Physics Opportunities with Meson Beams

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The George Washington University

- Hadron Spectroscopy.
- Opportunities with pion beams.
- Spectroscopy of hyperons.
- Meson spectroscopy.
- Lattice QCD.
- Physics opportunities.
- Summary.
- K-long Facility at Jlab.

Hadron Spectroscopy

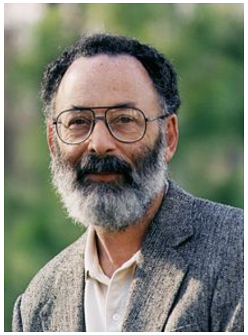
- To reap the full benefit of high-precision **EM** data, new high-statistics data from **measurements** with **meson beams**, with good angle & energy coverage for wide range of reactions, are critically needed to advance our knowledge in **Baryon** & **Meson Spectroscopy**.

- To address this situation, **state-of-the-art** **Meson Hadron Facility** needs to be constructed.

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." **Dick 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 – First: 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**.

*There are Many Ways to Study N**

- **Prolific source** of **N*** & **Δ*** baryons is to measure many channels with different combinations of quantum numbers.

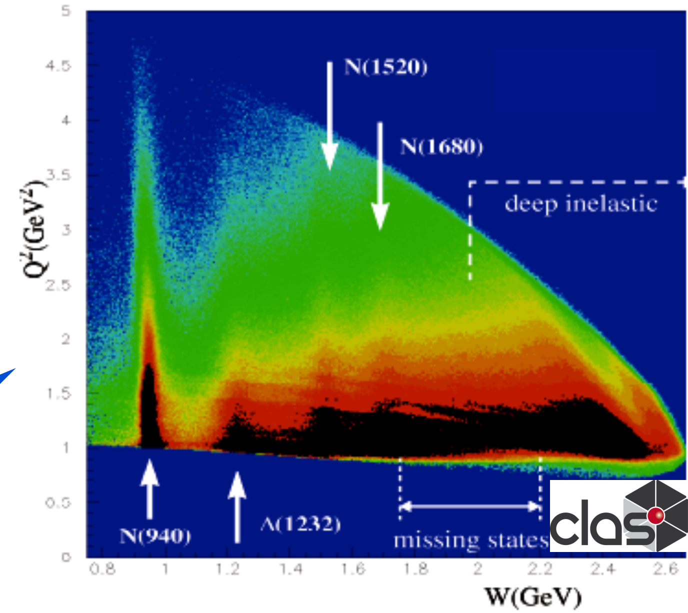
$\pi N \rightarrow \pi N, \pi\pi N, \ldots$

$\gamma N \rightarrow \pi N, \pi\pi N, \ldots$

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

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

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



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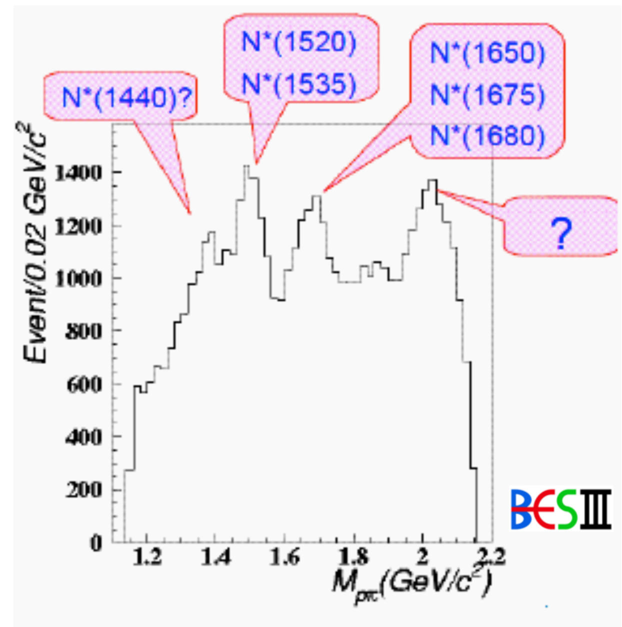
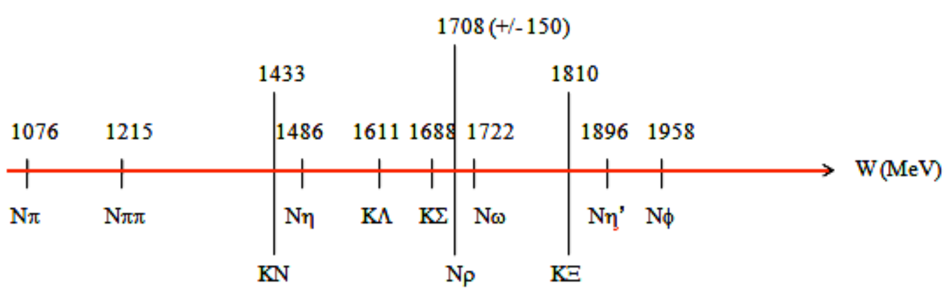


$J/\psi \rightarrow p\bar{n}\pi^-$

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



The First Baryon Resonance Discovery

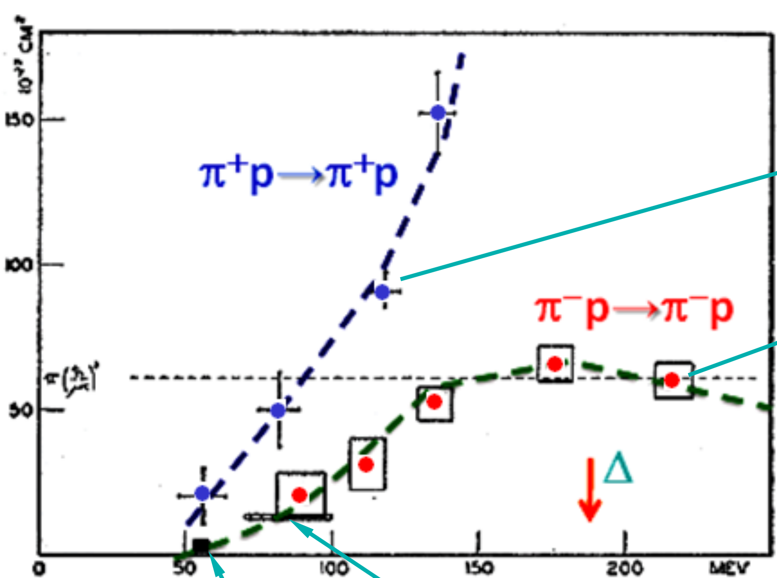
LETTERS TO THE EDITOR

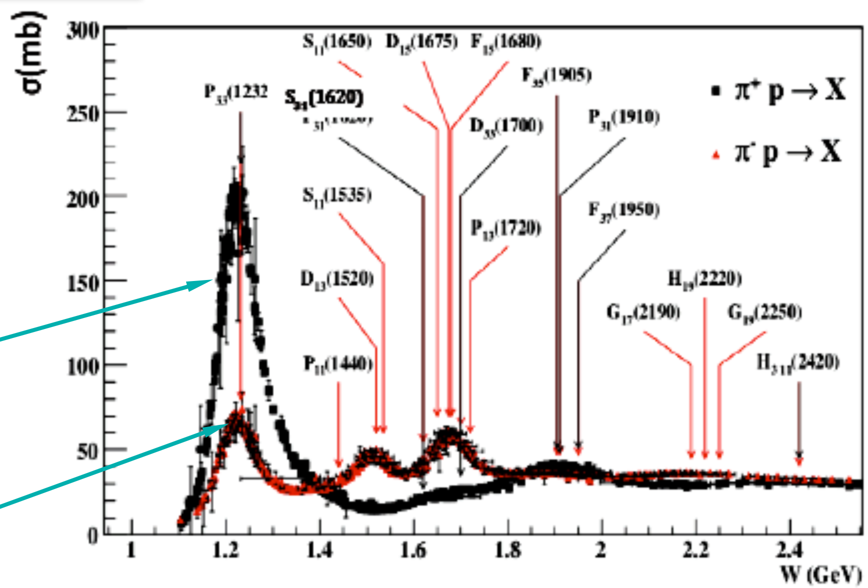
Total Cross Sections of Positive Pions in Hydrogen*

H. L. ANDERSON, E. FERMI, E. A. LONG,† AND D. E. NAGLE
Institute for Nuclear Studies, University of Chicago, Chicago, Illinois

(Received January 21, 1952)

$\Delta(1232)3/2^+$





- Since **1952** many states **discovered** in **πN→πN**.

Baryon Sector at PDG16

GW Contribution

C. Patrignani *et al,* Chin Phys C **40**, 090001 (2016)

Particle	J^P	Status
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+	[illegible]
N(19[illegible])	3/2−	[illegible]
N(1[illegible])	[illegible]	*
N(1[illegible])	[illegible]	**
N([illegible])	[illegible]	***
N([illegible])	[illegible]	**
N([illegible])	5/[illegible]	**
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+	**
Δ(1232)	3/2+	****
Δ(1600)	3/2+	***
Δ(1620)	1/2−	****
Δ(1700)	3/2−	****
Δ(1750)	1/2+	*
Δ(1900)	1/2−	**
Δ(1905)	5/2+	****
Δ(1910)	1/2+	****
Δ(1920)	3[illegible]	***
Δ(1930)	[illegible]	***
Δ(1940)	3/2−	*
Δ(1950)	7/2+	****
Δ(20[illegible])	5/2+	[illegible]
Δ([illegible])	[illegible]	[illegible]
Δ(2200)	7/2−	*
Δ(2300)	9/2+	**
Δ(2350)	5/2−	*
Δ(2390)	7/2+	*
Δ(2400)	9/2−	**
Δ(2420)	11/2+	****
Δ(2750)	13/2−	**
Δ(2950)	15/2+	**
Λ	1/2+	****
Λ(1405)	1/2−	****
Λ(1520)	3/2−	****
Λ(1600)	1/2+	***
Λ(1670)	1/2−	****
Λ(1690)	3/2−	****
Λ(1800)	1/2−	***
Λ(1810)	1/[illegible]	***
Λ(1820)	[illegible]	***
Λ(1830)	5/2−	***
Λ(1890)	3/2+	***
Λ(200[illegible])		[illegible]
Λ(2[illegible])	7/2+	[illegible]
Λ(2100)	7/2−	****
Λ(2110)	5/2+	***
Λ(2325)	3/2−	*
Λ(2350)	9/2+	***
Λ(2585)		**
Σ+	1/2+	****
Σ0	1/2+	****
Σ−	1/2+	****
Σ(1385)	3/2+	****
Σ(1480)		*
Σ(1560)		**
Σ(1580)	3/2−	*
Σ(1620)	1/2−	**
Σ(1660)	1/2+	***
Σ(1670)	3/2−	****
Σ(1690)		**
Σ(175[illegible])	[illegible]	[illegible]
Σ(1770)	1/2+	*
Σ(1775)	[illegible]	****
Σ(1840)	[illegible]	*
Σ(1880)	[illegible]	**
Σ(1915)	5/2+	****
Σ([illegible])	[illegible]	***
Σ(2000)	1/2−	*
Σ(2030)	7/2+	****
Σ(2070)	5/2+	*
Σ(2080)	3/2+	**
Σ(2100)	7/2−	*
Σ(2250)		***
Σ(2455)		**
Σ(2620)		**
Σ(3000)		*
Σ(3170)		*
Ξ0	1/2+	****
Ξ−	1/2+	****
Ξ(1530)	[illegible]	****
Ξ(16[illegible])		[illegible]
Ξ(1690)		***
Ξ(182[illegible])	[illegible]	***
Ξ(195[illegible])		***
Ξ(2030)	≥ 5/2?	***
Ξ([illegible])		*
Ξ(2250)		**
Ξ(2370)		**
Ξ(2500)		*
Ω−	3/2+	[illegible]
Ω([illegible])−		[illegible]
Ω([illegible])−		[illegible]
Ω([illegible])−		[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+	***
$\Xi_c'^+$	1/2+	***
$\Xi_c'^0$	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+	***

- **PDG16** has **109 Baryon Resonances** (**58** of them are **4*** & **3***).
- In case of **SU(6) X O(3)**, **434** states would be present if all revealed multiplets were fleshed out (**three 70** and **four 56**).

