# *Why Intense Pion Beams at GSI ?*

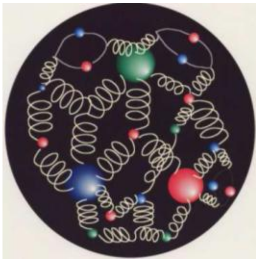
*Igor Strakovsky*

*The George Washington University*

# Mission of HADES

## There are Several Attractive & High Profile Tasks:

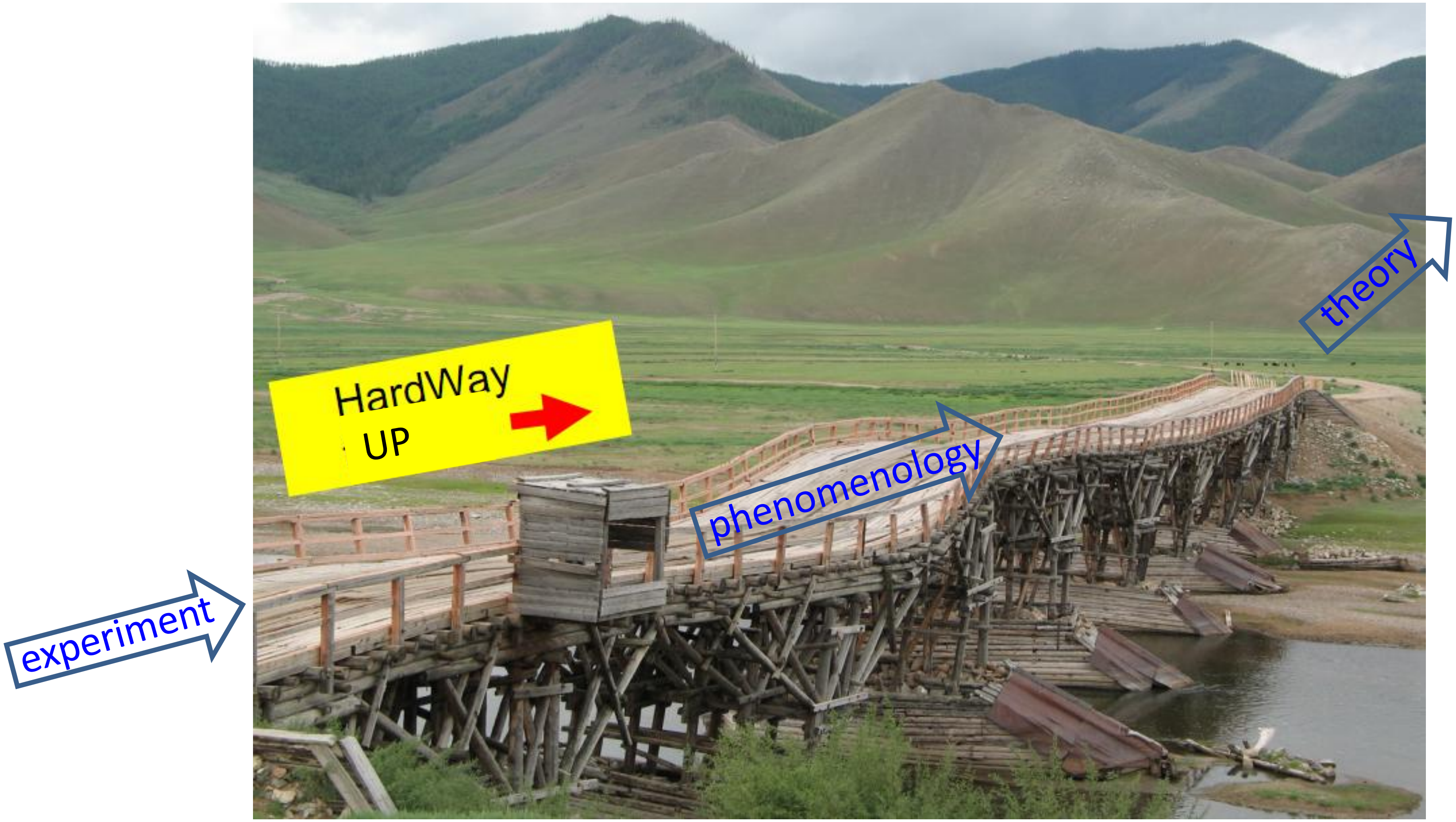
- **$\pi N \rightarrow \pi N$**, **$\eta N$**, **$\eta' N$**, **$\phi N$**, **$\omega N$**, **$K\Lambda$**, & **$K\Sigma$** [including **polarized** measurements for **$K\Lambda$** & **$K\Sigma$**].
- **$\pi N \rightarrow \pi\pi N$** [$\pi\Delta$ & **$\rho N$** contribution].



- **Inverse Pion Electroproduction** **$\pi^- p \rightarrow e^+ e^- n$**.
- **Exotics**:
  - **N(1680)** via **$\eta N$**, **$K\Lambda$**, & **$\pi\Delta$** decay channels.
    The width of N(1680) is much less than any known non-strange N*.

- The **HADES** potential is to make a significant contribution to our knowledge of **Baryon Resonances** and properties of them.

# Phenomenology for non-strange Resonances



# PWA for non-strange Baryons & SAID Database

**Originally:** PWA arose as the technology to determine amplitude of the reaction via fitting scattering data which is a non-trivial mathematical problem
[*Solution of ill-posed problem*
– Hadamard, Tikhonov, *et al*]

Resonances appeared as a by-product
[Bound states objects with quantum numbers and mass, lifetime, *etc*]

That is the strategy of the GW/VPI πN PWA since 1987

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Data Analysis Center

Partial-Wave Analyses at GW

[ See Instructions ]

**Below 4 GeV**

[W = 1320 to 1930 MeV ]

| | | |
|---|---|---|
| 31,402 | Pion-Nucleon | |
| | Pion-Pion-Nucleon | 241,214 evts |
| 5,267 | Kaon-Nucleon | |
| | Nucleon-Nucleon | 38,162 |
| 25,660 | Pion Photoproduction | |
| | Pion Electroproduction | 113,900 |
| 9,086 | Kaon Photoproduction | |
| | Eta Photoproduction | 6,235 |
| 1,030 | Eta-Prime Photoproduction | |
| | Pion-Deuteron (elastic) | 1,914 |
| 6,083 | Pion-Deuteron to Proton+Proton | |

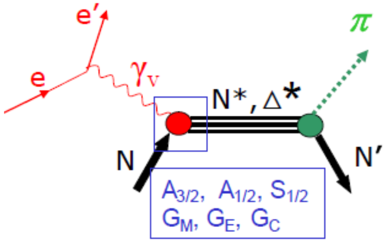
For $\pi \rightarrow 2\pi$, we use log-likelihood while for the rest – least-squares technologies

# $N^*$ and $\Delta^*$ States coupled to $\pi N$

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

- **GW SAID $N^*$ program consists of $\pi N \to \pi N$ $\Longrightarrow$ $\gamma N \to \pi N$ $\Longrightarrow$ $\gamma^* N \to \pi N$**
  **As was established by Dick Arndt on 1997**

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



- **One** of the most convincing ways to study **Spectroscopy** of **$N^*$** & **$\Delta^*$** is **$\pi N$ PWA**

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

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**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)

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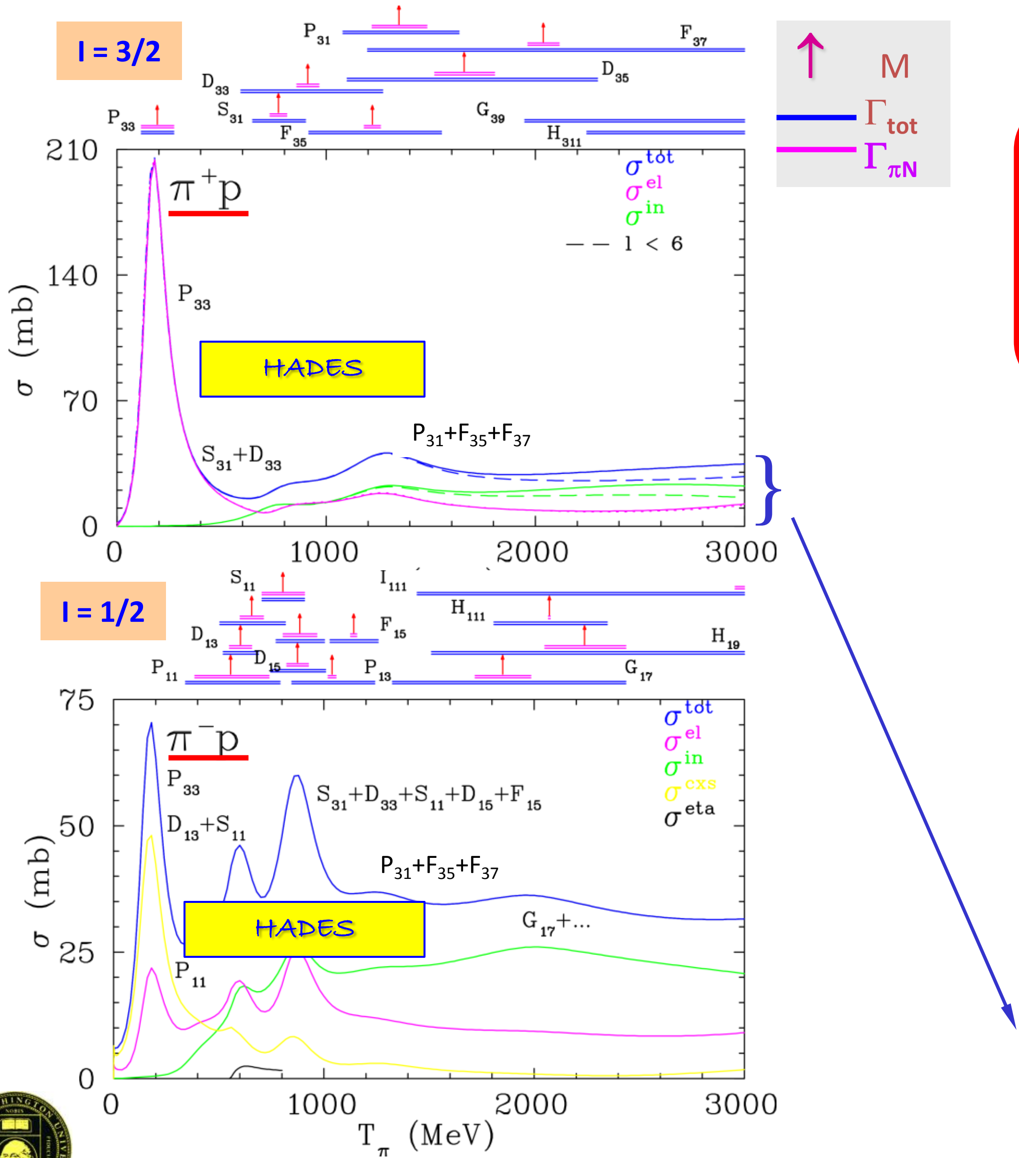
# Where is a Resonance ?

[R. Arndt, W. Briscoe, IS, R. Workman, Phys Rev C 74, 045205 (2006)]



## Here you are...

- **To determine Resonance parameters**:
  - Fit data to get $\mathbf{T_{\pi\pi}}$
  - Fit $\mathbf{T_{\pi\pi}}$ over narrow **W** range
    → **Pole** position
  - Then fit **DATA** over same W range
    → **BW** parameters

- **Main techniques**:
  - **Pole** on complex energy plane
  - **BW** fit (data, SES, or global)

- **Assertions**:
  - **Argand plot**, **Im(Re)**
  - **Speed plot**, **Sp(W) = |dT/dW|**
  - **Time-delay**, **$\tau = d\delta/dW$**
  - **Crossover energy**, **ReA = 0**
  - *etc*

- **Below W = 1900 MeV,**
  **The highest wave contribution is small**

# GW DAC Search for $N^*$ and $\Delta^*$

- We are considering a resonance as a Pole in the complex plane which is not far away from the physical axis

- **Applied** directly to the data via BW + Bckgr
- **Assume**: $S \rightarrow S_R S_B$ $\quad S_R = 1 + 2iT_R$

$$T_R = (\Gamma_e/2) \,/\, [W_R - W - i(\Gamma_e/2 + \Gamma_I/2)]$$

$$\Gamma = \Gamma_e + \Gamma_I \quad \Gamma_e = \rho_e \Gamma R \quad \Gamma_I = \rho_i \Gamma\,(1 - R)$$

$$T_B = K_B(1 - iK_B)^{-1} \quad K_B = a + b(W - W_R) + c$$

- **Map** $\chi^2[W_R,\Gamma]$ while searching all other PW parameters

  Look for significant improvement

- **Subjective variables are**
  - Energy binning
  - Strength of constraints
  - Which PW to be searched
- **Standard PWA**
  - Tends (by construction) to miss narrow Resonances with $\Gamma < 30$ MeV
  - Reveals only wide Resonances, but not too wide [$\Gamma < 500$ MeV]

    and possessing not too small BR [BR > 0.04]
- **Modified PWA**
  - Allows to put a resonance by hands with subsequent refitting the data

