

The George Washington University  
Data Analysis Center  
An Experimentalist's Point of View

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Researchers

**Task 1**

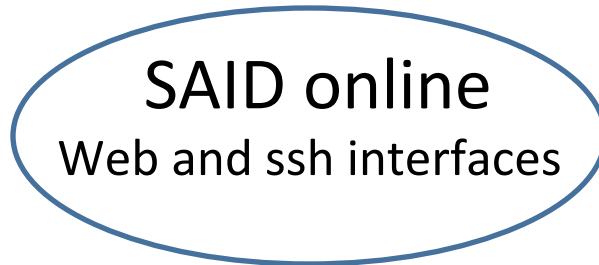
**Task 2**



SAID: <http://gwdac.phys.gwu.edu/>



Help Plan Experiments  
Predict Results  
Monte Carlo Simulation



Amplitudes  
from GW and  
other groups

$\pi N$  elastic  
NN elastic  
KN elastic  
 $\pi N, \eta N$  photoproduction  
electroproduction  
...etc.

Compare fits and data  
graphical user interface



CNS DAC Home  
▶ **CNS DAC [SAID]**  
CNS Home  
TUTORIALS

#### Partial-Wave Analyses at GW

[ See Instructions ]

Pion-Nucleon  
Pi-Pi-N (under construction)  
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)  
Bonn-Gatchina (PWA)

#### Contact

William J. Briscoe  
Diane Schott  
Igor I. Strakovsky  
Ron L. Workman

## CNS DAC Services [SAID Program]

- The SAID Partial-Wave Analysis Facility is based at GWU.
- New features are being added and will first appear at this site. Suggestions for improvements are always welcome.

### Instructions for Using the Partial-Wave Analyses

The programs accessible with the left-hand side navigation bar allow the user to access a number of features available through the SAID program. Contact a member of our group if you are unfamiliar with the SSH version. If you enter choices which are unphysical, you may still get an answer (in accordance with the 'garbage in, garbage out' rule). Please report unexpected garbage-out to the management.

**Note:** These programs use HTML forms to run the SAID code. If unfamiliar with the options, run the default setup first. The output is an (edited) echo of an interactive session which would have resulted had you used the SSH version. If the default example fails to clarify the specific task you have in mind, we can help ([just send an e-mail message](#)).

All programs expect energies in MeV units. All of the solutions and potentials have limited ranges of validity. Some are unstable beyond their upper energy limits. Extrapolated results may not make much sense.

**Increments:** The programs will not allow an arbitrary number of points to be generated. As a rule, stay below 100.

### ACKNOWLEDGMENTS

The **CNS Data Analysis Center** is partially funded by the U.S. Department of Energy, and the Research Enhancement Funds of The George Washington University, with strong support from the GW Northern Virginia Campus.

#### Today per Hour »



#### Visitors per Day »



#### Visitors per Week »



#### Visitors per Month »



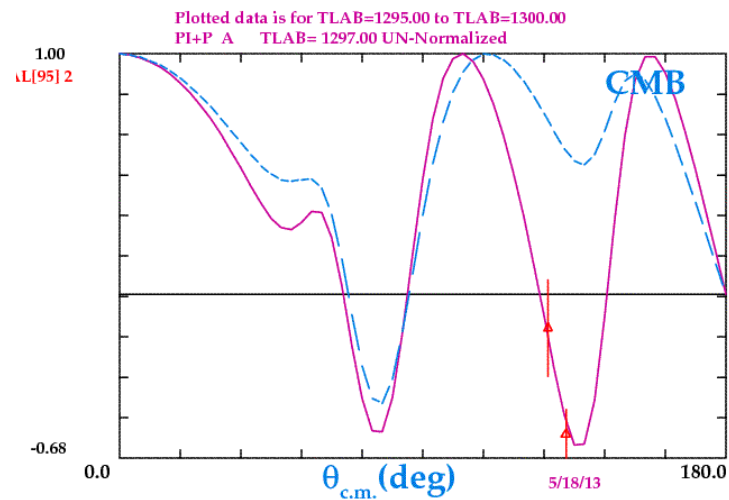
# Task 1

- Partial-wave analysis of fundamental medium-energy reactions
- SAID web/ssh site
  - evolving database for medium-energy reactions
  - current fits to data
  - graphical user interface for comparing fits/data sets



CNS DAC Home  
▶ Pion Nucleon  
CNS Home  
SAID Start

Analysis Options  
Data Base  
Observables  
Partial Wave Amplitudes  
Compare Different Analyses  
Compare Fits to Data  
3-D Pole Structures































Example: Compare CMB to GW for  $\pi N$

## PWA impact

- phase-shifts, partial-wave amplitudes used in **multi-channel fits**
- used in determinations of **N\*** masses, widths, pole parameters
- used in Monte Carlo simulations
- used in experimental design
- low-energy **np** result used as a standard for nuclear reactor design and other applications
- GW NN and  $\pi$ N amplitudes used as input for GW/ITEP **FSI** calculations  
→ extraction of neutron target data for pion photoproduction program

## GW PWA facility utilization

Country				
1.	 United States	7,930	38.27%	
2.	 Germany	3,988	19.25%	
3.	 Japan	1,494	7.21%	
4.	 Russian Federation	804	3.88%	
5.	 United Kingdom	618	2.98%	
6.	 Italy	481	2.32%	
7.	 China	444	2.14%	
8.	 France	438	2.11%	
9.	 Spain	359	1.73%	
10.	 Senegal	269	1.30%	
11.	 India	253	1.22%	
12.	 Sweden	229	1.11%	
13.	 Canada	223	1.08%	
14.	 Switzerland	222	1.07%	

## Current PWA projects:

### Collaborators

- Fits to recent **pion photoproduction** data:
  - $\Sigma$  data from CLAS → Arizona State
  - **FSI** for neutron data and EM couplings → ITEP (Moscow)
  - $d\sigma/d\Omega$ ,  $\Sigma$ , **F**, **T**, and **Cx** data from MAMI → Mainz (Germany)
- Comparison of **BW** vs **pole** photo-decay amplitudes extracted from photoproduction data → Mainz, Bonn
- Extraction of **pole** parameters from various sets of amplitudes using novel expansion schemes → Mainz, Zagreb, Tuzla
- Effects of baryon contamination on **meson** spectroscopy → JLab PWA group
- New fit to recent precise EPECUR  $\pi N$  cross section data → ITEP, PNPI

# CLAS Data Impact for Neutron $N^*$ Couplings

[W. Chen, *et al*, Phys Rev C **86**, 015206 (2012)]

Resonance	$\pi N$ SAID	$A_{1/2}$	$A_{3/2}$
$N(1535)1/2^-$ $S_{11}$ -63	$W_R=1547$ MeV	$-58\pm 6$	
	$\Gamma=188$ MeV	$-60\pm 3$	
	$\Gamma_\pi/\Gamma=0.36$	$-46\pm 27$	
		$-93\pm 11$	
$N(1650)1/2^-$ $S_{11}$ -35	$W_R=1635$ MeV	$-40\pm 10$	
	$\Gamma=115$ MeV	$-26\pm 8$	
	$\Gamma_\pi/\Gamma=1.00$	$-15\pm 21$	
		$25\pm 20$	
$N(1440)1/2^+$ $P_{11}$ -6	$W_R=1485$ MeV	$48\pm 4$	
	$\Gamma=284$ MeV	$45\pm 15$	
	$\Gamma_\pi/\Gamma=0.79$	$40\pm 10$	
		$43\pm 12$	
$N(1520)3/2^-$ $D_{13}$ -38 -114	$W_R=1515$ MeV	$-46\pm 6$	$-115\pm 5$
	$\Gamma=104$ MeV	$-47\pm 2$	$-125\pm 2$
	$\Gamma_\pi/\Gamma=0.63$	$-59\pm 9$	$-139\pm 11$
		$-49\pm 8$	$-113\pm 12$
$N(1675)5/2^-$ $D_{15}$ -35 -51	$W_R=1674$ MeV	$-58\pm 2$	$-80\pm 5$
	$\Gamma=147$ MeV	$-42\pm 2$	$-60\pm 2$
	$\Gamma_\pi/\Gamma=0.39$	$-43\pm 12$	$-58\pm 13$
		$-60\pm 7$	$-88\pm 10$
$N(1680)5/2^+$ $F_{15}$ 19 -23	$W_R=1680$ MeV	$26\pm 4$	$-29\pm 2$
	$\Gamma=128$ MeV	$50\pm 4$	$-47\pm 2$
	$\Gamma_\pi/\Gamma=0.70$	$29\pm 10$	$-33\pm 9$
		$34\pm 6$	$44\pm 9$

S. Capstick, Phys Rev D **46**, 2864 (1992).

**GB12**  
**SN11**  
  
**BnGa13**

• **BnGa13** and **SAID GB12** use similar datasets in fit.

- New (**GB12**)  $A_{1/2}$  &  $A_{3/2}$  couplings show some significant deviations from our previous SAID determination (**SN11**) and **PDG12** average values, e.g., for  $N(1650)1/2^-$ ,  $N(1675)5/2^-$ , and  $N(1680)5/2^+$ .
- Recent **BnGa13** finds some different sign vs. **GB12**, **PDG12**, and the **relativized quark model**, e.g., for  $N(1650)1/2^-$  and  $N(1680)5/2^+$ .

**BnGa13**: A. Anisovich *et al*, arXiv:1304.2177

## Notable Changes in 2012 PDG Edition

Ron Workman

- Notation  $L_{2l, 2J}$  changed to  $N, \Delta J^P$   
[ $S_{11} \rightarrow N 1/2^-$ ,  $P_{33} \rightarrow \Delta 3/2^+$ , *etc.*]
- Overall status from photo-production added.
- Name-mass mismatch addressed (partially)  
[*e.g.*  $N(2000)5/2^+$  with 'mass' 1860 MeV]
- Some new states added – mainly from the Bonn-Gatchina fits.
- Pole parameters more prominent  
[photo-decay, inelastic residues]

Expanded Baryons@PDG activities/larger group  
to be centered at JLab.