- First hyperon was discovered in **1947**.

- **Pole** position in complex energy plane for **hyperons** has been made only recently, **first of all** for **Λ(1520)3/2⁻**.

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

PWA for Baryons

Originally **PWA** arose as the technology to determine amplitude of reaction via **fitting** scattering data.
That is **non-trivial mathematical problem** – looking for solution of **ill-posed** problem following to **Hadamard** and **Tikhonov**.

Resonances appeared as **by-product**
[bound states objects with definite quantum numbers, mass, lifetime & so on].

PDG particle data group

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

Karlsruhe-Helsinki,

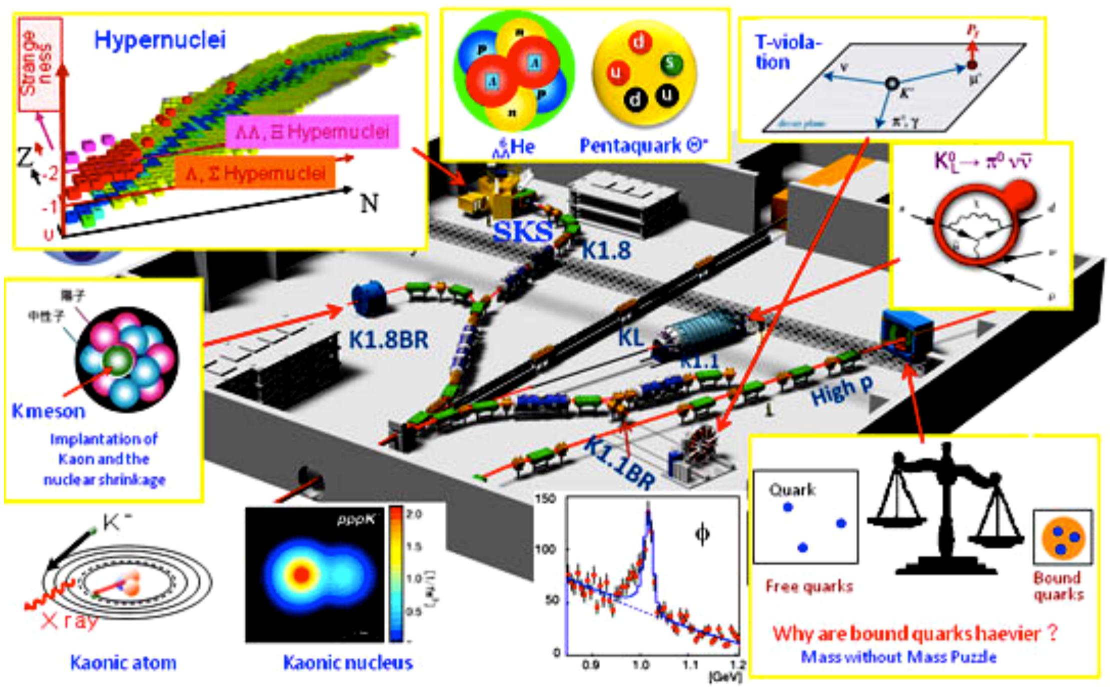
Carnegie-Mellon-Berkeley,

and **GW**

Main sources of **EM** couplings are **GW** & **BnGa** analyses.

Opportunities with Pion Beams

Nuclear & Hadron Physics at J-PARC



Why We Need Meson Beams

- Great strides have been made over last **two decades** to increase our knowledge of **Baryon** & **Meson Spectroscopy** with help of **meson photo**- and **electro**production data of unprecedented quality and quantity coming out of major **EM** facilities such as **JLab**, **MAMI**, **ELSA**, **SPring-8**, **BEPC**, & others.

- Regrettably, **meson-beam data** for different final states are mostly **outdated** & **largely of poor quality**, or even **non-existent**, & thus limit us in fully exploiting full potential of **new EM data**.

- CM energy range up to **2.5 GeV** is rich in opportunities for physics with **pion** & **Kaon beams** to study **Baryon** & **Meson Spectroscopy** questions complementary to **EM programs** underway at **EM facilities**.

- This talk **highlights** some of these **opportunities** & describes how facilities with **high-energy** & **high-intensity meson beams** can contribute to full understanding of high-quality data now coming from **EM facilities**.

- We emphasize that what we advocate here is not a competing effort, but an **experimental program** that provides **hadronic** complement of ongoing **EM program**, to furnish common ground for better & more reliable **phenomenological** & **theoretical** analyses based on **high-quality data**.

World Neutral & Charged PionPR Data

GW INS
— Data Analysis Center —
Institute for Nuclear Studies
THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON, DC

W < 2.5 GeV

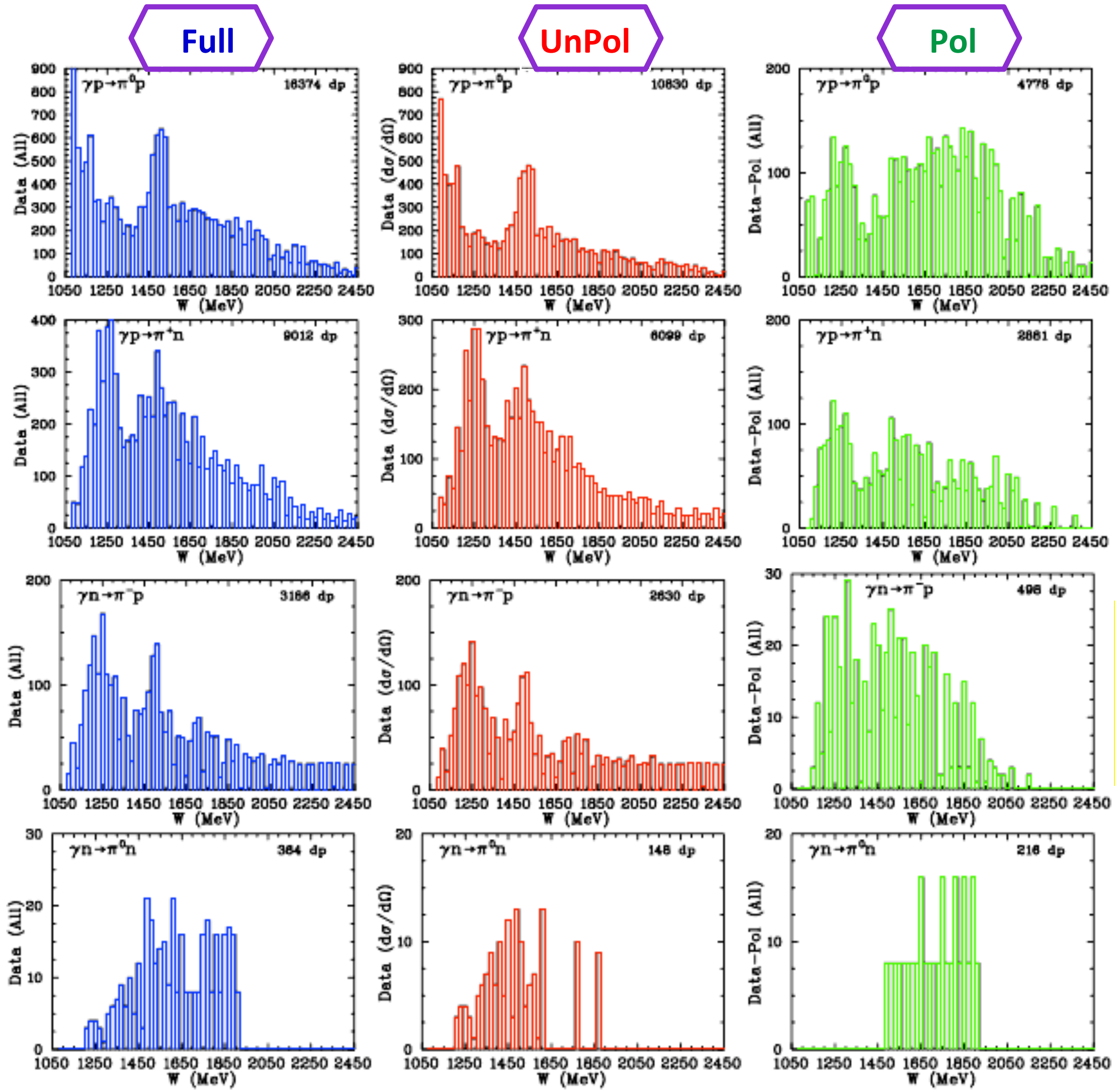
SAID: http://gwdac.phys.gwu.edu/

$\gamma p \to \pi^0 p$

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

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

$\gamma n \to \pi^0 n$



- The existing $\gamma n \to \pi^- p$ data contains mainly $d\sigma/d\Omega$, **15%** of which are from **polarized** measurements.