    Then the search will allow to see how reliable/tolerable it is

# GW DAC [SAID] for $\pi N \rightarrow \pi N$ & $\pi^- p \rightarrow \eta n$

[R. Arndt, W. Briscoe, IS, 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, πΔ, ρN, ηN]
- 3 mapping variables: $g^2/4\pi$, $a[\pi^- p]$, Eth
- PWs = 30 πN {15 [I=1/2] + 15 [I=3/2]} + 4 ηN [l < 9]
- Prms = 99 [I=1/2] + 89 [I=3/2]

- **1st generation** ('57–'79)
  **Used by CMB79 and KH84 analyses**
  **10k $\pi^\pm p$ each & 1.5k CXS**
  **17% data is polarized**
- **2nd generation** ('80–'06)
  **→SAID fits**
  **13k $\pi^\pm p$ each, 3k CXS & 0.3k $\pi^- p \rightarrow \eta n$**
  **25% data is polarized**
  **Meson Factories [LAMPF, TRIUMF, & PSI] are the main source of new measurements**
  **There is no discrimination against data**
- **3rd generation** (07'+)
  **New data may come from J-PARC, HADES, *etc***

| Reaction | Data | $\chi^2$ |
|---|---|---|
| $\pi^+ p \rightarrow \pi^+ p$ | 13,354 | 27,136 |
| $\pi^- p \rightarrow \pi^- p$ | 11,978 | 22,632 |
| $\pi^- p \rightarrow \pi^0 n$ | 3,115 | 6,068 |
| $\pi^- p \rightarrow \eta n$ | 257 | 650 |
| DR constraint | 2,775 | 671 |
| Total | 31,479 | 57,157 |

**[0 – 2600 MeV] → 10 data/MeV**

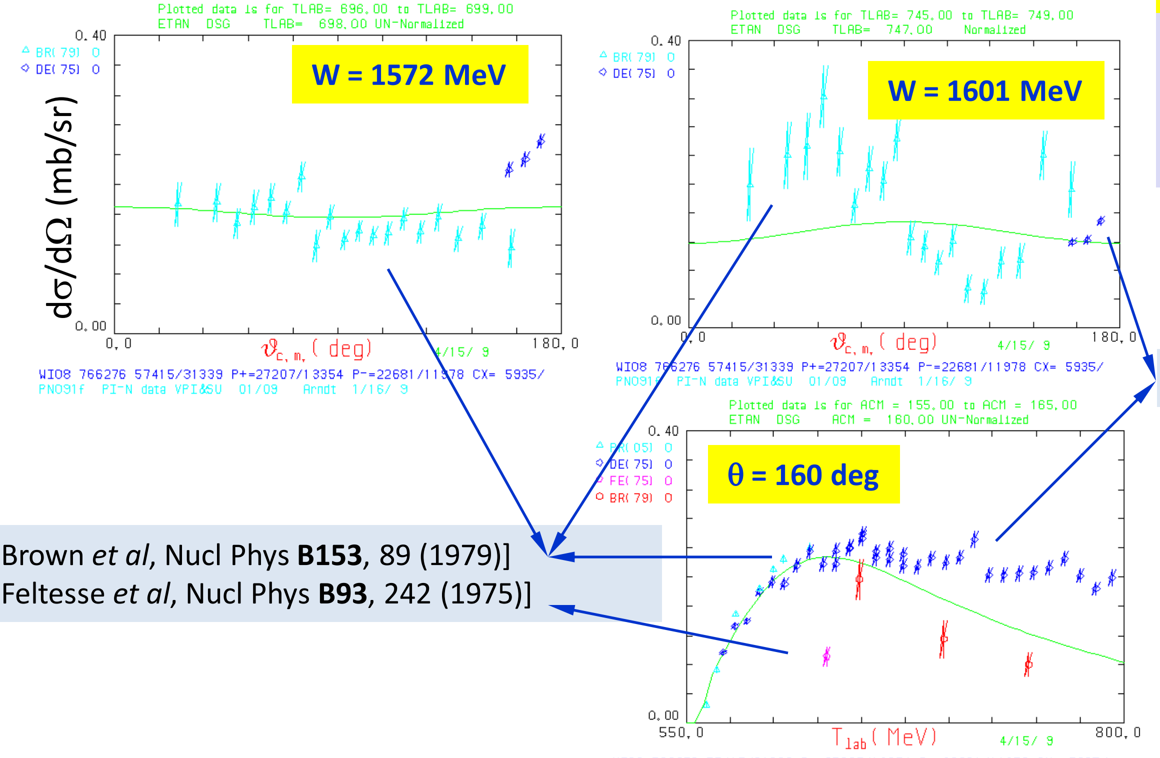
**[550 – 800 MeV] → 1 data/MeV**

**27 $\sigma^{tot}$ & 37 P data above 800 MeV → 0.03 data/MeV**

**DRs have been derived from the *first principles***

# $\pi^- p \to \eta n$ Puzzle

[R. Arndt, W. Briscoe, IS, R. Workman, Phys Rev C **74**, 045205 (2006)]



[Brown *et al*, Nucl Phys **B153**, 89 (1979)]
[Feltesse *et al*, Nucl Phys **B93**, 242 (1975)]

[Debenham *et al*, Phys Rev D **12**, 2545 (1975)]

- **Several groups evaluated data before 1992**
  - Clajus & Nefkens, πN News Lett **7**, 76 (1992)
  - Cutkosky *et al* Phys Rev D **20**, 2804 (1979)
  - Koch & Pietarinen, Nucl Phys **A336**, 331 (1980)
  - Wighman *et al* Phys Rev D **38**, 3365 (1988)

Nimrod was the 7 GeV proton synchrotron operating in the Rutherford Appleton Laboratory in UK between **1964** and **1978**

- Most of Nimrod data do not satisfy requirements
  [systematics (10% or more), momentum err (up to 50 MeV/c), and so on]
- For that reason, **SAID** is not able to use them in $\pi^- p \to \pi^- p$, $\pi^0 n$, & $\eta n$ PWAs

- **Similar evaluations for reactions with η'N, ωN, φN, KΛ, & KΣ final states are not possible because of small databases**

# Partial Waves $[L_{(2I)(2J)}]$

[R. Arndt, W. Briscoe, IS, R. Workman, Phys Rev C **74**, 045205 (2006)]

- **Overall: the difference between KH and GW/VPI is rather small but… resonances may be essentially different**

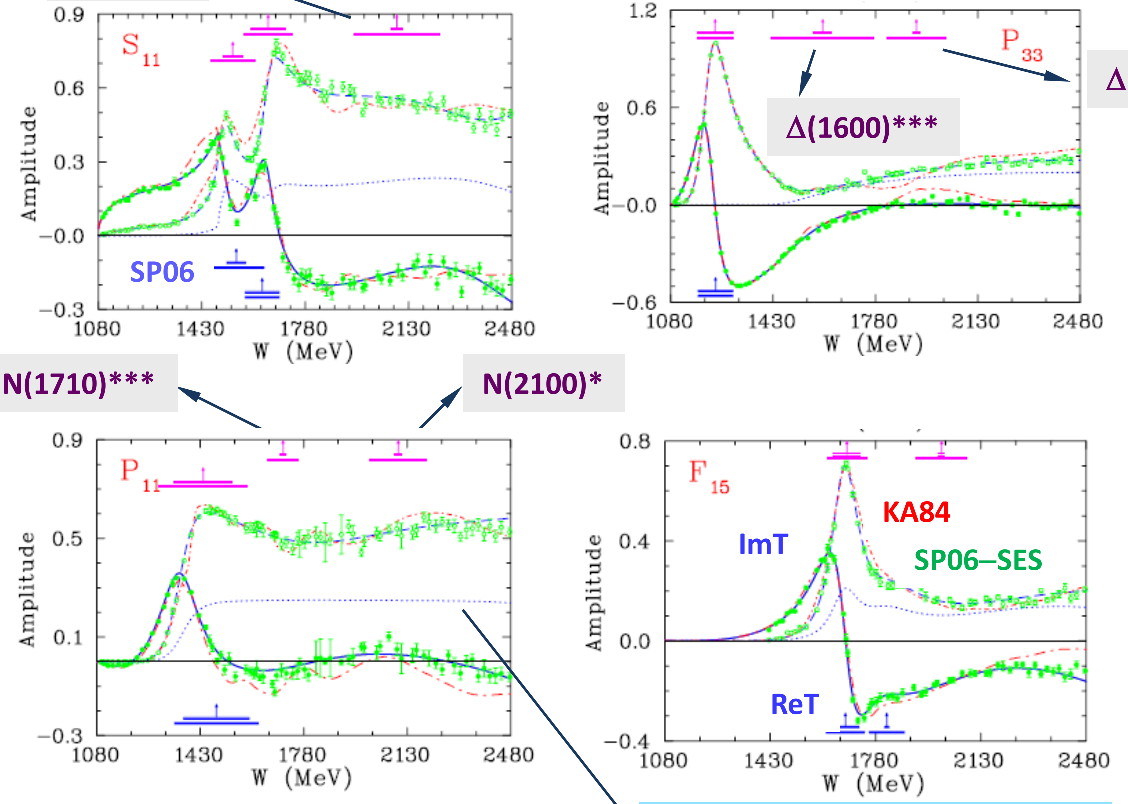
**N(2090)***

**Δ(1920)*****

**Δ(1600)*****

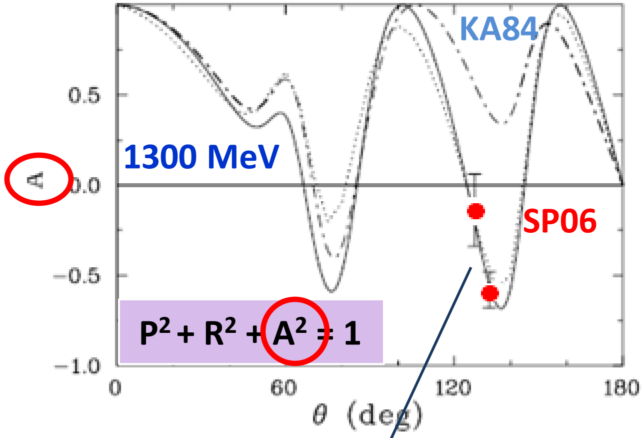
**N(1710)*****

**N(2100)***



**ImT-T*T ≥ 0 [unitarity boundary]**

- **Old solutions may be not able to reproduce new measurements**



**Data:**

**ITEP: $\pi^+p \rightarrow \pi^+p$ @ 1300 MeV**
**[I. Alekseev *et al* Phys Lett B 351, 585 (1995)]**

**PWA:**

**KA84: Karlsruhe-Helsinki fit, 1984**
**KB84: KH Barrelet corrected solution, 1997**
**SP06: GW fit, 2006**

I. Alekseev *et al* Phys Rev C **55**, 2049 (1997)

PDG10 [K. Nakamura *et al* [RPP] J Phys G **37**, 075021 (2010)]
KA84 [R. Koch, Z Phys C **29**, 597 (1985)]

# Summary of $N^*$ and $\Delta^*$ Finding from GW $\pi N$ PWA

[R. Arndt, W. Briscoe, IS, R. Workman, Phys Rev C **74**, 045205 (2006)]

- Standard PWA
  - Allows to determine the $N^*$s, $\Delta^*$s, and their quantum numbers using
    - The complex energy plane &
    - Breit-Wigner technique
  - Tends (by construction) to miss narrow Resonances with $\Gamma < 30$ MeV
  - Reveals only wide Resonances, but not too wide ($\Gamma < 500$ MeV) & possessing not too small BR (BR > 4%)

- PDG10 states

*The latest GWU analysis (Arndt06) finds no evidence for those resonances*

PDG10 *** $\Delta(1600)P_{33}$, $N(1700)D_{13}$, $N(1710)P_{11}$, $\Delta(1920)P_{33}$

PDG10 ** $N(1900)P_{13}$, $\Delta(1900)S_{31}$, $N(1990)F_{17}$, $\Delta(2000)F_{35}$, $N(2080)D_{13}$, $N(2200)D_{15}$, $\Delta(2300)H_{39}$, $\Delta(2750)I_{313}$

PDG10 * $\Delta(1750)P_{31}$, $\Delta(1940)D_{33}$, $N(2090)S_{11}$, $N(2100)P_{11}$, $\Delta(2150)S_{31}$, $\Delta(2200)G_{37}$, $\Delta(2350)D_{35}$, $\Delta(2390)F_{37}$

- Our study does suggest several 'new' N*s & Δ*s:

PDG10 **** $\Delta(2420)H_{311}$

PDG10 *** $\Delta(1930)D_{35}$, $N(1900)F_{15}$

PDG10 ** $\Delta(2400)G_{39}$

PDG10 new $N(2245)H_{111}$

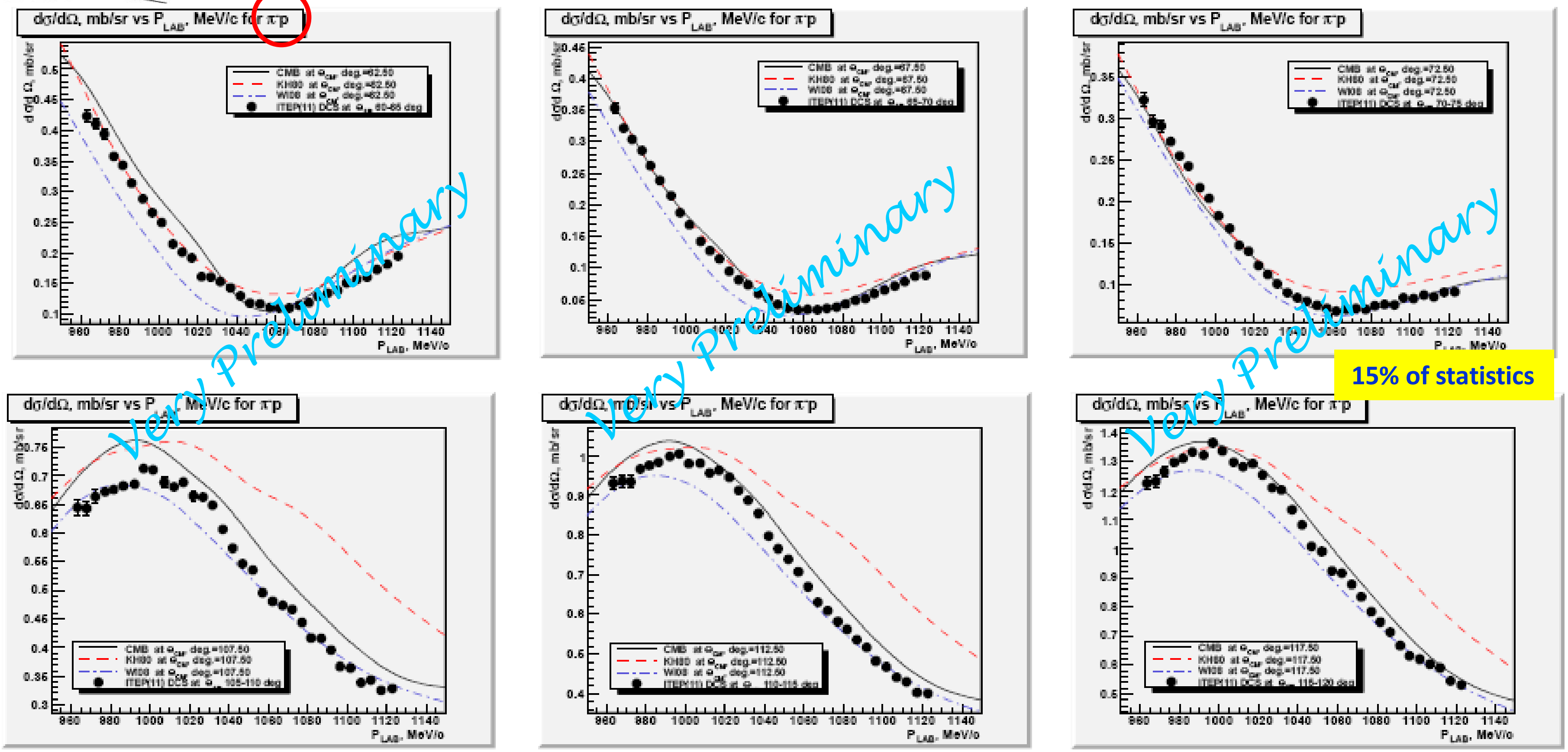
# ITEP for $\pi^{\mp}p \to \pi^{\mp}p$ & $\pi^{-}p \to K^{0}\Lambda$

[I.G. Alekseev *ea* arXiv:1204.6433]

- **Precise cross section measurements**:

$\pi p \to \pi p$: $d\sigma/d\Omega$ – **0.5%** statistical precision and 1 MeV momentum step

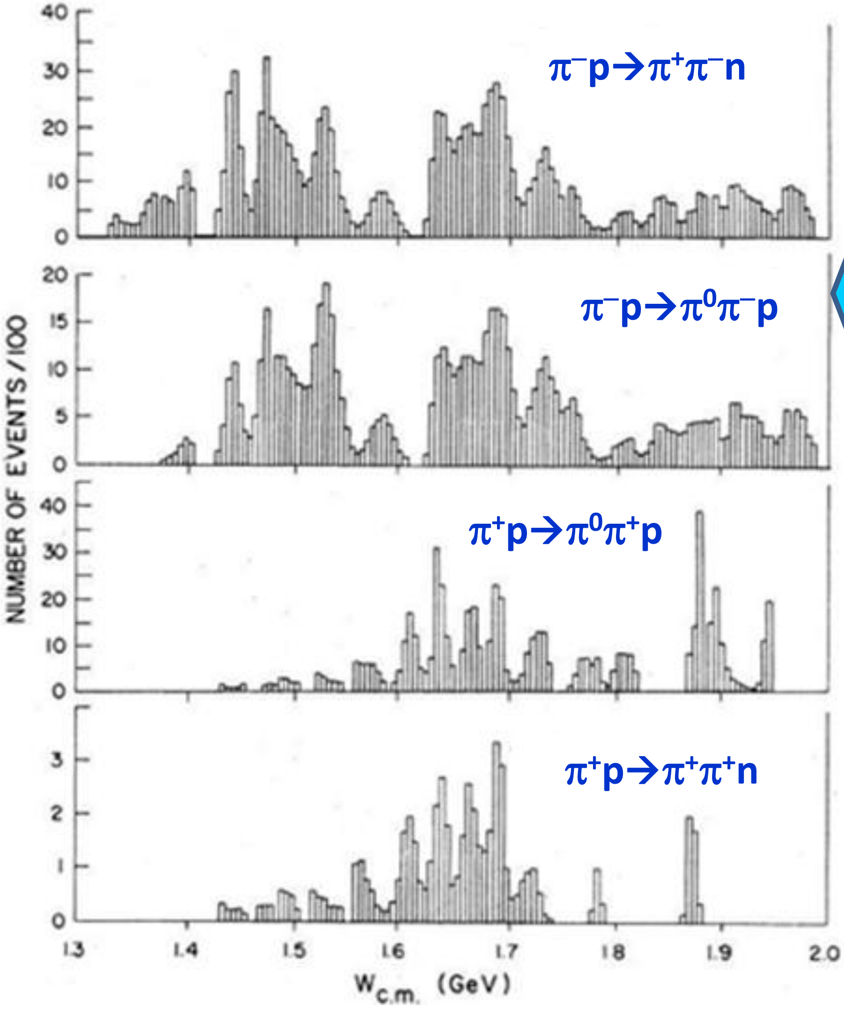
$\pi^{-}p \to K^{0}\Lambda$: $\sigma_{REAC}$ – **1%** statistical precision and the same mom step



15% of statistics

$$\left.\begin{array}{l}\pi^- p \rightarrow \pi^+ \pi^- n \\ \pi^- p \rightarrow \pi^0 \pi^0 n \\ \pi^- p \rightarrow \pi^- \pi^0 p \\ \pi^+ p \rightarrow \pi^+ \pi^0 p \\ \pi^+ p \rightarrow \pi^+ \pi^+ n\end{array}\right\} \quad \pi \rightarrow 2\pi$$

# $\pi N \rightarrow \pi\pi N$ Measurements



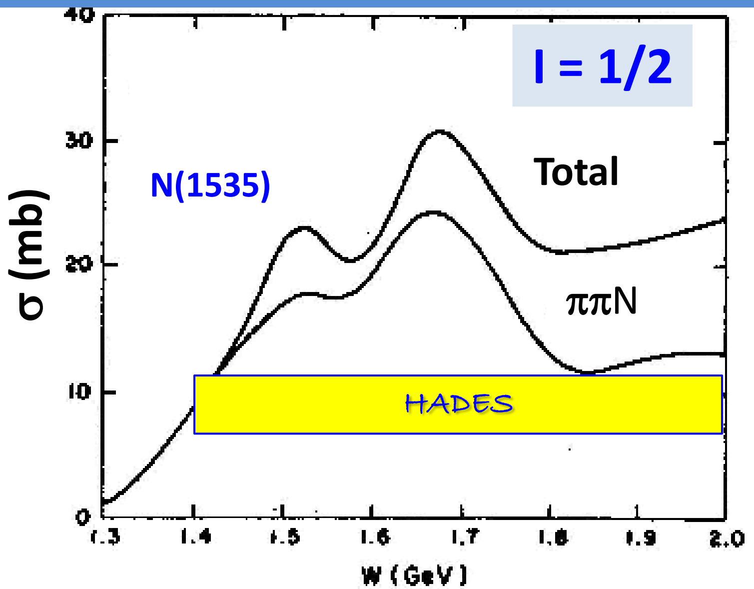
HADES

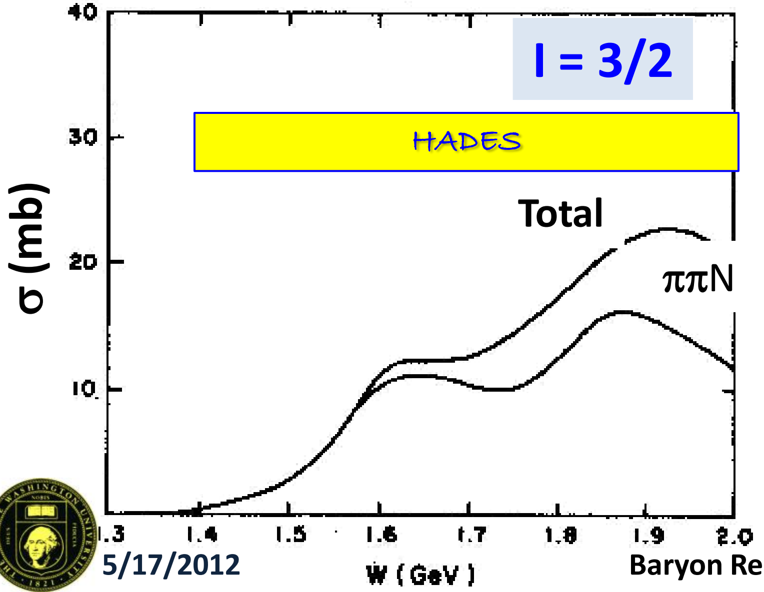
- **241,214** **<u>Bubble Chamber</u>** events for $\pi N \rightarrow \pi\pi N$ have been analyzed in **Isobar-model** **PWA** at W = **1320** to **1930** MeV.
  [D.M. Manley, **R. Arndt**, Y. Goradia, V. Teplitz, Phys Rev D **30**, 904 (1984)]
- Our knowledge of **πΔ**, **ρN**, and other quasi-two-body **ππN** channels comes mainly from **Isobar-model** analyses of these **πN→ππN** data.

- <u>Recent **post-BC** measurements</u>:
  - **349,611** events for $\pi^- p \rightarrow \pi^0\pi^0 n$ from **CB@BNL** at W = **1213** to **1527** MeV.
    [S. Prakhov *et al* Phys Rev C **69**, 045202 (2004)]
  - **20,000** events for $\pi^{+-} p \rightarrow \pi^{+-}\pi^{-+} n$ from **CHAOS@TRIUMF** at W = **1257** to **1302** MeV.
    [M. Kermani *et al* Phys Rev C **58**, 3431 (1998)]
  - **40,000** events for $\pi^- \vec{p} \rightarrow \pi^-\pi^+ n$ from **ITEP** at W = **2060** MeV.
    [I. Alekseev *et al* Phys At Nucl **61**, 174 (1998)]

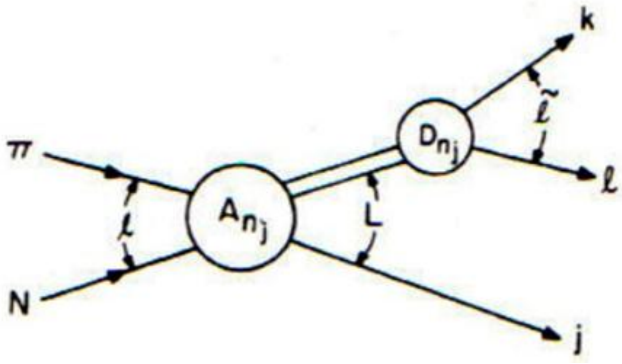
# πN→ππN in Isobar Model

[D.M. Manley, R. Arndt, Y. Goradia, V. Teplitz, Phys Rev D **30**, 904 (1984)]





- **πN→ππN** is essential above **1300** MeV, σ(ππN) ~ $\sigma_{inel}$.



- The **total amplitude** for a given charge channel can be written as a coherent sum over all **isobars** and **partial waves**.