## PDG-related Projects

Relations between real **PDG** Breit-Wigner photo-decay amplitudes and complex pole values were studied.

[ R.Workman , L. Tiator , A. Sarantsev ]

### **$N(1520)$ PHOTON DECAY AMPLITUDES**

Papers on  $\gamma N$  amplitudes predating 1981 may be found in our 2006 edition, Journal of Physics, G, **33** 1 (2006).

#### **$N(1520) \rightarrow p\gamma$ , helicity-1/2 amplitude $A_{1/2}$**

VALUE ( $\text{GeV}^{-1/2}$ )	DOCUMENT ID	TECN	COMMENT
<b><math>-0.024 \pm 0.009</math> OUR ESTIMATE</b>			
$-0.022 \pm 0.004$	ANISOVICH 12A	DPWA	Multichannel
$-0.028 \pm 0.002$	DUGGER 07	DPWA	$\gamma N \rightarrow \pi N$
$-0.038 \pm 0.003$	AHRENS 02	DPWA	$\gamma N \rightarrow \pi N$
$-0.020 \pm 0.007$	ARNDT 96	IPWA	$\gamma N \rightarrow \pi N$
$-0.028 \pm 0.014$	CRAWFORD 83	IPWA	$\gamma N \rightarrow \pi N$
$-0.007 \pm 0.004$	AWAJI 81	DPWA	$\gamma N \rightarrow \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •			
$-0.032 \pm 0.006$	ANISOVICH 10	DPWA	Multichannel
$-0.027$	DRECHSEL 07	DPWA	$\gamma N \rightarrow \pi N$
$-0.003$	PENNER 02D	DPWA	Multichannel
$-0.052 \pm 0.010 \pm 0.007$	<sup>6</sup> MUKHOPAD... 98		$\gamma p \rightarrow \eta p$
$-0.020 \pm 0.002$	LI 93	IPWA	$\gamma N \rightarrow \pi N$
$-0.012$	WADA 84	DPWA	Compton scattering

#### **$N(1520) \rightarrow p\gamma$ , helicity-3/2 amplitude $A_{3/2}$**

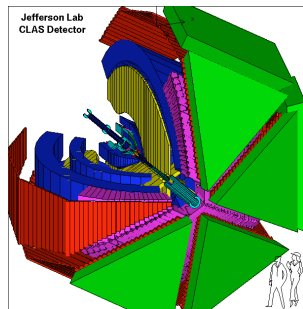
VALUE ( $\text{GeV}^{-1/2}$ )	DOCUMENT ID	TECN	COMMENT
<b><math>0.190 \pm 0.018</math> OUR ESTIMATE</b>			
$0.131 \pm 0.010$	ANISOVICH 12A	DPWA	Multichannel
$0.143 \pm 0.002$	DUGGER 07	DPWA	$\gamma N \rightarrow \pi N$
$0.147 \pm 0.010$	AHRENS 02	DPWA	$\gamma N \rightarrow \pi N$
$0.167 \pm 0.005$	ARNDT 96	IPWA	$\gamma N \rightarrow \pi N$
$0.156 \pm 0.022$	CRAWFORD 83	IPWA	$\gamma N \rightarrow \pi N$
$0.168 \pm 0.013$	AWAJI 81	DPWA	$\gamma N \rightarrow \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •			
$0.138 \pm 0.008$	ANISOVICH 10	DPWA	Multichannel
$0.161$	DRECHSEL 07	DPWA	$\gamma N \rightarrow \pi N$
$0.151$	PENNER 02D	DPWA	Multichannel
$0.130 \pm 0.020 \pm 0.015$	<sup>6</sup> MUKHOPAD... 98		$\gamma p \rightarrow \eta p$
$0.167 \pm 0.002$	LI 93	IPWA	$\gamma N \rightarrow \pi N$
$0.168$	WADA 84	DPWA	Compton scattering

Resonance	Breit-Wigner Values				Pole Values			
	(Mass,Width)	$\Gamma_{\pi}/2$	$A_{1/2}$	$A_{3/2}$	$(\text{Re}W_p, -2\text{Im}W_p)$	$R_{\pi}$	$A_{1/2}$	$A_{3/2}$
$\Delta(1232) 3/2^+$	(1233 , 119)	60	$-141 \pm 3$	$-258 \pm 5$	(1211 , 99)	52 $[-47^\circ]$	$-135 \pm 5$ $[-17^\circ]$	$-255 \pm 5$ $[-5^\circ]$
$N(1440) 1/2^+$	(1485 , 284)	112	$-60 \pm 2$		(1359 , 162)	38 $[-98^\circ]$	$-65 \pm 5$ $[-37^\circ]$	
$N(1520) 3/2^-$	(1515 , 104)	33	$-19 \pm 2$	$+153 \pm 3$	(1515 , 113)	38 $[-5^\circ]$	$-22 \pm 3$ $[-10^\circ]$	$+156 \pm 6$ $[+11^\circ]$
$N(1535) 1/2^-$	(1547 , 188)	34	$+92 \pm 5$		(1502 , 95)	16 $[-16^\circ]$	$+77 \pm 5$ $[+5^\circ]$	
$N(1650) 1/2^-$	(1635 , 115)	58	$+35 \pm 5$		(1648 , 80)	14 $[-69^\circ]$	$+36 \pm 3$ $[-16^\circ]$	

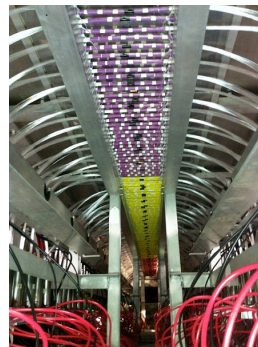
TABLE I. Breit-Wigner and pole values for selected nucleon resonances. Masses, widths and residues are given in units of  $\text{MeV}$ , the helicity 1/2 and 3/2 photo-decay amplitudes in units of  $10^{-3} \times (\text{GeV})^{-1/2}$ . Errors on the phases are generally 2 – 5 degrees. For isospin 1/2 resonances the values of the proton target are given.

## Task 2

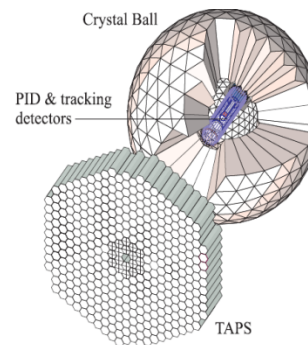
- Baryon Spectroscopy Measurements
  - FROST Collaboration using CLAS at JLab Hall B
  - HD-ICE Collaboration using CLAS at JLab Hall B
    - GW + CUA + ASU designed, built, and installed tagged-photon system
    - GW designed and installed polarized photon system
  - CB&TAPS@MAMI A2 Collaboration at KPH JGU
    - GW assumed UCLA scientific responsibilities within CB Collaboration
- Very Strange Physics Collaboration using CLAS12 at JLab Hall B
  - Current work in preparatory stage
    - CTOF detector development (summer undergraduate students)
- Charged Radius of the Proton – MUSE Collaboration at PSI