GW INS

— Data Analysis Center —

Institute for Nuclear Studies

THE GEORGE WASHINGTON UNIVERSITY

WASHINGTON, DC

World Pion-Nucleon Elastic Data

W < 2.5 GeV

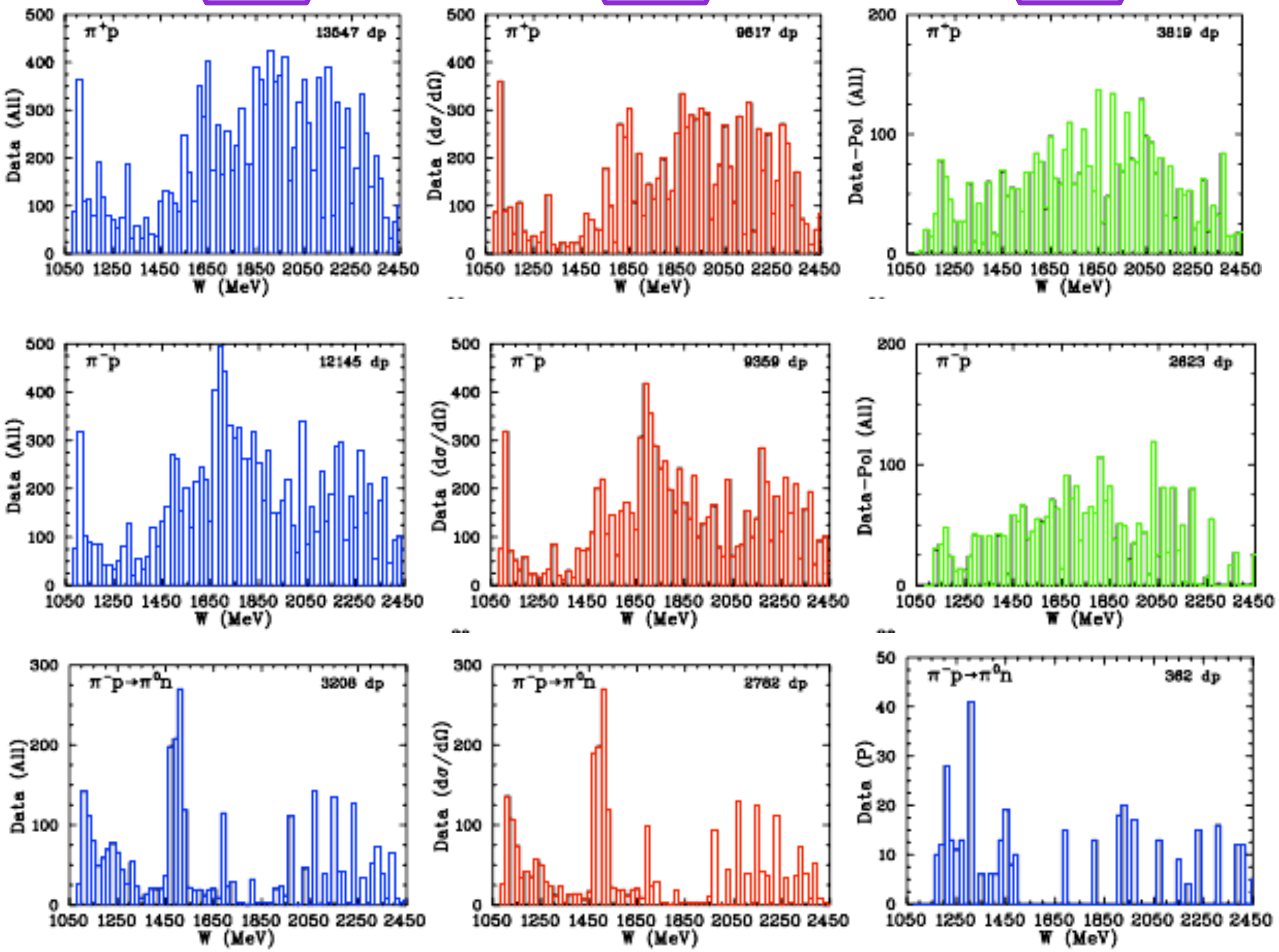
SAID: http://gwdac.phys.gwu.edu/

Full | **UnPol** | **Pol**

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

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

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

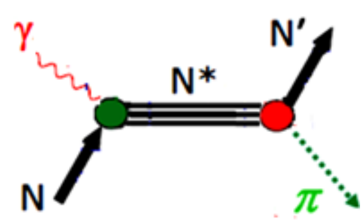


Status of Data for Specific Reactions

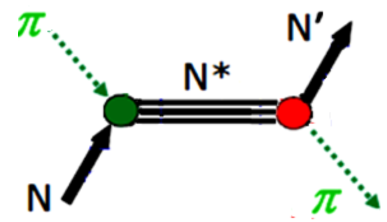
- Measurements of final states involving single **pseudoscalar meson** & **spin-1/2 baryon** are particularly important.

- *Reactions involving* ***πN*** *channels include*:

$$\gamma p \rightarrow \pi^0 p$$
$$\gamma p \rightarrow \pi^+ n$$
$$\gamma n \rightarrow \pi^- p$$
$$\gamma n \rightarrow \pi^0 n$$



$$\pi^- p \rightarrow \pi^0 n$$
$$\pi^- p \rightarrow \pi^- p$$
$$\pi^+ p \rightarrow \pi^+ p$$



PDG: **πN** elastic scattering data allowed establishment of **4**-star resonances.

- Many of data were taken **long ago** & suffer from **systematic** uncertainties.

GW Data Analysis Center, Institute for Nuclear Studies: Available data for **πN** elastic scattering are **incomplete**.

- Measurements of **A** & **R** observables (limited number of data available) are needed to construct truly unbiased **PW amplitudes**.

New Observables

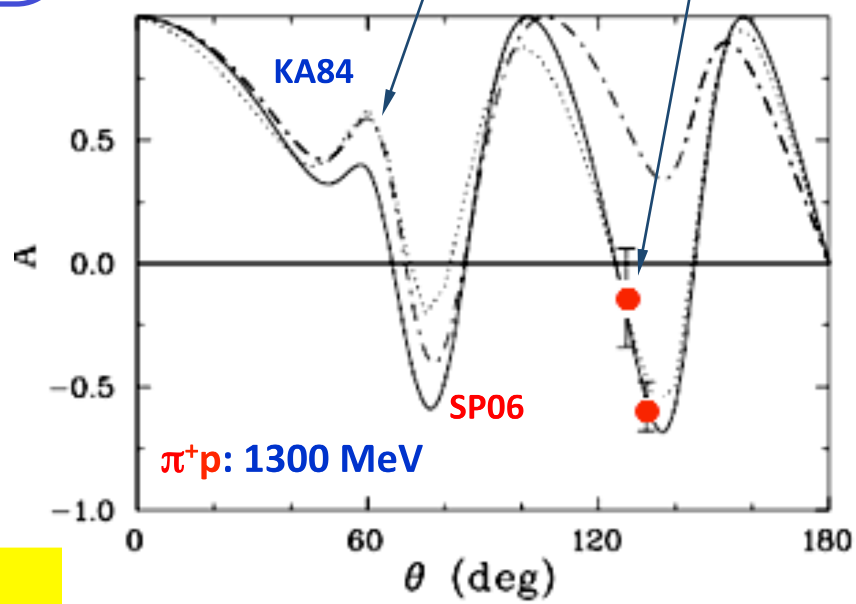
R. Arndt, W. Briscoe, IS, R. Workman, Phys Rev C **74**, 045205 (2006)

- πN scattering data:

dσ/dΩ (unpolarized)
P (polarized target or recoil nucleon)
R and A (polarized target and recoil measured)

Not Independent: $P^2 + R^2 + A^2 = 1$

- **Old PWA** solutions may be not able to reproduce **New** measurements.



$$P\left(\frac{d\sigma}{d\Omega}\right) = 2\,\mathrm{Im}(fg^*)$$

$$R\left(\frac{d\sigma}{d\Omega}\right) = (|f|^2 - |g|^2)\cos\theta - 2\,\mathrm{Re}(fg^*)\sin\theta$$

$$A\left(\frac{d\sigma}{d\Omega}\right) = (|f|^2 - |g|^2)\sin\theta + 2\,\mathrm{Re}(fg^*)\cos\theta$$

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

- **Polarized measurements** would also be important part of **hadron program**.

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

EPECUR

- New precise cross section measurements:
  $\Delta\sigma$ = **0.5%** stat, **Δp** = **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

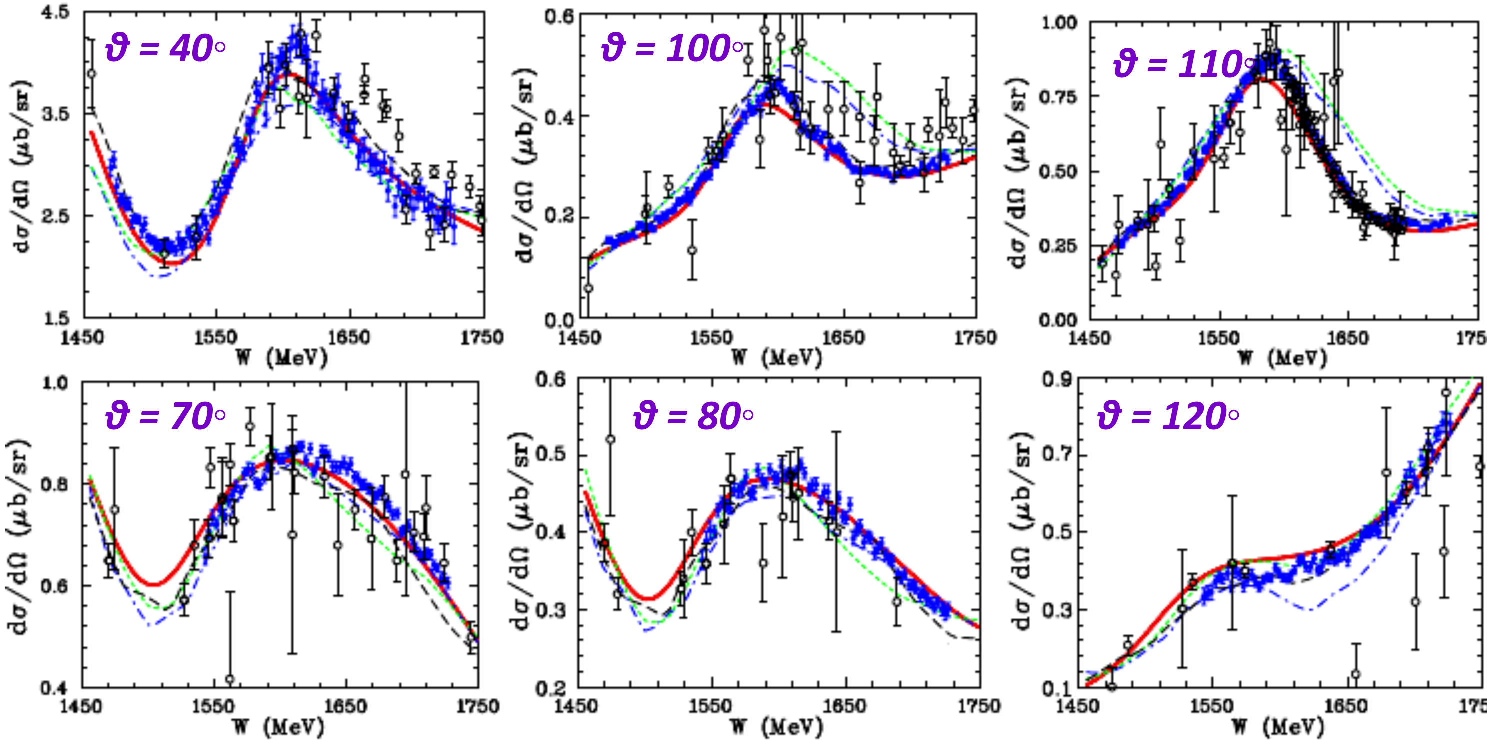
I. G. Alekseev,[1] V. A. Andreev,[3] I. G. Bordyuzhin,[1,5] W. J. Briscoe,[2] Ye. A. Filimonov,[3] V. V. Golubev,[3] A. B. Gridnev,[3] D. V. Kalinkin,[1] L. I. Koroleva,[1] N. G. Kozlenko,[3] V. S. Kozlov,[3] A. G. Krivshich,[3] B. V. Morozov,[1] V. M. Nesterov,[1] D. V. Novinsky,[3] V. V. Ryltsov,[1] 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 dσ/dΩ:
800 – 1243 MeV/c
40 – 122 deg

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

2638 dσ/dΩ:
918 – 1240 MeV/c
40 – 122 deg



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

Predictions: WI08, KH80, KA84, CMB

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

Status of Data for specific Reactions

- *Reactions that involve the **ηN** and **KΛ** channels are **notable** because they have pure isospin-**1/2** contributions:*

$$\gamma p \to \eta p \qquad \pi^- p \to \eta n$$
$$\gamma n \to \eta n$$
$$\gamma p \to K^+ \Lambda \qquad \pi^- p \to K^0 \Lambda$$
$$\gamma n \to K^0 \Lambda$$

- Analyses of **photoproduction** combined with **pion-induced** reactions permit separating **EM** & **hadronic** **vertices**.

