Update on SAID

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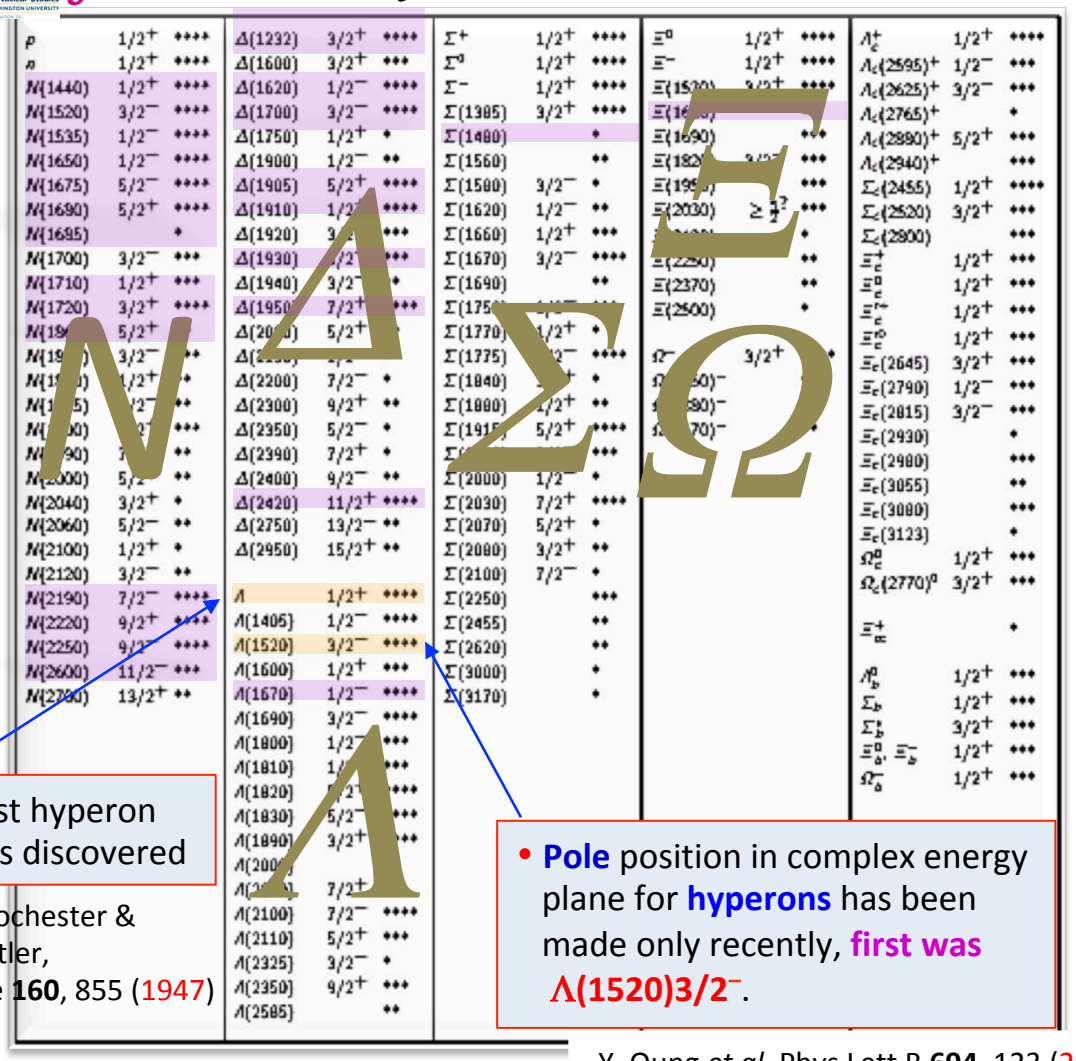
The George Washington University

- **πN elastic** for Baryon Spectroscopy.
- **Pion PhotoProd** for Baryon Spectroscopy.
- **Pion ElectroProd** for Baryon Spectroscopy.
- **First pole** for hyperons from Hall A.
- **Very Strange** study with CLAS12.
- **KLF** study with GlueX.
- Summary.

Supported by DE-SC0016583

Baryon Sector @ PDG

GW Contribution *for* M. Tanabashi *et al,* Phys Rev D **98**, 030001 (2018)



p	$1/2^+$	****
n	$1/2^+$	****
$N(1440)$	$1/2^+$	****
$N(1520)$	$3/2^-$	****
$N(1535)$	$1/2^-$	****
$N(1650)$	$1/2^-$	****
$N(1675)$	$5/2^-$	****
$N(1680)$	$5/2^+$	****
$N(1685)$		*
$N(1700)$	$3/2^-$	***
$N(1710)$	$1/2^+$	***
$N(1720)$	$3/2^+$	****
$N(19[illegible])$	$5/2^+$	
$N(19[illegible])$	$3/2^-$	**
$N(1[illegible])$	$1/2^+$	*
$N(1[illegible])$	$1/2^-$	**
$N([illegible])$	[illegible]	***
$N([illegible])$	[illegible]	**
$N(2000)$	$5/2^+$	**
$N(2040)$	$3/2^+$	*
$N(2060)$	$5/2^-$	**
$N(2100)$	$1/2^+$	*
$N(2120)$	$3/2^-$	**
$N(2190)$	$7/2^-$	****
$N(2220)$	$9/2^+$	****
$N(2250)$	$9/2^-$	****
$N(2600)$	$11/2^-$	***
$N(2700)$	$13/2^+$	**

$\Delta(1232)$	$3/2^+$	****
$\Delta(1600)$	$3/2^+$	***
$\Delta(1620)$	$1/2^-$	****
$\Delta(1700)$	$3/2^-$	****
$\Delta(1750)$	$1/2^+$	*
$\Delta(1900)$	$1/2^-$	**
$\Delta(1905)$	$5/2^+$	****
$\Delta(1910)$	$1/2^+$	****
$\Delta(1920)$	$3/2^+$	***
$\Delta(1930)$	$5/2^-$	***
$\Delta(1940)$	$3/2^-$	*
$\Delta(1950)$	$7/2^+$	****
$\Delta(20[illegible])$	$5/2^+$	
$\Delta([illegible])$	[illegible]	
$\Delta(2200)$	$7/2^-$	*
$\Delta(2300)$	$9/2^+$	**
$\Delta(2350)$	$5/2^-$	*
$\Delta(2390)$	$7/2^+$	*
$\Delta(2400)$	$9/2^-$	**
$\Delta(2420)$	$11/2^+$	****
$\Delta(2750)$	$13/2^-$	**
$\Delta(2950)$	$15/2^+$	**
Λ	$1/2^+$	****
$\Lambda(1405)$	$1/2^-$	****
$\Lambda(1520)$	$3/2^-$	****
$\Lambda(1600)$	$1/2^+$	***
$\Lambda(1670)$	$1/2^-$	****
$\Lambda(1690)$	$3/2^-$	****
$\Lambda(1800)$	$1/2^-$	***
$\Lambda(1810)$	$1/2^+$	***
$\Lambda(1820)$	$5/2^+$	****
$\Lambda(1830)$	$5/2^-$	***
$\Lambda(1890)$	$3/2^+$	***
$\Lambda(200[illegible])$		
$\Lambda([illegible])$	$7/2^+$	
$\Lambda(2100)$	$7/2^-$	****
$\Lambda(2110)$	$5/2^+$	***
$\Lambda(2325)$	$3/2^-$	*
$\Lambda(2350)$	$9/2^+$	***
$\Lambda(2585)$		**

Σ^+	$1/2^+$	****
Σ^0	$1/2^+$	****
Σ^-	$1/2^+$	****
$\Sigma(1385)$	$3/2^+$	****
$\Sigma(1480)$		*
$\Sigma(1560)$		**
$\Sigma(1580)$	$3/2^-$	*
$\Sigma(1620)$	$1/2^-$	**
$\Sigma(1660)$	$1/2^+$	***
$\Sigma(1670)$	$3/2^-$	****
$\Sigma(1690)$		**
$\Sigma(175[illegible])$	[illegible]	
$\Sigma(1770)$	$1/2^+$	*
$\Sigma(1775)$	$5/2^-$	****
$\Sigma(1840)$	[illegible]	*
$\Sigma(1880)$	$1/2^+$	**
$\Sigma(191[illegible])$	$5/2^+$	****
$\Sigma([illegible])$		***
$\Sigma(2000)$	$1/2^-$	*
$\Sigma(2030)$	$7/2^+$	****
$\Sigma(2070)$	$5/2^+$	*
$\Sigma(2080)$	$3/2^+$	**
$\Sigma(2100)$	$7/2^-$	*
$\Sigma(2250)$		***
$\Sigma(2455)$		**
$\Sigma(2620)$		**
$\Sigma(3000)$		*
$\Sigma(3170)$		*

Ξ^0	$1/2^+$	****
Ξ^-	$1/2^+$	****
$\Xi(1530)$	$3/2^+$	****
$\Xi([illegible])$		
$\Xi(1690)$		***
$\Xi(182[illegible])$	[illegible]	***
$\Xi(195[illegible])$		***
$\Xi(2030)$	$\geq \frac{1}{2}$?	***
[illegible]		*
$\Xi(2250)$		**
$\Xi(2370)$		**
$\Xi(2500)$		*
Ω^-	$3/2^+$	*
$\Omega([illegible])^-$		
$\Omega([illegible])^-$		
$\Omega([illegible])^-$		*

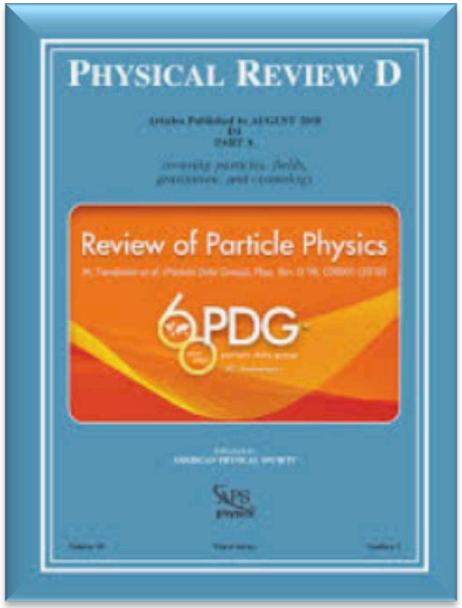
Λ_c^+	$1/2^+$	****
$\Lambda_c(2595)^+$	$1/2^-$	***
$\Lambda_c(2625)^+$	$3/2^-$	***
$\Lambda_c(2765)^+$		*
$\Lambda_c(2880)^+$	$5/2^+$	***
$\Lambda_c(2940)^+$		***
$\Sigma_c(2455)$	$1/2^+$	****
$\Sigma_c(2520)$	$3/2^+$	***
$\Sigma_c(2800)$		***
Ξ_c^+	$1/2^+$	***
Ξ_c^0	$1/2^+$	***
$\Xi_c^{\prime +}$	$1/2^+$	***
$\Xi_c^{\prime 0}$	$1/2^+$	***
$\Xi_c(2645)$	$3/2^+$	***
$\Xi_c(2790)$	$1/2^-$	***
$\Xi_c(2815)$	$3/2^-$	***
$\Xi_c(2930)$		*
$\Xi_c(2980)$		***
$\Xi_c(3055)$		**
$\Xi_c(3080)$		***
$\Xi_c(3123)$		*
Ω_c^0	$1/2^+$	***
$\Omega_c(2770)^0$	$3/2^+$	***
Ξ_{cc}^+		*
Λ_b^0	$1/2^+$	***
Σ_b	$1/2^+$	***
Σ_b^*	$3/2^+$	***
Ξ_b^0, Ξ_b^-	$1/2^+$	***
Ω_b^-	$1/2^+$	***

- First hyperon was discovered

G.D. Rochester & C.C Butler, Nature **160**, 855 (1947)

- **Pole** position in complex energy plane for **hyperons** has been made only recently, **first was $\Lambda(1520)3/2^-$**.