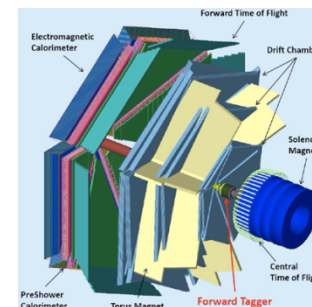
CLAS



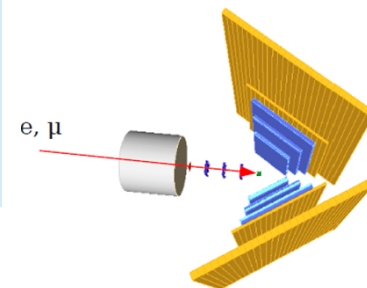
Tagger Focal Plane



Crystal Ball  
And TAPS

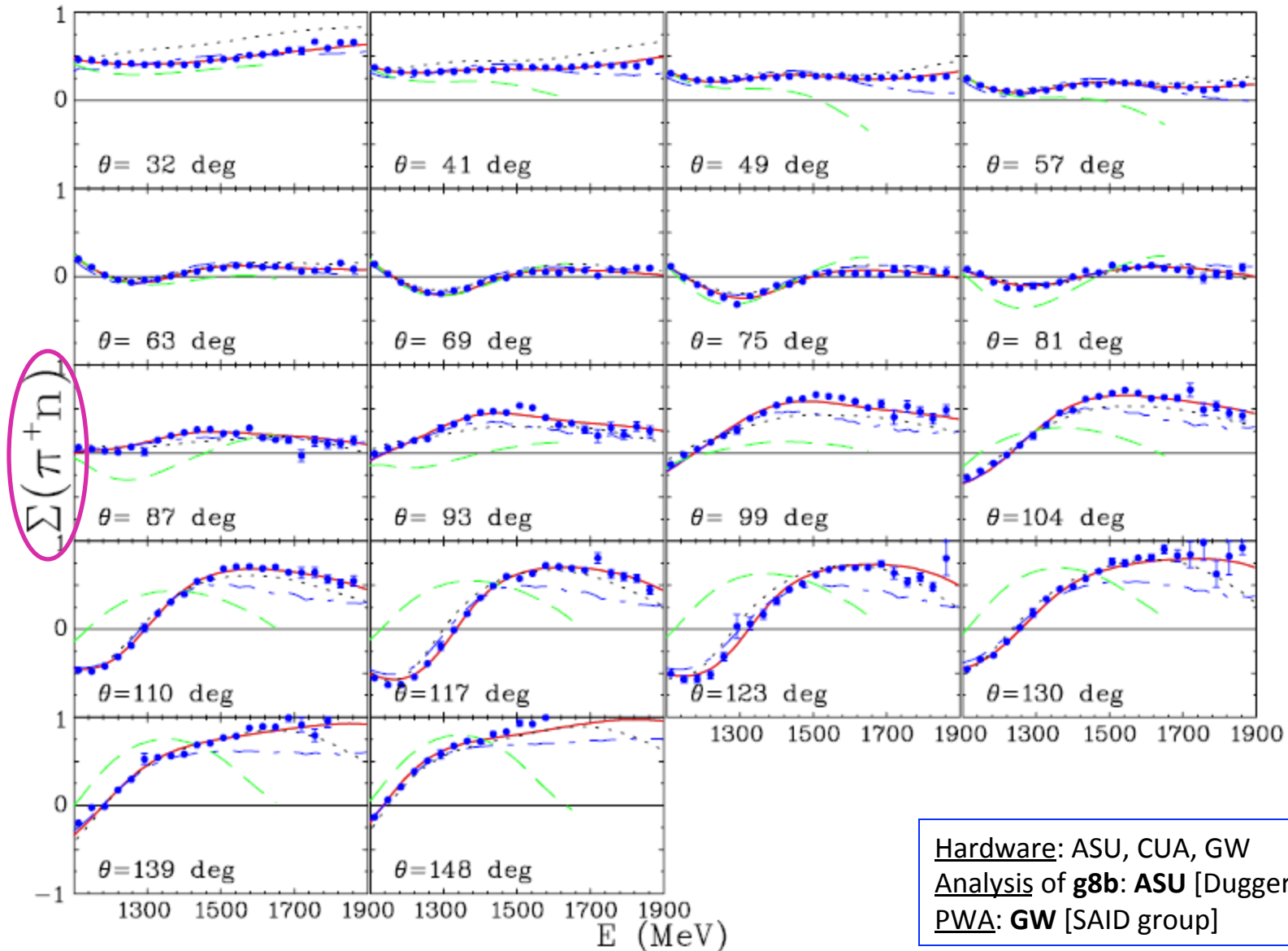


CLAS 12



MUSE

# CLAS for $\vec{\gamma} p \rightarrow \pi^+ n$ above 1 GeV



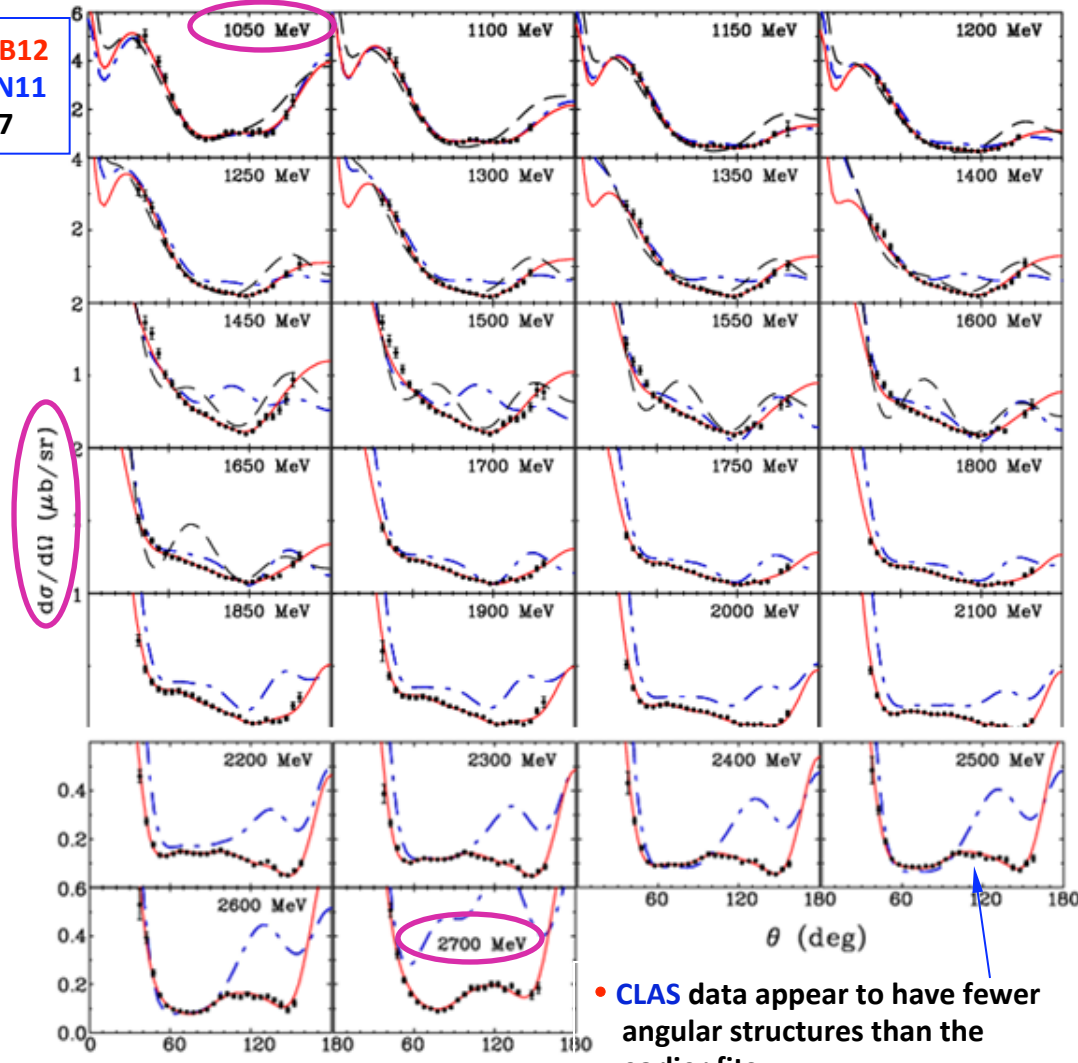
SAID CM12  
 SAID DU12  
 MAID07  
 BnGa12

Hardware: ASU, CUA, GW  
 Analysis of **g8b**: ASU [Dugger and Ritchie]  
 PWA: **GW** [SAID group]

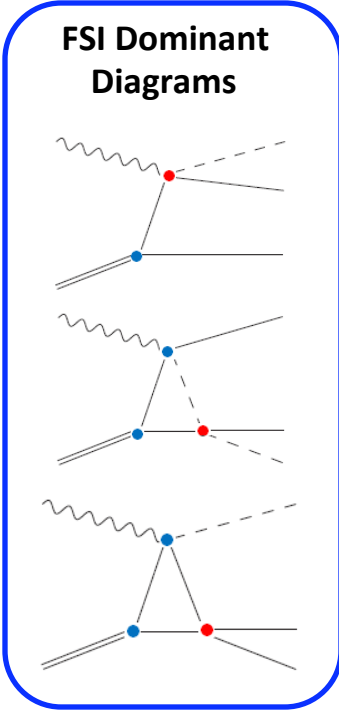
# CLAS for $\gamma n \rightarrow \pi^- p$ above 1 GeV

[W. Chen, *et al*, Phys Rev C **86**, 015206 (2012) ; Phys Rev Lett **103**, 012301 (2009)]

SAID-GB12  
SAID-SN11  
MAID07



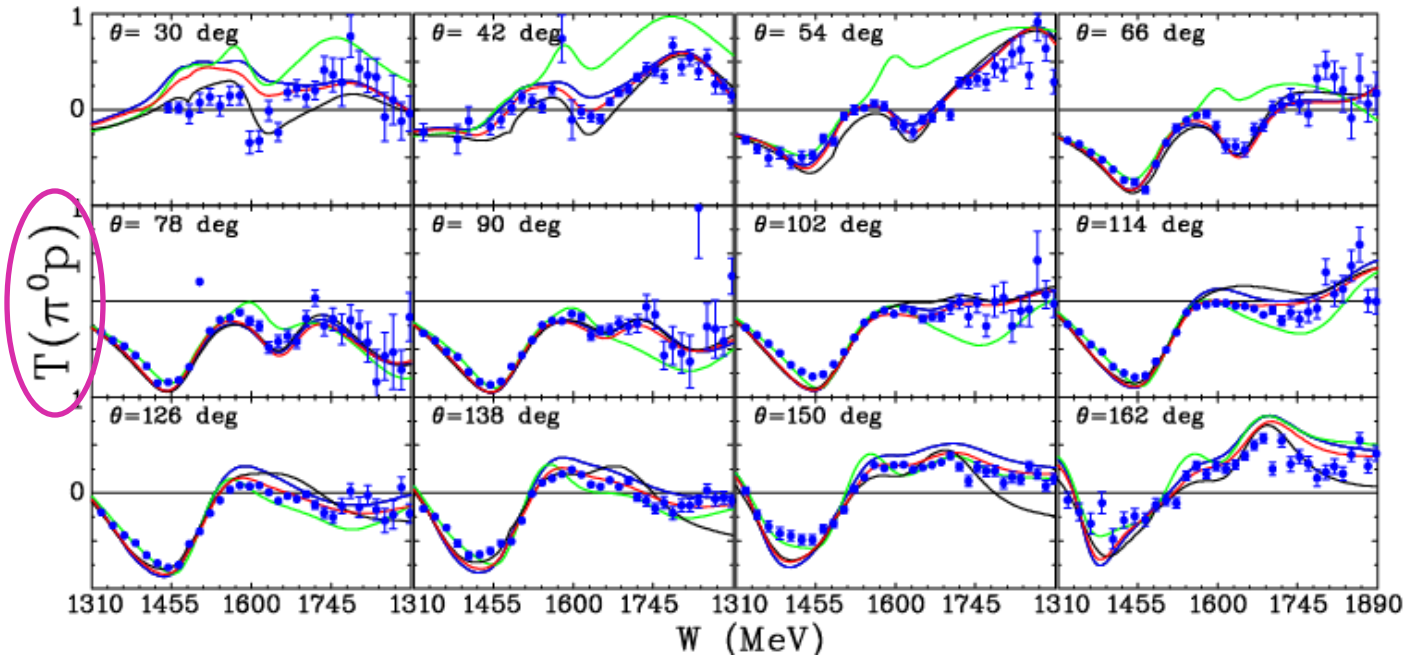
• CLAS data appear to have fewer angular structures than the earlier fits.