- It is only by **combining information** from analyses of both **πN** elastic scattering & **γN → πN** that make it possible to determine $\mathbf{A_{1/2}}$ & $\mathbf{A_{3/2}}$ helicity couplings for **N*** & **Δ*** resonances.

$\pi^- p \rightarrow \eta n$ *Revival*

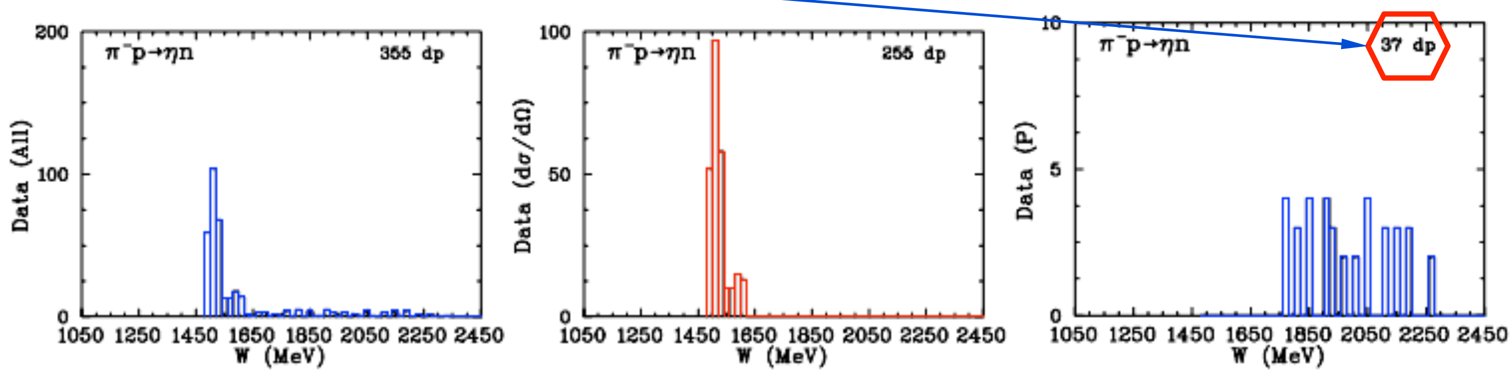
- *$\gamma p \rightarrow \eta p$ is one of **key reactions** for which colleagues in EM community hope to do ``complete measurement" & determine PW amplitudes **directly**.*

- Any **coupled-channel analysis** of those measurements will need precise data for $\pi^- p \rightarrow \eta n$.
- Most of available data for that reaction come from measurements published in **1970**s, which have been **evaluated** by **several groups** as being **unreliable** above **W** = **1620** MeV.

- Precise new data were measured by **Crystal Ball** Collaboration, but these extend only up to peak of first S_{11}-resonance.

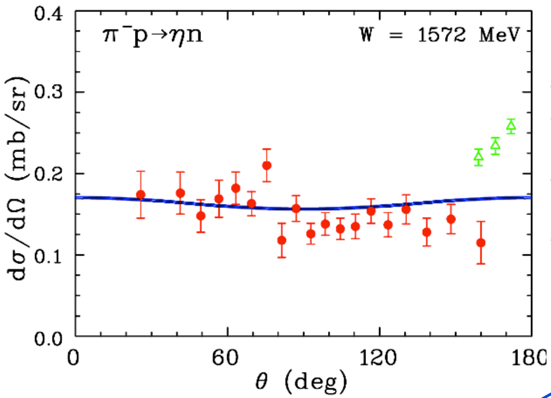
S. Prakhov *et al*, Phys Rev C **72**, 015203 (2005)

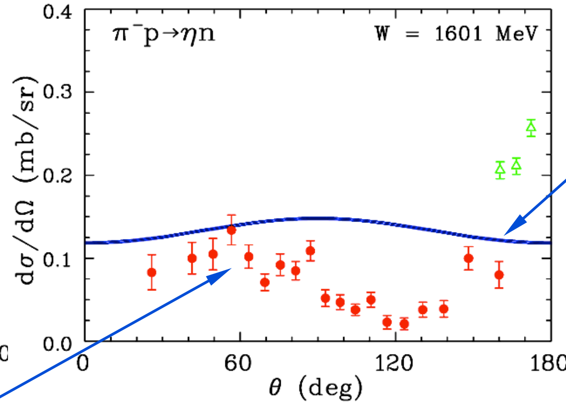
Very few polarization data for this reaction exist out of range of $d\sigma/d\Omega$.



- Available data for $\pi^- p$ reactions with **KY**, **η'N**, **ωN**, & **φN** final states are generally as **bad** or **worse**.

Where we are in $\pi^- p \rightarrow \eta n$

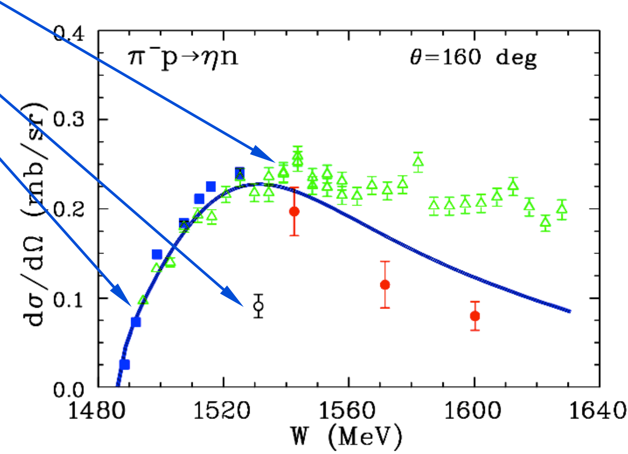




- **There were several independent evaluations:**
  - Arndt *et al*, Phys Rev C **69**, 035213 (2004)
  - Clajus & Nefkens, πN News Lett **7**, 76 (1992)
  - Wighman *et al*, Phys Rev D **38**, 3365 (1988)
  - Koch & Pietarinen, Nucl Phys **A336**, 331 (1980)
  - Cutkosky *et al*, Phys Rev D **20**, 2804 (1979)

There are 27 σ^{tot} & 37 P reliable data above T = 800 MeV → 0.03 data/MeV

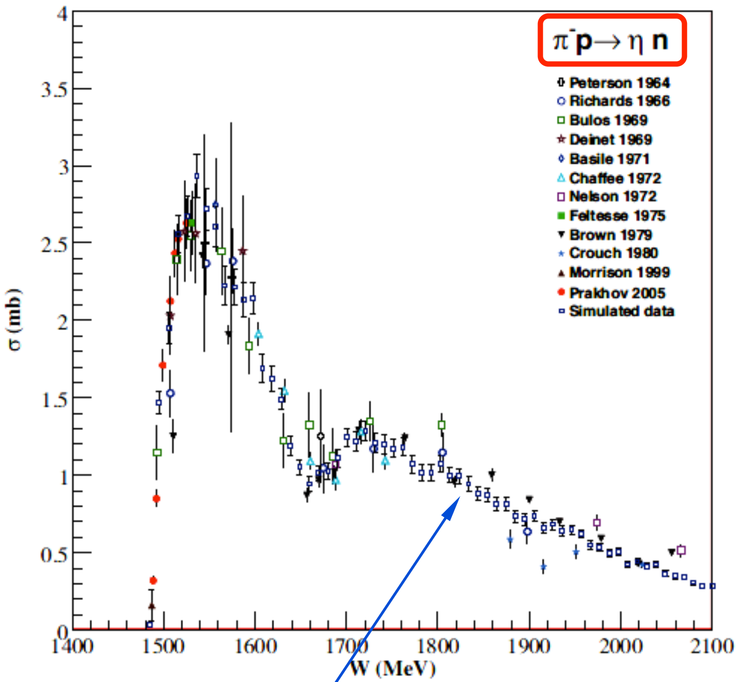
RHEL: Brown *et al*, Nucl Phys **B153**, 89 (1979)
RHEL: Debenham *et al*, Phys Rev D **12**, 2545 (1975)
Saclay: Feltesse *et al*, Nucl Phys **B93**, 242 (1975)
BNL: Prakhov *et al*, Phys Rev C **72**, 015203 (2005)

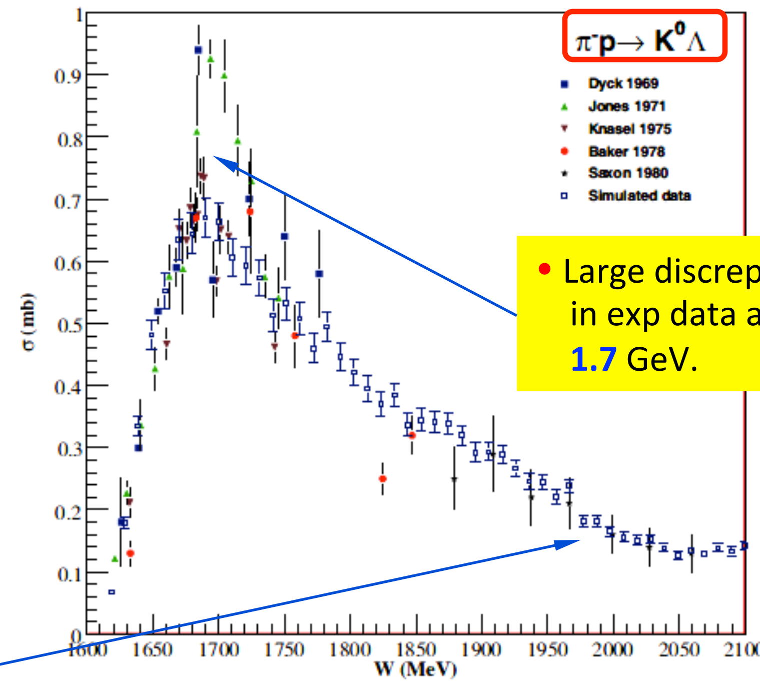


- Most of previous data do not satisfy requirements [systematics (10% or more), momentum err (up to 50 MeV/c), and so on].

- **Evaluation** for reactions with **KY**, **η'N**, **ωN**, **ϕN**, & so on final states are **not possible now** because of small/limited databases.

Possible Improvement of $\pi^- p \to \eta n$ & $\pi^- p \to K^0 \Lambda$ *Data*





- Large discrepancy in exp data around **1.7** GeV.

- **Projection data** with **5**% uncertainties & with energy scan at **10** MeV intervals, which is comparable to **modern photoproduction** measurements.

- More precise data for reaction $\pi^- p \to K^0 \Lambda$ (in combination with $K^- p \to K^0 \Sigma^0$) would also enable the study of **SU(3) flavor** symmetry & its breaking.