Y. Qung *et al,* Phys Lett B **694**, 123 (2010)



- **PDG18** has **109 Baryon Resonances** (**64** are **4*** or **3***).
- In case of **SU(6) X O(3)**, **434** states if all revealed multiplets were developed.

There are Many Ways to Study N*

Prolific source of **N*** & **Δ*** baryons

Measure many channels with different combinations of quantum numbers.

$\pi N \to \pi N, \pi\pi N, \ldots$

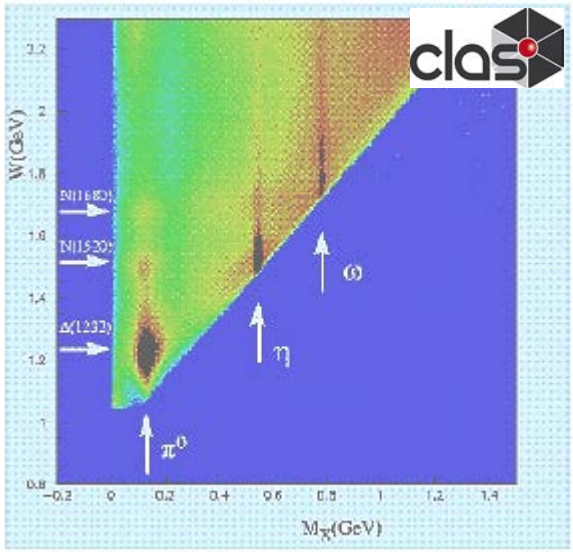
$\gamma N \to \pi N, \pi\pi N, \ldots$

$\gamma^* N \to \pi N, \pi\pi N, \ldots$

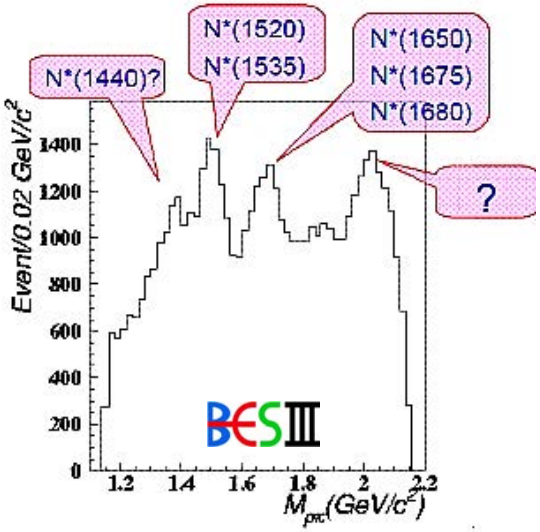
$pp \to pp\pi^0, pp\pi\pi, \ldots$

$J/\psi \to p\bar{p}\pi^0, p\bar{n}\pi^-, \ldots$

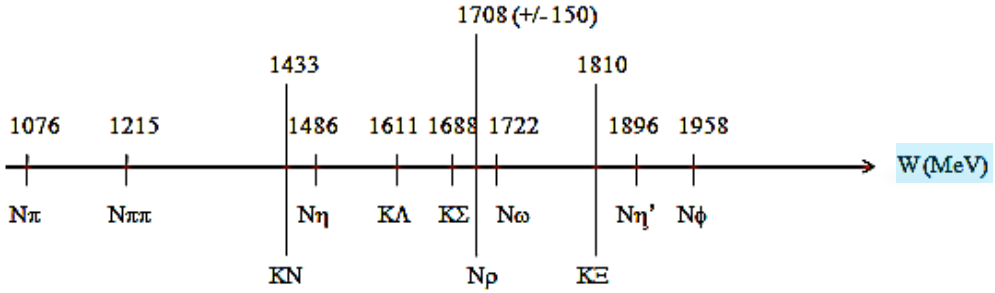
- Most of **PDG** info comes from these a **PWA** of these.
- **πN elastic** scattering is highly constrained.
- Resonance structure is highly correlated.
- Two-body final state, fewer amplitudes.



ep → epX



$J/\psi \to p\bar{n}\pi^-$



Phenomenology for Baryons

- **PWA** arose as a means to determine amplitudes by fitting scattering data.
- A **non-trivial mathematical problem** – looking for a **solution** to an **ill-posed** problem – **Hadamard** & **Tikhonov**.

- **Resonances** appeared as a **by-product**

- **Standard PWA**
  - ⇒ Reveals only **wide** Resonances, but not too wide (Γ < 500 MeV) and possessing not too **small** BR (BR > 4%).
  - ⇒ Tends to **miss** narrow Res with Γ < 20 MeV.

Most of our current knowledge about bound states of **three light quarks** has came mainly from **$\pi N \rightarrow \pi N$ PWAs**:

Karlsruhe–Helsinki,

Carnegie–Mellon–Berkeley,

GW & **Kent State**.

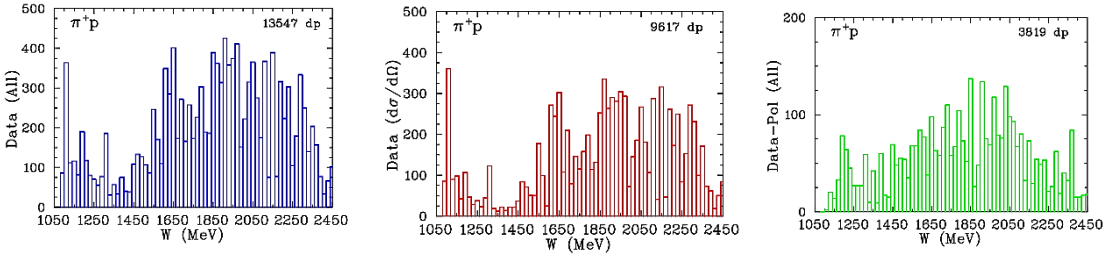
Main source of **EM** couplings is **GW**, **MAID**, **BnGa**, & **JuBo** analyses.

for $\pi N \to \pi N$ & $\pi^- p \to \eta n$

R. Arndt, WJB, I. Strakovsky, R. Workman, Phys Rev C **74**, 045205 (2006)

- Energy dependent SP06/WI08 and associated SES
- T = 0 – 2600 MeV [W = 1078 – 2460 MeV]
- 4-channel Chew-Mandelstam K-matrix parameterization [πN, $\pi\Delta$, ρN, ηN]
- DR constraint
- 3 mapping variables: $g^2/4\pi$, $a[\pi^- p]$, η–th
- PWs = 30 πN {15 [I=1/2] + 15 [I=3/2]} + 4 ηN [l < 9]
- Prms = 99 [I=1/2] + 89 [I=3/2]

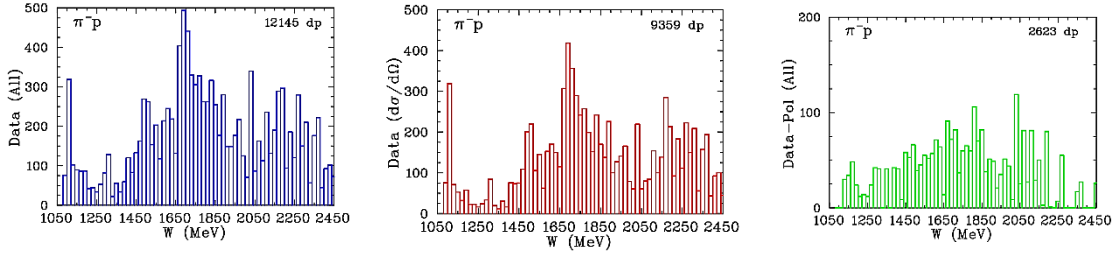
$\pi^+ p \to \pi^+ p$



10 data/MeV

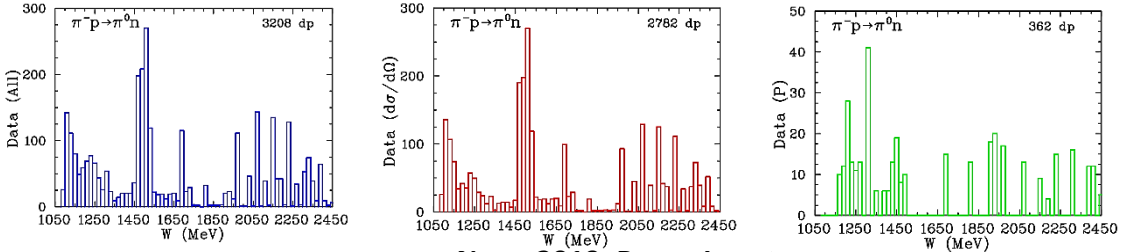
Pol=28%

$\pi^- p \to \pi^- p$



Pol=22%

$\pi^- p \to \pi^0 n$



Pol=11%

Recent for $\pi^{-+} p \rightarrow \pi^{-+} p$

I. Alekseev *et al*, Phys Rev C **91**, 025205 (2015)

- New precise cross section measurements:
  $\Delta\sigma$ = **0.5%** stat, Δ**p** = **1 MeV**, $\Delta\vartheta$ = **±1°**


PHYSICAL REVIEW C 91, 025205 (2015)

High-precision measurements of πp elastic differential cross sections in the second resonance region

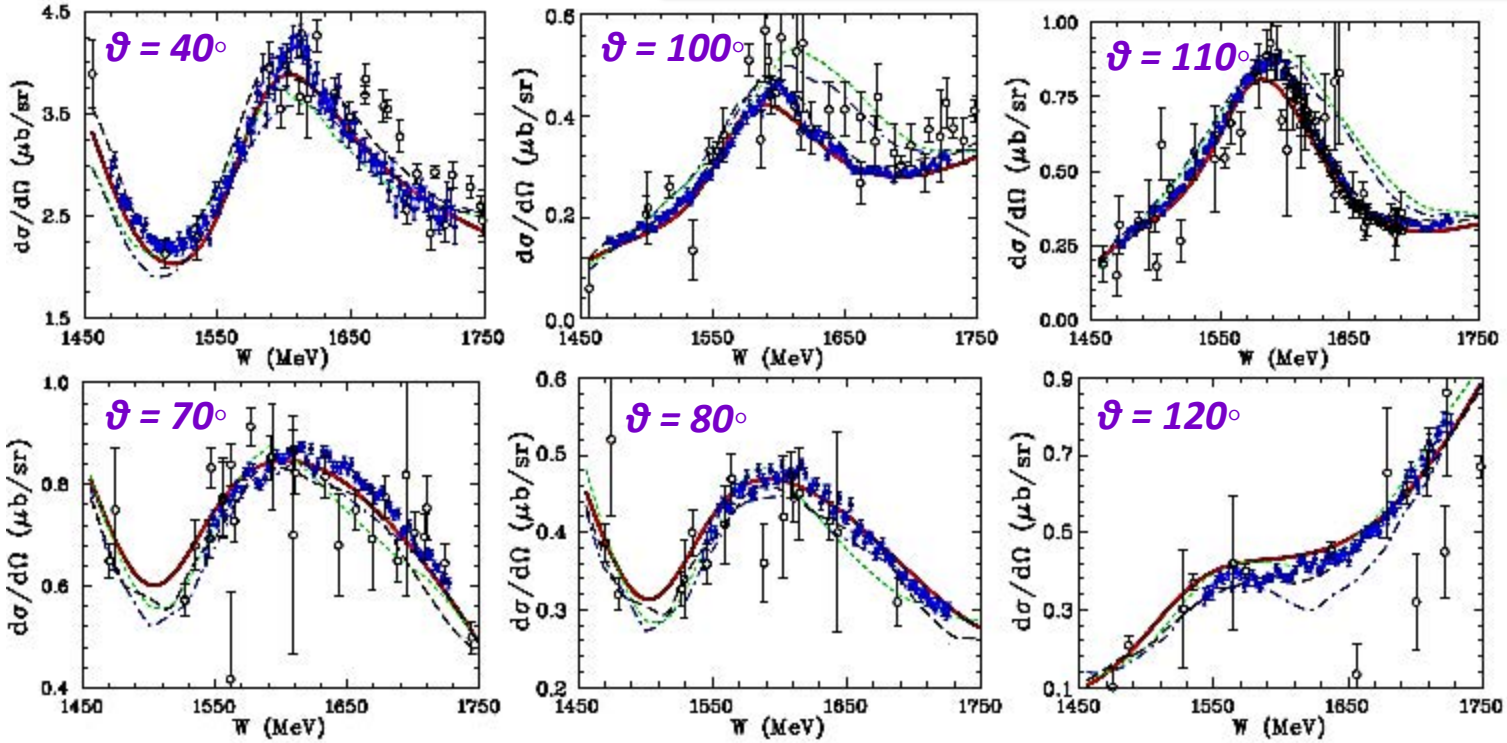
I. G. Alekseev,[1] V. A. Andreev,[3] I. G. Bordyuzhin,[1,5] W. J. Briscoe,[2] Ye. A. Filimonov,[3] V. V. Golubev,[3] A. B. Gridnev,[3] D. V. Kalinkin,[1] L. I. Koroleva,[1] N. G. Kozlenko,[3] V. S. Kozlov,[3] A. G. Krivshich,[3] B. V. Morozov,[1] V. M. Nesterov,[1] D. V. Novinsky,[3] V. V. Ryltsov,[1] M. Sadler,[4] B. M. Shurygin,[1] I. I. Strakovsky,[2] A. D. Sulimov,[1] V. V. Sumachev,[3] D. N. Svirida,[1] V. I. Tarakanov,[3] V. Yu. Trautman,[3] and R. L. Workman[2]
(EPECUR Collaboration and GW INS Data Analysis Center)