• The new **CLAS** cross sections have **quadrupled** the world database for  $\gamma n \rightarrow \pi^- p$  above  $E_\gamma = 1 \text{ GeV}$ .

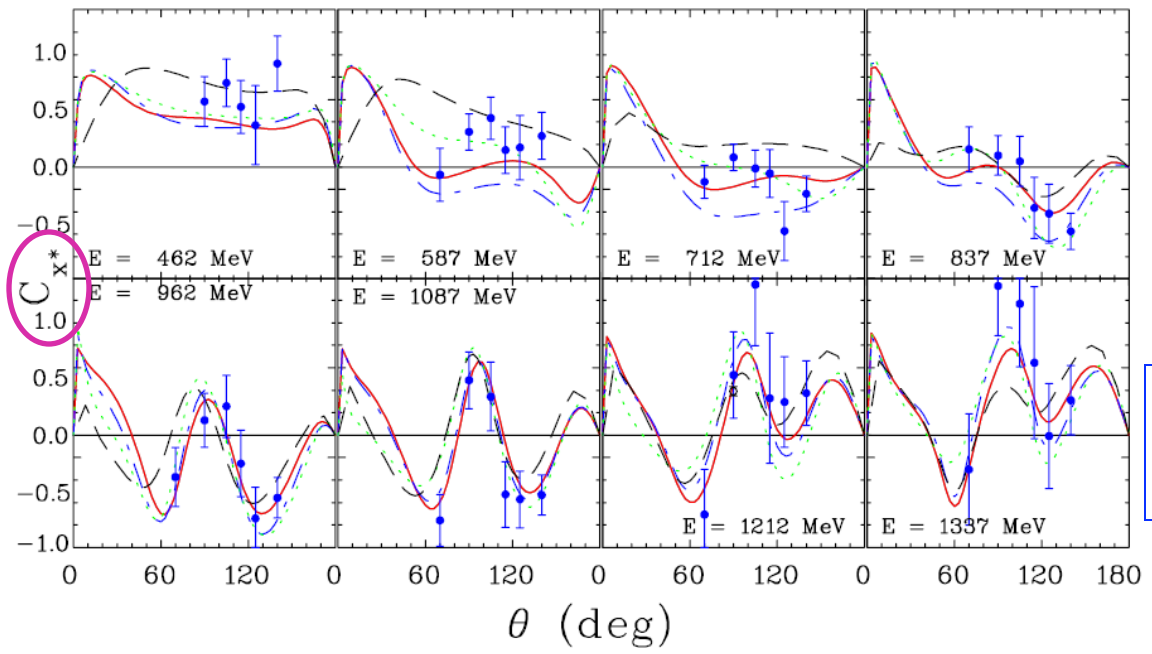
Hardware: ASU, CUA, GW  
Analysis of **g10**: Duke [Chen & Gao]  
FSI: ITEP/GW [Tarasov & Kudryavtsev]  
PWA: GW [SAID group]

# CB@MAMI for $\gamma\vec{p}\rightarrow\pi^0p$



SAID CM12  
SAID KA12  
MAID07  
BnGa12

Hardware: GW, UCLA  
Analysis: JGU [Kashevato]v  
PWA: GW [SAID group]



SAID CN11  
SAID DU12  
MAID07  
BnGa12

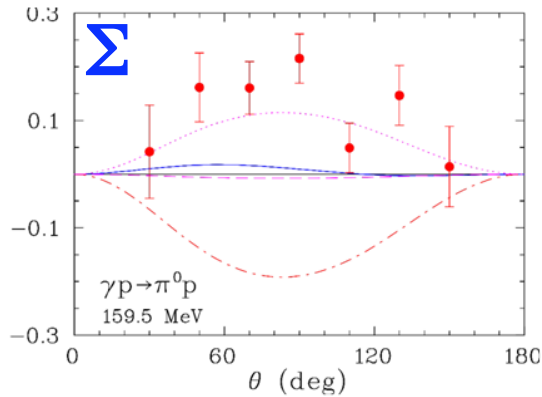
Hardware: EU, GW, UCLA  
Analysis: EU [Sikora and Watts]  
PWA: GW [SAID group]

DOE funds provided support  
For electronics, PID, Recoil

# CB@MAMI-C for $\vec{\gamma}p \rightarrow \pi^0 p$ at threshold and above



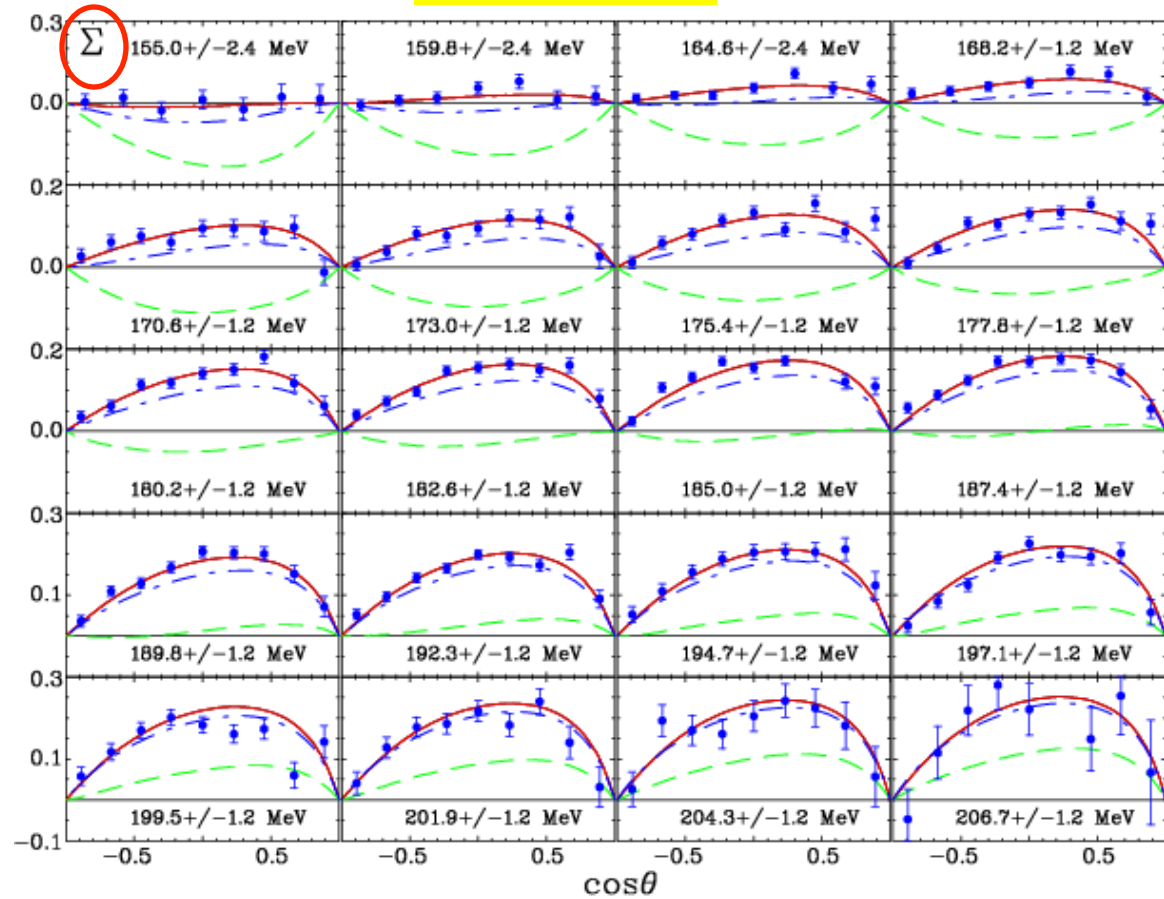
**MAMI-B**



- **MAMI-B** [Schmidt *ea* PRL87(2001)]
- $\chi$ PT [Bernard *ea* ZPC70 (1996)]
- DR [Hanstein *ea* PLB399 (1997)]
- MAID07 [Drechsel *ea* EPJA34 (2007)]
- SAID07 [Dugger *ea* PRC76 (2007)]

Hardware: GW, UCLA  
 Analysis: GW [Prakhov]  
 PWA: GW [SAID group]

