	χ^2/dp
MAID07	27
SP09	89
MA09	4.9



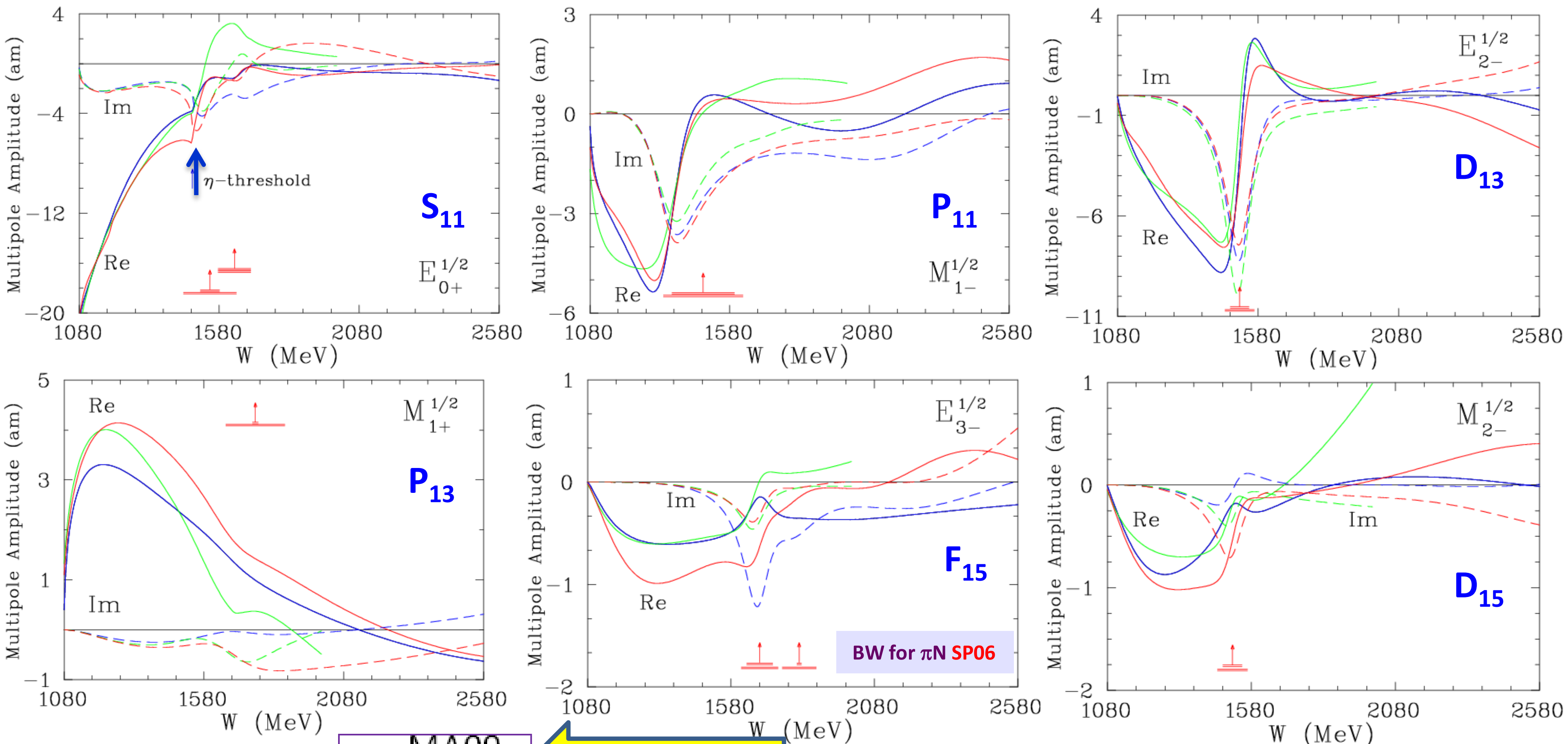
GRAAL data are in

No FSI included

Neutron Multipoles for MA09 [GRAAL $\pi^0 n$ & $\pi^- p$ data included]

[G. Mandaglio *et al* Phys Rev C **82**, 045209 (2010)]

- **Overall**: the difference between MAID07 and SAID MA09 is rather small but… Resonances may be essentially different

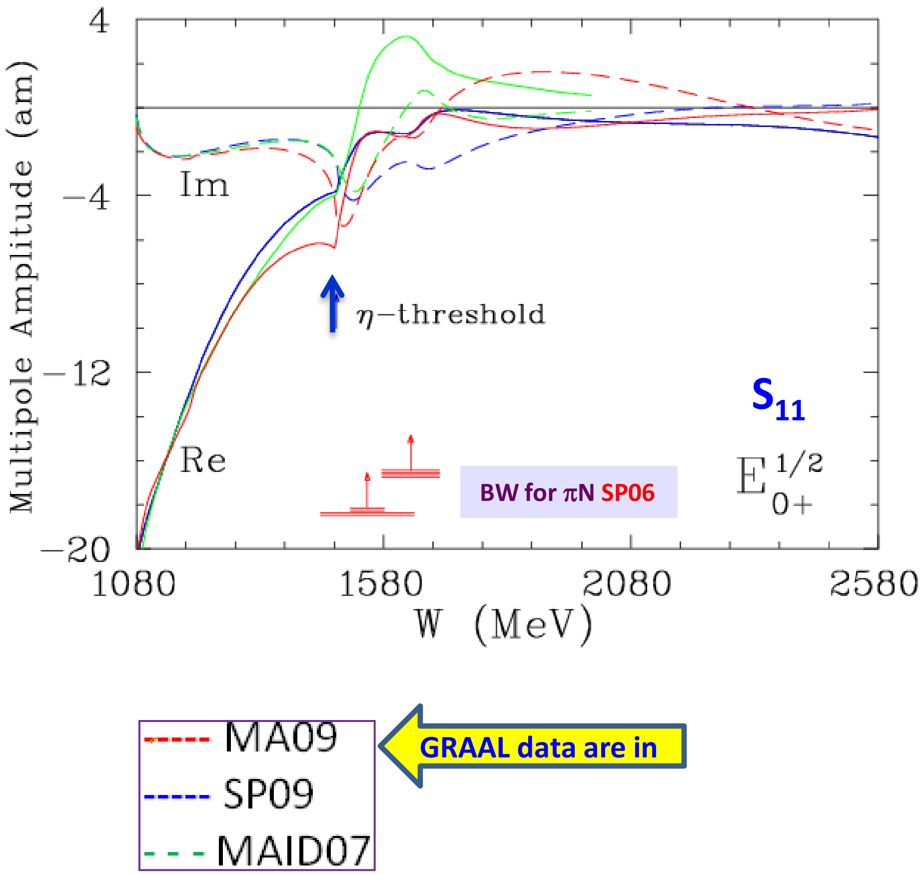


MA09
SP09
MAID07

GRAAL data are in

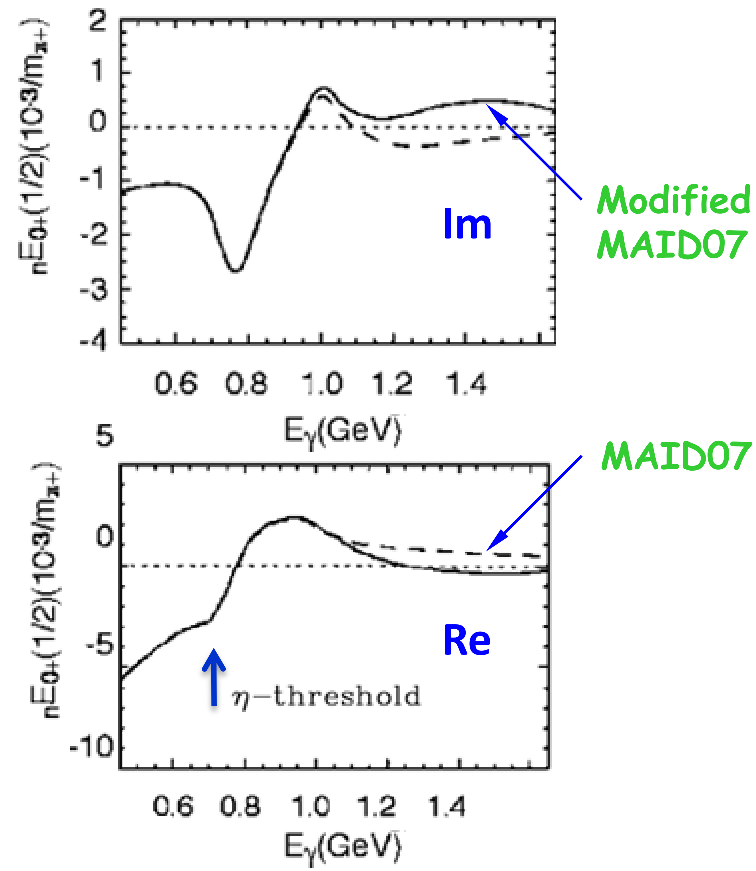
E_{0+} Neutron Multipole

[G. Mandaglio *et al* Phys Rev C **82**, 045209 (2010)]