Status of Data with Strangeness Production

- *Another group of related reactions involve $K\Sigma$ channel:*

$$\gamma p \to K^+\Sigma^0$$
$$\gamma p \to K^0\Sigma^+$$
$$\gamma n \to K^+\Sigma^-$$
$$\gamma n \to K^0\Sigma^0$$

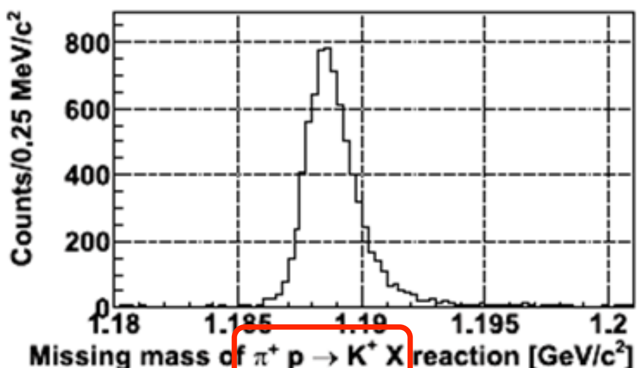
$$\pi^- p \to K^0\Sigma^0$$
$$\pi^- p \to K^+\Sigma^-$$
$$\pi^+ p \to K^+\Sigma^+$$

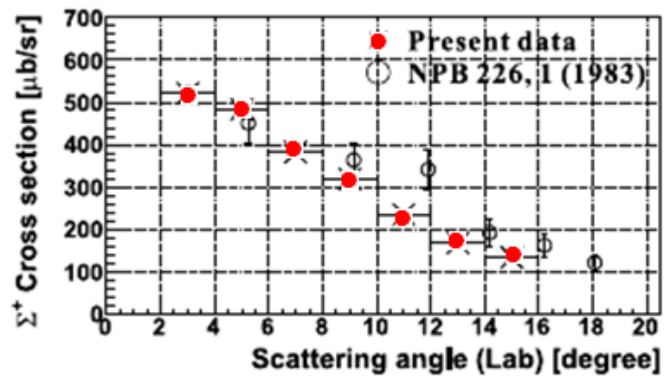
- Except for $\pi^+ p \to K^+\Sigma^+$, these reactions involve mixture of **isospin 1/2** & **3/2**.
- Although there have been number of recent high-quality measurements involving **KΣ** photoproduction, status of complementary reactions measured with **pion beams** is rather **dismal**.

The Durham HepData Project

- There are generally fewer available data for $\pi^- p$ reactions with **KΣ**, **η'N**, **ωN**, & **ϕN** final states than for $\pi^- p \to \eta n$.

K. Shirotori *et al,* Phys. Rev Lett **109**, 132002 (2012)



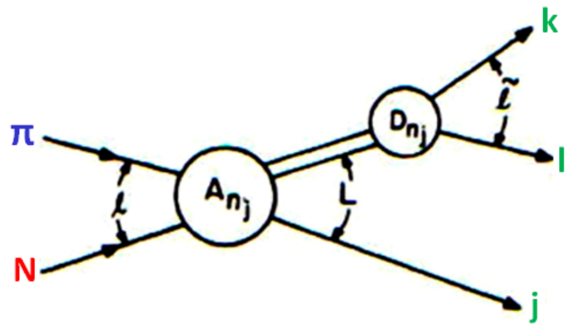


- Measurements like these, over more comprehensive energy range, will greatly improve **PWA**s of **KΣ** final state &, in return, help to extract the **S**-wave contribution needed, e.g., in approaches based on **unitarized chiral perturbation theory**.

Status of Data for multi-pion Reactions

- *Other important reactions that can be studied are those with* ***ππN*** *final states:*

$$\gamma p \to \pi^0\pi^0 p \qquad \pi^- p \to \pi^0\pi^0 n$$
$$\gamma p \to \pi^0\pi^+ n \qquad \pi^- p \to \pi^0\pi^- p$$
$$\gamma p \to \pi^+\pi^- p \qquad \pi^- p \to \pi^+\pi^- n$$
$$\gamma n \to \pi^0\pi^0 n \qquad \pi^+ p \to \pi^0\pi^+ p$$
$$\gamma n \to \pi^0\pi^- p \qquad \pi^+ p \to \pi^+\pi^+ n$$
$$\gamma n \to \pi^+\pi^- n$$



- Analysis & interpretation of data from these reactions is more complicated because they involve **three-body** final states.

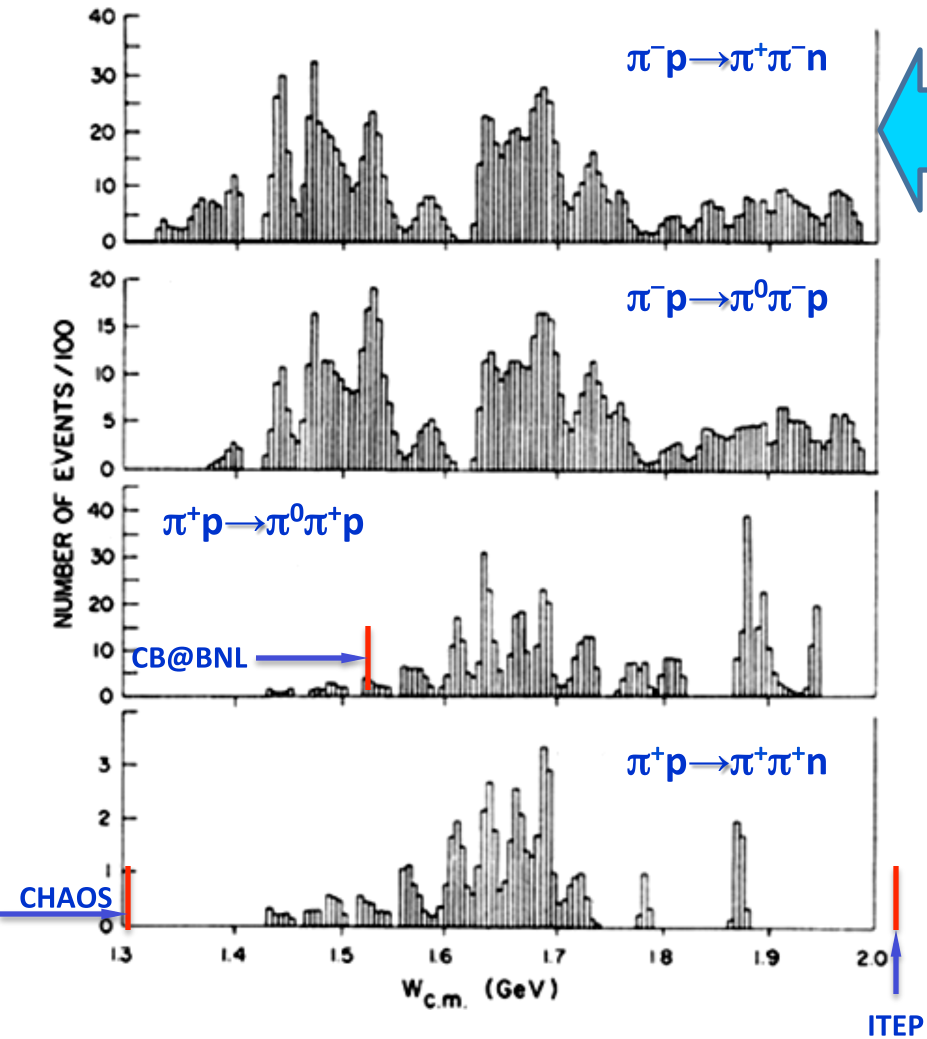
- However, **πN→ππN** reactions have the **lowest energy threshold** of any **inelastic hadronic** channel & some of **largest cross sections**.

PDG: For most established **N*** & **Δ*** resonances, **dominant inelastic decays** are to **ππN** final states.

- Our knowledge of **πΔ**, **ρN**, & other quasi-two-body **ππN** channels comes mainly from **Isobar-model** analyses of **πN→ππN** data.

- A large **experimental database** (including **pol** measurements) is **needed** to determine precisely **PW** amplitudes because so many amplitudes are needed to describe **three-body** final states.

$\pi p \rightarrow \pi\pi N$ *Measurements*



- **241,214** **Bubble Chamber** events for $\pi p \rightarrow \pi\pi N$ have been analyzed in **Isobar-model PWA** at **W** = **1320** to **1930** MeV.

  Manley, Arndt *et al,* Phys Rev D **30**, 904 (1984)

- Post-Bubble Chamber measurements:
  - **349,611** events for $\pi^- p \rightarrow \pi^0\pi^0 n$ from **CB@BNL** at **W** = **1213** to **1527** MeV.

    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.

    Kermani *et al,* Phys Rev C **58**, 3431 (1998)
  - **40,000** events for $\vec{\pi^- p} \rightarrow \pi^-\pi^+ n$ from **ITEP** at **W** = **2060** MeV.

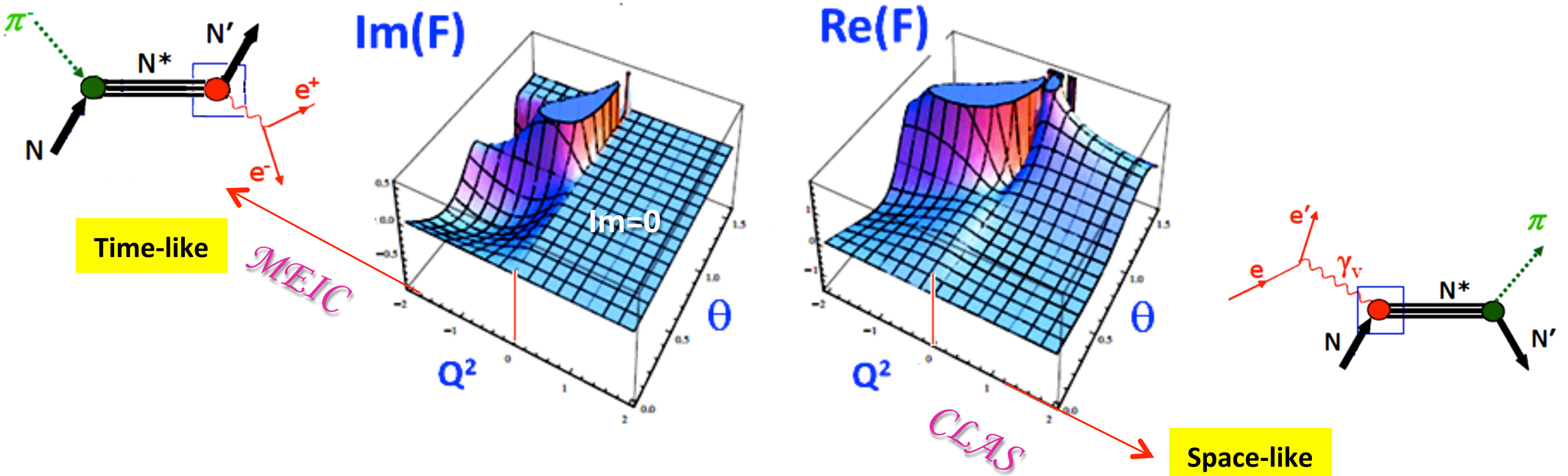
    Alekseev *et al,* Phys At Nucl **61**, 174 (1998)

Form-Factor Measurements

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

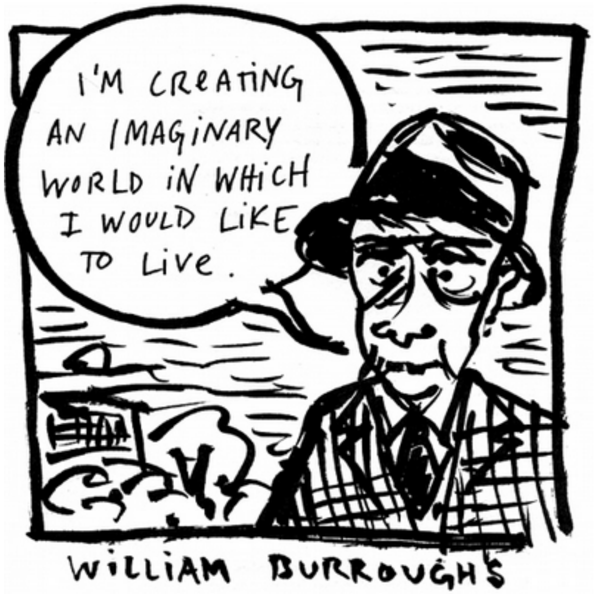
$0 < k^2 < 4M^2$ $\quad$ $0 < k^2 < 4m_\pi^2$

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



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

Spectroscopy of Hyperons



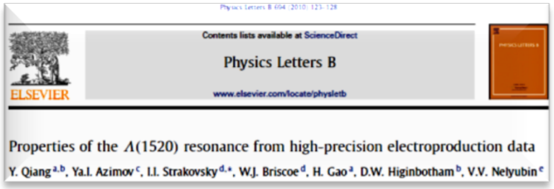
Spectroscopy of Strange Sector Resonances

- Our current experimental knowledge of **Λ*** & **Σ*** resonances is far **worse** than our knowledge of **N*** & **Δ*** resonances; however, within **quark model**, they are no less fundamental.