**CB@MAMI-C**

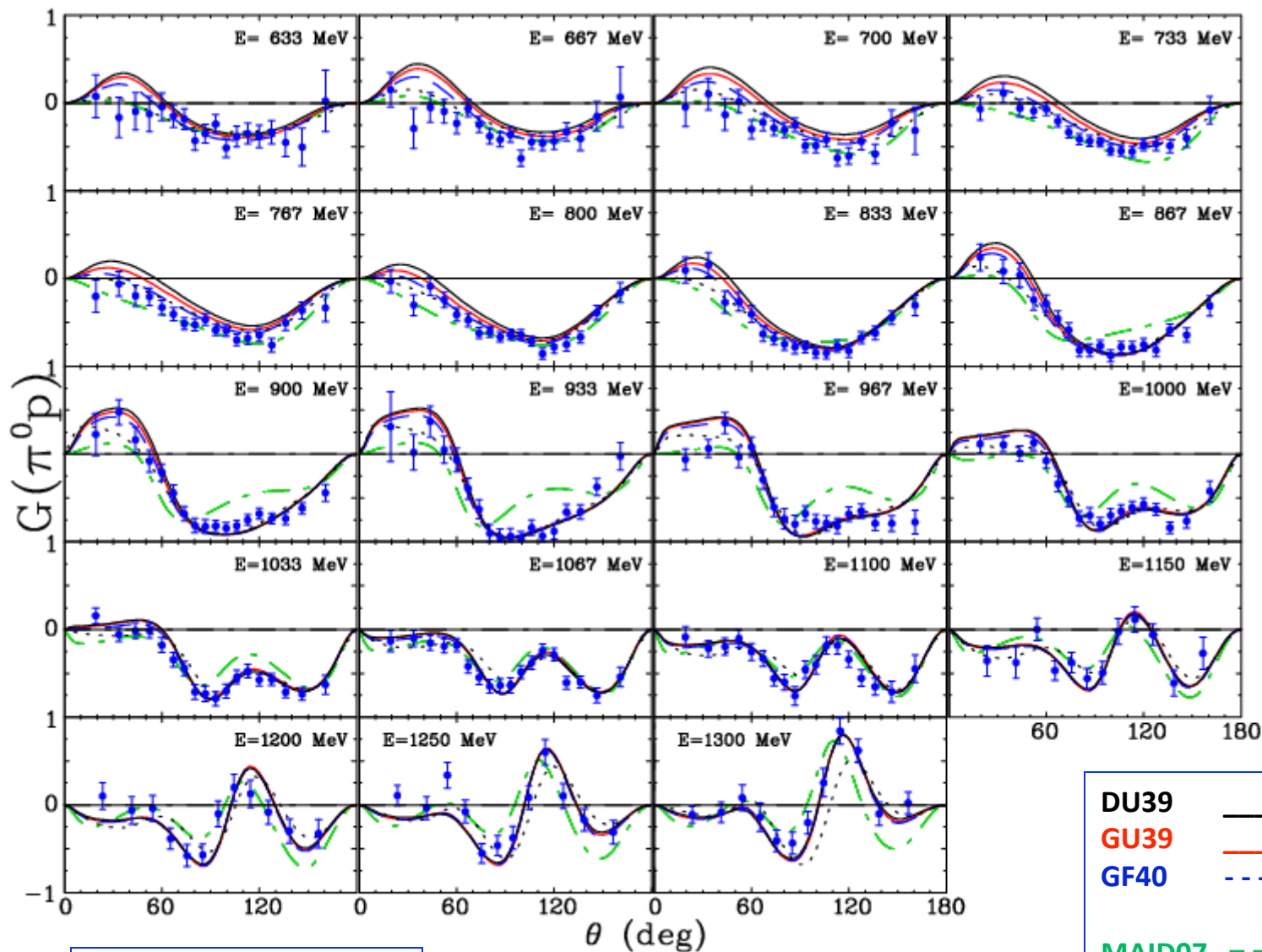


• No fits, predictions only

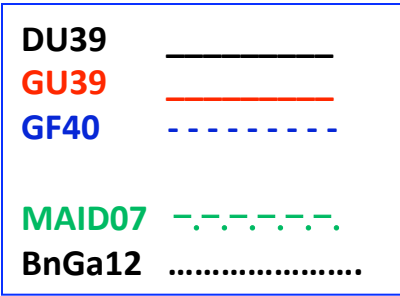
- CB@MAMI [Dugger *ea* PRC79 (2009)]
- SAID-SPO9 [Kamalov *ea* PRC64 (2001)]
- DTM [Kamalov *ea* PRC64 (2001)]
- MAID07 [Drechsel *ea* EPJA34 (2007)]

DOE funds provided support  
 For electronics, PID, Recoil

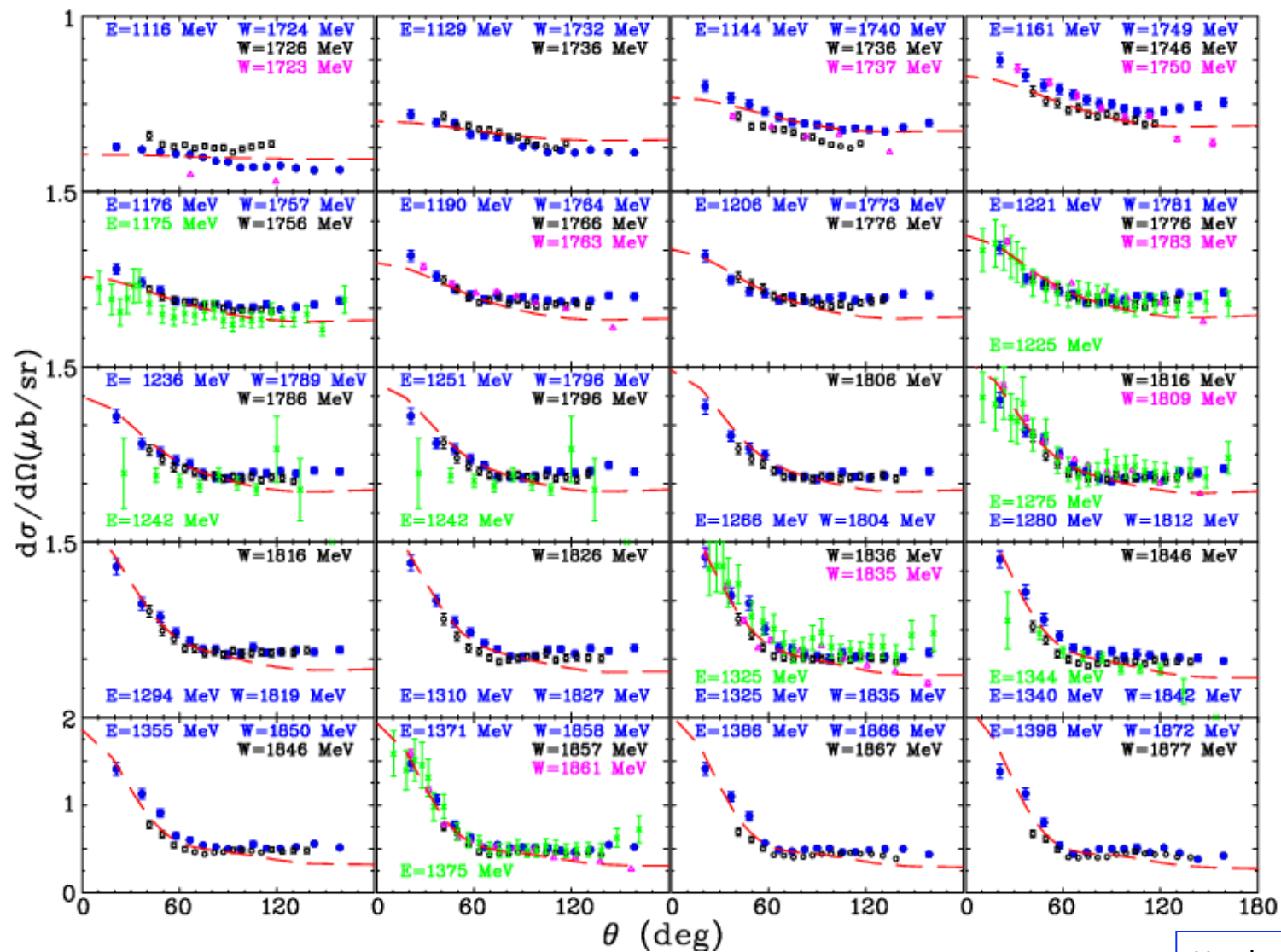
# CB-ELSA for $\gamma p \rightarrow \pi^0 p$



Analysis: **Bonn U** [Beck]  
 PWA: **GW**, BnGa, MAID



# CB@MAMI-C for $\gamma p \rightarrow \omega p$ at threshold



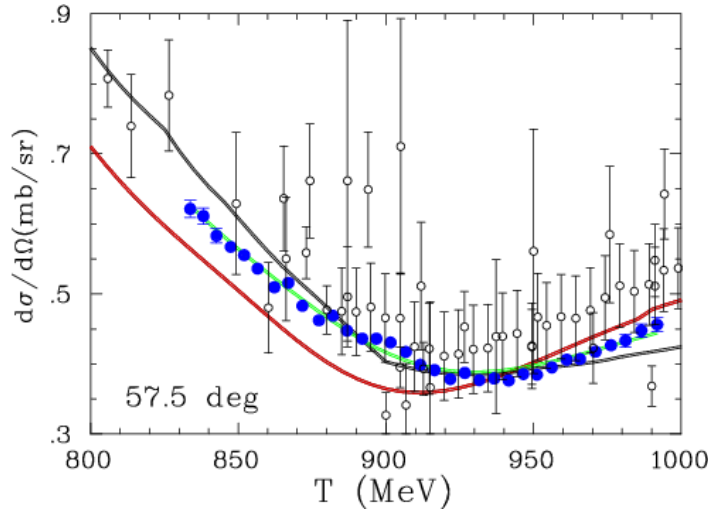
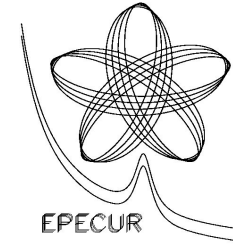
CB@MAMI-13  
 SAPHIR-03  
 CLAS g11-09  
 CB-ELSA-13&5