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

4277 $d\sigma/d\Omega$:
800 – 1243 MeV/c
40 – 122 deg

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

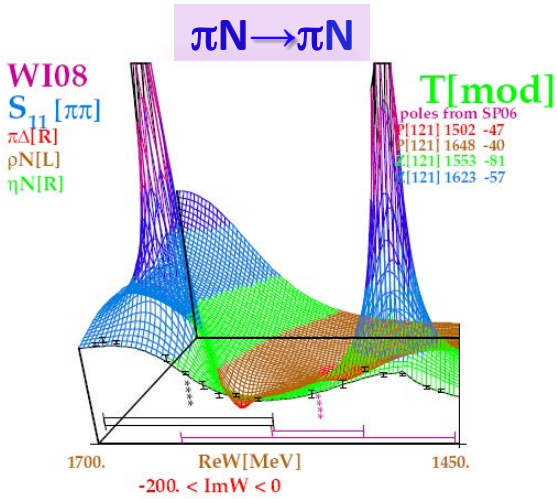
2638 $d\sigma/d\Omega$:
918 – 1240 MeV/c
40 – 122 deg

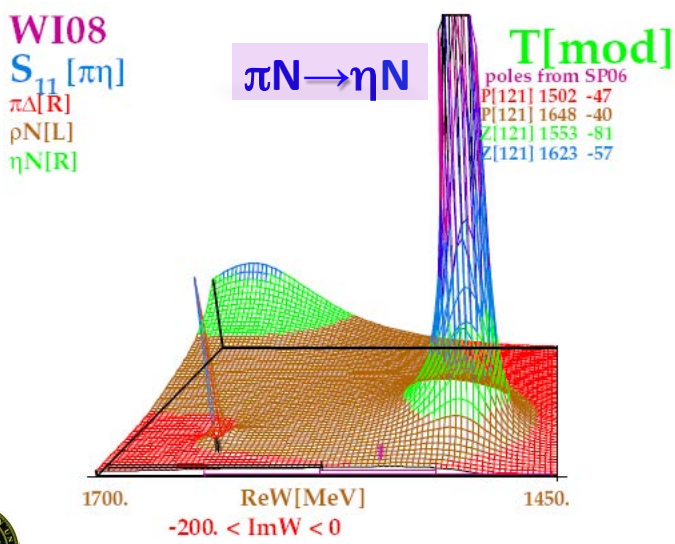


- **CMB** analysis significantly more **predictive** when compared to versions of **KH** analyses.

Predictions: WI08, KH80, KA84, CMB

Determination Pole Positions & Residues for πN scattering amplitudes





- **Interpretation** of **PW amplitudes** not simple.
- **Resonances** found through search for **Poles** in **complex plane and** NOT put in by hand, contrary to **BW** parameterization.
- There is **shift** between **Pole** & **BW mass** (**0** − **10%**) & **width**.

SAID for Pion PhotoProduction

P. Mattione *et al*, Phys. Rev. C **96**, 035204 (2017)

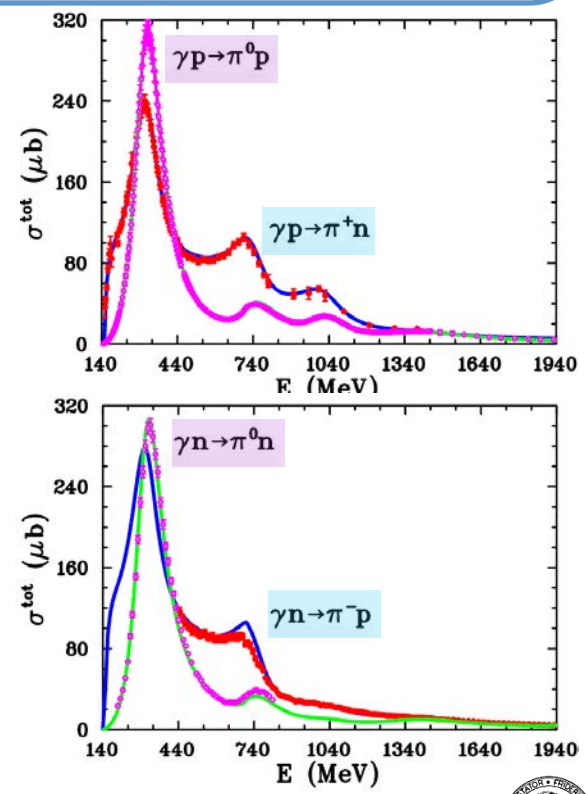
- Data driven (model independent) analysis [No Adhoc resonances in]
- Energy dependent MA27
- E = 145 – 2700 MeV [W = 1080 – 2460 MeV]
- PWs = 60 [EM multipoles] [J < 6]
- Prms = 210
- Constraint: Born [no free parameters to fit] πN-PWA [no theoretical input]

GW SAID PWA facility allows one
- To fit new data vs SAID Database.
- To calculate acceptance & flux for proposals and papers.
- To estimate systematics.
- To provide realistic event generator for MC simulations.

Reaction	Data (Pol)	χ^2
$\gamma p \to \pi^0 p$	25,540 (23 %)	55,529
$\gamma p \to \pi^+ n$	8,959 (38 %)	20,736
$\gamma n \to \pi^- p$	11,590 (4 %)	16,453
$\gamma n \to \pi^0 n$	364 (59 %)	1,540
Total	46,453	94,258

34,499 data

11,954 data



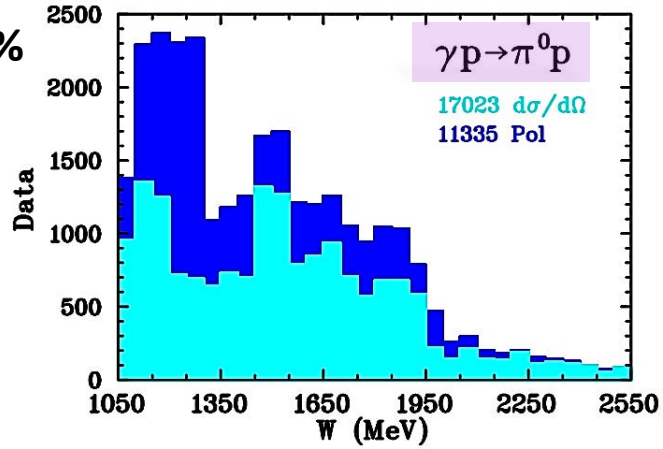
- Pion photoproduction on the neutron much less known, 35%.

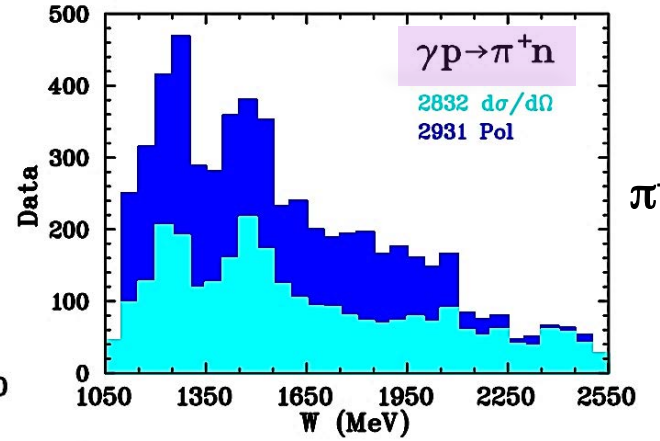
- There is disbalance between π^0 & π^+ data, 35%.

World Progress in Pion PhotoProduction

1996–2018

Pol = 40%

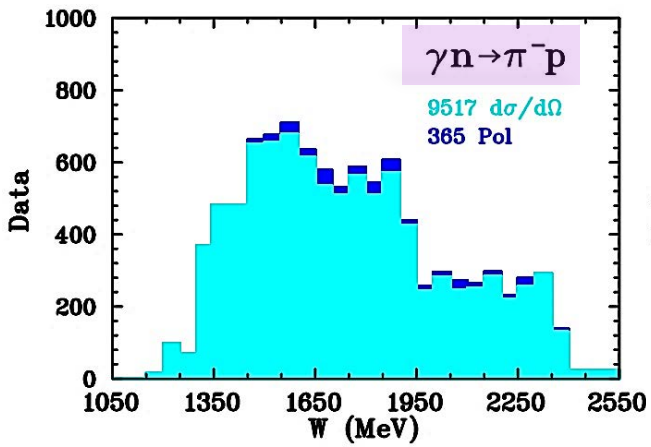


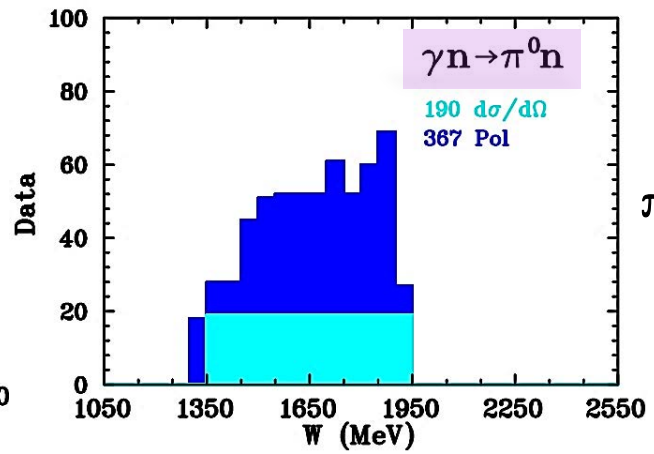


Pol = 51%

π^+n/π^0p = 20%

Pol = 4%





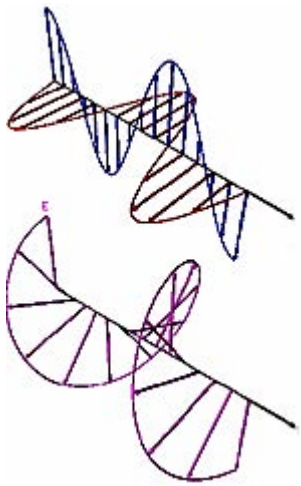
Pol = 66%

π^-p/π^0n = 6%

- There is disbalance between **π^0p** & **π^+n** data, **π^+n / π^0p=20%**.
- Pion photoproduction on **neutron** much less known, **n /p=31%**.