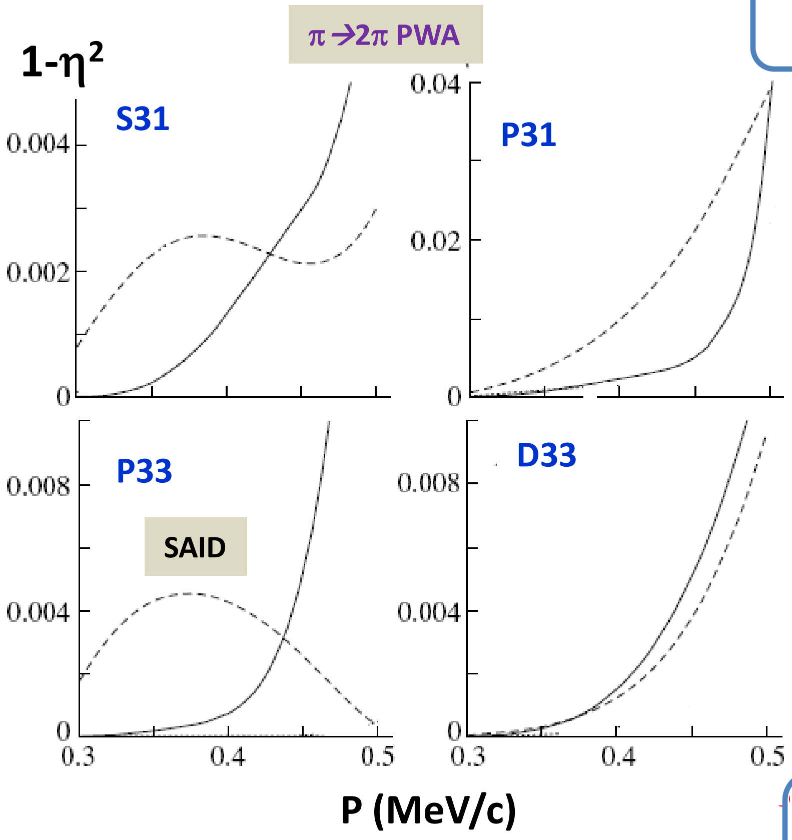
- Most of the **3**- and **4**-star resonances in the **PDG** listings were determined primarily from **PWA**s of **πN→πN** data.

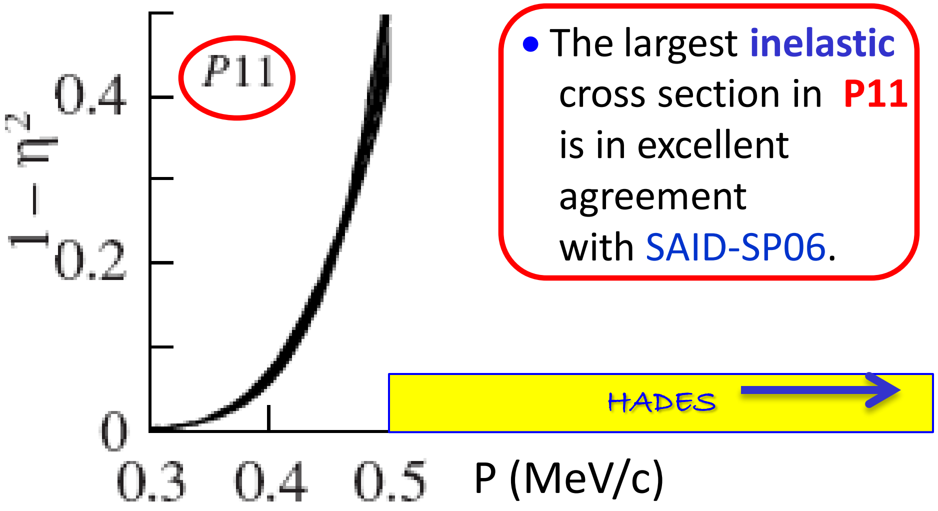
- Many of these states have large decay branching ratios to **ππN** channels.

# $\pi N \rightarrow \pi\pi N$ in Isobar Model at low Energies

[V. Kozhevnikov & S. Sherman, Phys Atom Nucl **71**, 1860 (2008)]

- Unfortunately, it is hard to merge **πN→πN** and **πN→ππN** databases to make a joint **PWA**.





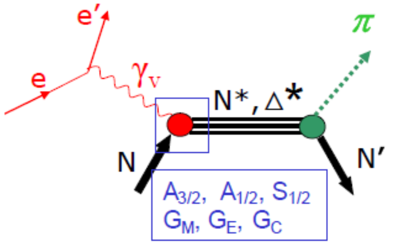
- The largest **inelastic** cross section in **P11** is in excellent agreement with SAID-SP06.

- A complete analysis of **γN→ππN** ideally would require fitting all data obtained with both **pion** and **photon** beams.

# Inverse Pion Electroproduction

# SAID for Pion Electro Prod

- Energy dependent SM08 and associated SES & SQS
- W = 1080 – 2000 MeV $Q^2$ = 0 – 6 $GeV^2$
- PWs = 60 [multipoles] [J < 6]
- Prms = 171
- Constraint: πN + Pion Photo Prod PWAs [no theoretical input]



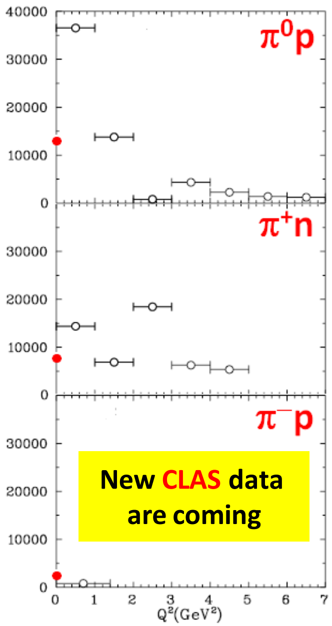
- 0.85 World Electro Prod from JLab CLAS

- **PWA Problems:**
  - Additional [S] Multipoles
  - $Q^2$ dependence

- **Database Problems:**
  - Most of data are unPolarized measurements
  - There are no $\pi^0 n$ data and very few $\pi^- p$ [no Pol measurements] That does not allow to determine n-couplings at $Q^2 > 0$

| Reaction | Data | $\chi^2$ |
|---|---|---|
| $\gamma^* p \to \pi^0 p$ | 55,766 | 81,284 |
| $\gamma^* p \to \pi^+ n$ | 51,312 | 80,004 |
| Redundant | 14,772 | 17,375 |
| Total | 121,850 | 178,663 |
| $\gamma N \to \pi N$ | 25,358 | 53,458 |
| All Photo* | 147,208 | 232,121 |
| $\pi N \to \pi N$ | 31,479 | 57,157 |
| All πN | 178,687 | 289,278 |
| $\gamma^* n \to \pi^- p$ | 801 | |
| $\gamma^* n \to \pi^0 n$ | No Data | |

$Q^2$-Data



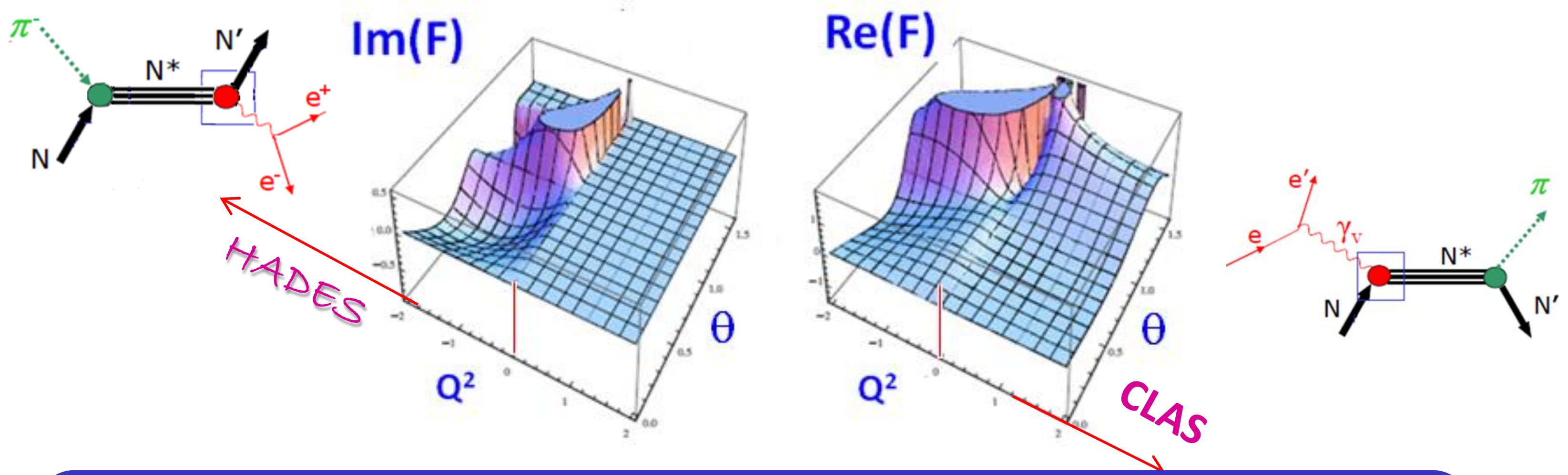
New CLAS data are coming

# Inverse Pion Electroproduction (IPE)

- **IPE** is the only process which allows the determination of **EM nucleon** & pion **formfactors** in the intervals

$0 < k^2 < 4\,M^2 = 3.53\ \mathrm{GeV}^2$ $0 < k^2 < 4\,m_\pi = 0.08\ \mathrm{GeV}^2$

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



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

# Experimental Difficulties of IPE

- **Difficulties in the experimental study of IPE arise from the need of a high rejection of competitive processes:**

- The Xsection of $\pi^-p$ elastic is $d\sigma/d\Omega \sim 10^{-27}$ cm$^2$/sr and is concentrated in the forward direction.
  Therefore **e**$^-$ and **e**$^+$ of IPE are conveniently detected at ~**90$^0$** with respect of $\pi^-$-beam, where the elastically scattered hadrons are strongly reduced.

- Xsection for $\pi^+$ production, i.e., $\pi^-p \rightarrow n\pi^-\pi^+$ is about **1000** times greater than that of IPE.
  The corresponding pions at **90$^0$** are very soft and can be suppressed strongly by threshold Cherenkov counters.

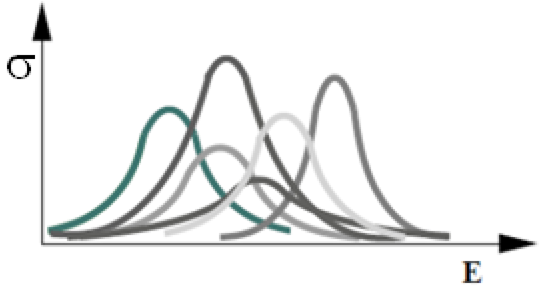
- The reactions with a **gamma** ray converted into a **Dalitz pair**, contribute a rather unpleasant background.
  The most important processes are $\pi^-p \rightarrow n\pi^0$ & $\pi^-p \rightarrow n\gamma$, which contribute ~ **60%** and **40%** of the counting rate due to capture in hydrogen of $\pi^-$ at rest against **0.7%** from IPE.

# Baryon Spectroscopy

# Spectroscopy of Baryons

- Many more states in the **QCD** inspired **models** than currently observed.

- **Properties** even of lowest-lying and isolated states often not too well understood.



- **Problems:**
  - All states are broad.
  - All states overlap.

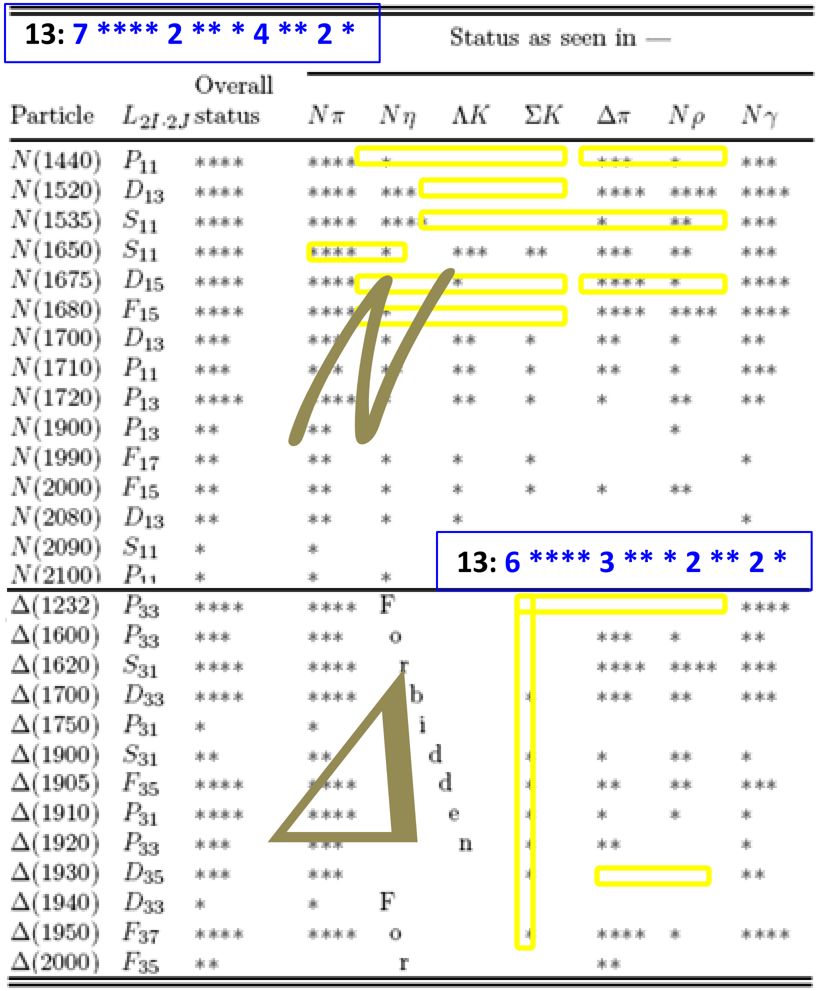
- **Prolific source** of N* & Δ* baryons: **πN**→πN, **$e^+e^-n$** , ηN, ωN, η'N, ϕN, KΛ, KΣ, & **multi-meson** final states [πΔ & ρN included].