- **First determinations** of **pole** positions, for instance for **Λ(1520)**, were obtained only recently.

Jefferson Lab
Thomas Jefferson National Accelerator Facility

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


Physics Letters B 694 (2010) 123–128
Contents lists available at ScienceDirect
Physics Letters B
www.elsevier.com/locate/physletb
ELSEVIER

Properties of the Λ(1520) resonance from high-precision electroproduction data
Y. Qiang[a,b], Ya.I. Azimov[c], I.I. Strakovsky[d,*], W.J. Briscoe[d], H. Gao[a], D.W. Higinbotham[b], V.V. Nelyubin[e]

- Clearly, there is need to learn about baryon resonances in ``**strange sector**" to have complete understanding of **three-quark bound** states.

- One of secondary beam problem is that **Kaon yield** has factor of about **500+** less than **pion one**.
- This is the main reason why there are limited exp data for **Kaon** induced measurements & there are limited **pol** measurements.

- Line shape of **Λ(1405)1/2$^-$** can be studied in **K^-p** and **K^-d** (**K^-n**) reactions. Comparison between **pion**- & **Kaon**-induced reactions together with **photoprod** is important.
- **H-dibaryon**, which has **quark** configuration of **uuddss**, will be searched for in (**K^-**, **K^+**).
- Measured **$\pi\Sigma/\pi\pi\Sigma$ BR** for **Σ(1670)** produced in reaction **$K^-p \to \pi^-\Sigma(1670)^+$** depends strongly on momentum transfer, & it has been suggested that there exist two **Σ(1670)s** with same mass & quantum numbers, one with large **$\pi\pi\Sigma$** branching fraction & the other with large **$\pi\Sigma$** BR.

Status of Data for Kaon Induced Reactions

- ***Hyperons Λ^*& Σ^*** have been systematically studied in following formation processes:*

$K^-p \to K^-p$	$K^-p \to \pi^+\Sigma^-$	$K^-n \to \pi^-\Lambda$
$K^-p \to \overline{K}^0 n$	$K^-p \to \pi^0\Sigma^0$	$K^-n \to \pi^0\Sigma^-$
$K^-p \to \pi^0\Lambda$	$K^-p \to \pi^-\Sigma^+$	$K^-n \to \pi^-\Sigma^0$

- Most of our knowledge about **multi-strange baryons** was obtained from old data measured with **Bubble Chambers**.

- **Cascade baryons** could be studied with high-momentum **Kaon beams** & modern **multi particle spectrometers**.
- Lack of appropriate **beams** & **detectors** in **past** greatly **limited** our **knowledge**.

PDG particle data group: Currently only the **cascade** ground states of **spin-1/2** & **spin-3/2** are well identified.

- *For excited states, possible production reactions with **Kaon** beams are following:*

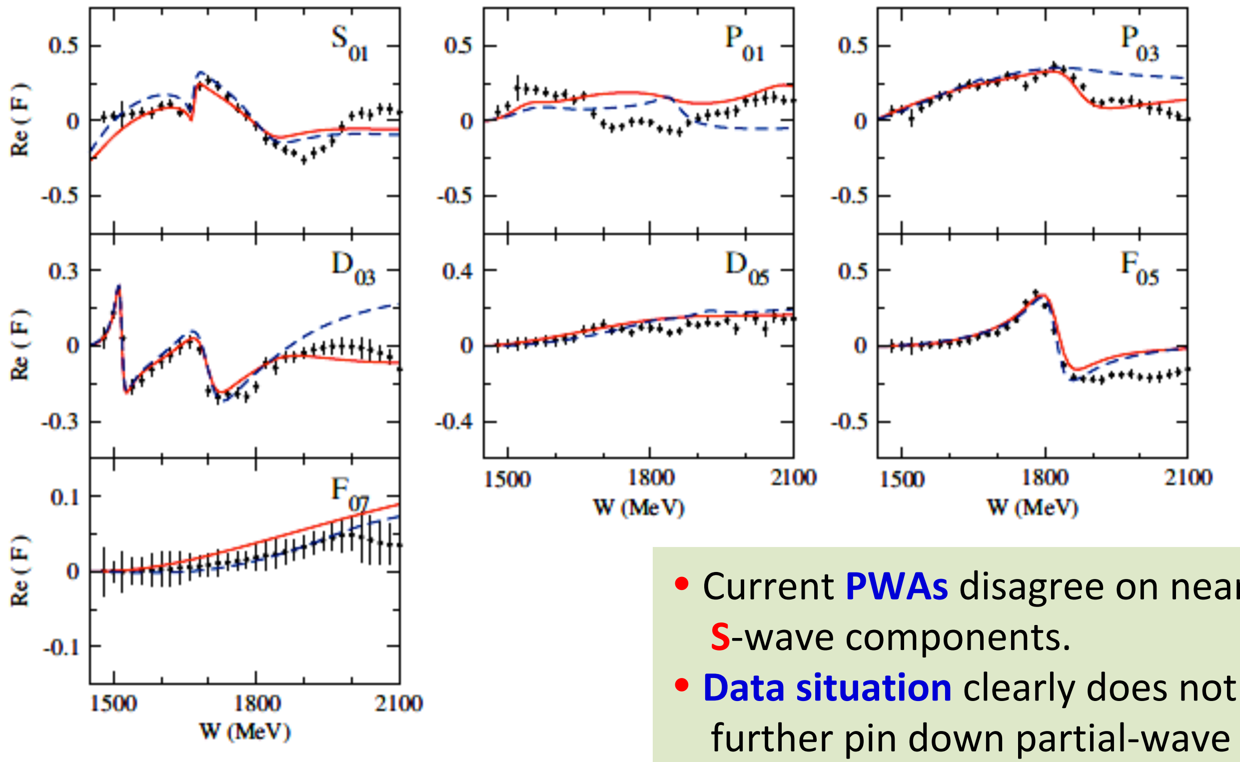
$$K^-p \to K^+\Xi^{*-}$$
$$K^-p \to K^{*+}\Xi^{*-}$$
$$K^-p \to K^{*0}\Xi^{*0}$$

- *There are other production processes with single or **multi pions**:*

$$K^-p \to K^+\pi^+\pi^-\Xi^{*-}$$
$$K^-p \to K^+\pi^-\Xi^{*0}$$

Samples of Analyses of $\bar{K}N \rightarrow \bar{K}N$ Data

- Real part of **$\bar{K}N \rightarrow \bar{K}N$** amplitude in isospin channel of **Λ(1405)1/2⁻** (**I = 0**).

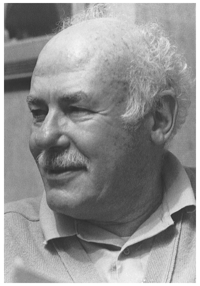


- Current **PWAs** disagree on near-threshold **S**-wave components.
- **Data situation** clearly does not allow to further pin down partial-wave content.

ANL/Osaka: H. Kamano *et al*, Phys Rev C **90**, 065204 (2014)
Kent State: H. Zhang *et al*, Phys Rev C **88**, 035204 (2013)

Meson Spectroscopy

Spectroscopy of Mesons



``The di-quark or meson-baryon puzzle: Why is the quark-quark interaction just enough weaker than the quark-anti-quark interaction so that di-quarks near the meson mass are not observed, but three-quark systems have masses comparable to those of mesons?" **Harry Lipkin**, **1973**.

``For the region below 1 GeV, the debate centers on whether the phenomena are truly resonant or driven by attractive t-channel exchanges, and if the former, whether they are molecules or $qq\bar{q}\bar{q}$." **Frank Close**, **2007**.

``QCD predicts there should be a far richer spectrum, with states made predominantly of glue, we call glueballs, tetra-quark states made of two quarks and two anti-quarks... For almost forty years we have been searching for these additional states. Indeed we may well have observed some of these, but there is little certainty of what has been found." **Michael Pennington**, **2015**.

``A simple picture for both mesons and baryons is inconsistent with any version of relativistic field theory, where one can not exclude presence of an arbitrary number of virtual quark-anti-quark pairs and/or gluons. Therefore, adequate description of any hadron should use a Fock column, where lines correspond to particular configurations (but with the same ``global" quantum numbers, like I, J, P, C, and so on).." **Yakov Azimov**, **2015**.

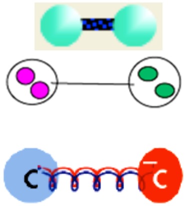
Spectroscopy of Mesons

- Although it was **light Hadron Spectroscopy** that led the way to discovery of **color degrees** of freedom & **QCD**, much of field remains poorly understood, both **theoretically** & **experimentally**.

- **Availability** of **pion** & **Kaon** beams provide important opportunity to improve this situation.

- Experimentally, **Meson Spectroscopy** can be investigated by using **PWA**s to determine quantum numbers from angular distributions of final-state particle distributions.

- **Chief areas** of interest in **Meson Spectroscopy** are



light scalar mesons,
multiquark states,
glueballs, and
hybrids.

- Experimental effort with **meson beams** will complement the **GlueX** experiment at **JLab**, which seeks to explore properties of **hybrids** with photon beam.

Status of search for Glueballs

- Quantum numbers for exotics: multiquark, glueball, or hybrid are **0^{--}**, **(odd)$^{-+}$**, and **(even)$^{+-}$**.

- Lattice **glueball** spectrum below **3** GeV.

Y. Chen *et al*, Phys Rev D **73**, 014516 (2006)

J^{PC}	Mass (MeV)
0^{++}	1710 (50)(80)
2^{++}	2390 (30)(120)
0^{-+}	2560 (35)(120)
1^{+-}	2989 (30)(140)

- Unfortunately, there are no **glueballs** have been **definitively identified**.

- Promising earlier candidate called ξ(**2200**) has not withstood careful analysis.

- At present, best candidate is **f_0(1500)** [or possibly **f_0(1710)**], which appears as supernumerary state in enigmatic scalar meson sector .

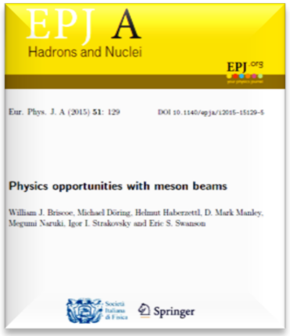
C. Amsler and F.E. Close, Phys Rev D **53**, 295 (1996)

Physics Opportunities

- Current run plans at modern **Hadron Facilities** [**J-PARC**, **HADES**, **COMPASS**, & **PANDA**] will greatly improve database; however, there are no plans for polarized measurements.