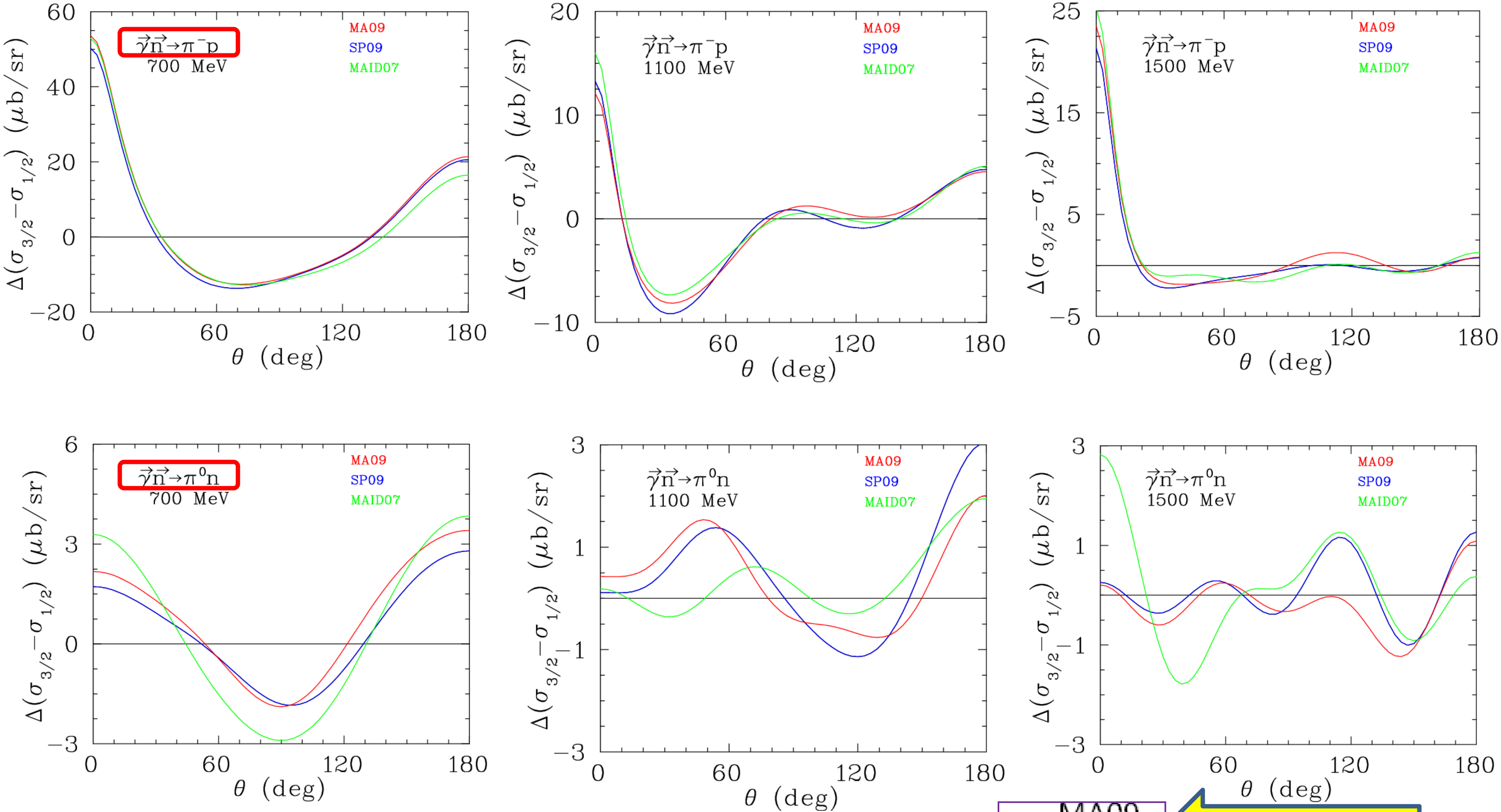
GRAAL data are in

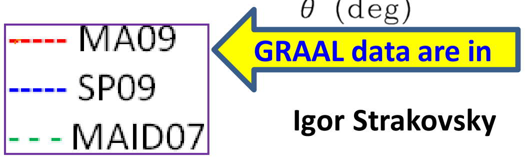
[R. Di Salvo *et al* Eur Phys J A **42**, 151 (2009)]



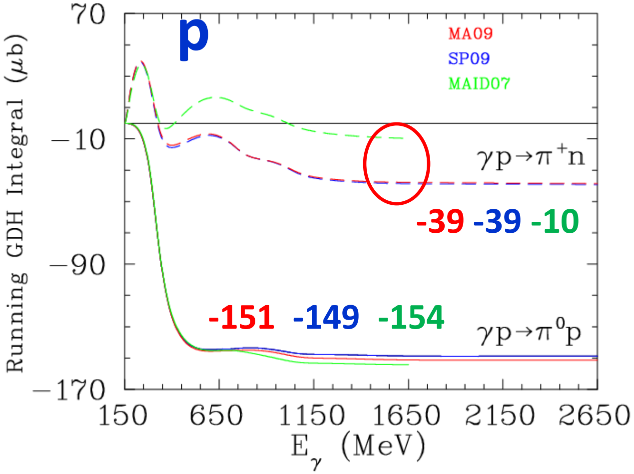
η−cusp is more pronounced for **MA09**

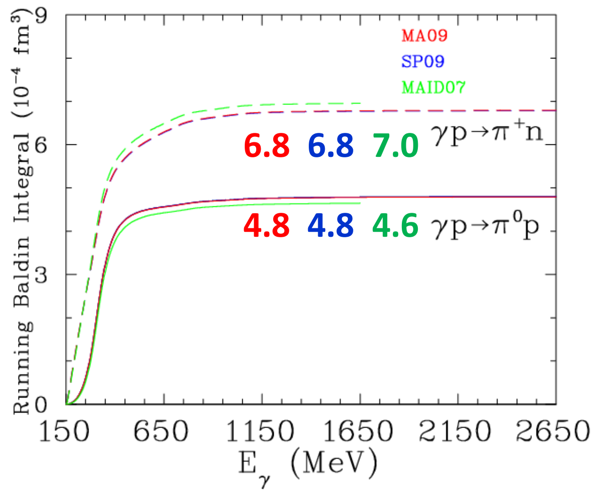
Helicity-Dependent Photoabsorption Cross Sections on the Neutron above the Δ–Isobar