- **Measure** many channels with different combinations of quantum numbers.

# HADES [1.4 – 2 GeV] for Baryon Spectroscopy

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

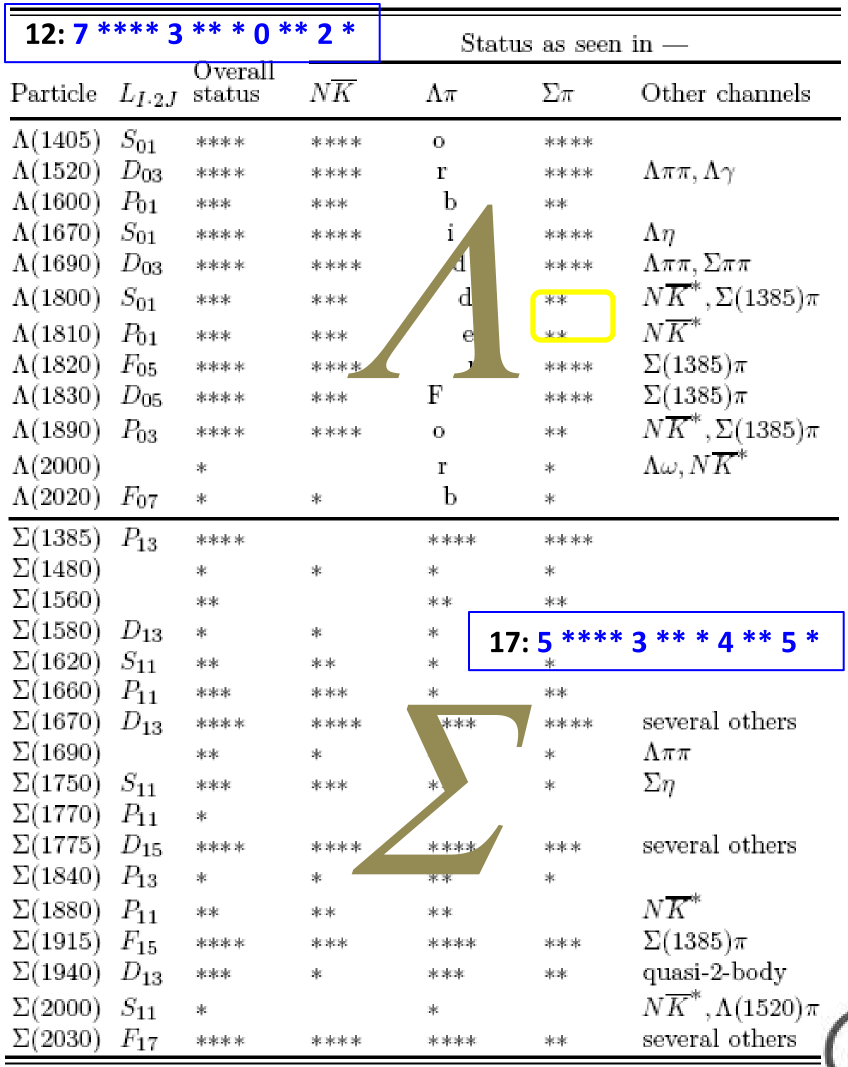
- A quick check of the **PDG** listings reveals that resonance parameters of many established states are not well determined.



13: 7 **** 2 ** * 4 ** 2 *

13: 6 **** 3 ** * 2 ** 2 *

| Particle | $L_{2I\cdot 2J}$ | Overall status | Status as seen in — $N\pi$ | $N\eta$ | $\Lambda K$ | $\Sigma K$ | $\Delta\pi$ | $N\rho$ | $N\gamma$ |
|---|---|---|---|---|---|---|---|---|---|
| $N(1440)$ | $P_{11}$ | **** | **** | * | | | *** | * | *** |
| $N(1520)$ | $D_{13}$ | **** | **** | *** | | | **** | **** | **** |
| $N(1535)$ | $S_{11}$ | **** | **** | **** | | | * | ** | *** |
| $N(1650)$ | $S_{11}$ | **** | **** | * | *** | ** | *** | ** | *** |
| $N(1675)$ | $D_{15}$ | **** | **** | * | | | **** | * | **** |
| $N(1680)$ | $F_{15}$ | **** | **** | * | | | **** | **** | **** |
| $N(1700)$ | $D_{13}$ | *** | *** | * | ** | * | ** | * | ** |
| $N(1710)$ | $P_{11}$ | *** | *** | ** | ** | * | ** | * | *** |
| $N(1720)$ | $P_{13}$ | **** | **** | * | ** | * | * | ** | ** |
| $N(1900)$ | $P_{13}$ | ** | ** | | | | | * | |
| $N(1990)$ | $F_{17}$ | ** | ** | * | * | * | | | * |
| $N(2000)$ | $F_{15}$ | ** | ** | * | * | * | * | ** | |
| $N(2080)$ | $D_{13}$ | ** | ** | * | * | | | | * |
| $N(2090)$ | $S_{11}$ | * | * | | | | | | |
| $N(2100)$ | $P_{11}$ | * | * | * | | | | | |
| $\Delta(1232)$ | $P_{33}$ | **** | **** | F | | | | | **** |
| $\Delta(1600)$ | $P_{33}$ | *** | *** | o | | | *** | * | ** |
| $\Delta(1620)$ | $S_{31}$ | **** | **** | r | | | **** | **** | *** |
| $\Delta(1700)$ | $D_{33}$ | **** | **** | b | | * | *** | ** | *** |
| $\Delta(1750)$ | $P_{31}$ | * | * | i | | | | | |
| $\Delta(1900)$ | $S_{31}$ | ** | ** | d | | * | * | ** | * |
| $\Delta(1905)$ | $F_{35}$ | **** | **** | d | | * | ** | ** | *** |
| $\Delta(1910)$ | $P_{31}$ | **** | **** | e | | * | * | * | * |
| $\Delta(1920)$ | $P_{33}$ | *** | *** | n | | * | ** | | * |
| $\Delta(1930)$ | $D_{35}$ | *** | *** | | | * | | | ** |
| $\Delta(1940)$ | $D_{33}$ | * | * | F | | | | | |
| $\Delta(1950)$ | $F_{37}$ | **** | **** | o | | * | **** | * | **** |
| $\Delta(2000)$ | $F_{35}$ | ** | | r | | | ** | | |



12: 7 **** 3 ** * 0 ** 2 *

17: 5 **** 3 ** * 4 ** 5 *

| Particle | $L_{I\cdot 2J}$ | Overall status | Status as seen in — $N\overline{K}$ | $\Lambda\pi$ | $\Sigma\pi$ | Other channels |
|---|---|---|---|---|---|---|
| $\Lambda(1405)$ | $S_{01}$ | **** | **** | o | **** | |
| $\Lambda(1520)$ | $D_{03}$ | **** | **** | r | **** | $\Lambda\pi\pi, \Lambda\gamma$ |
| $\Lambda(1600)$ | $P_{01}$ | *** | *** | b | ** | |
| $\Lambda(1670)$ | $S_{01}$ | **** | **** | i | **** | $\Lambda\eta$ |
| $\Lambda(1690)$ | $D_{03}$ | **** | **** | d | **** | $\Lambda\pi\pi, \Sigma\pi\pi$ |
| $\Lambda(1800)$ | $S_{01}$ | *** | *** | d | ** | $N\overline{K}^*, \Sigma(1385)\pi$ |
| $\Lambda(1810)$ | $P_{01}$ | *** | *** | e | ** | $N\overline{K}^*$ |
| $\Lambda(1820)$ | $F_{05}$ | **** | **** | n | **** | $\Sigma(1385)\pi$ |
| $\Lambda(1830)$ | $D_{05}$ | **** | *** | F | **** | $\Sigma(1385)\pi$ |
| $\Lambda(1890)$ | $P_{03}$ | **** | **** | o | ** | $N\overline{K}^*, \Sigma(1385)\pi$ |
| $\Lambda(2000)$ | | * | | r | * | $\Lambda\omega, N\overline{K}^*$ |
| $\Lambda(2020)$ | $F_{07}$ | * | * | b | * | |
| $\Sigma(1385)$ | $P_{13}$ | **** | | **** | **** | |
| $\Sigma(1480)$ | | * | * | * | * | |
| $\Sigma(1560)$ | | ** | | ** | ** | |
| $\Sigma(1580)$ | $D_{13}$ | * | * | * | | |
| $\Sigma(1620)$ | $S_{11}$ | ** | ** | * | * | |
| $\Sigma(1660)$ | $P_{11}$ | *** | *** | * | ** | |
| $\Sigma(1670)$ | $D_{13}$ | **** | **** | **** | **** | several others |
| $\Sigma(1690)$ | | ** | * | * | * | $\Lambda\pi\pi$ |
| $\Sigma(1750)$ | $S_{11}$ | *** | *** | * | * | $\Sigma\eta$ |
| $\Sigma(1770)$ | $P_{11}$ | * | | | | |
| $\Sigma(1775)$ | $D_{15}$ | **** | **** | **** | *** | several others |
| $\Sigma(1840)$ | $P_{13}$ | * | * | ** | * | |
| $\Sigma(1880)$ | $P_{11}$ | ** | ** | ** | | $N\overline{K}^*$ |
| $\Sigma(1915)$ | $F_{15}$ | **** | *** | **** | *** | $\Sigma(1385)\pi$ |
| $\Sigma(1940)$ | $D_{13}$ | *** | * | *** | ** | quasi-2-body |
| $\Sigma(2000)$ | $S_{11}$ | * | | * | | $N\overline{K}^*, \Lambda(1520)\pi$ |
| $\Sigma(2030)$ | $F_{17}$ | **** | **** | **** | ** | several others |

# HADES for Flavor-spin SU(6)

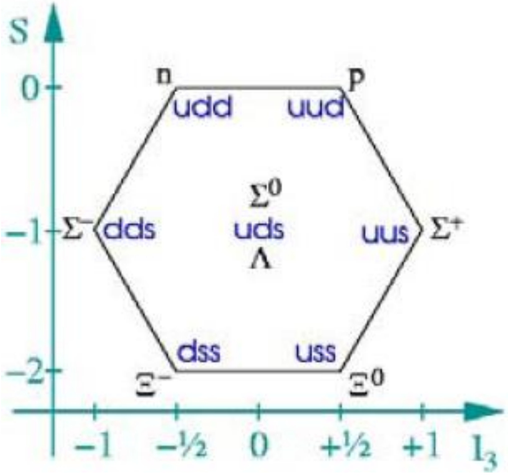
[K. Nakamura *et al* [RPP] J Phys G **37**, 075021 (2010)]

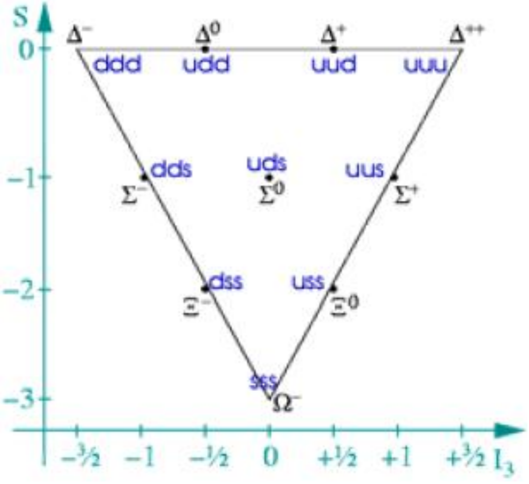
| $J^P$ | $(D, L^P_N)$ | $S$ | Octet members | | | | Singlets |
|---|---|---|---|---|---|---|---|
| $1/2^+$ | $(56,0^+_0)$ | $1/2$ | $N(939)$ | $\Lambda(1116)$ | $\Sigma(1193)$ | $\Xi(1318)$ | |
| $1/2^+$ | $(56,0^+_2)$ | $1/2$ | $N(1440)$ | $\Lambda(1600)$ | $\Sigma(1660)$ | $\Xi(?)$ | |
| $1/2^-$ | $(70,1^-_1)$ | $1/2$ | $N(1535)$ | $\Lambda(1670)$ | $\Sigma(1620)$ | $\Xi(?)$ | $\Lambda(1405)$ |
| $3/2^-$ | $(70,1^-_1)$ | $1/2$ | $N(1520)$ | $\Lambda(1690)$ | $\Sigma(1670)$ | $\Xi(1820)$ | $\Lambda(1520)$ |
| $1/2^-$ | $(70,1^-_1)$ | $3/2$ | $N(1650)$ | $\Lambda(1800)$ | $\Sigma(1750)$ | $\Xi(?)$ | |
| $3/2^-$ | $(70,1^-_1)$ | $3/2$ | $N(1700)$ | $\Lambda(?)$ | $\Sigma(?)$ | $\Xi(?)$ | |
| $5/2^-$ | $(70,1^-_1)$ | $3/2$ | $N(1675)$ | $\Lambda(1830)$ | $\Sigma(1775)$ | $\Xi(?)$ | |
| $1/2^+$ | $(70,0^+_2)$ | $1/2$ | $N(1710)$ | $\Lambda(1810)$ | $\Sigma(1880)$ | $\Xi(?)$ | $\Lambda(?)$ |
| $3/2^+$ | $(56,2^+_2)$ | $1/2$ | $N(1720)$ | $\Lambda(1890)$ | $\Sigma(?)$ | $\Xi(?)$ | |
| $5/2^+$ | $(56,2^+_2)$ | $1/2$ | $N(1680)$ | $\Lambda(1820)$ | $\Sigma(1915)$ | $\Xi(2030)$ | |
| $7/2^-$ | $(70,3^-_3)$ | $1/2$ | $N(2190)$ | $\Lambda(?)$ | $\Sigma(?)$ | $\Xi(?)$ | $\Lambda(2100)$ |
| $9/2^-$ | $(70,3^-_3)$ | $3/2$ | $N(2250)$ | $\Lambda(?)$ | $\Sigma(?)$ | $\Xi(?)$ | |
| $9/2^+$ | $(56,4^+_4)$ | $1/2$ | $N(2220)$ | $\Lambda(2350)$ | $\Sigma(?)$ | $\Xi(?)$ | |