- New **Hadron Facility** would need large-acceptance detector & availability of polarized target.

- In particular, such dedicated facility should be able to provide features listed in following, together with short summary of **key** arguments made in **White Paper**:


EPJ A
Hadrons and Nuclei
Eur. Phys. J. A (2015) 51: 129
DOI 10.1140/epja/i2015-15129-6

Physics opportunities with meson beams

William J. Briscoe, Michael Döring, Helmut Haberzettl, D. Mark Manley, Megumi Naruki, Igor I. Strakovsky and Eric S. Swanson

Springer

Treasure box

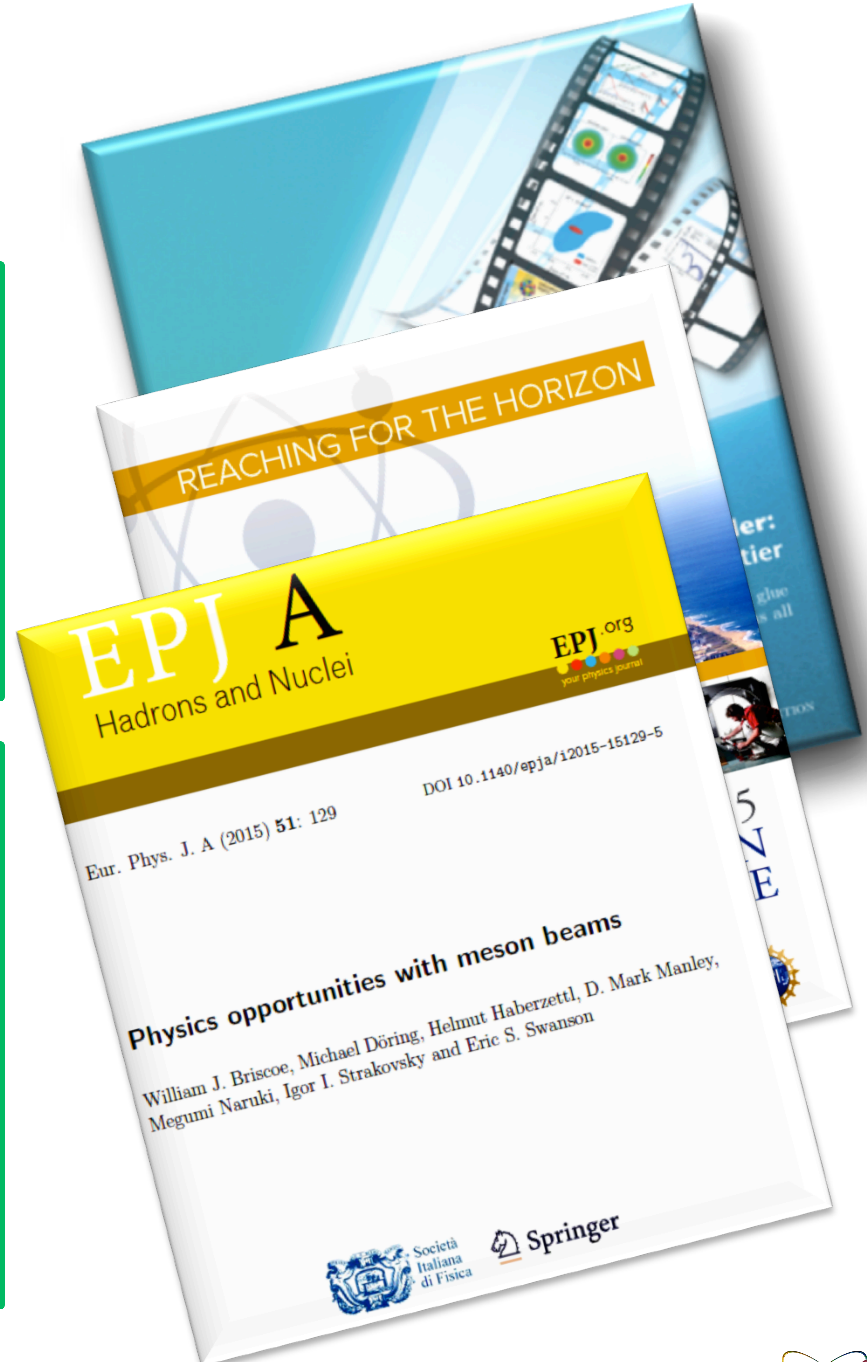
Electron Ion Collider

NSAC LRP 2015:

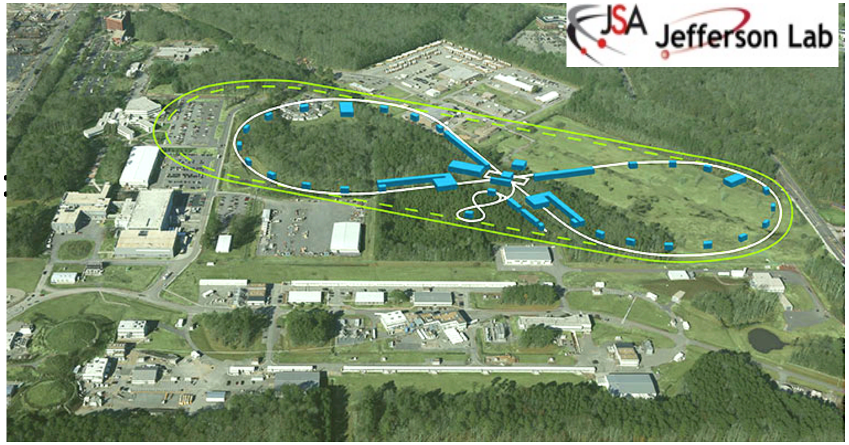
1. *``Continue existing projects: CEBAF, FRIB, RHIC.”*
2. *``…a U.S.-led ton-scale neutrinoless double beta decay experiment.”*
3. ***``…a high-energy high-luminosity polarized EIC as the highest priority for new facility construction following the completion of FRIB.”***
4. *``…small-scale and mid-scale projects and initiatives that enable forefront research at universities and labs.”*

*``A major **experimental initiative** continues to be the search for the so-called `**missing baryons**’. If each of the three quarks in a baryon interacted equally, one would predict the existence of more baryons than observed by experiments. The **experimental data** are, therefore, suggestive of a more intricate manifestation of **QCD** in baryons…“*

*``For many years, there were both theoretical and experimental reasons to believe that the **strange sea quarks** might play a significant role in the nucleon's structure; a better understanding of the role of strange quarks became an important priority.”*

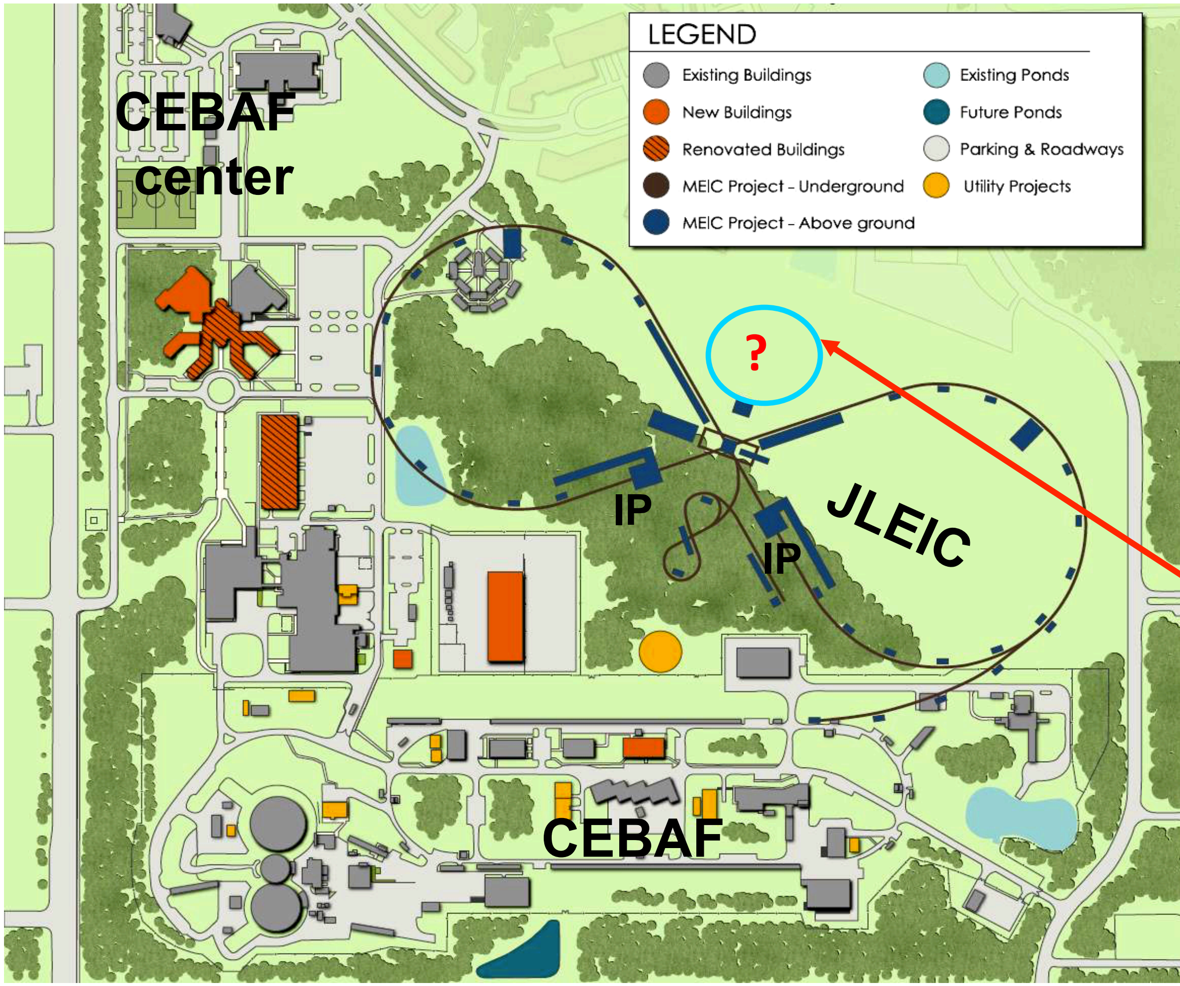


Why EIC and Why at Jefferson Lab ?



- Large established **user community** in field.
- ***JLEIC Facility*** design meets experimental needs:
  - Broad CM energy range.
  - High luminosity.
  - Wide range of ion species.
- ***Green Field*** new ion complex provide opportunity for modern design for highest performance.
- Low **technical** risk:
  - ***EIC*** design largely based on conventional technologies.
- ***Meson Hadron Facility*** will allow keep longer **JLab Ion Booster** busy (to use much more then ``**several minutes**" a day), which would be much more effective use of ***JLEIC Facility***, **without significant increase of cost of JLab Ion Booster**.

JLab Campus Layout



JLEIC:

- *W* = **15** – **65** GeV.
- *Protons*: **20** – **100** GeV.
- *Luminosity*: 10^{33} to 10^{34} $cm^{-2}s^{-1}$ per IP.
- *Circumference*: **2.2** km.

Ion Booster:

- *Protons*: **8** GeV.
- Booster design based on super-ferric magnet technology.
- *Circumference*: **273** m.

Meson Hadron Facility [good to have]:

- *Pions*:
  - < **3** GeV.
  - 10^{7} s^{-1}.
  - Δp/p < **2**%.
- *Kaons*:
  - < **2** GeV.
  - 10^{5} s^{-1}.