Theory:  
 Giessen-05

Hardware: GW, UCLA  
 Analysis: GW [Prakhov]



# EPECUR for $\pi p \rightarrow \pi p$



	Wi08	KA84
$\pi^- p \rightarrow \pi^- p$	$\chi^2/dp = 6090/495$	$36394/495$
$\pi^+ p \rightarrow \pi^+ p$	$\chi^2/dp = 4748/528$	$11980/528$

$\pi^- p \rightarrow \pi^- p$   
 $\pi^+ p \rightarrow \pi^+ p$

• **EPECUR**  
time]:

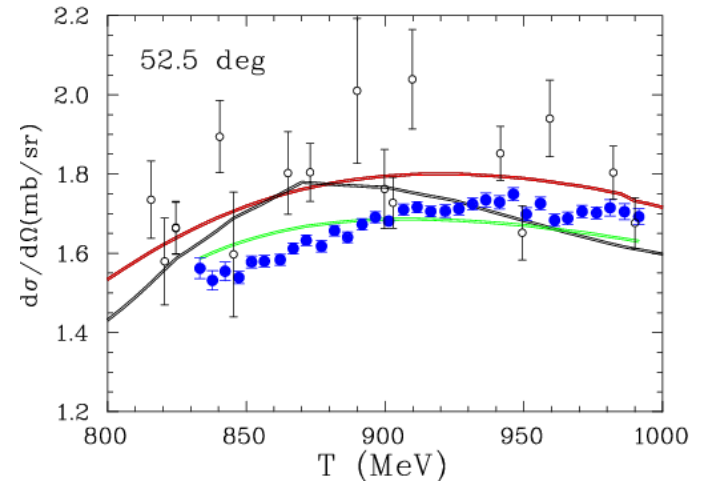
$T_\pi = 834\text{--}992$  MeV

$\theta = 48\text{--}117$  deg

o Previous [available in Hoehler's

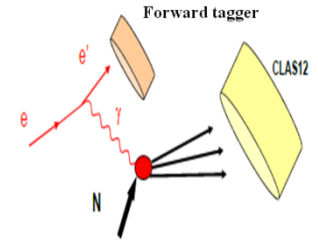
$\pm 2.5$  deg or

$\pm 2$  MeV



Analysis: **ITEP** [Alekseev & Svirida]  
PWA: **GW** [SAID group]

- Cross section measurement for  $\gamma p \rightarrow \Omega^- K^+ K^0$  which is still unknown.



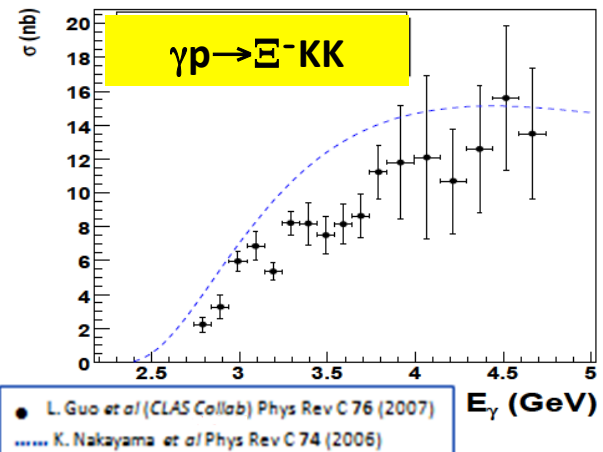
- Study of a **mechanism** for the  $\Omega^-$  photoproduction which is unique in that it is the **first baryon** with constituents none of which could come from the target proton.

CLAS6 g12 [Max  $E_\gamma = 5.4$  GeV] may have **10,000  $\Omega^-$**  while CLAS6 acceptance for  $\Omega^-$  is  $10^{-4}$ .

### Further Physics Goals

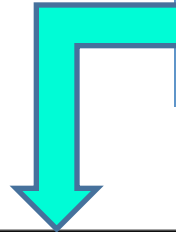
- Mass Splitting measurements for  $\Xi$ s.
- Excited cascade resonances (Spin-Parity).
- Polarization measurement of  $\Xi$ .

GW Contribution: Theoretical support, MC, and CTOF detector development (summer undergraduate students)



## Beam Time and Expected Particle Rate

cross sections used in the estimate are 0.3 nb for  $\Omega^-$ ,  
 15 nb for  $\Xi^-$ ,  
 6 nb for  $\Xi^-(1530)$ ,  
 3 nb for  $\Xi^-(1820)$ .

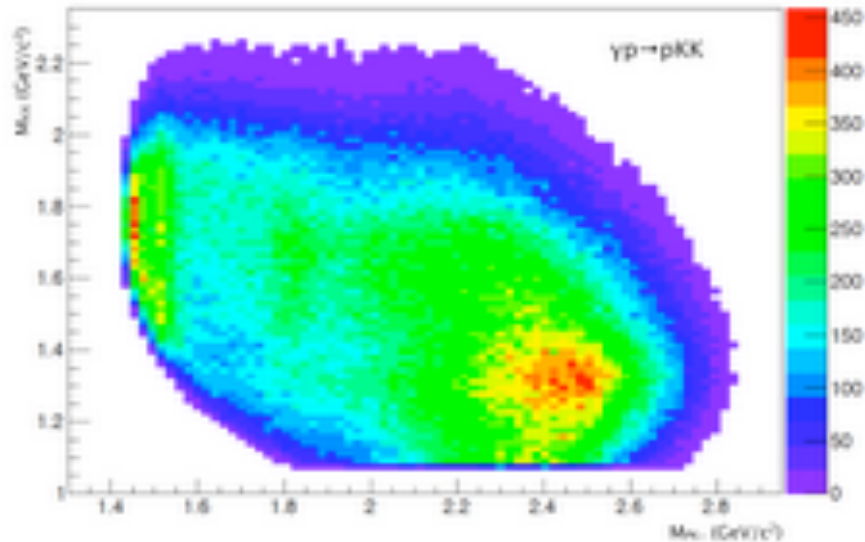


State	Detected Particles	Measured decays	Overall Efficiency	Total detected
$\Omega^-$	$K^+K^+K^0(\Omega^-)$		2.28%	4.1k
$\Omega^-$	$K^+K^+K^0K^-(\Lambda)$	$\Omega^-$	0.25%	0.5k
$\Xi^-$	$K^+K^+\pi^-(\Lambda)$	$\Xi^-$	9.3%	0.9M
$\Xi^-(1530)$	$K^+K^+\pi^-(\Xi^0)$	$\Xi^-(1530)$	7.4%	270k
$\Xi^-(1820)$	$K^+K^+K^-\pi^-(\Lambda)$	$\Xi^-(1820), \Lambda$	0.52%	10k

- Approved beam time for **E12-11-005** (80 days) is sufficient for us to achieve most of goals.

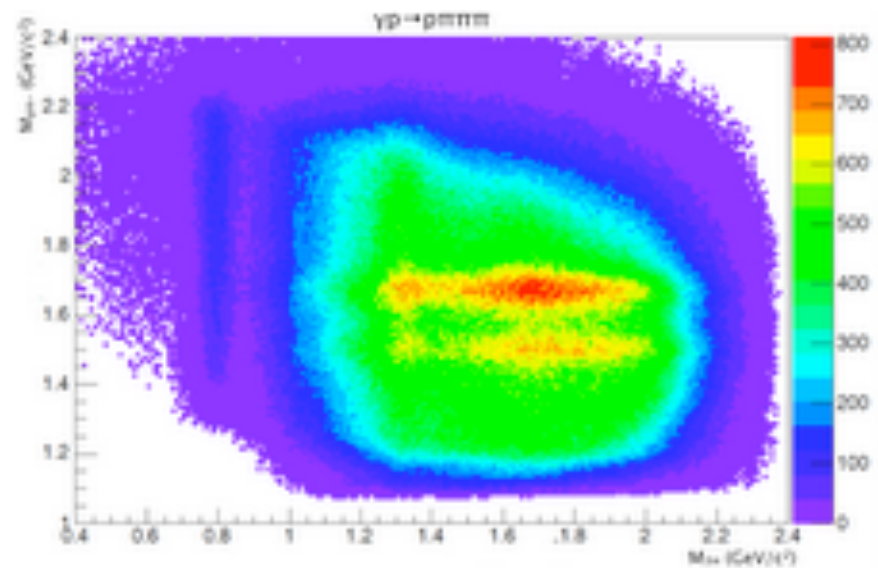
# Modeling Baryon Contamination in Meson Spectroscopy

## Diane Schott



- The  $p\pi^+\pi^-\pi^0$  channels is important in the search for exotics.

- Baryon/meson resonances overlap at **CLAS 6** and **JLab 12 GeV** energies.
- Work in progress for  $pK^+K^-$  analysis as stepping stone to more complex channels.