| | | | Decuplet members | | | |
|---|---|---|---|---|---|---|
| $3/2^+$ | $(56,0^+_0)$ | $3/2$ | $\Delta(1232)$ | $\Sigma(1385)$ | $\Xi(1530)$ | $\Omega(1672)$ |
| $1/2^-$ | $(70,1^-_1)$ | $1/2$ | $\Delta(1620)$ | $\Sigma(?)$ | $\Xi(?)$ | $\Omega(?)$ |
| $3/2^-$ | $(70,1^-_1)$ | $1/2$ | $\Delta(1700)$ | $\Sigma(?)$ | $\Xi(?)$ | $\Omega(?)$ |
| $5/2^+$ | $(56,2^+_2)$ | $3/2$ | $\Delta(1905)$ | $\Sigma(?)$ | $\Xi(?)$ | $\Omega(?)$ |
| $7/2^+$ | $(56,2^+_2)$ | $3/2$ | $\Delta(1950)$ | $\Sigma(2030)$ | $\Xi(?)$ | $\Omega(?)$ |
| $11/2^+$ | $(56,4^+_4)$ | $3/2$ | $\Delta(2420)$ | $\Sigma(?)$ | $\Xi(?)$ | $\Omega(?)$ |

HADES

There are too many question marks





# Summary: HADES for Spectroscopy

- Reliable theoretical and phenomenological [**PW** & coupled channel] analyses need high-precision complementary hadron induced measurements as, e.g.,

  **$\pi N \rightarrow$**$\pi N$, **$e^+e^-n$**, $\eta N$, $\omega N$, $\eta' N$, $\phi N$, $\phi N$, $K\Lambda$, $K\Sigma$, &

  **multi-meson** final states [$\pi\Delta$ & $\rho N$ included].

  Does allow to have polarized results

- **SAID** may extend the current **K-matrix** approach to add new hadronic channels which will provide a constraint for PWA.

- Hadronic measurements would complement current studies using **EM** probes at **JLab**, **CB@MAMI-C**, **CB-ELSA**, & **SPring-8**.

# Exotics – N(1680)

# N(1710)*** – What was Known

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

The latest GWU analysis (ARNDT 06) finds no evidence for this resonance. [R. Arndt, W. Briscoe, IS, R. Workman, Phys Rev C **74**, 045205 (2006)]

**No Pole, No BW, No Sp(W), No $\Delta t(W)$**

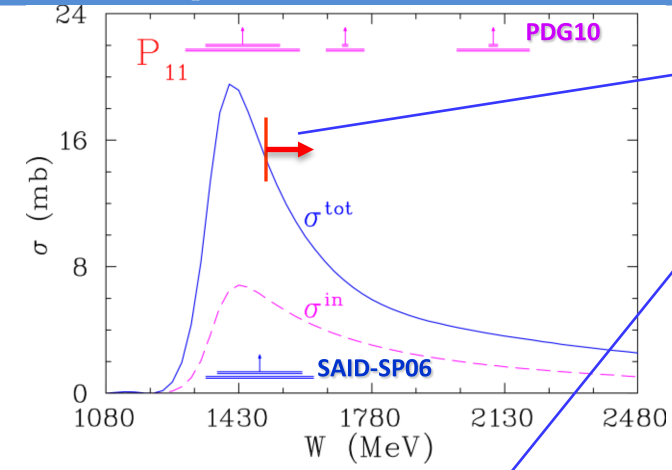
| PWA-Pole | Ref | Re(MeV) | −2xIm(MeV) |
|---|---|---|---|
| | SAID-SP06 | | not seen |
| | KH93 | 1690 | 200 |
| | CMU90 | 1698 | 88 |
| | CMU80 | 1690 ± 20 | 80 ± 20 |

| PWA-BW | Ref | Mass(MeV) | Width(MeV) | BR |
|---|---|---|---|---|
| | SAID-SP06 | | not seen | |
| | KSU92 | 1717 ± 28 | 480 ± 230 | 0.09 ± 0.04 |
| | CMU80 | 1700 ± 50 | 90 ± 30 | 0.20 ± 0.04 |
| | KH79 | 1723 ± 9 | 120 ± 15 | 0.12 ± 0.04 |

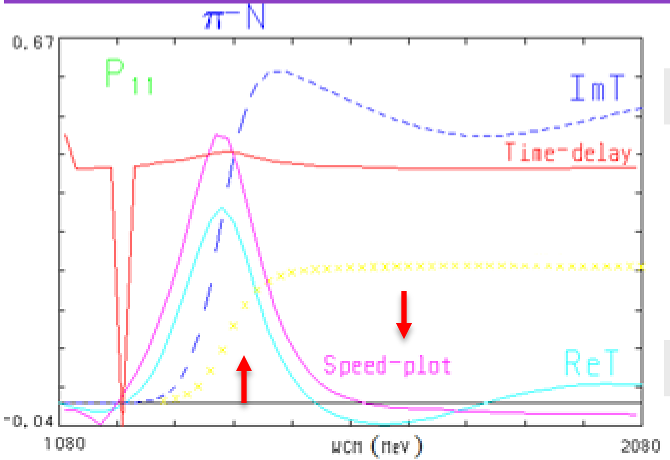
- Spread of $\Gamma$, $\Gamma_\pi/\Gamma$, & $\Gamma_\eta/\Gamma$, selected by **PDG**, is very large
- **Total width** is too large, ≥ **100** MeV

# $P_{11}$ Puzzle above N(1440)

[R. Arndt, W. Briscoe, M. Paris, IS, R. Workman, Chinese Phys C **33**, 1063 (2009)]



- **Above W = 1500 MeV**: $\sigma^t \cong 2\sigma^{el} \cong 2\sigma^{in}$ $[\sigma^t = \sigma^{el} + \sigma^{in}]$
- **It means**: $P_{11}$ is strongly inelastic: $\eta \to \infty$, $S \cong 0$, $A \cong i/2$, and $\delta$ is badly defined

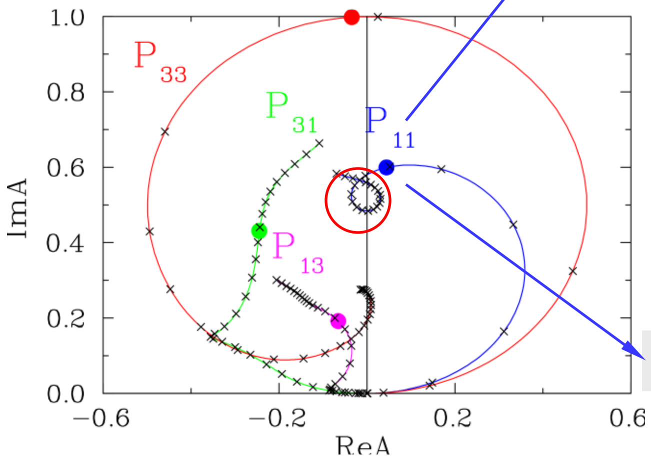


ImT~0.5

$ImT - T^*T \geq 0$

ReT<|0.1|

- **Above W = 1.5 GeV, Sp(W) & Δt(W) are flat**
- **Sp(W) = |dT/dW| → peak at W=M (pole) at NonRes→0** [G. Hoehler, πN Newslett **7**, 94 (1992)]
- **Δt(W) = dδ/dW → peak at W=M (pole)** L. Eisenbud, Ph.D. Thesis, 1948



$W_p = M_R$

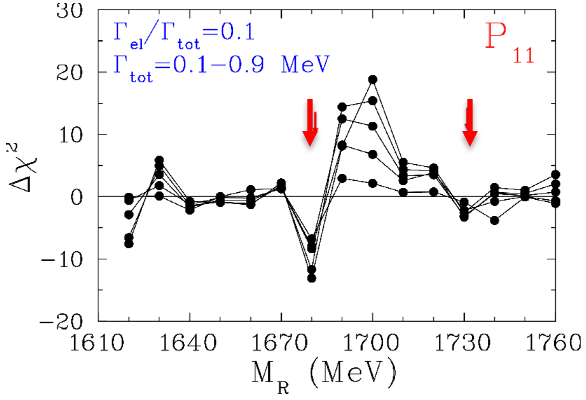
x W = 1080 [50] 2480 MeV

- **There is no `standard' Res in $P_{11}$ above W=1500 MeV, except possible state(s) with small $\Gamma_{el}$**

# Modified πN PWA & Expected Decay Properties of N(1680)

[R. Arndt, Ya. Azimov, M. Polyakov, IS, R. Workman, Phys Rev C **69**, 035208 (2004)]

**$\pi N \rightarrow \pi N$**



- We look for $\Delta\chi^2$ due to insertion of a Res into $P_{11}$ ($J^P = 1/2^+$)

- At $|M_R - W| >> \Gamma_R$, **Res** contributes ~ $\Gamma_{el}/(M_R - W)$
- The procedure is less sensitive to $\Gamma$ than to $\Gamma_{el}$ **[$\Gamma$ < 25 MeV]**
- The mass uncertainties of Resonances are **±10 MeV** (**step of scan**)
- Check other Partial Waves (**$S_{11}$** & **$P_{13}$**) shown –
  No effects at M = **1680** MeV and possible (small) effects at 1730 MeV

- <u>Two candidates:</u>

| | | |
|---|---|---|
| | $M_R$ = **1680** MeV | 1730 MeV |
| | $\Gamma_{\pi N}$ < **0.5** MeV | < 0.3 MeV |

- **Expected decay properties are essentially model-dependent**

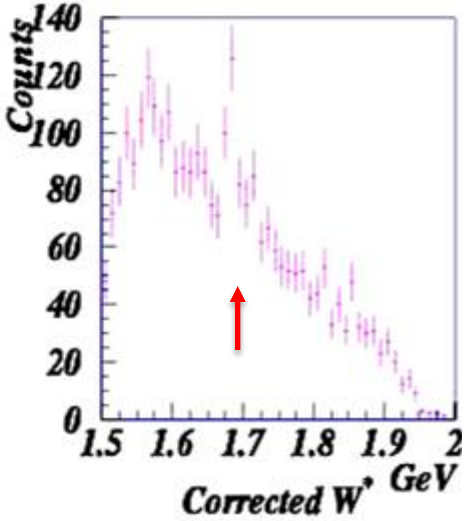
- **The χiral Quark Soliton Approach with violated $SU(3)_F$ [mixing $N_{10*} - N_8$] gives**
  - $\Gamma(\pi\Delta)$ ~ **4** MeV; forbidden by $SU(3)_F$, opened by mixing with $N_8$ large coupling ($\pi N\Delta$) may make $\pi\Delta$ the most intensive decay channel of N(1680)
  - $\Gamma(\eta N)$ ~ **2** MeV
  - $\Gamma(K\Lambda)$ ~ **1** MeV
  - $\Gamma(\pi N)$ ~ **0.5** MeV [**from fitting**] is too small and may be explained only by mixing with (>2) $N_8$'s [N(940) + N(1440) **?**]
  - $\Gamma$(**tot**) may achieve ~ **10** MeV

# Direct Evidences for N(1680) in Photoproduction

[Unpol Measurements]

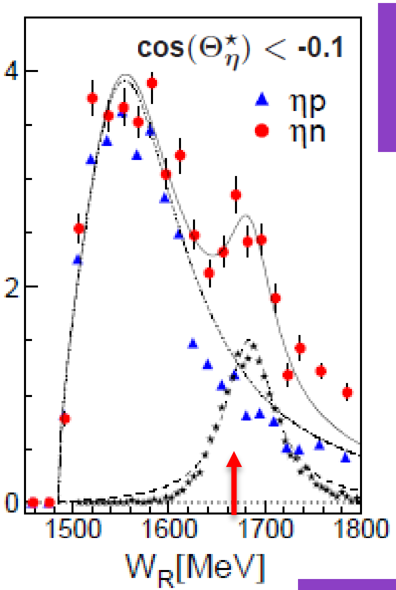
- **GRAAL:** **backward** $\gamma n \to \eta n$

[V. Kuznetsov *et al*, Phys Lett B **647**, 23 (2007)]