"Complete Experiment" for Pion PhotoProduction

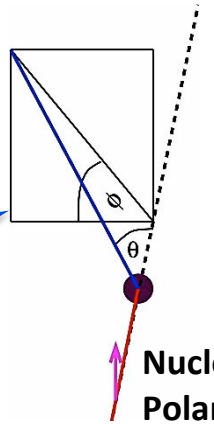
- There are **16** non-redundant observables.
- They are **not completely independent** from each other.



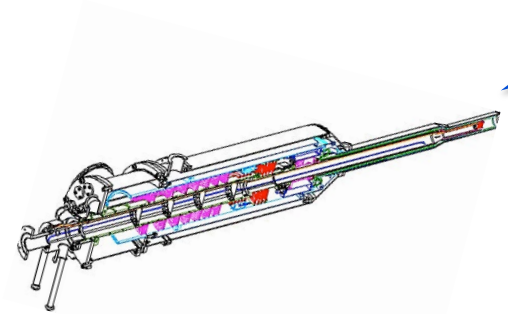
Linear Polarized *Beam*

Circular Polarized *Beam*

$$\vec{\gamma}\ \vec{N} \rightarrow \vec{N}\ \pi$$



Nucleon *Recoil* **Polarization**



Longitudinally Polarized Nucleon *Target*

Transverse Polarized Nucleon *Target*

1 un-pol measurement: **$d\sigma/d\Omega$**
3 single pol measurements: **Σ, T, P**
12 double pol measurements: **E, F, G, H, C_x, C_z, O_x, O_z, L_x, L_z, T_x, T_z**
18 triple polarization asymmetries
[9 for linear pol beam]
[9 for circular pol beam]
13 of them are non-vanishing

A. Sandorfi *et al,* AIP Conf. Proc. **1432**, 219 (2012)
K. Nakayama, arXiv:1903.05015, 2019

Single Pion PhotoProduction on "Neutron" Target

- Accurate evaluation of **EM** couplings **$N^* \rightarrow \gamma N$** & **$\Delta^* \rightarrow \gamma N$** from **meson photoproduction** data remains paramount in **hadron** physics.

- Only with good data on both **proton** & **neutron targets**, one can hope to disentangle **isoscalar** & **isovector EM** couplings of various **N^* & Δ^*** resonanc K.M. Watson, Phys Rev **95**, 228 (1954); R.L. Walker, Phys Rev **182**, 1729 (1969) as well as **isospin** properties of non-resonant **background amplitudes**.

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

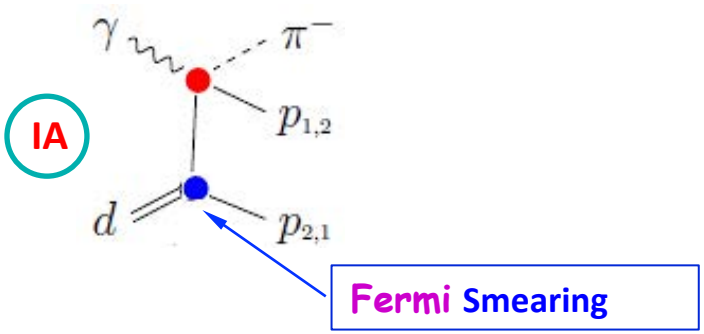
- **Radiative decay** width of **neutral baryons** may be extracted from **π^-** & **π^0** photoproduction off **neutron**, which involves **bound neutron target** & needs use of **model-dependent nuclear** (**FSI**) **corrections**.

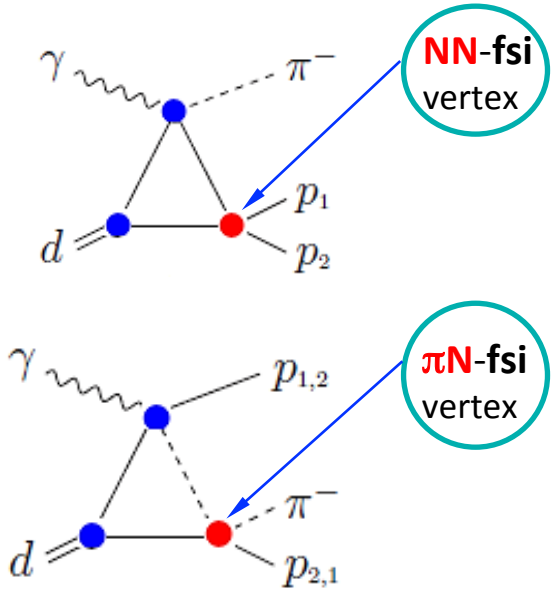
A.B. Migdal, JETP **1**, 2 (1955); K.M. Watson, Phys Rev **95**, 228 (1954)

FSI for $\gamma d \rightarrow \pi p N$ ⇒ $\gamma n \rightarrow \pi N$

V. Tarasov, A. Kudryavtsev, WJB, H. Gao, I. Strakovsky, Phys Rev C **84,** 035203 (2011)
V. Tarasov, A. Kudryavtsev, WJB, B. Krusche, I. Strakovsky, M. Ostrick, Phys At Nucl **79**, 216 (2016)

- **FSI plays critical role in state-of-the-art analysis of $\gamma n \rightarrow \pi N$ data.**
- For $\gamma n \rightarrow \pi N$, effect is **5%** – **60%**. It depends on (**E**,θ).





Input: **SAID**: $\gamma N \rightarrow \pi N$, $\pi N \rightarrow \pi N$, $NN \rightarrow NN$ amplitudes for **3** leading terms.
DWF: full Bonn NN Potential (there is no sensitivity to DWF).

$$R = (d\sigma/d\Omega_{\pi p})/(d\sigma^{IA}/d\Omega_{\pi p}) \Rightarrow \frac{d\sigma}{d\Omega}(\gamma n) = R^{-1}\frac{d\sigma}{d\Omega}(\gamma d)$$

FSI for $\gamma d \rightarrow \pi^0 np$ ⟹ $\gamma n \rightarrow \pi^0 n$ & $\gamma p \rightarrow \pi^0 p$

V. Tarasov, A. Kudryavtsev, WJB, B. Krusche, I. Strakovsky, M. Ostrick, Phys At Nucl **79**, 216 (2016)

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

- **$\gamma n \rightarrow \pi^0 n$** case is much more complicated vs. **$\gamma n \rightarrow \pi^- p$** because **$\pi^0$** can come from both **$\gamma n$** & **$\gamma p$ initial** interactions.

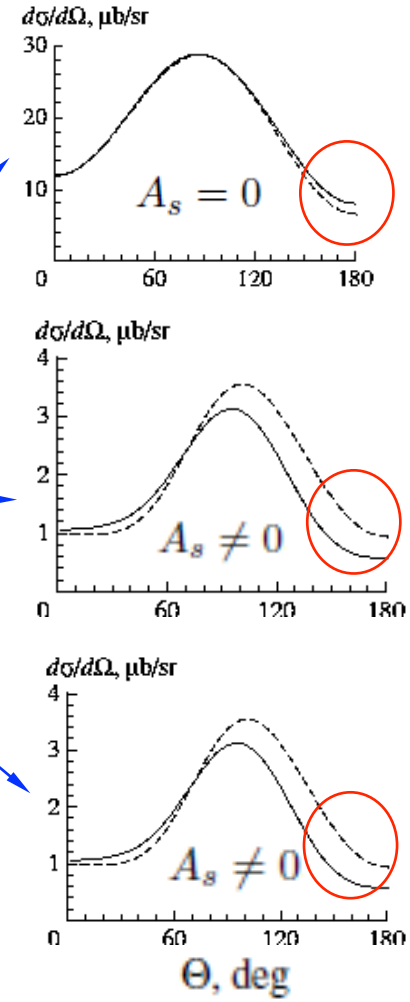
$$A(\gamma p \rightarrow \pi^0 p) = A_v + A_s$$
$$A(\gamma n \rightarrow \pi^0 n) = A_v - A_s$$

- The corrections for both target nucleons are **practically identical** for **π^0** production in energy range of **$\Delta(1232)3/2^+$** due to **isospin structure** of **$\gamma N \rightarrow \pi N$** amplitude:

isoscalar *isovector*

$A_s = 0$ or $A_v = 0$

$$R_n = R_p$$



$\gamma p \rightarrow \pi^0 p$ (solid curves)

$\gamma n \rightarrow \pi^0 n$ (dashed curves)

$\Delta(1232)3/2+$

N(1440)1/2+

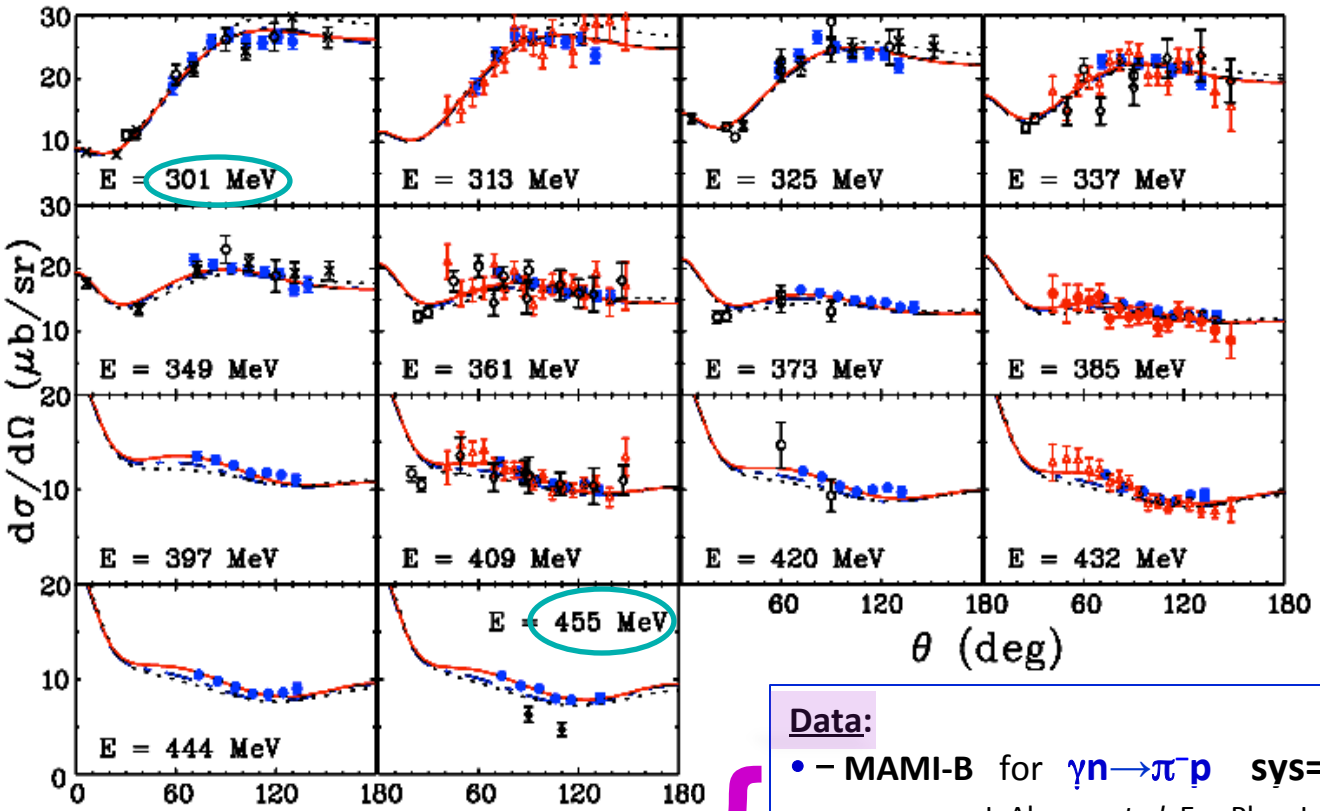
N(1535)1/2−

- In general case, $R_n \neq R_p$

MAMI-B for $\gamma n \to \pi^- p$ around Δ

WJB, A.E. Kudryavtsev, P. Pedroni, I. Strakovsky, V.E. Tarasov, R.L. Workman, Phys Rev C **86**, 065207 (2012)

- **MAMI-B** data for $\gamma n \to \pi^- p$ (including **FSI** corrections) & previous hadronic data for $\pi^- p \to n\gamma$ appear to **agree well**.