# Proton Radius Data

## CODATA, 2006

- $r_p = 0.8768 (69)$  fm

## Electronic Hydrogen

- $r_p = 0.875 (6)$  fm Gärching (2006)

## Electron-Proton Scattering

- $r_p = 0.879 (6)$  fm Mainz (2010)
- JLab result forthcoming

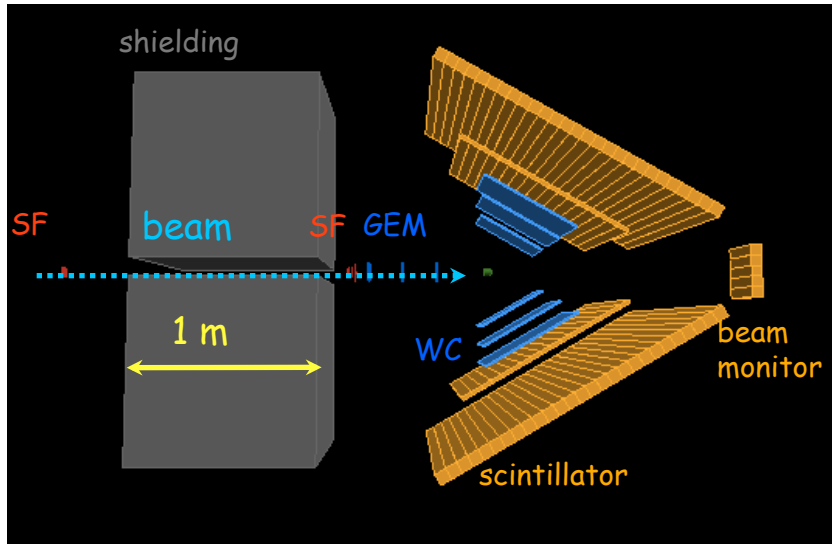
Results from  $ep$  scattering and electronic hydrogen support each other

## Muonic Hydrogen, 2010

- $r_p = 0.841 84 (67)$  fm PSI
- 10 times more accurate!

Courtesy of Michael Eides

# MUSE: $\mu^\pm p$ & $e^\pm p$ elastic scattering at PSI



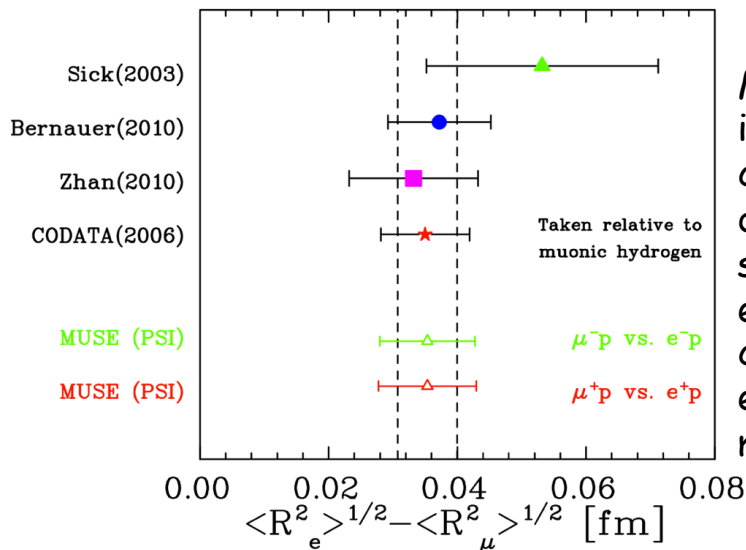
## Idea

- ◆ Precise relative proton $_{e,\mu}$  radius test
- ◆ Simultaneous elastic  $\mu p$  and  $e p$  scattering at 3 beam momenta
- ◆ Measure both polarities for  $2\gamma$  exchange
- ◆ Improved lepton universality test

## Technique

- ◆ Use SciFis, GEMs, Cerenkov for beam
- ◆ Use chambers and scintillators for scattered particles
- ◆ Use beam monitor scintillator for stability

## Previous & Projected Results



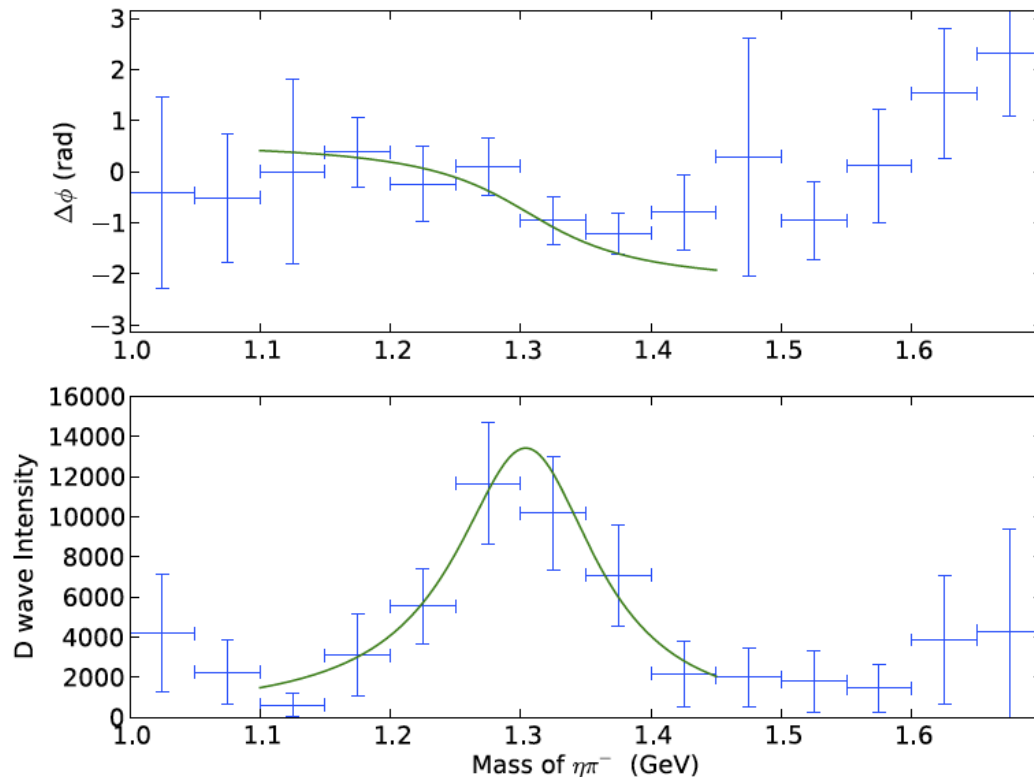
MUSE gives an independent, self-contained radius difference in a scattering experiment, comparable to existing measurements.

## Schedule

- ◆ Summer 2013: 2<sup>nd</sup> test run
- ◆ 2013: request equipment funding
- ◆ 2014-15: construct equipment
- ◆ 2015-17: 1-month test run, then 2 6-month data runs

GW: WC frames, beam-line hardware, cryogenic target, radiative correction calculations (AA), DAC (EJD).

# Meson Spectroscopy: Photoproduction of $\eta\pi^-$ using CLAS (g12)

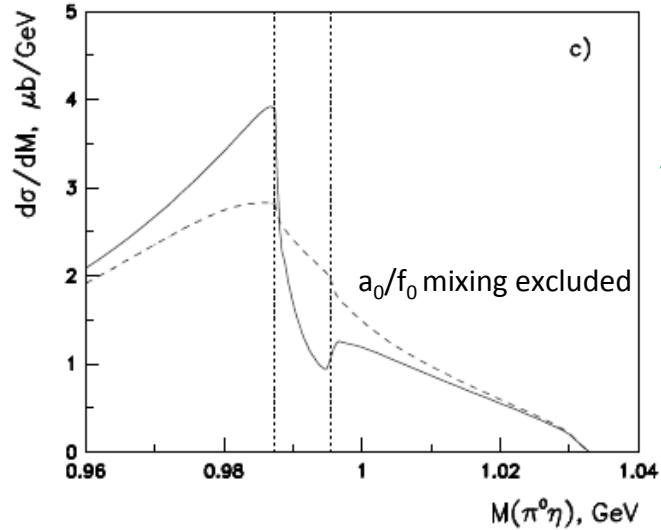
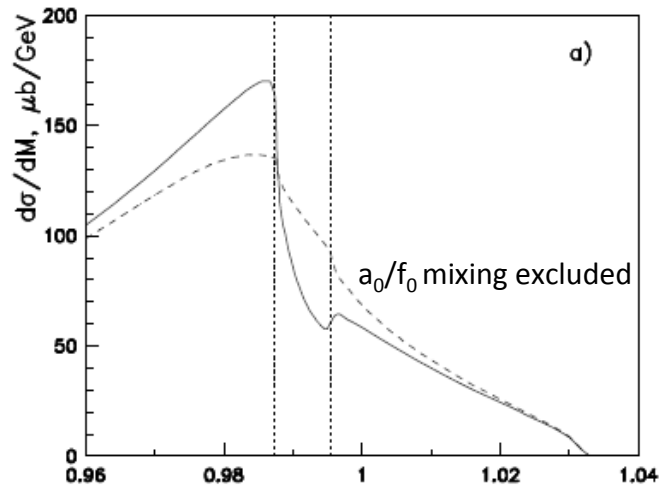


- A **PWA** revealed a strong **D-wave** contribution with the mass and width of the  **$a_2(1320)$** . No **P-wave** was concluded to be seen in the final fit, this would have coincided with the presence of a  **$\pi_1(1400)$** .
- This is the first look into  **$\eta\pi^-$**  using photoproduction.
- Theory has predicted photoproduction of  **$\pi_1$**  to be comparable to the  **$a_2$** . The ratio of the  **$\pi_1$**  to  **$a_2$**  does not support the initial hypothesis.
- Experiment sensitive to the predicted level but not for levels seen in pion production (from **E852** analysis,  **$\pi_1/a_2 \sim 0.055$** ).
- Future meson spectroscopy experiment with greater luminosity and beam energy is a planned with **GlueX**.