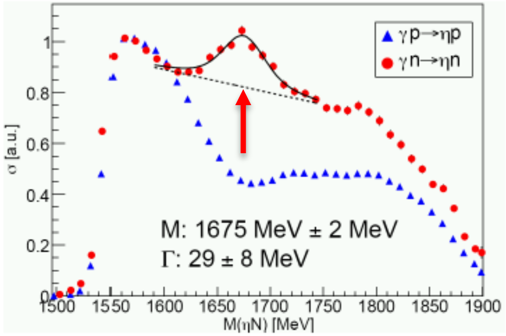
- **CB-ELSA:** $\gamma n \to \eta n$

[I. Jaegle *et al*, Phys Rev Lett **100**, 252002 (2008)]



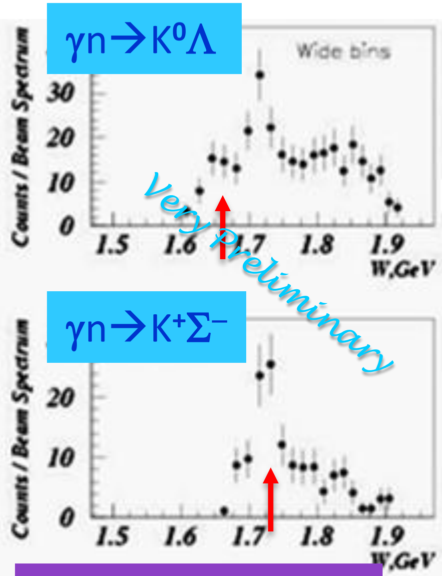
- **CB-MAMI-C:** $\gamma n \to \eta n$

[B. Krusche, *PrimeNet Workshop, Bonn, Oct 2009*]



- **GRAAL:** $\gamma n \to K^0\Lambda$ & $K^+\Sigma$

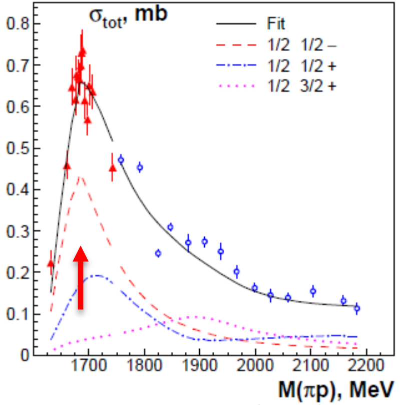
[V. Kuznetsov, Trento, Feb 2004]

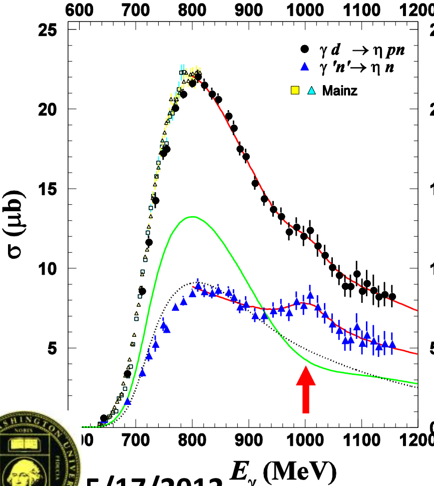


$\gamma n \to K^0\Lambda$

$\gamma n \to K^+\Sigma^-$

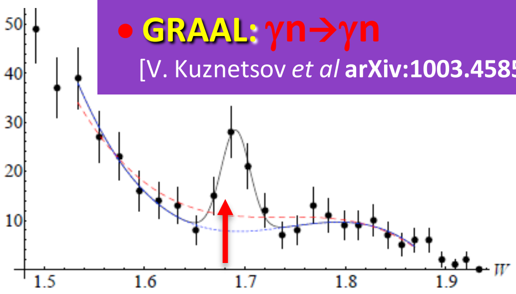
- **NIMROD:** $\pi^- p \to K\Lambda$





- **Tohoku-LNS:** $\gamma n \to \eta n$

[F. Miyahara *et al*, Prog Theor Phys Suppl **168**, 90 (2007)]



- **GRAAL:** $\gamma n \to \gamma n$

[V. Kuznetsov *et al* **arXiv:1003.4585** [hep-ex]]

# N(~~1710~~ 1680) – Current Status

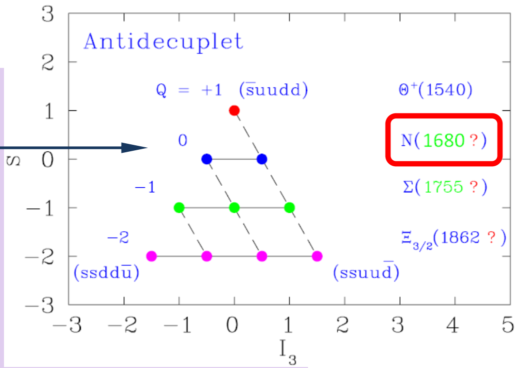
More details about **N(1680)** are at
the recent **Edinburgh** Workshop
http://gwdac.phys.gwu.edu/~igor/Edinburgh**2009**/

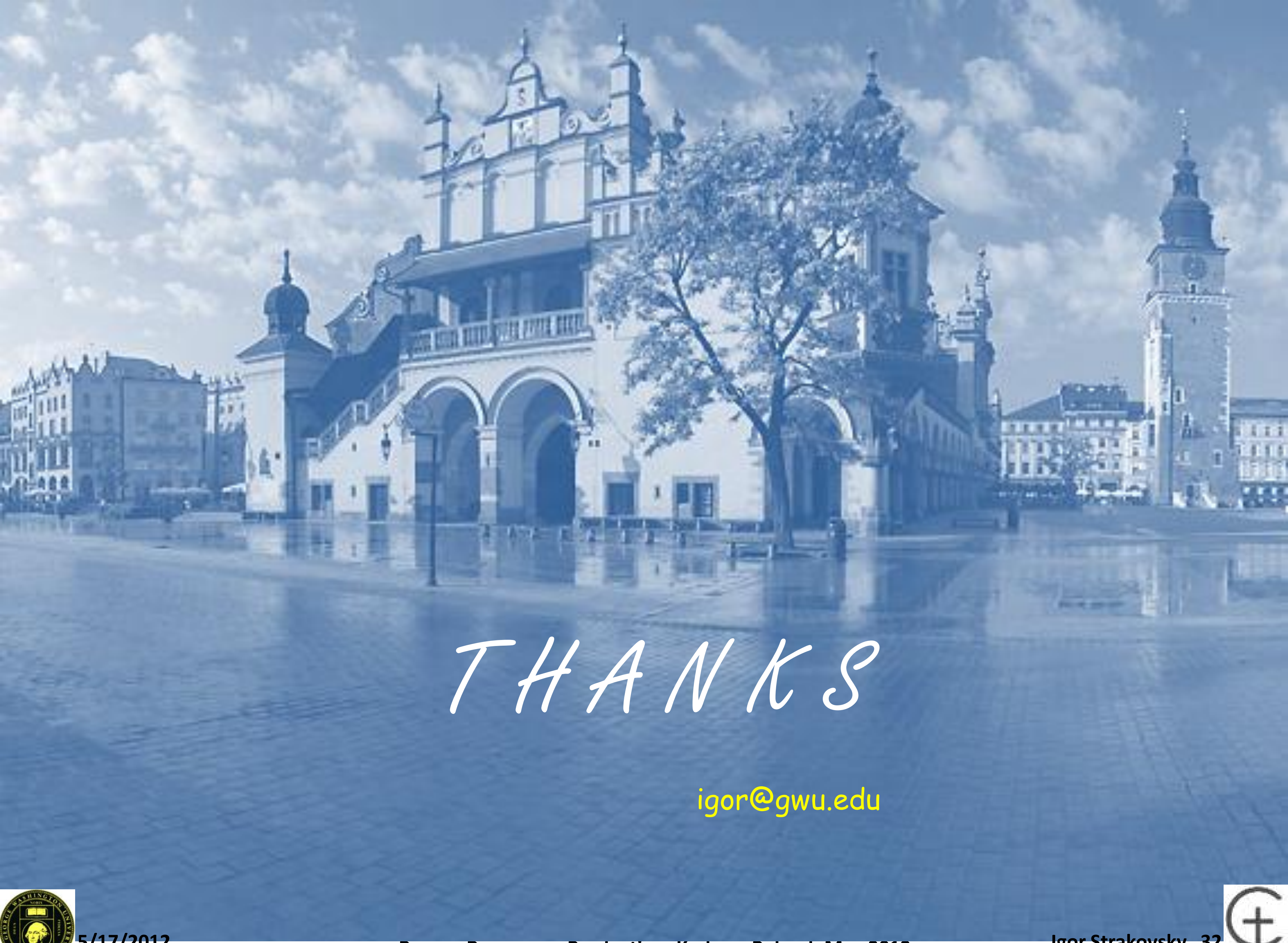
**Narrow Nucleon Resonances:**
**Predictions, Evidences, Perspectives**
June 8 - 10

- **Interpretation of the signals is still open question**
- **The width of N(1680) is much less than any known non-strange N***

- Small ratio of photo yields (off p/off n)
  agrees with 10* members
  [would completely vanish for exact $SU(3)_F$]

- If there is the narrow N(1680),
  transition magnetic moment is very small
  $\boxed{\mu(n^* \rightarrow n) = (0.13 - 0.37)\ \mu_N}$
  [Ya. Azimov, V. Kuznetsov, M.V. Polyakov, IS, Eur Phys J A 25, 325 (2005)]
  agrees with expectation of χQSA
  but is much smaller than familiar values [eg, $\mu(\Delta \rightarrow N) \sim 3\ \mu_N$]





THANKS

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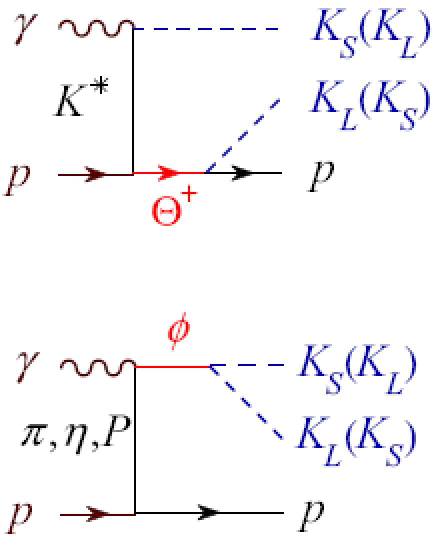
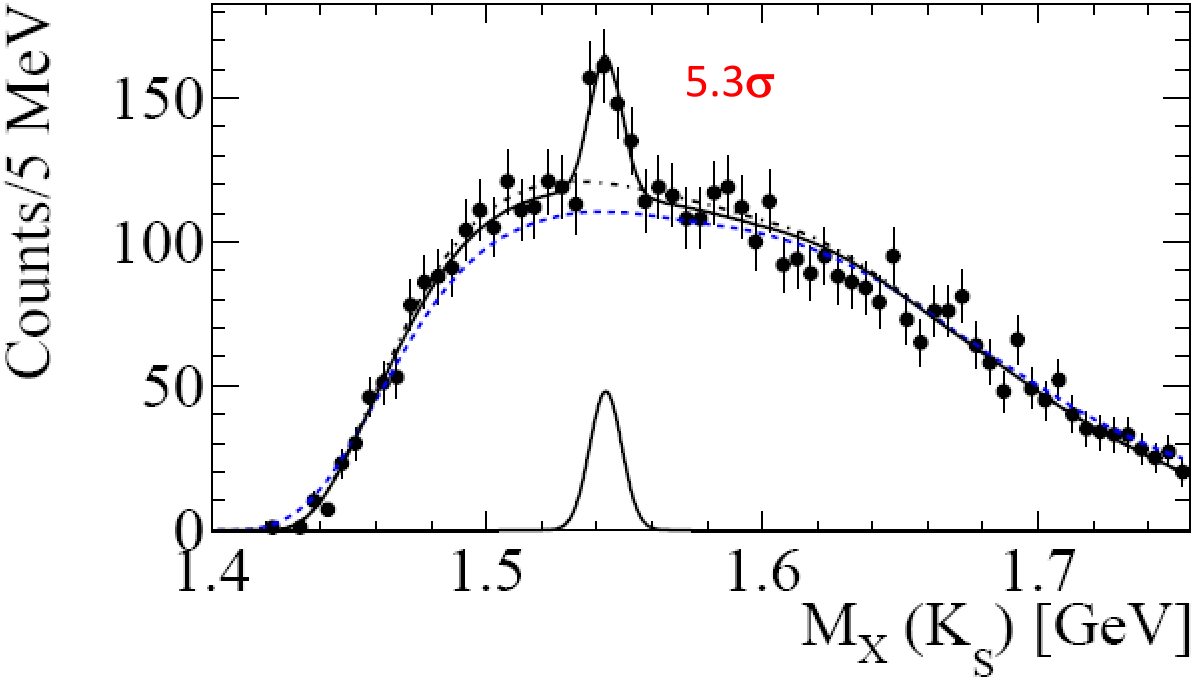
# Observation of a Narrow Structure in $p(\gamma, K_s)X$ via Interference with $\phi$-meson Production

[M. J. Amaryan *et al*, Phys Rev C **85**, 035209 (2012)]