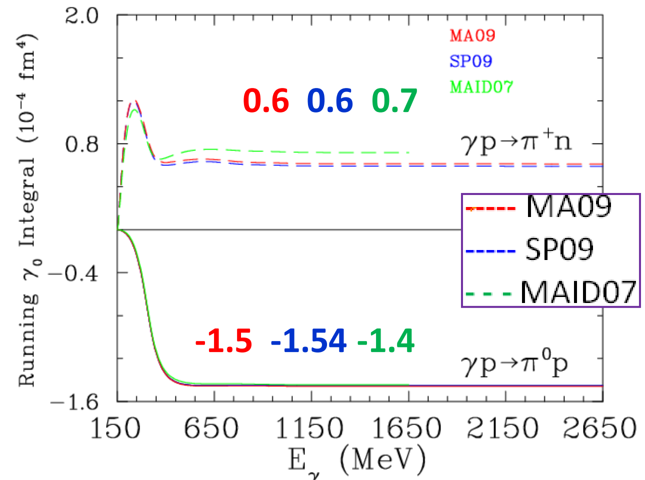




Sum Rules for γN→πN - Revisited



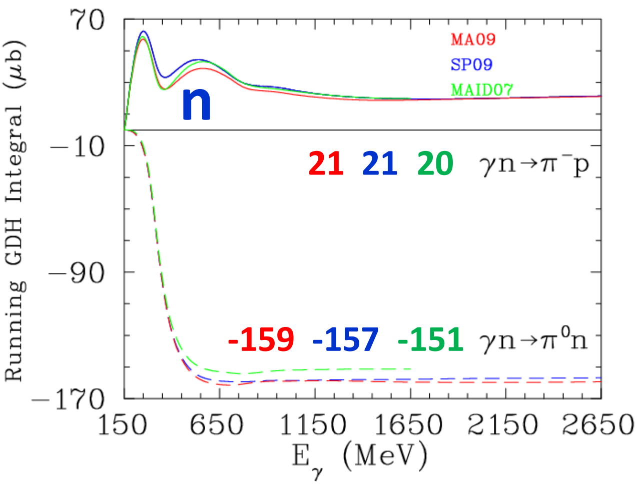


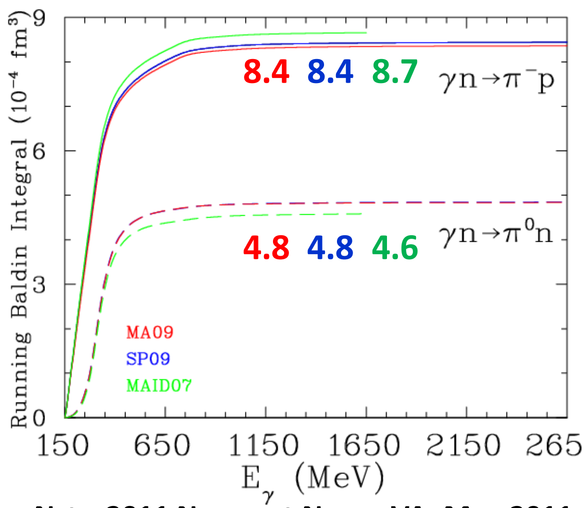


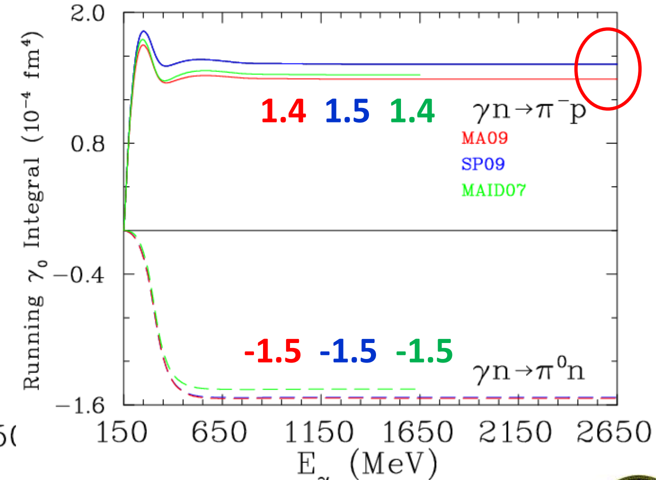
$$I_{GDH}=\int_{\nu_0}^{\infty}\frac{\sigma_{1/2}-\sigma_{3/2}}{\nu}d\nu=-\frac{\pi e^2}{2M^2}\kappa^2$$

$$I_{Baldin}=\frac{1}{2\pi^2}\int_{\nu_0}^{\infty}\frac{\sigma_{tot}}{\nu^2}d\nu=\frac{1}{2\pi^2}\int_{\nu_0}^{\infty}\frac{\sigma_{1/2}+\sigma_{3/2}}{2\nu^2}d\nu$$

$$\gamma_0=\frac{1}{4\pi^2}\int_{\nu_0}^{\infty}\frac{\sigma_{1/2}-\sigma_{3/2}}{\nu^3}d\nu$$



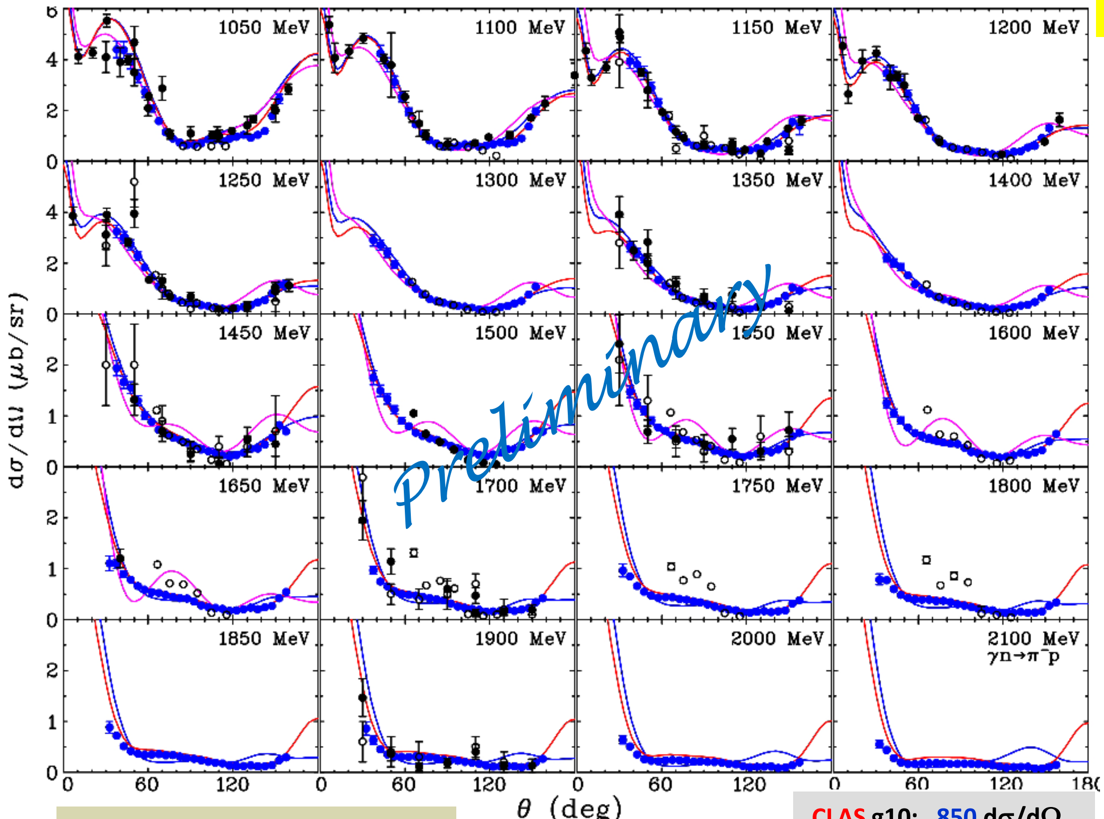




CLAS for $\gamma n \rightarrow \pi^- p$

[g10: W. Chen *et al* Phys Rev Lett **103**, 012301 (2009) g13: P. Mattione *et al* in progress]

- **Complementary measurements of π^- Photo Production, required for an isospin decomposition of the multipoles**