SAID-PE12
SAID-SN11
MAID07

FSI included

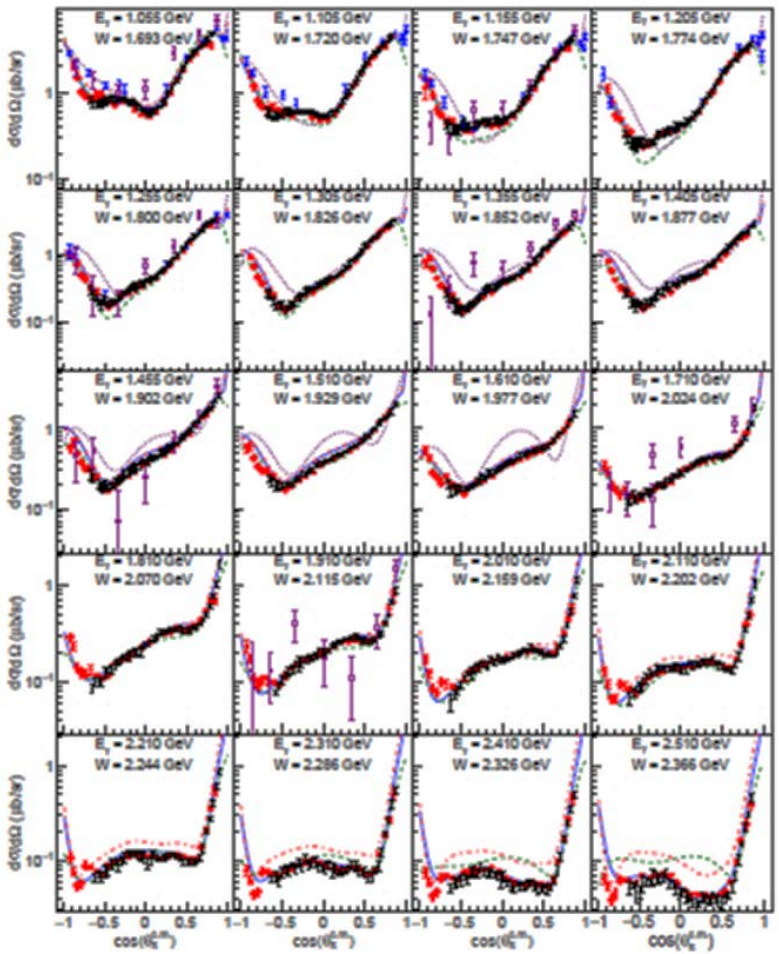
- *T-invariance is good as 2 x 10^{-3}*

Data:

- – **MAMI-B** for $\gamma n \to \pi^- p$ **sys=2%**
  J. Ahrens *et al*, Eur Phys J A **44**, 189 (2010)
- Δ – **CB@BNL** for $\pi^- p \to n\gamma$ **sys=5%**
  A. Shafi *et al*, Phys Rev C **70**, 035204 (2004)
- o – **TRIUMF, CERN, LBL, LAMPF** for $\pi^- p \to n\gamma$

g13 for $\gamma n \rightarrow \pi^- p$ above 0.5 GeV

P. Mattione *et al*, Phys. Rev. C **96**, 035204 (2017)



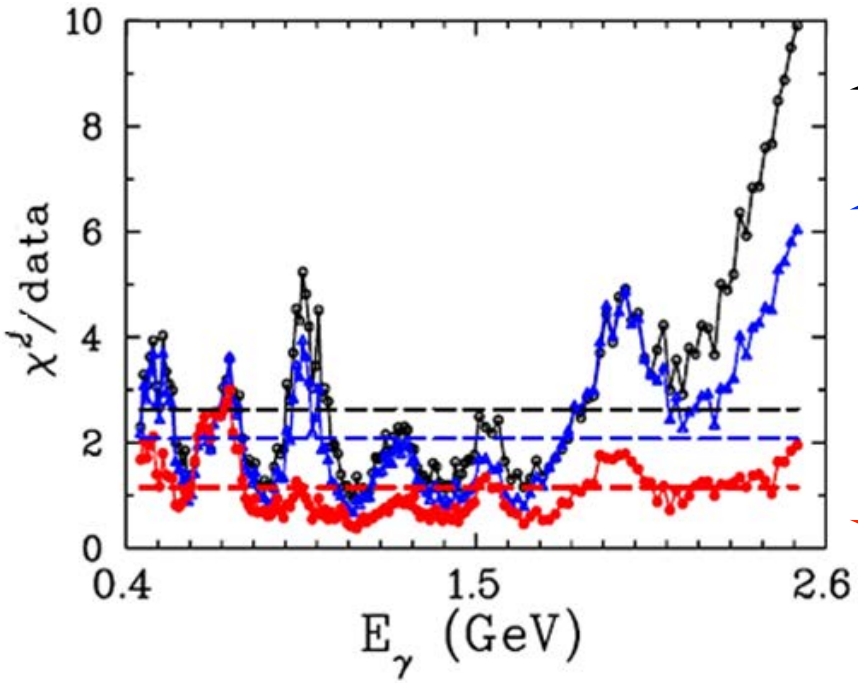
E = 445−2510 MeV
π^-p: 8428 dσ/dΩ

- These **data** a factor of nearly **three** increase in world statistics for this channel in this kinematic range.

FSI included

Comparison of Previous & New Fits for g13

MA27: P. Mattione *et al*, Phys. Rev. C **96**, 035204 (2017)
PR15: P. Adlarson *et al*, Phys Rev C **92**, 024617 (2015)



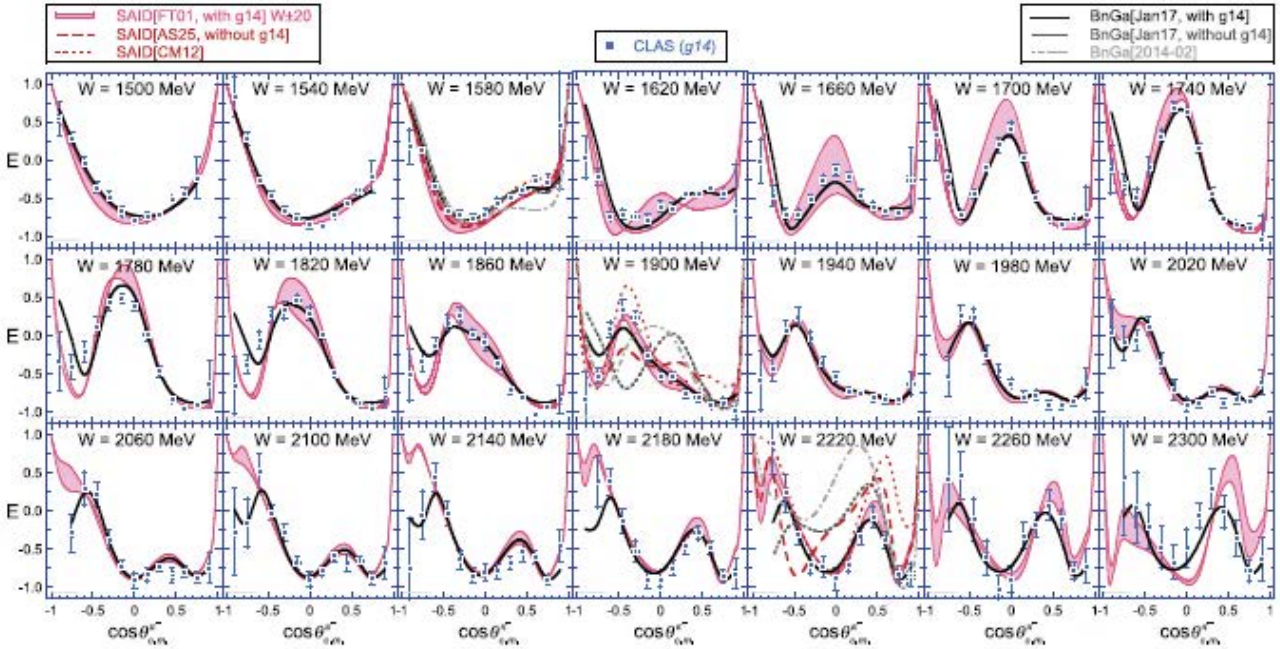
- Recent SAID **PR15** applied to **g13** data **without** & **with** **FSI** corrections.

- New SAID **MA27** fit obtained after adding new **g13** data **with FSI** corrections.

- Obviously, **FSI** plays important role in $\gamma n \rightarrow \pi^- p$ $d\sigma/d\Omega$ determination.
- Same for $\gamma n \rightarrow \pi^0 n$ $d\sigma/d\Omega$.

g14 Data Impact for Neutron $S = 0$ & $I = ½$ Couplings

D. Ho *et al*, Phys Rev Lett **118**, 242002 (2017)

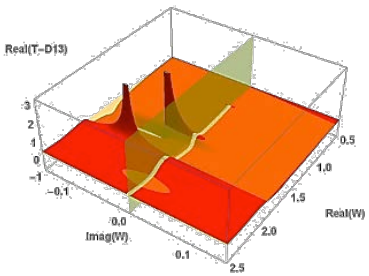


E = **730–2345** MeV
π⁻p: **266 E**

Assumption is FSI is small

g13 Impact for Neutron $S = 0$ & $I = ½$ Couplings

MA27: P. Mattione *et al*, Phys. Rev. C **96**, 035204 (2017)



- Selected **photon decay amplitudes N*→γn** at resonance **poles** are determined for **the first time**.

g13

Moduli & phases

BW neutron photo-decay amplitudes

Resonance	Coupling	MA27 modulus, phase	GB12 [g10]	BG2013 [g10]	MAID2007	Capstick	PDG particle data group
N(1440)1/2$^+$	$A_{1/2}(n)$	0.065±0.005, 5°±3°	0.048± 0.004	0.043±0.012	0.054	-0.006	0.040±0.010
N(1535)1/2$^-$	$A_{1/2}(n)$	-0.055±0.005, 5°±2°	-0.058± 0.006	-0.093±0.011	-0.051	-0.063	-0.075±0.020
N(1650)1/2$^-$	$A_{1/2}(n)$	0.014±0.002, -30°±10°	-0.040± 0.010	0.025±0.020	0.009	-0.035	-0.050±0.020
N(1720)3/2$^+$	$A_{1/2}(n)$	-0.016±0.006, 10°±5°		-0.080±0.050	-0.003	0.004	-0.080±0.050
N(1720)3/2$^+$	$A_{3/2}(n)$	0.017±0.005, 90°±10°		-0.140±0.065	-0.031	0.011	-0.140±0.065