Hardware: ASU, CUA, GW  
Analysis of g12 data: **GW** [Schott]

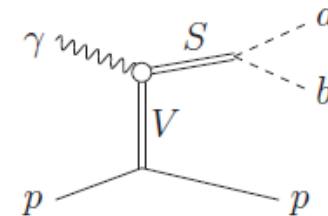
# Photoproduction of Scalar $a_0$ and $f_0$ Mesons and their Mixing Effect

[In Collaboration with ITEP - topic for new experiment(s)]



$\sigma^t$  [ $\mu\text{b}$ ] for  $\gamma p \rightarrow a_0/f_0$  at  $E_\gamma = 1.6$  GeV

Model	$\pi^0\eta$	$\pi^0\pi^0$	$\pi^+\pi^-$	$K^+K^-$
1)	12.21	2.59	5.12	2.58
A, 2)	12.08	0.86	1.70	1.28
3)	12.15	1.73	3.42	1.97
B	0.234	0.093	0.184	0.083
C	0.444	0.070	0.138	0.072

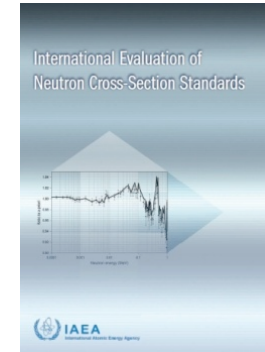


Vector-meson-exchange diagrams



# Why np Xsections at Low Energies are Critical

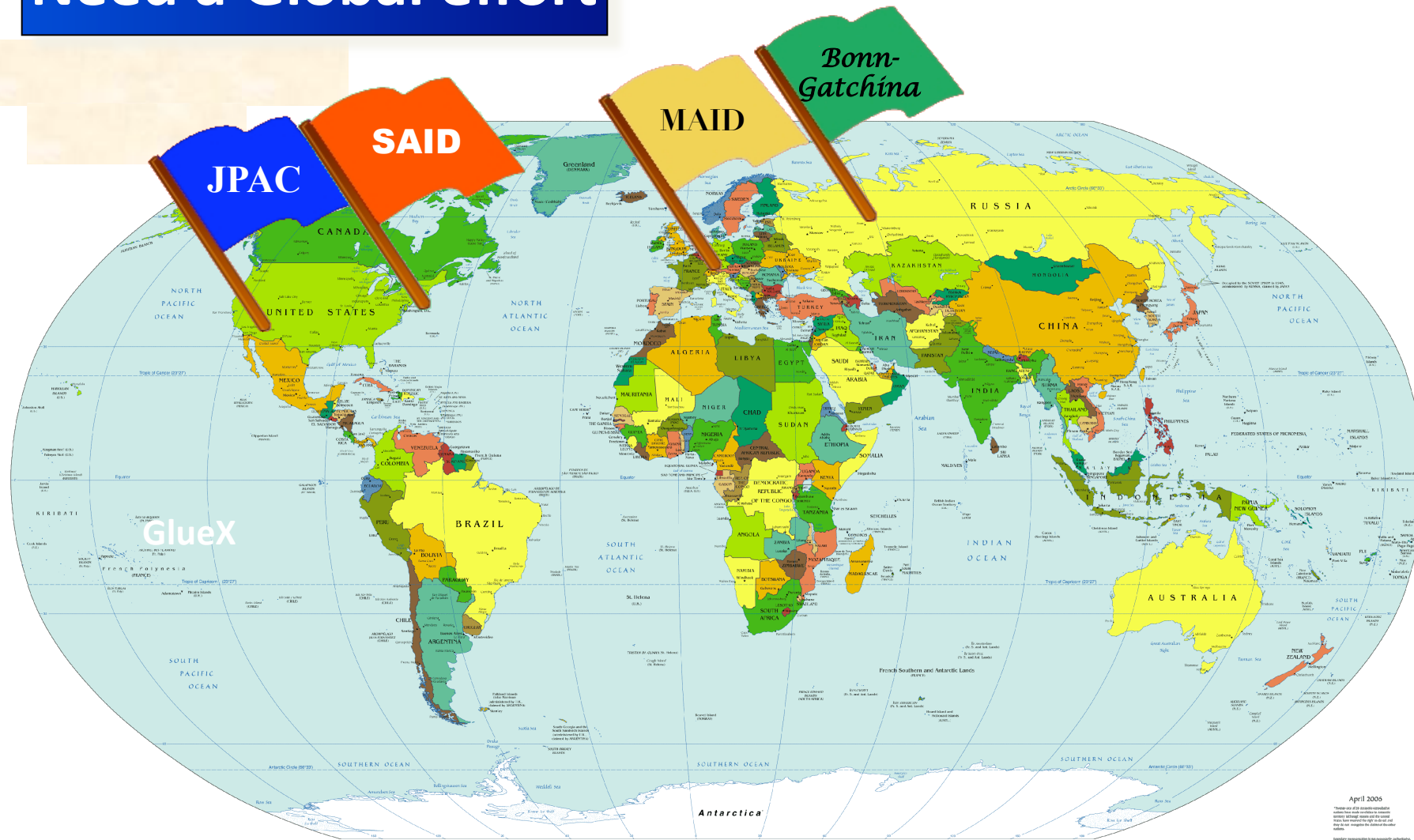
- **Neutron-proton** scattering is used as the **primary standard** in measurements involving neutron-induced nuclear reactions. Its cross section is used in determining the flux of incoming neutrons.
- In **2007**, the International Atomic Energy Agency (**IAEA**) within the **International Evaluation of Neutron Cross Section Standards** highly rated the GW DAC [**SAID**] group work:



*The **Arndt** evaluation was accepted by the NEANDC/INDC as a primary standard for cross section measurements in the 20–350 MeV range.*

- The information about the **neutron-nucleus** interaction is important in many applications:
  - **Medical** physics,
  - **Astrophysics** [(n,  $\gamma$ ), (n,  $\alpha$ ), and others],
  - **Transmutation** of nuclear waste [(n, f), (n,  $\gamma$ ), and others],
  - **Energy generation**, and
  - The conceptual design of an innovative **nuclear reactor** being carried out in the course of the **Generation IV** initiative and
  - **Acceleration Driven System (ADS)** [(n, f), and neutron-actinoid elastic and inelastic scattering].

# Need a Global effort



Courtesy of Mike Pennington

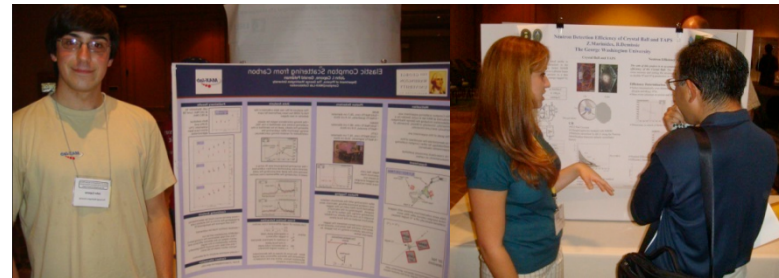
# Research and Conference Experience for Students

Supported in part by DOE/NP, NSF/OISE and GW/REF. Our program:

- involved undergraduate and graduate students with international research.
- engaged students with diverse backgrounds in scientific exploration.
- allowed students research at the cutting-edge of science.
- had students work side-by-side with international researchers.
- actively supported under-represented groups in physics.
- actively supported gender equality (12F + 12M = 24 Students Trained in last 5 years).



Mainz, Germany – Summer 2009



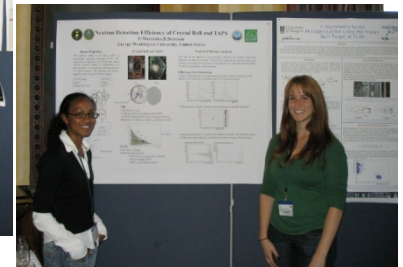
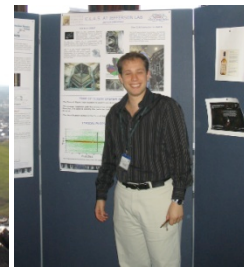
APS DNP, Hawaii – October 2009



Lund, Sweden – Summer 2010



CEU @ APS DNP, Santa Fe – Nov 2010



NNR Workshop, Edinburgh, Scotland – June 2009

# GWU Student Wins First JSA Undergrad Research Assistantship for Minority Students

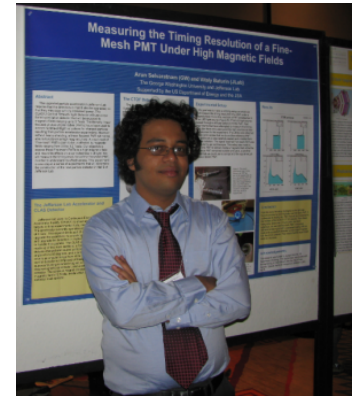
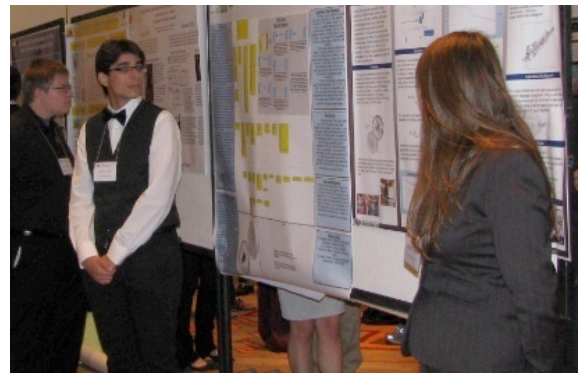


In June 2010, GW student Arun Selvaratnam was selected to participate in the Jefferson Science Associates' Undergraduate Research Assistantship Program for Minority Science and Engineering Students at Jefferson Lab. Arun worked with Vitaly Baturin of Jlab on the development of the detection system for the CLAS12 Central Detector assisting in selection of PMTs. He presented his work at the DNP Meeting in Santa Fe later that same year under the sponsorship of the DNP/NSF Conference Experience for Undergraduates. The assistantship was funded through the SURA/JSA Initiatives Fund.

**Conference Experience for Undergraduates (CEU)**



Fall 2010 Meeting - Division of Nuclear Physics  
American Physical Society  
Santa Fe, NM  
2-6 November, 2010



Summer 2012 at Mainz  
A2 – CB&TAPS at MAMI