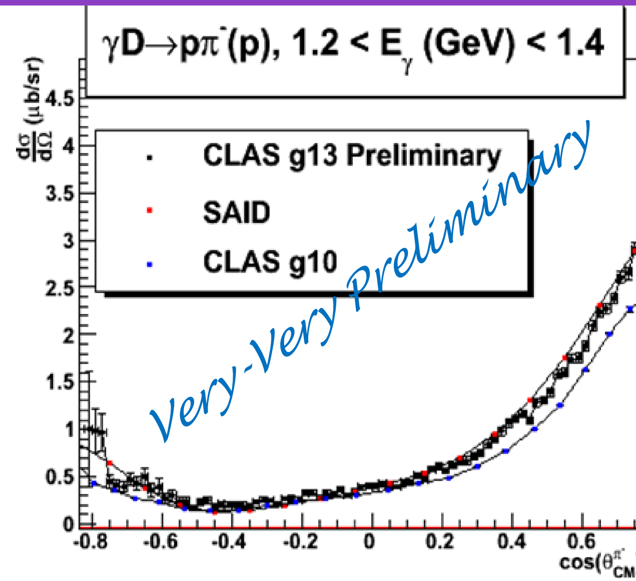


PWA/Model:
- ____ FA07 [No CLAS π^-]
- ____ MAID07 [No CLAS π^-]
- ____ WE09 [CLAS π^- is in]

CLAS g10: 850 dσ/dΩ
E_γ = 1050–3500 MeV
θ = 37– 152 deg
Stat = 3 %
Syst = 7 %

- **Principal π^- experiments were done at Meson Factories: LAMPF, PSI, & TRIUMF**

[Courtesy of Paul Mattione, CLAS Meeting 2010]



- **No FSI included in both CLAS g10 & g13 [2% of statistics] data**

- **G13 vs g10:**
  - broad angular coverage
  - smaller errs
  - smaller energy binning

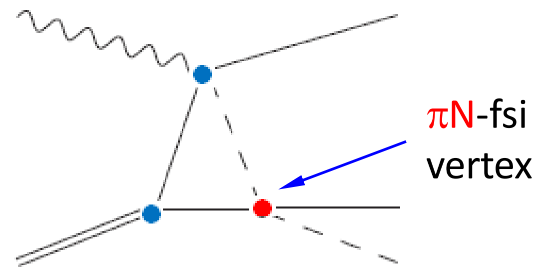
FSI for $\gamma n \to \pi^- p$

[V. Tarasov, A. Kudryavtsev, W. Briscoe, H. Gao, IS, arXiv: 1105.0225]

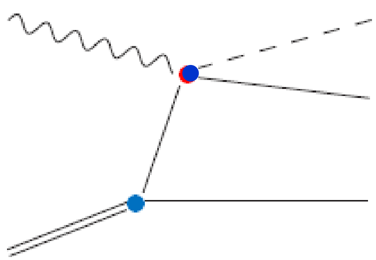
- FSI plays a critical role in the state-of-the-art analysis
- Prlm: 5% – 60% It depends on E and θ

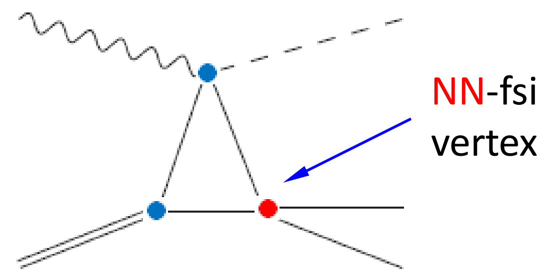
Input: SAID $\gamma N \to \pi N$, πN, NN amplitudes for 3 leading terms

DWF: CD-Bonn



IA





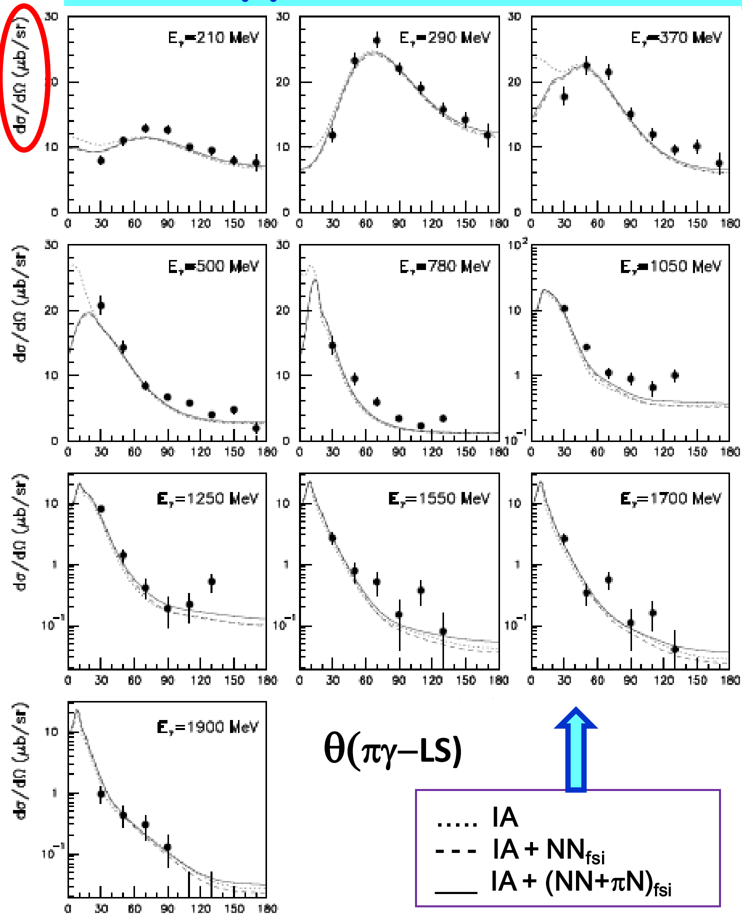
Fermi motion included

$$R_{FSI} = (d\sigma/d\Omega_{\pi p})/(d\sigma^{IA}/d\Omega_{\pi p})$$

FSI & $\gamma d \to \pi^- pp$ ⟶ $\gamma n \to \pi^- p$

[V. Tarasov, A. Kudryavtsev, W. Briscoe, H. Gao, IS, arXiv: 1105.0225]

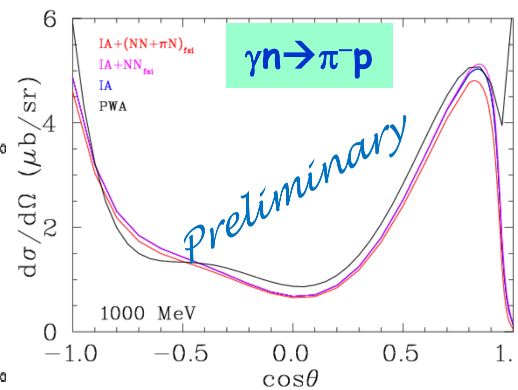
$\gamma d \to \pi^- pp$ – No fit to the data



θ(πγ–LS)

..... IA
\- - - IA + NN_{fsi}
___ IA + $(NN+\pi N)_{fsi}$

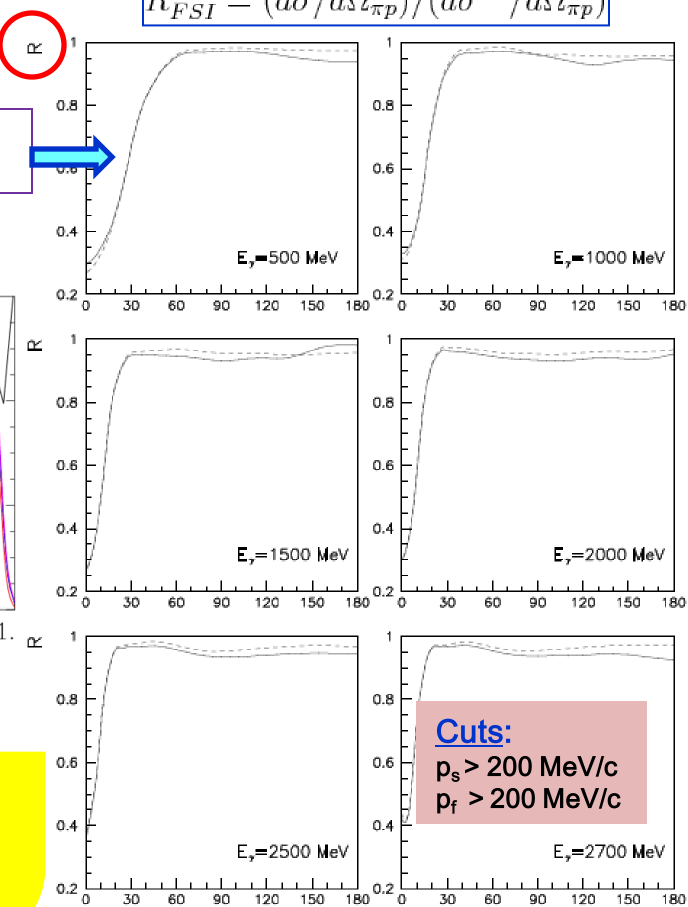
DESY [Bubble Chamber data]:
P. Benz *ea* Nucl Phys **B65**, 158 (1973)