- If **HADES** is interested in, then let us talk about it as well…





**More Events are coming…**

# Exotics – N'(1100)

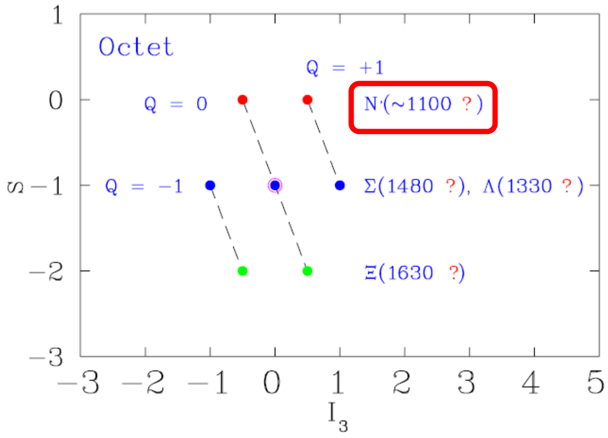
# N'(1100) – Current Status

[Ya. Azimov, R. Arndt, IS, R. Workman, Phys. Rev. C **68**, 045204 (2003); Ya. Azimov, Phys. Lett. **32B**, 499 (1970)]

- UNITARY PARTNERS (?)

| State | Mass (MeV) | Width (MeV) | Decay Modes | Hadron Production Xsections |
|---|---|---|---|---|
| N′ | ~1100 ? | <0.05 | $N\gamma$ ? | $< 10^{-4}$ of ”normal’ |
| Λ | 1330 ? | | $\Lambda\gamma$ | $\sim 10 \mu b$ |
| Σ | 1480 | 30-80 ? | $\Lambda\pi$, $\Sigma\pi$, $N\bar{K}$ | $\sim 1 \mu b$ |
| Ξ | 1630 | 20-50 ? | $\Xi\pi$ | $\sim 1 \mu b$ |

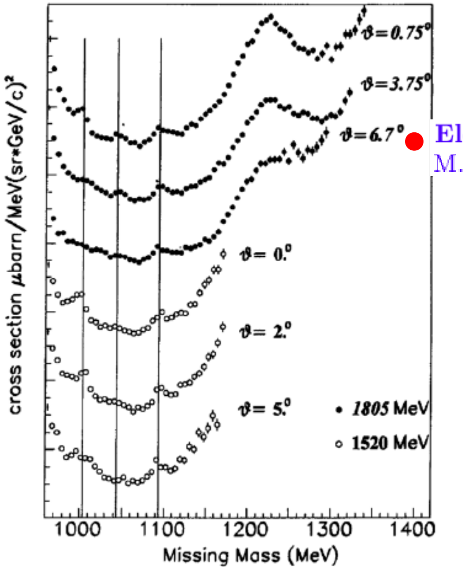
**S**-wave cousin of **10***



# Hunting for N'(1100)

- $pp \to \pi^+ p X^0$, **$M_X > 960$ *MeV* at Saclay**

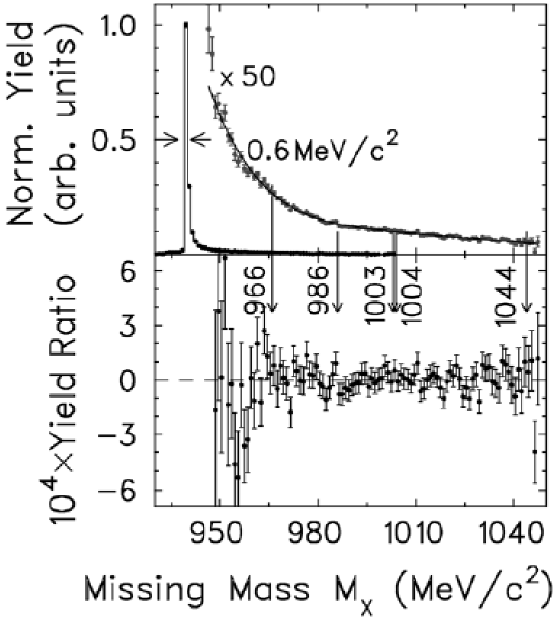
  B. Tatischeff *et al.* Phys. Rev. Lett. **79**, 601 (1997)
  B. Tatischeff *et al.* Eur. Phys. J. A **17**, 245 (2003)



There is no solid signal below & above **πN** threshold

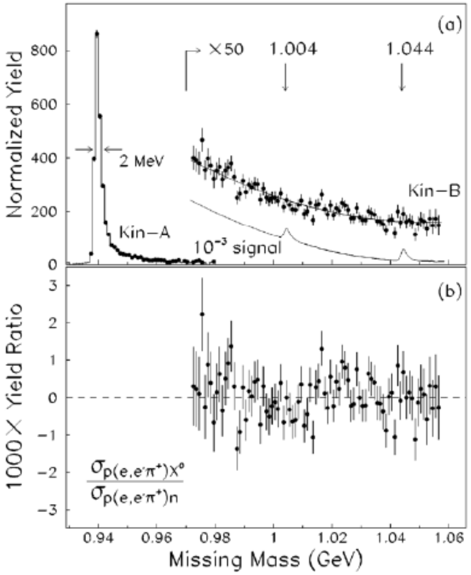
- **Electroproduction at Mainz** $ep \to e'\pi^+X^0$ $[ed \to e'pX^0]$

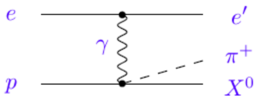
  M. Kohl *et al.* Phys. Rev. C **67**, 065204 (2003)

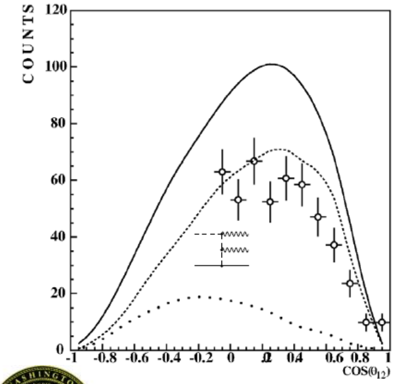


- **Electroproduction at JLab (Hall A)** $ep \to e'\pi^+X^0$

  X. Jiang *et al.* Phys. Rev. C **67**, 028201 (2003)







- $\pi^- p \to \gamma\gamma n$ **at rest at TRIUMF**

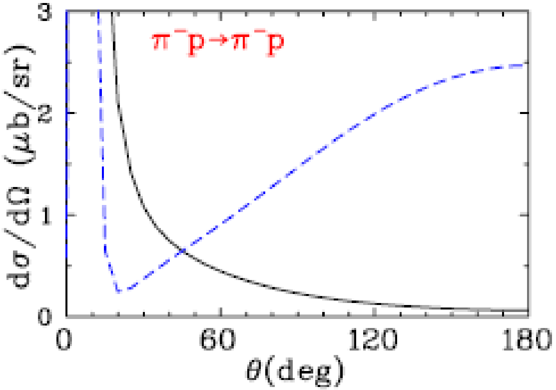
  S. Tripathi *et al.* Phys. Rev. Lett. **89**, 252501 (2002)

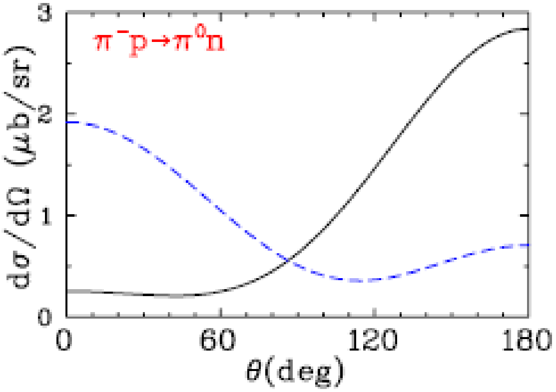
# Predictions for N'(1100)

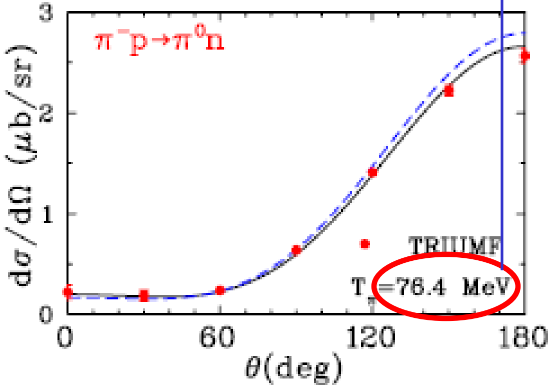
[Ya. Azimov, R. Arndt, IS, R. Workman, Phys. Rev. C **68**, 045204 (2003)]

- $S_{11}$: $M = 1145$ MeV, $\Gamma = 50$ keV [$T_\pi = 79.6$ MeV]

**$\Delta T_\pi = 3$ MeV**



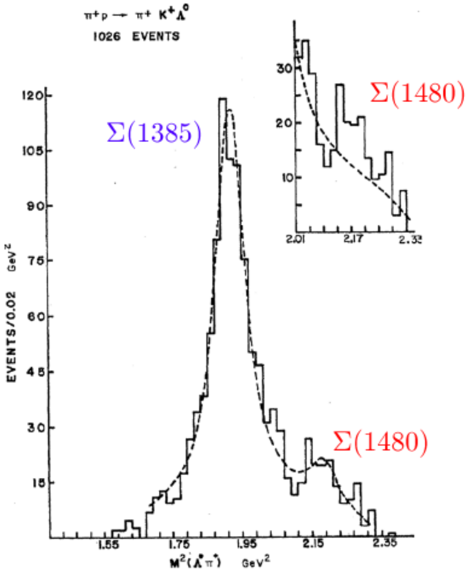


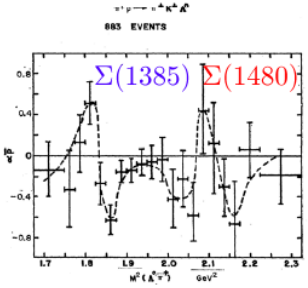


# N'(1100) Partners

## $\Sigma(1480)$ via $\pi^+p \to \pi^+K^+\Lambda^0$ at PPA

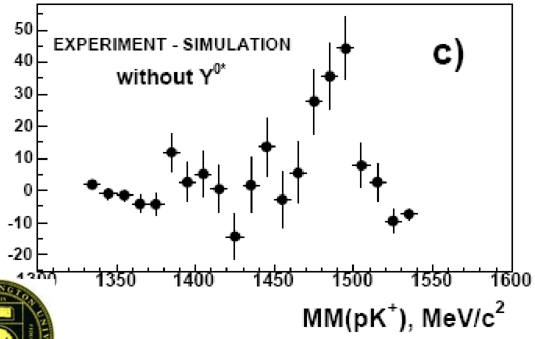
Yu-Li Pan *et al.* Phys. Rev. D **2**, 449 (1970)





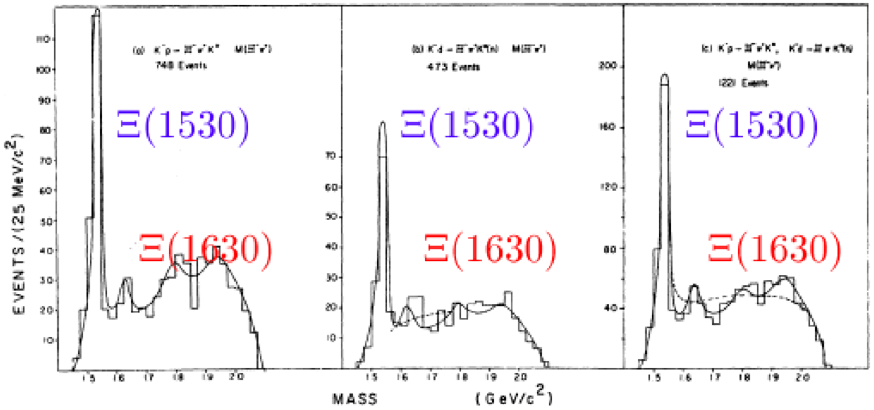
## $\Sigma(1480)$ via $pp \to K^+pX^0$ from COSY

I. Zychor *et al*. Phys. Rev. Lett. **96**, 012002 (2006)



## $\Xi(1630)$ from $K^-p \to \Xi^-\pi^+K^0$ at BNL

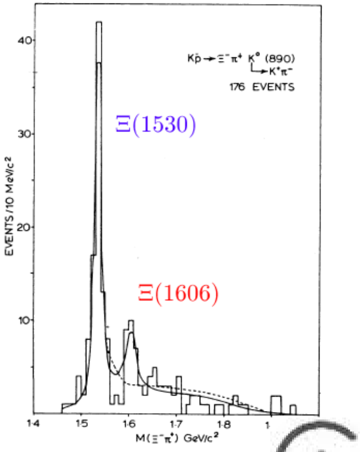
E. Briefel *et al.* Phys. Rev. D **16**, 2706 (1977)



proton deuteron p+d

## $\Xi(1606)$ from $K^-p \to \Xi^-\pi^+K^{*0}$ at CERN

R. T. Ross *et al.* Phys. Lett. **38B**, 177 (1972)



## $\Lambda(1330)$ via $\pi^-p \to \Lambda\gamma X^0$ from JINR

N. P. Bogachev *et al.* JETP Lett. **10**, 105 (1969)