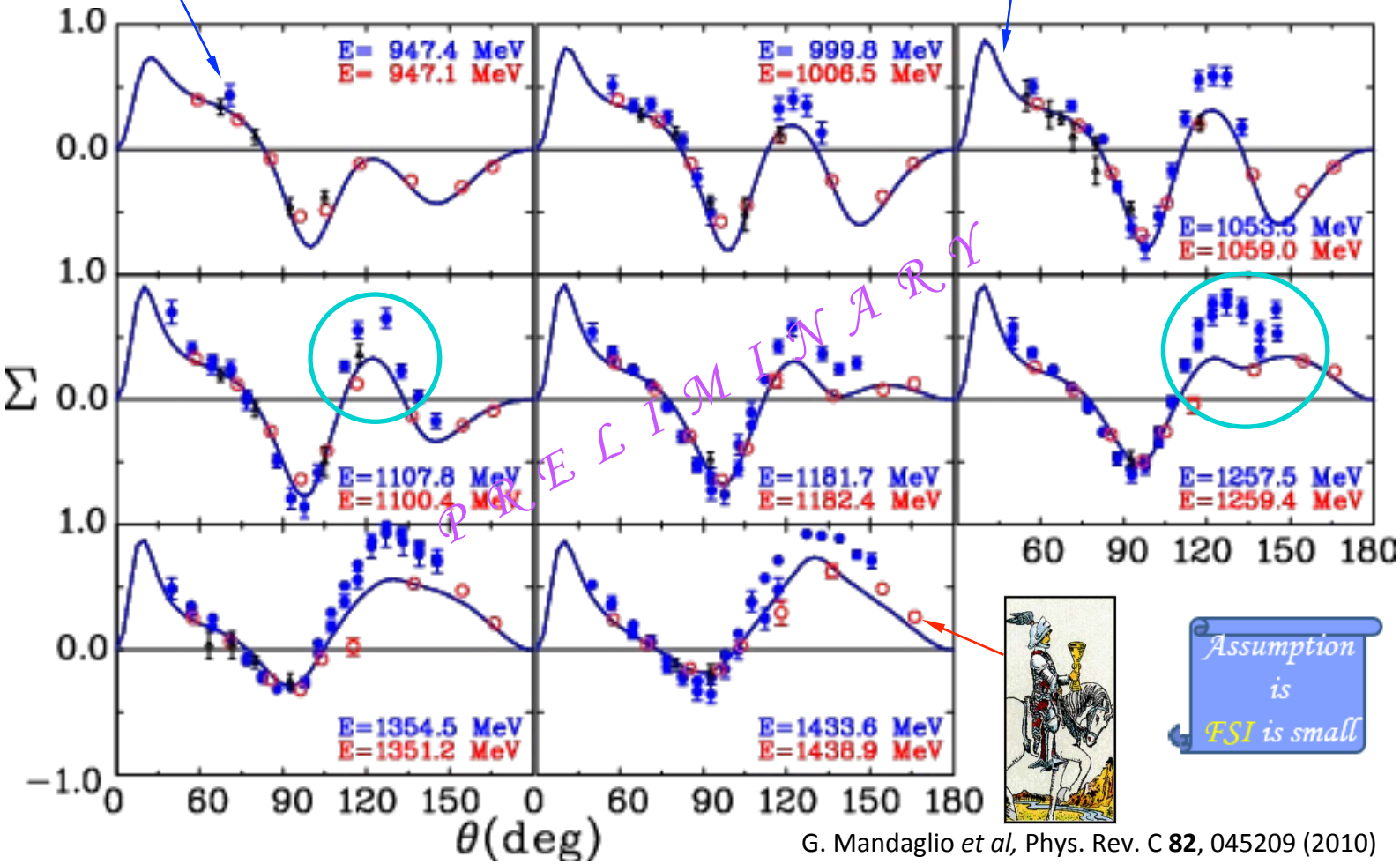
MA27

MAID

$g13\ \Sigma$ for $\vec{\gamma} n \rightarrow \pi^- p$

D. Sokhan *et al*, in progress

P. Mattione *et al*, Phys. Rev. C **96**, 035204 (2017)



Assumption is FSI is small

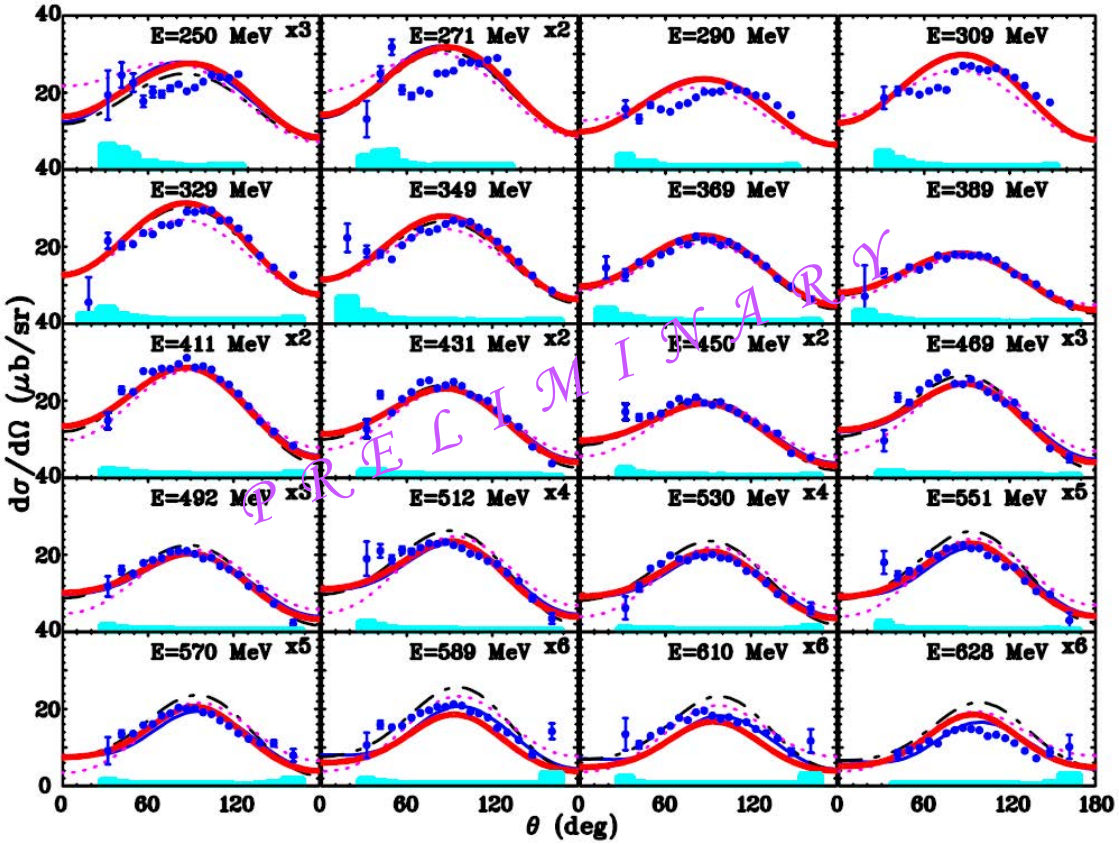
G. Mandaglio *et al*, Phys. Rev. C **82**, 045209 (2010)

Meson Production off Deuteron with CB

M. Martemianov *et al*, in progress

- Differential cross sections for $\gamma n \rightarrow \pi^0 n$.

E = **200 – 800** MeV
π^0**n**: **523** $d\sigma/d\Omega$



FSI included

- Data up to **E** = **1500** MeV are coming.

PDG particle data group

N(1680)5/2$^+$→Nγ
pA$^{3/2}$=+133 ±12 **pA$^{1/2}$**=−15 ±6
nA$^{3/2}$=−33 ±9 **nA$^{1/2}$**=+29 ±10
- It couples **weakly** to **neutron**.

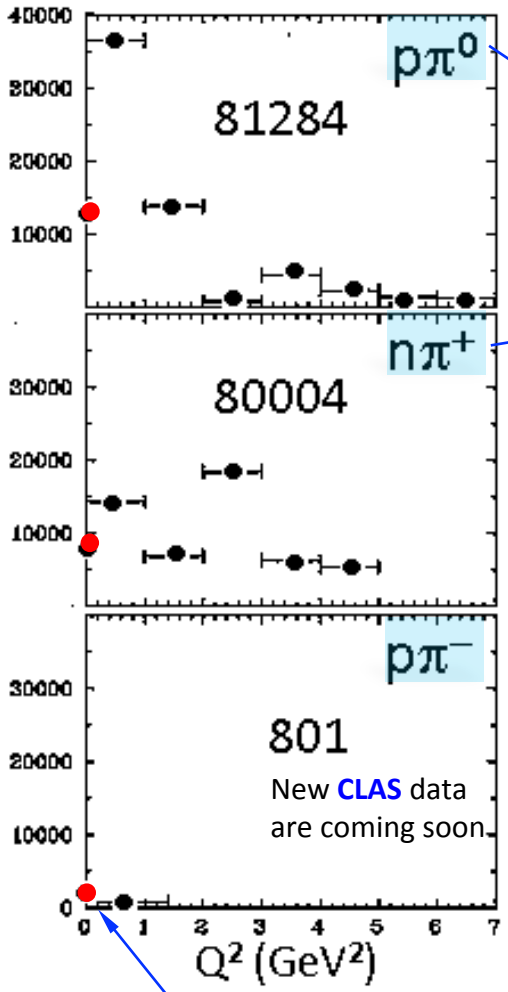
N(1675)5/2$^-$→Nγ
pA$^{3/2}$=+20 ±5 **pA$^{1/2}$**=+19 ±8
nA$^{3/2}$=−85 ±10 **nA$^{1/2}$**=−60 ±5
- It couples **strongly** to **neutron**.

- New **dσ/dΩ**s by **A2** contribution is **200%** to previous world π^0**n** data.

World Neutral & Charged PionEPR Data

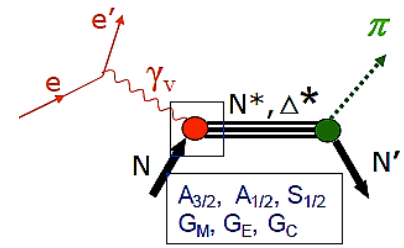
R. Arndt, WJB, M. Paris, I. Strakovsky, R. Workman, Chin Phys C **33**, 1063 (2009)

W < 2 GeV @ 2009



Pion PhotoProduction

- **85**% of them are clas data



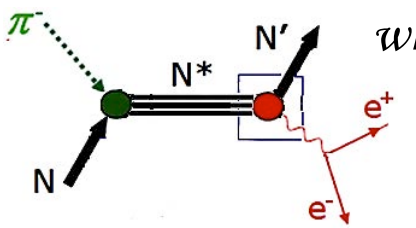
reaction	data	χ^2
$\gamma^* p \to \pi^0 p$	55,766	81,284
$\gamma^* p \to \pi^+ n$	51,312	80,004
redundant	14,772	17,375
total	124,453	178,663
$\gamma p \to \pi N$	24,888	50,684
all photo	159,341	229,317
$\pi N \to \pi N$	31,876	57,255
all πN	191,217	286,572

- **Problem 1:18** new Multipoles.
  [Parameterization as E, M]
- **Problem 2:** Q^2 dependence.