$\gamma n \to \pi^- p$

$R_{FSI} = (d\sigma/d\Omega_{\pi p})/(d\sigma^{IA}/d\Omega_{\pi p})$

\- - - $[IA + NN_{fsi}]$ / IA
___ $[IA + (NN+\pi N)_{fsi}]$ / IA



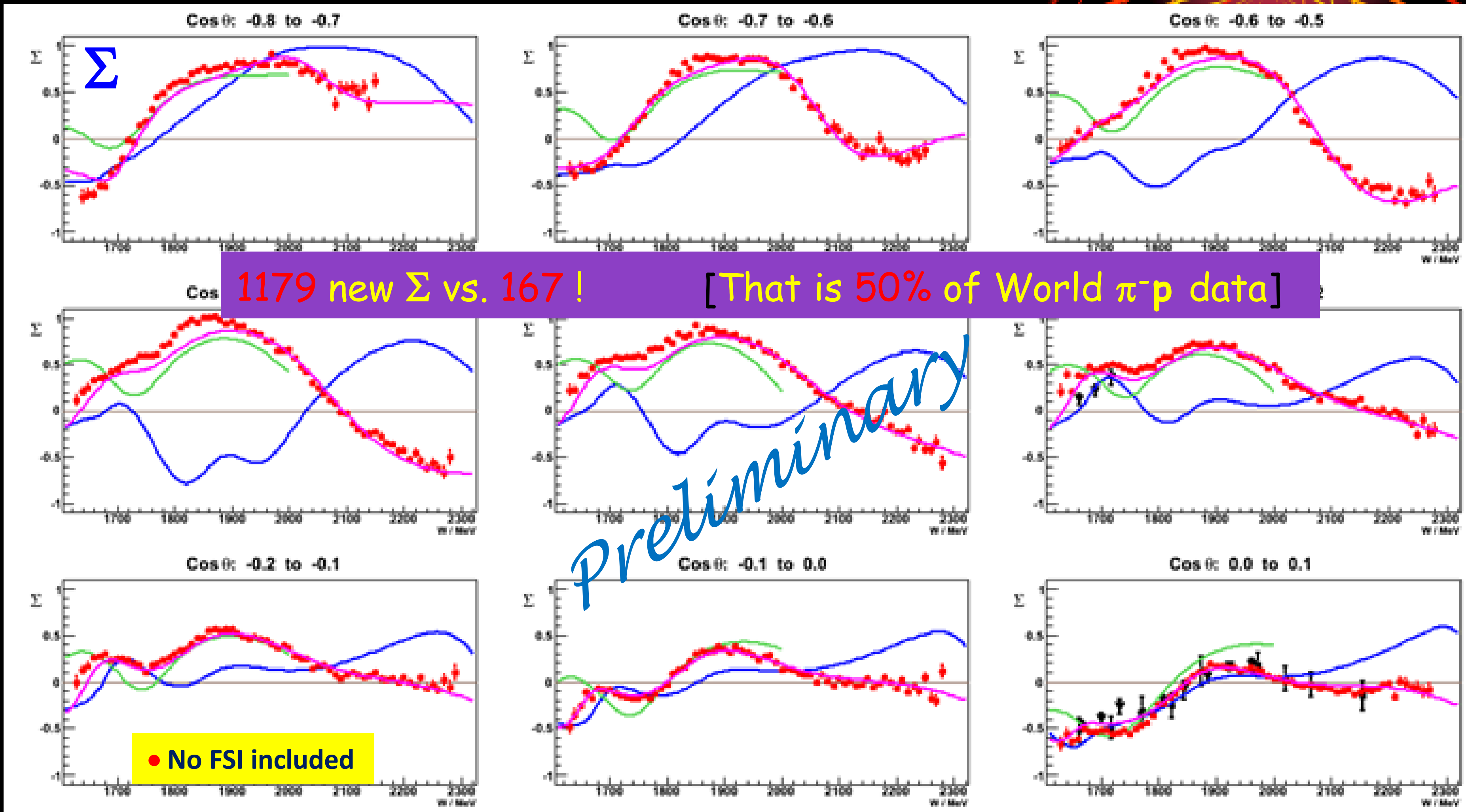
Cuts:
p_s > 200 MeV/c
p_f > 200 MeV/c

θ(πp–CM)

There is a sizeable FSI effect R < 1 from S- wave part of pp-FSI at small angles
This region narrows as the E_γ increases