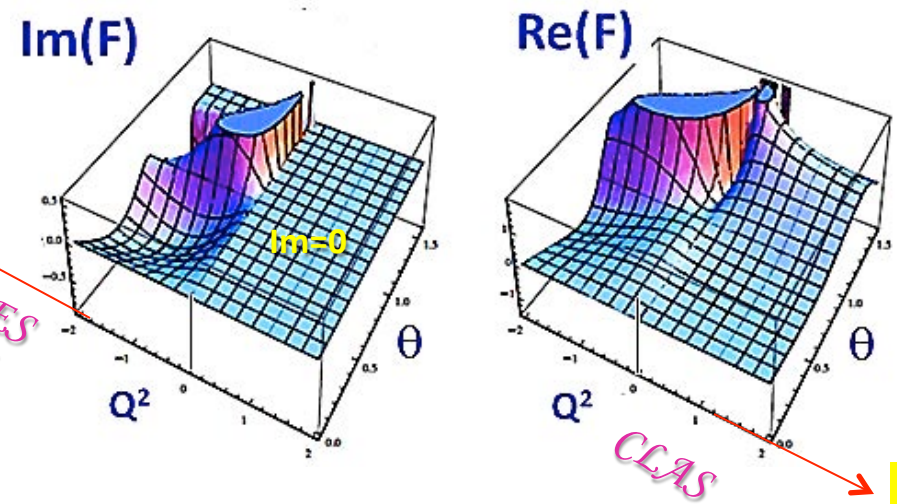
Form-Factor Measurements

- *Inverse Pion Electroproducion is only process which allows determination of EM nucleon & pion form factors in intervals:*

$0 < k^2 < 4\,M^2$ $\qquad$ $0 < k^2 < 4\,m_\pi^2$

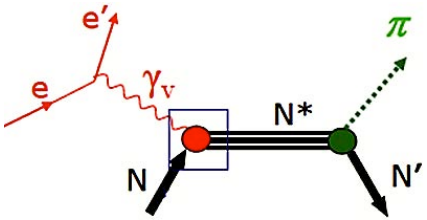


which are kinematically unattainable from e^+e^- initial states.



Time-like

Space-like

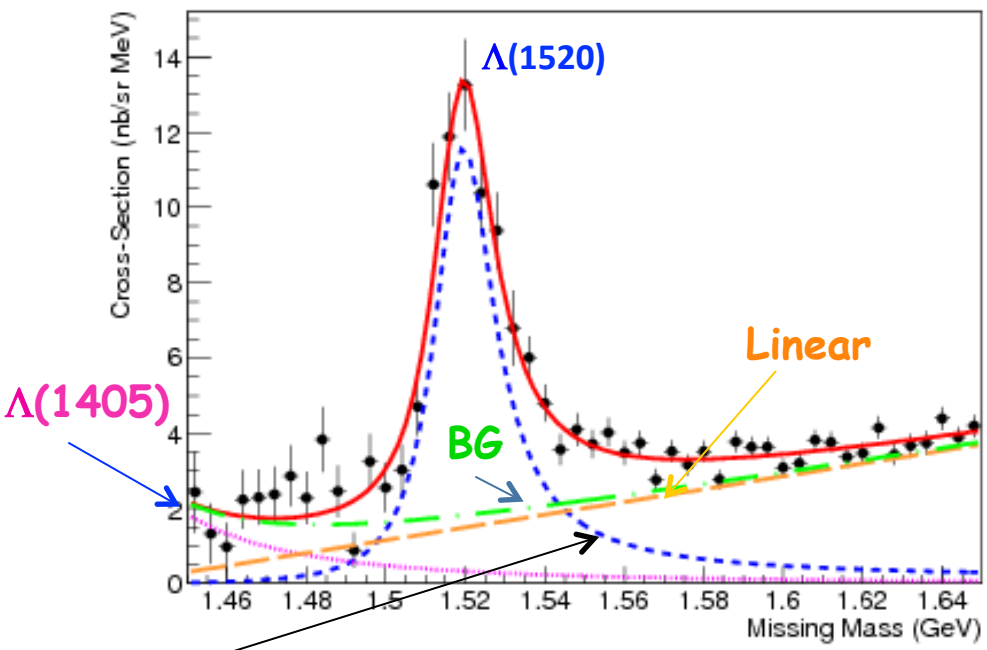


- $\pi^- p \rightarrow e^+ e^- n$ measurements will significantly complement current **electroproduction**.
- $\gamma^* N \rightarrow \pi N$ study for evolution of **baryon** properties with increasing momentum transfer by investigation of case for ***time-like virtual photon***.

Hall A Results for Λ(1520)

Y. Qung *et al,* Phys Lett B **694**, 123 (2010)

- e + p ⟶ e' + $K^+(\pi^+,K^-)$ + MM [**Hall A**: **E** = **5.09** GeV **Q^2** ~ **0.1** $(GeV/c)^2$ **Statistics** = **13k**]
- In fitting, we applied MM resolution, σ = **1.5** MeV
- We did not take into account any **Res** with M > **1670** MeV



BW [Asymmetry form due to Γ(W)]

- **BW** with **Least-Squares** & **Log-Likelihood**

  M = 1520.4 ± 0.6 ± **1.0** MeV
  Γ= 18.6 ± 1.9 ± **1.0** MeV

- **Pole** position

  M = 1518.3 MeV
  Γ= 17.2 MeV

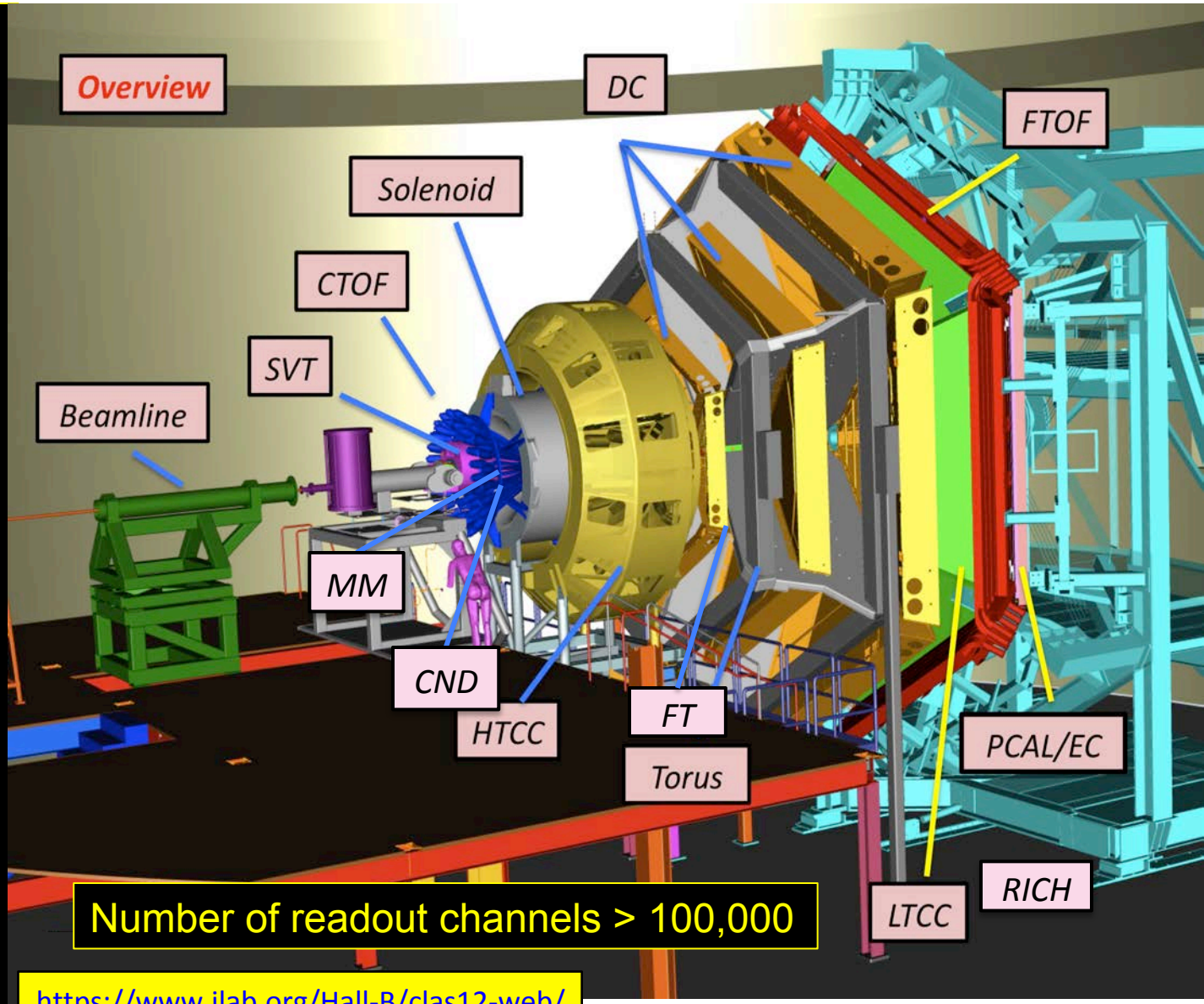
- Having **BW** mass & width, we also give **first** estimate of **pole** parameters for **Λ(1520)**.
- **Pole** values for both mass & width tend to be lower than **BW** values.

CLAS12 Detector Systems

Forward Detector (FD)
- TORUS magnet
- HT Cherenkov Counter
- Drift chamber system
- LT Cherenkov Counter
- Forward ToF System
- Pre-shower calorimeter
- E.M. calorimeter
- Forward Tagger
- RICH detector

Central Detector (CD)
- Solenoid magnet
- Silicon Vertex Tracker
- Central Time-of-Flight
- Central Neutron Detector
- MicroMegas

Beamline
- Diagnostics
- Shielding
- Targets
- Polarimeter
- Faraday Cup



Number of readout channels > 100,000

https://www.jlab.org/Hall-B/clas12-web/

Cross Section Estimations for Jefferson Lab (RGA)

E12-11-005a

Exp sensitivity: 50 – 100 pb

- **Andrey Afanasev:**

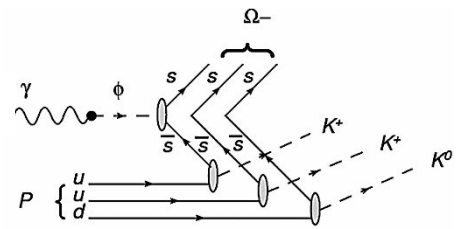
Translation hadronic into EM Xsec:

- SLAC $K^-p \to \Xi^- X$ Xsec,
- ϕ-VMD,
- CLAS $\gamma p \to \Xi^- KK$ Xsec

➡ **σ ~ 400 pb**

- SLAC $K^-p \to \Xi^- X$,
- $K^-p \to \Omega^- X$ Xsec,
- CLAS $\gamma p \to \Xi^- KK$ Xsec

➡ **σ ~ 500 pb**

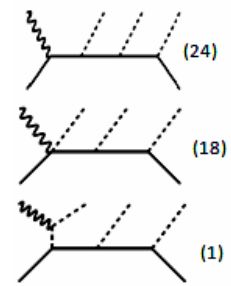


- **Winston Roberts:**

Phenomenological Lagrangian:

- Not all couplings known
- Born terms are in

➡ **σ ~ 200–1000 pb**

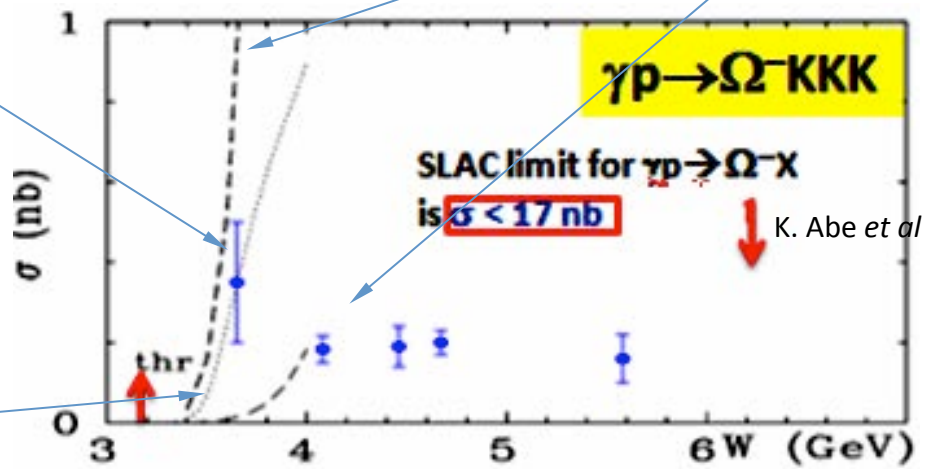


- **Vitaly Shklyar:**

Effective Lagrangian:

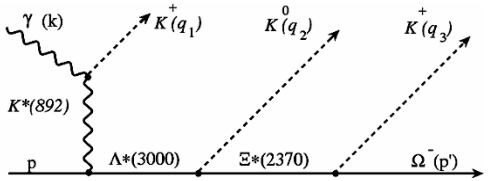
There are three additional diagrams obtained by permutations of final Kaon momenta

➡ **σ ~ 2000 pb**

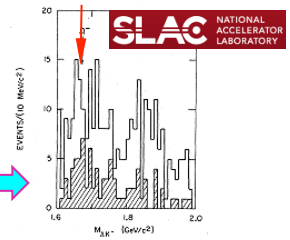


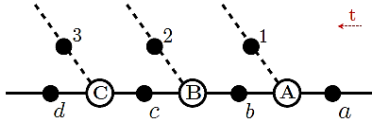
K. Abe *et al* Phys Rev D **32**, 2869 (1985)

- Alternative Xsec estimation came recently, it resulted in ~**1 pb**.