Preliminary Σ Measurement I

Backward $\vec{\gamma} n \to \pi^- p$

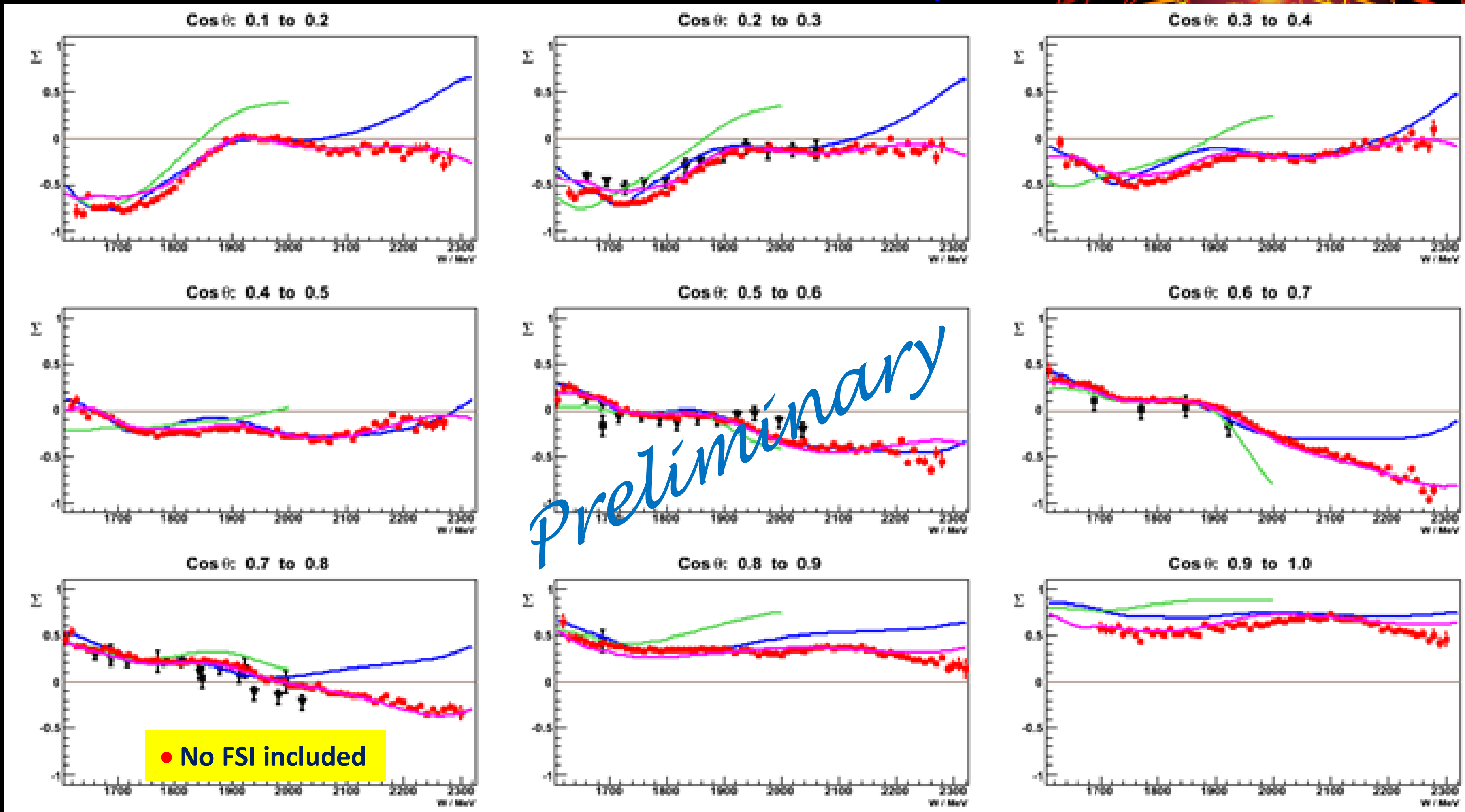


SAID 09 MAID 07

χ^2 from new SAID PWA fit: 2.6

Preliminary Σ Measurement II

Forward $\vec{\gamma}n \rightarrow \pi^- p$



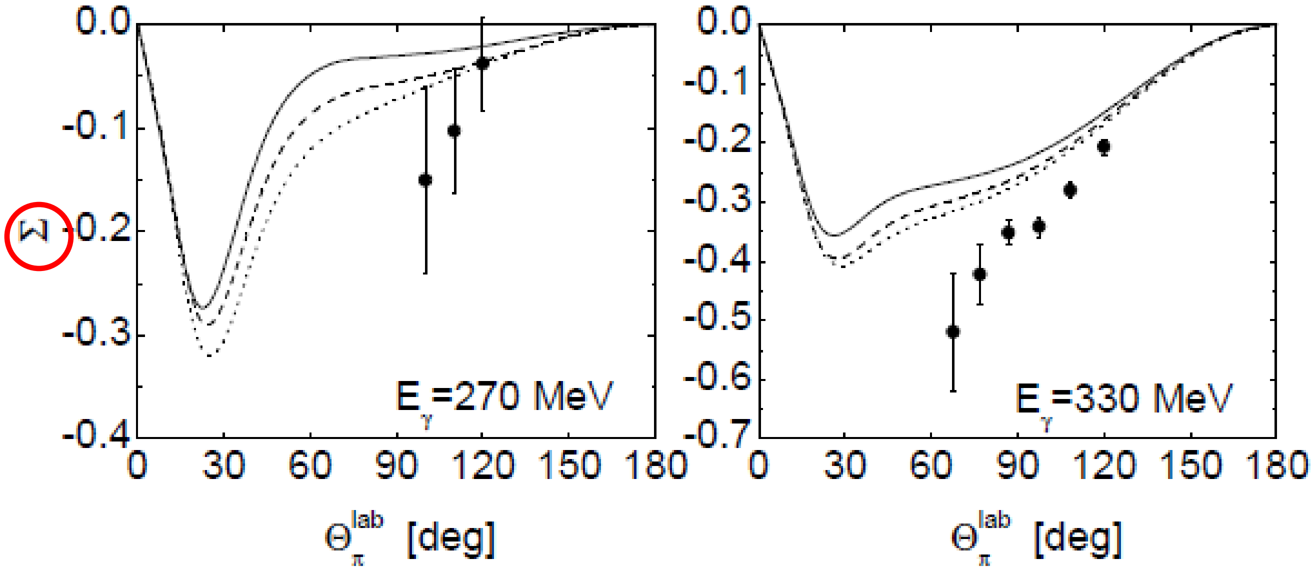
SAID 09

MAID 07

χ^2 from new SAID PWA fit: 2.6

FSI for Polarized Measurements

- There were several attempts to estimate FSI for $\vec{\gamma}d \rightarrow \pi^- pp$



FSI: M. Levchuk *ea* Phys Rev C **74**, 014004 (2006)
Data: prlm by LEGS Collab at BNL

- There are no estimations below and above the Δ-region
- The effect from **FSI** is small and at the lowest energy has a noticeable impact on Σ

Summary and Prospects

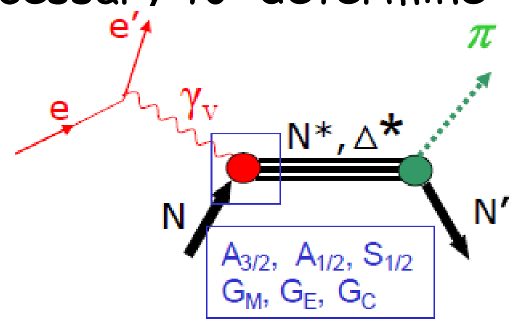
- There is a significant impact of the recent GRALL Σ $\vec{\gamma}n \to \pi^0 n$ data for neutron multipoles

- Photo Prod measurements on the 'neutron' target are necessary to determine neutron couplings at $Q^2 = 0$ GeV^2

- JLab FROST & HD-ICE, CB@MAMI-C, LEPS, CB-ELSA, & MAX-lab data could yield surprises

- Complete experiment would make possible a direct reconstruction of helicity amplitudes for Pseudo-Scalar meson Photo Prod

- Neutron Electro Prod measurements are necessary to determine neutron couplings at $Q^2 > 0$ GeV^2



Thank You

Coming π and η Photo Prod Data on Nucleon

On Proton:

Mike Dugger, ASU:	– CLAS g8b:	Σ for $\gamma p \to \pi^+ n, \pi^0 p$
Patrick Collins, ACU:	– CLAS g8b:	Σ for $\gamma p \to \eta p$
Hideko Iwamoto & Bill Briscoe, GW:	– CLAS g9a:	E for $\gamma p \to \pi^0 p$
Steffen Strauch, USC:	– CLAS g9a:	E for $\gamma p \to \pi^+ n$
Brian Vernarsky & Mike Dugger, ASU:	– CLAS g9a:	E & G for $\gamma p \to \eta p$
Jo McAndrew & Dan Watts, EU:	– CLAS g9a:	G for $\gamma p \to \pi^+ n, \pi^0 p$
Wei Chen & Haiyan Gao, Duke U:	– CLAS g12:	$d\sigma/d\Omega$ for $\gamma p \to \pi^+ n$
Arthur Sabintsev & Bill Briscoe, GW:	– CLAS g9b:	T, H, F, & P for $\gamma p \to \pi^+ n$
Steffen Strauch, USC:	– CLAS g9b:	T, H, F, & P for $\gamma p \to \pi^0 p$
Reinhard Beck, Bonn U:	– CB-ELSA:	Σ, E, G, & T for $\gamma p \to \pi^0 p, \eta p$
Wei Luo & Charles Perdrisat, W&M	– Hall C:	C_x, C_z & P for $\gamma p \to \pi^0 p$
Derek Glazier & Dan Watts, EU:	– MAMI-C :	P & C_x for $\gamma p \to \pi^0 p, \eta p$
Viktor Kashevarov , INP:	– CB@MAMI-C:	F & T for $\gamma p \to \pi^0 p, \eta p$
Kevin Fissum, Lund U/GW:	– MAX-lab:	σ-tot for $\gamma p \to \pi^+ n$
Andy Sandorfi, JLab:	– LEGS:	E & G for $\gamma p \to \pi^0 p, \pi^+ n$
David Hornidge, MTA & Sergey Prakhov, UCLA:	– CB@MAMI-C:	$d\sigma/d\Omega$ & Σ for $\gamma p \to \pi^0 p$

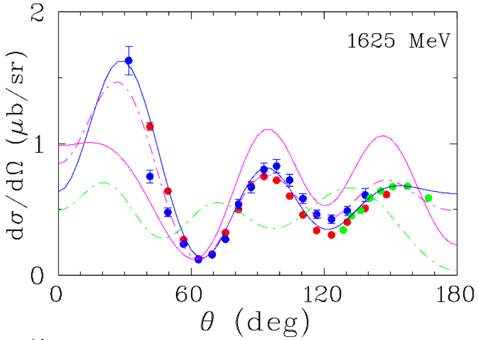
On Neutron:

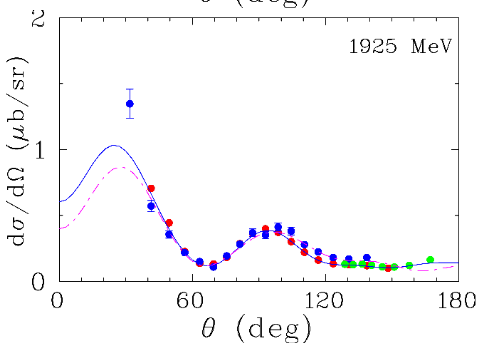
Wei Chen & Haiyan Gao, Duke U:	– CLAS g10:	$d\sigma/d\Omega$ for $\gamma n \to \pi^- p$
Daria Sokhan & Dan Watts, EU:	– CLAS g13:	Σ for $\gamma n \to \pi^- p$
Paul Mattione & Dan Carman, JLab:	– CLAS g13:	$d\sigma/d\Omega$ for $\gamma n \to \pi^- p$
Andy Sandorfi, JLab & Franz Klein, ACU:	– CLAS g14:	E for $\gamma n \to \pi^- p$
Berhan Demissie & Bill Briscoe, GW:	– CB@MAMI-C:	$d\sigma/d\Omega$ for $\gamma n \to \pi^0 n$
Berndt Krusche, Basel U:	– CB@MAMI-C:	$d\sigma/d\Omega$ & Σ for $\gamma n \to \eta n$
Berndt Krusche, Basel U:	– CB-ELSA:	E for $\gamma n \to \eta n$
Kevin Fissum, Lund U/GW & Bill Briscoe, GW:	– MAX-lab:	$d\sigma/d\Omega$ for $\gamma n \to \pi^- p, \pi^0 n$
Hajime Shimizu, Tahoku U:	– LNS:	$d\sigma/d\Omega$ for $\gamma n \to \eta n$
Andy Sandorfi, JLab:	– LEGS:	E & G for $\gamma n \to \pi^- p, \pi^0 n$

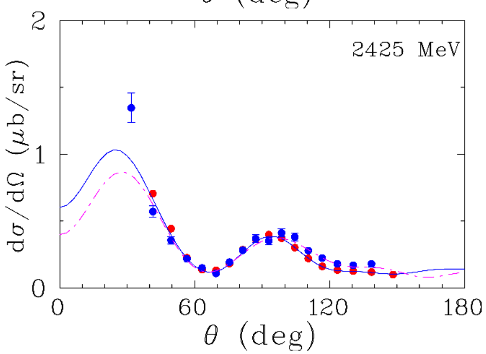
FSI is critical to determine Neutron Multipoles

Forward Cross-Sections for π^0 Photo Prod

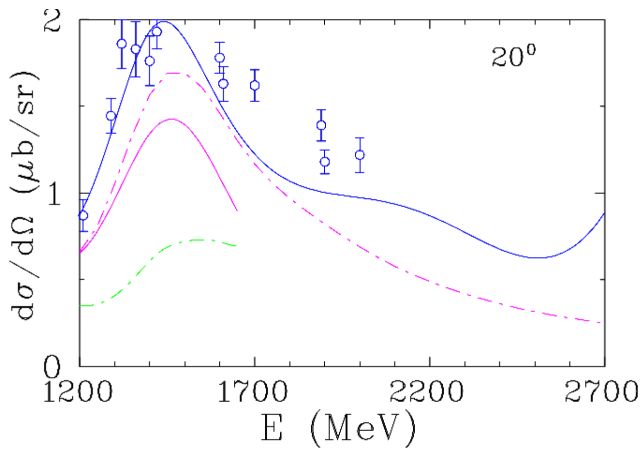
[M. Dugger *et al* Phys Rev C **76**, 025211 (2007)]







- Forward [< **40** deg in CM] measurements above E = **1200** MeV are **5%** of the world data, they are Brem, and 30 years old
- No Forward measurements above E = **2100** MeV



Data:		Syst
● CLAS g1c	[2007]	[5 %]
● CB-ELSA	[2005]	[15 %]
● LEPS	[2007]	[10 %]
o Brem before 1977		

PWA/Model:

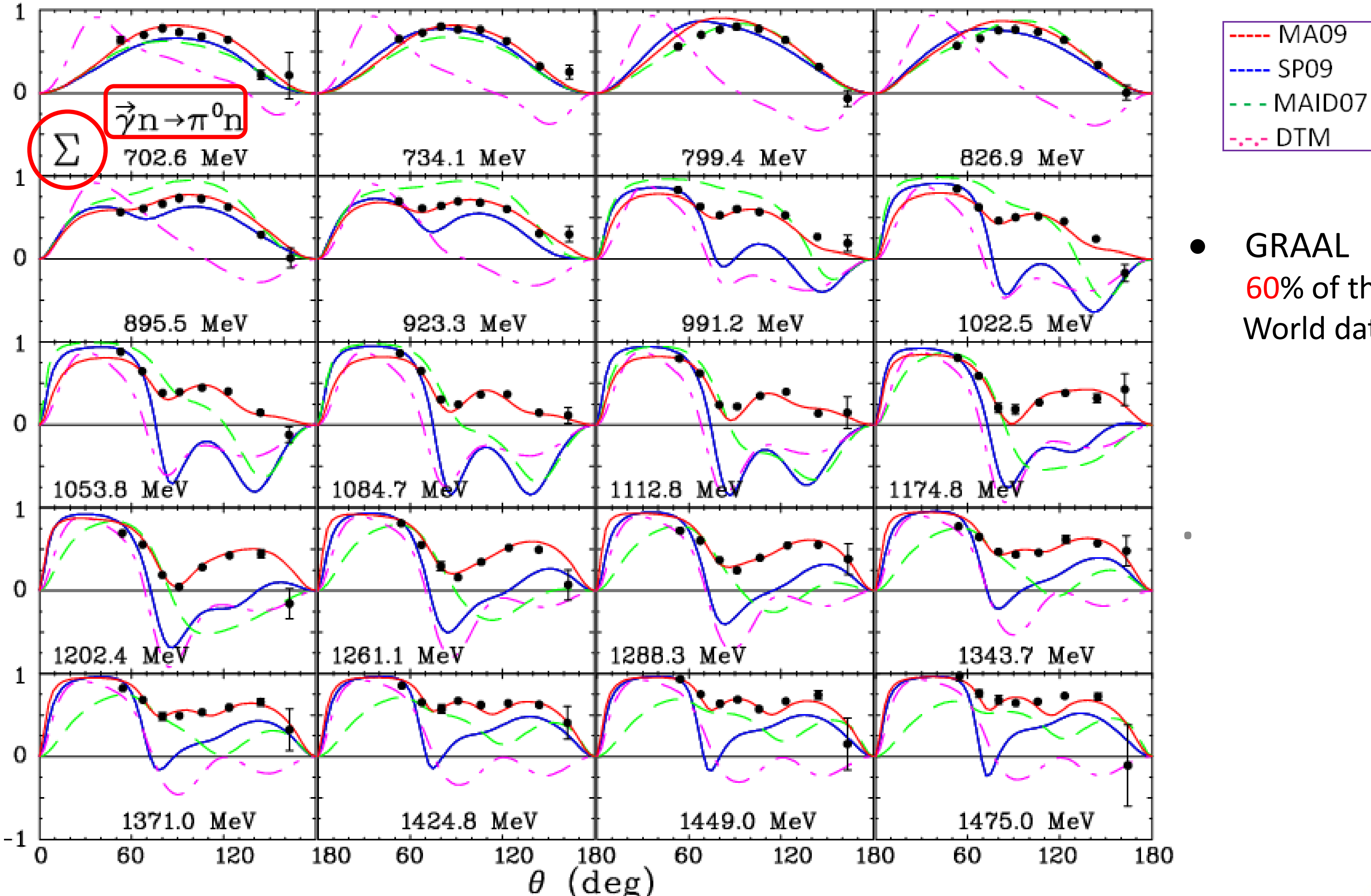
——	FA07		
——	MAID07	[No CLAS+LEPS data in]	[L. Tiator, Fall 2007]
– · –	Gießen	[No CLAS+LEPS data in]	[V. Shklyar, July 2006]
– · –	BoGa	[No CLAS+LEPS data in]	[A. Sarantsev, Sept 2005]

[No MAID07 & Gießen above 1650 MeV]

- There is a disagreement at forward angles
  - CLAS vs CB-ELSA
  - SAID vs MAID

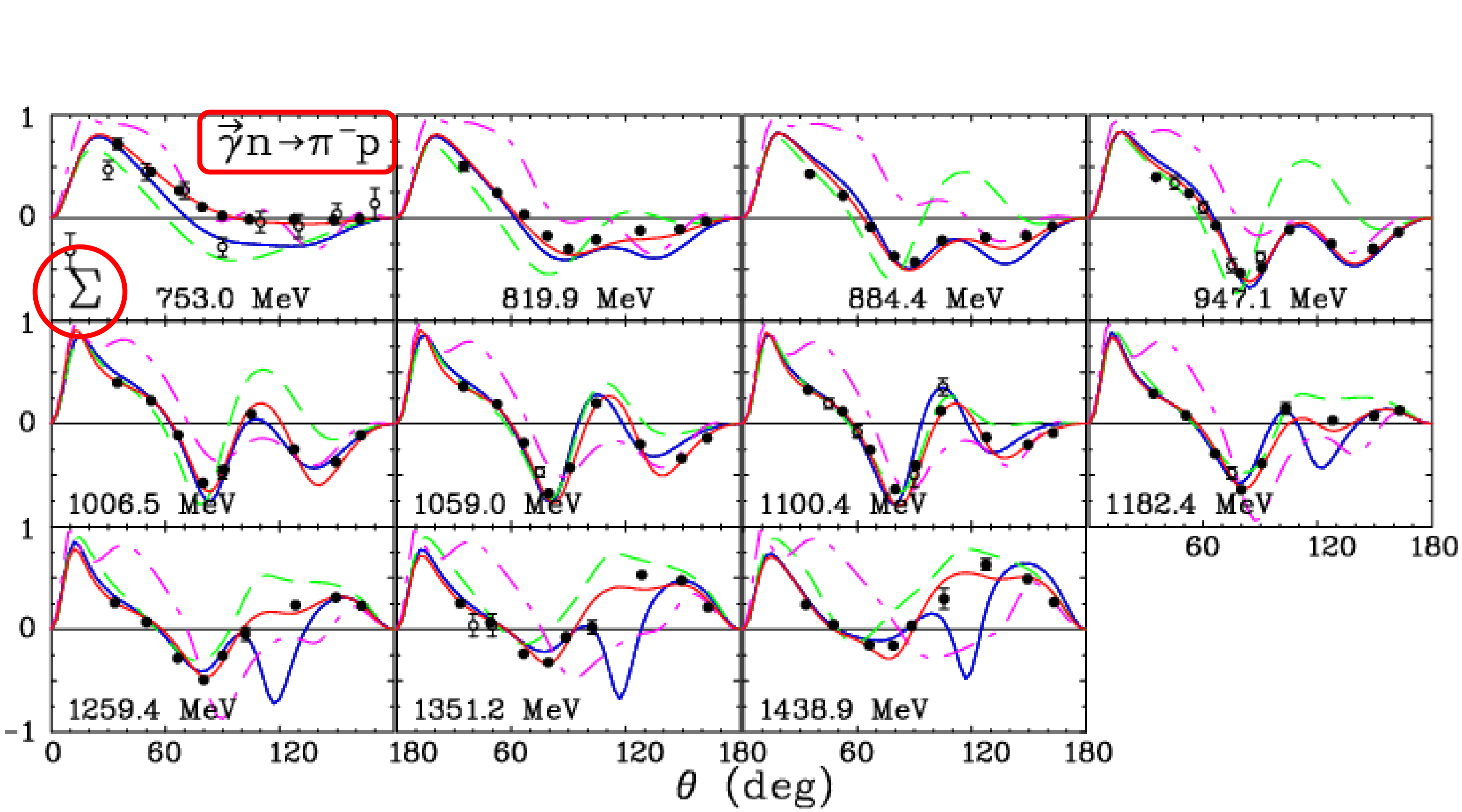
- Forward data are sensitive to highest **N*** [most of them are inelastic]

New GRAAL Σ for $\vec{\gamma}n \rightarrow \pi^0 n$



- GRAAL 60% of the World data

New GRAAL Σ for $\vec{\gamma} n \rightarrow \pi^- p$



- ● GRAAL 11% of World data
- o old

PDG10 for the N* Neutron Couplings

[K. Nakamura *et al* [RPP] J Phys G **37**, 075021 (2010)]

This work studies the region from η-threshold, where there are **two** closely spaced states: N(1520)3/2⁻ and N(1535)1/2⁻, up to CM energies of W = 1940 MeV, encompassing a sequence of **five** overlapping states: N(1650)1/2⁻, N(1675)5/2⁻, N(1680)5/2⁺, N(1700)3/2⁻, and N(1720)3/2⁺

N(1440)P11:

A1/2= +40±10 PDG10 ESTIMATE

+45±15	ARNDT-96
+37±10	AWAJI-81
+30± 3	FUJII-81

N(1520)D13:

A1/2= –59± 9 PDG10 ESTIMATE

–48± 8	ARNDT-96
–66±13	AWAJI-81
–67± 4	FUJII-81

A3/2= –139±11 PDG10 ESTIMATE

–140±10	ARNDT-96
–124± 9	AWAJI-81
–158± 3	FUJII-81

N(1535)S11:

A1/2= –46±27 PDG10 ESTIMATE

–80±20	ANISOVICH-09A
–20±35	ARNDT-96
+35±14	AWAJI-81
–62± 3	FUJII-81

N(1650)S11:

A1/2= –15±21 PDG10 ESTIMATE

–55±20	ANISOVICH-09A
–15± 5	ARNDT-96
–8± 4	AWAJI-81
	FUJII-81

			SAID	MAID	
		PDG	GW02	2003	2007
$P_{11}(1440)$	$A_{1/2}$	40±10	47±5	52	54
$D_{13}(1520)$	$A_{1/2}$	-59 ±9	-67 ±4	-85	-77
	$A_{3/2}$	-139 ±11	-112 ±3	-148	-154
$S_{11}(1535)$	$A_{1/2}$	-46±27	-16±5	-42	-51
$S_{11}(1650)$	$A_{1/2}$	-15±21	-28±4	27	9
$D_{15}(1675)$	$A_{1/2}$	-43 ±12	-50 ±4	-61	-62
	$A_{3/2}$	-58 ±13	-71 ±5	-74	-84
$F_{15}(1680)$	$A_{1/2}$	29 ±10	29 ±6	25	28
	$A_{3/2}$	-33 ±9	-58 ±9	-35	-38
$P_{13}(1720)$	$A_{1/2}$	1 ±15		17	3
	$A_{3/2}$	-29 ±61		-75	-31

[**GW02:** R. Arndt *et al* Phys Rev C **66**, 055213 (2002)]

[**MAID07:** D. Drechsel *et al* Eur Phys J A **34**, 69 (2007)]

For modified MAID07: –23

R. Di Salvo et al Eur J Phys A **42**, 151 (2009)]

N(1675)D15:

A1/2= –43±12 PDG10 ESTIMATE

–49±10	ARNDT-96
–57±24	AWAJI-81
–33± 4	FUJII-81

A3/2= –58±13 PDG10 ESTIMATE

–51±10	ARNDT-96
–77±18	AWAJI-81
–69± 4	FUJII-81

N(1680)F15:

A1/2= +29±10 PDG10 ESTIMATE

+30± 5	ARNDT-96
+17±14	AWAJI-81
+32± 3	FUJII-81

A3/2= –33± 9 PDG10 ESTIMATE

–40±15	ARNDT-96
–33±13	AWAJI-81
–23± 5	FUJII-81

N(1720)P13:

A1/2= +1±15 PDG10 ESTIMATE

+7±15	ARNDT-96
+2± 5	AWAJI-81

A3/2= –29±61 PDG10 ESTIMATE

–5±25	ARNDT-96
–15±19	AWAJI-81