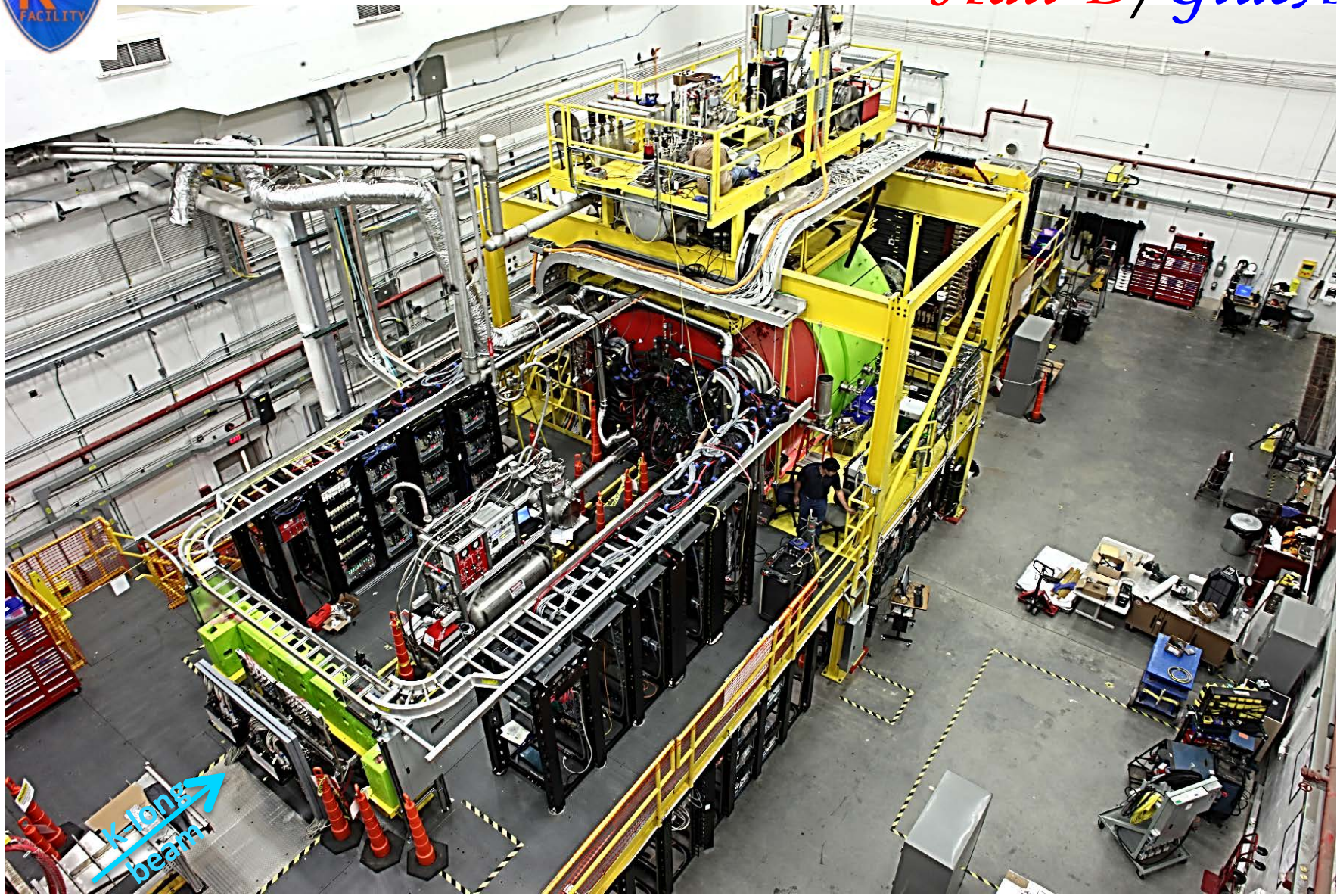
No Ω-signal is seen ➡



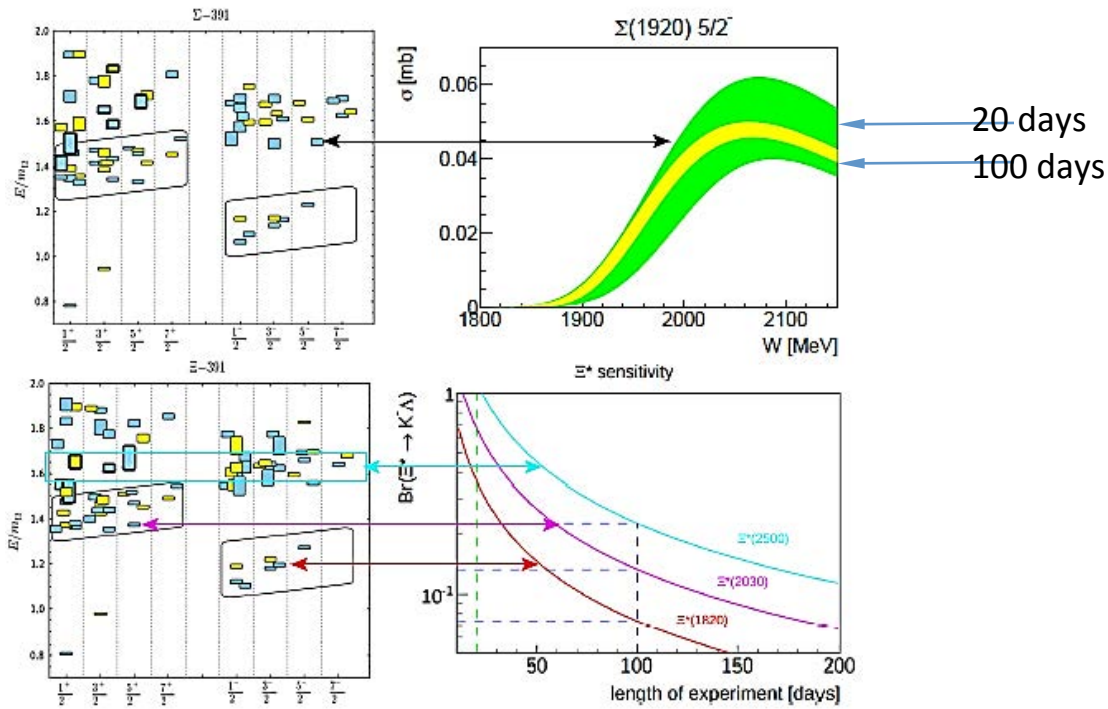


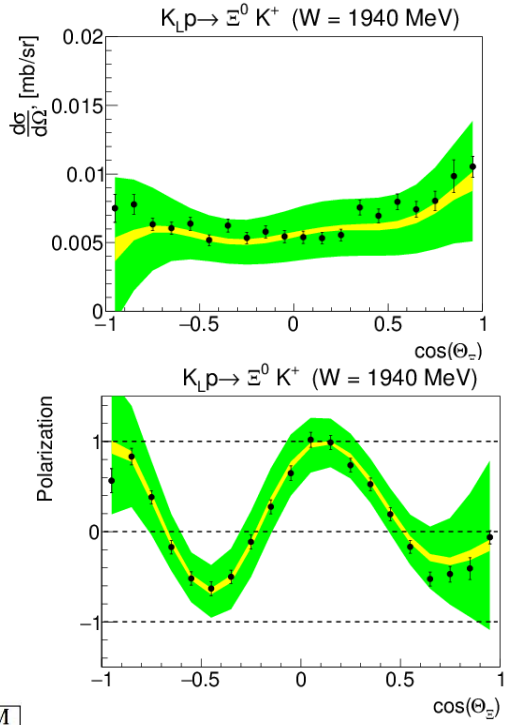
H. Y. Ryu *et al*, PoS Hadron **2013**, 140 (2013)

Hall D/GlueX

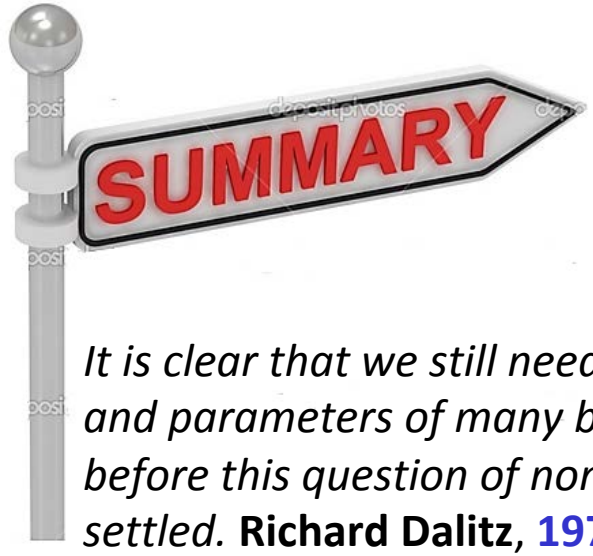


Expected KLF Measurements





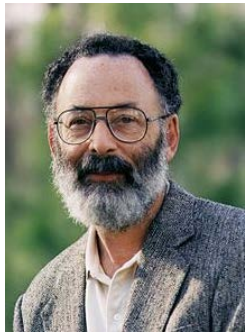
Resonance	20 days: M, Γ	100 days: M, Γ	PDG2018: M, Γ	LQCD: M
$\Sigma(1920)5/2^-$	1977±21±25 327±25±25	1923±10±10 321±10±10		2027 2487 2659 2781
$\Sigma(2030)7/2^+$	1981±30±30 350±80	1930±20±30 400±40	2030±10 180±30	2686 2709 2793 2806



Spectroscopy of Baryons

It is clear that we still need much more information about the existence and parameters of many baryon states, especially in the N=2 mass region, before this question of non-minimal SU(6) x O(3) super-multiplet can be settled. **Richard Dalitz**, **1976**.

The first problem is the notion of a resonance is not well defined. The ideal case is a narrow resonance far away from the thresholds, superimposed on slowly varying background. It can be described by a Breit-Wigner formula and is characterized by a pole in the analytic continuation of the partial wave amplitude into the low half of energy plane. **Gerhard Höhler, 1987**.



*Why N*s are important – The first is that nucleons are the stuff of which our world is made. My second reason is that they are simplest system in which the quintessentially non-Abelian character of QCD is manifest. The third reason is that history has taught us that, while relatively simple, Baryons are sufficiently complex to reveal physics hidden from us in the mesons*. **Nathan Isgur**, **2000**.

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