- We have outlined some of the **physics programs** that could be advanced with **Meson Hadron Facility**.

- These include studies of **baryon** spectroscopy, particularly search for ``**missing resonances**” with hadronic beam data that would be analyzed together with **photo**- & **electro**production data using modern **coupled-channel** analysis methods.

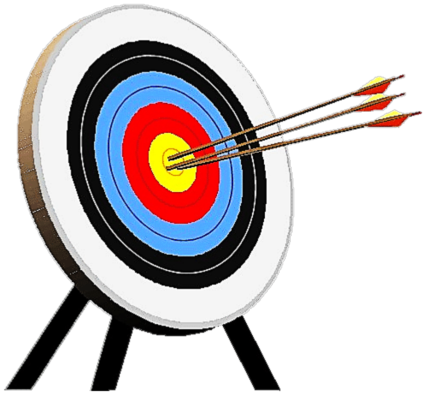
- **Meson Hadron Facility** would also advance **hyperon spectroscopy** & study of **strangeness** in nuclear & hadronic physics.

- Furthermore, searches for highly anticipated, but never unambiguously observed, **exotic states** such as **multiquarks**, **glueballs**, & **hybrids**, would be greatly enhanced by availability of **Hadron Facility**.

- Simply observing many of missing **low-lying meson states** would also assist in constructing new models of emergent **properties** of **QCD**, thereby improving our understanding of this strongly coupled **quantum field theory.**

Strange Hadron Spectroscopy with Secondary KL Beam at GlueX

Aims of Jlab KLF Project



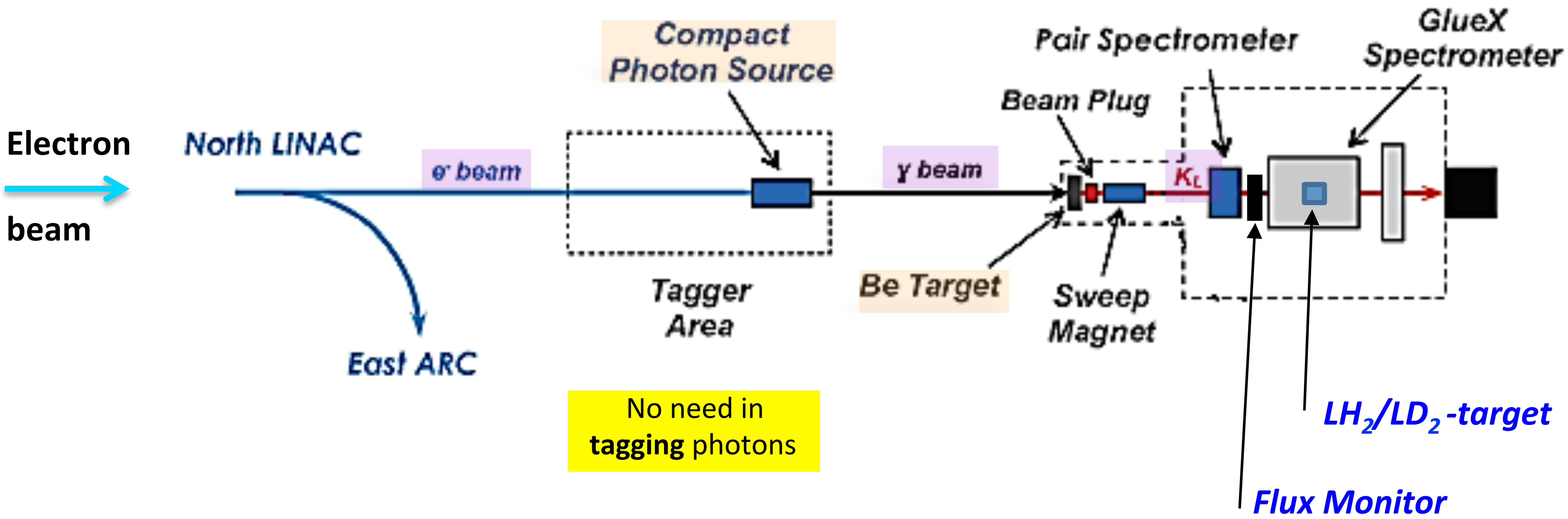
- **KLF** project has to **establish** secondary **K_L** beam line at Jefferson Lab Thomas Jefferson National Accelerator Facility with **flux** of ***three order of magnitude*** higher than SLAC NATIONAL ACCELERATOR LABORATORY had

- for scattering experiments on both **proton** & **neutron** (first time **!**) targets in order to determine **differential cross sections** & **self-polarization** of strange **hyperons** with GlueX detector to enable precise **PWA** in order to determine all **resonances** up to **3** GeV in spectra of **Λ***, **Σ***, **Ξ***, & **Ω***.

- In addition, we intend to do **strange meson spectroscopy** by studies of **π-K** interaction to locate **pole** positions in **I** = **1/2** & **3/2** channels.

- **KLF** has link to **ion-ion high energy** facilities as CERN & BROOKHAVEN NATIONAL LABORATORY & will allow understand formation of our world in **several microseconds** after **Big Bang**.

Hall D Beam Line Set up for K-longs



I_e = **5** μA
W-radiator = **0.1** R.L.
Be-target = **1.7** R.L.

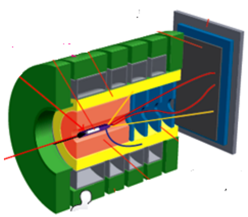
- **Electrons** are hitting **W**-radiator at **CPS**.
- **Photons** are hitting **Be**-target at **cave**.
- **K_Ls** are hitting the **LH_2/LD_2** target within **GLueX** setting.

Expected Cross Sections vs Bubble Chamber Data

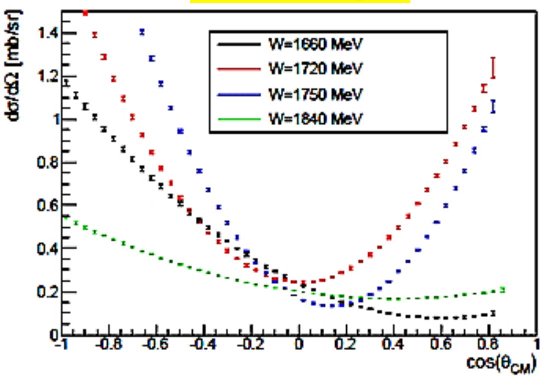
- **GlueX** measurements will span **cosθ** from **−0.95** to **0.95** in CM above **W** = **1490** MeV.

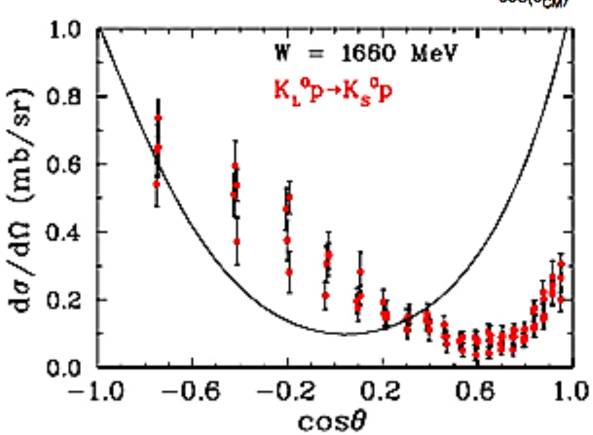
- **K_L** rate is **10^4** K_L/s = **2500 x** SLAC NATIONAL ACCELERATOR LABORATORY
- Uncertainties (statistics only) correspond to **100** days of running time for:

GEANT4

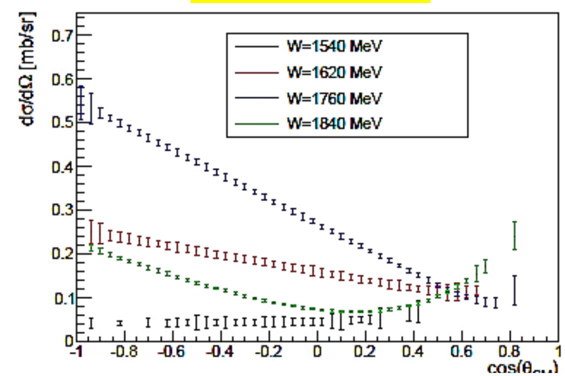


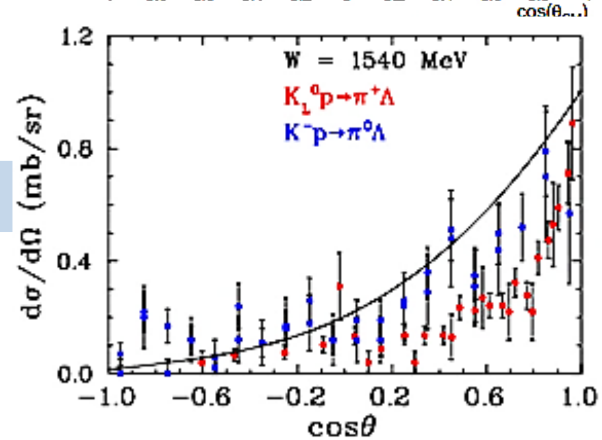
$K_L p \rightarrow K_S p$





$K_L p \rightarrow \pi^+ \Lambda$





Expected **GlueX Data**

BC Data

Why We Have to Measure Double-Strange Cascades in JLab

- **Heavy quark symmetry** (**Isgur–Wise symmetry**) suggests that multiplet splittings in **strange**, **charm**, & **bottom** **hyperons** should scale as approximately inverses of corresponding **quark masses**:

  $$1/m_s : 1/m_c : 1/m_b$$

  N. Isgur & M.B. Wise, Phys Rev Lett **66** 1130 (1991)

- If they don't, that scaling failure implies that structures of corresponding states are **anomalous**, & very **different** from one another.

- So far only **hyperon** resonance multiplet, where this scaling can be ``tested" & seen is lowest **negative parity** multiplet:

$$\Lambda(1405)1/2^- - \Lambda(1520)3/2^-, \quad \Lambda_c(2595)1/2^- - \Lambda_c(2625)3/2^-, \quad \Lambda_b(5912)1/2^- - \Lambda_b(5920)3/2^-$$

- It works **approximately** (30%) well for those Λ-splittings. It would work **even better** for Ξ, Ξ_c, Ξ_b splittings, & should be **very good** for Ω, Ω_c, Ω_b splittings.

PDG particle data group

Particle	J^P	Overall status	Status as seen in — $\Xi\pi$	ΛK	ΣK	$\Xi(1530)\pi$	Other channels
$\Xi(1318)$	1/2+	****					Decays weakly
$\Xi(1530)$	3/2+	****	****				
$\Xi(1620)$		*	*				
$\Xi(1690)$		***		***	**		
$\Xi(1820)$	3/2−	***	**	***	**	**	
$\Xi(1950)$		***	**	**		*	
$\Xi(2030)$		***		**	***		
$\Xi(2120)$		*		*			
$\Xi(2250)$		**					3-body decays
$\Xi(2370)$		**					3-body decays
$\Xi(2500)$		*		*	*		3-body decays

- Jefferson Lab Thomas Jefferson National Accelerator Facility can do **double cascade** spectrum. As LHCb is doing **double charm cascade** spectrum.

  $$\Xi_c(2790)1/2^- - \Xi_c(2815)3/2^-$$

  R. Aaij *et al*, Phys Rev Lett **119**, 112001 (2017)

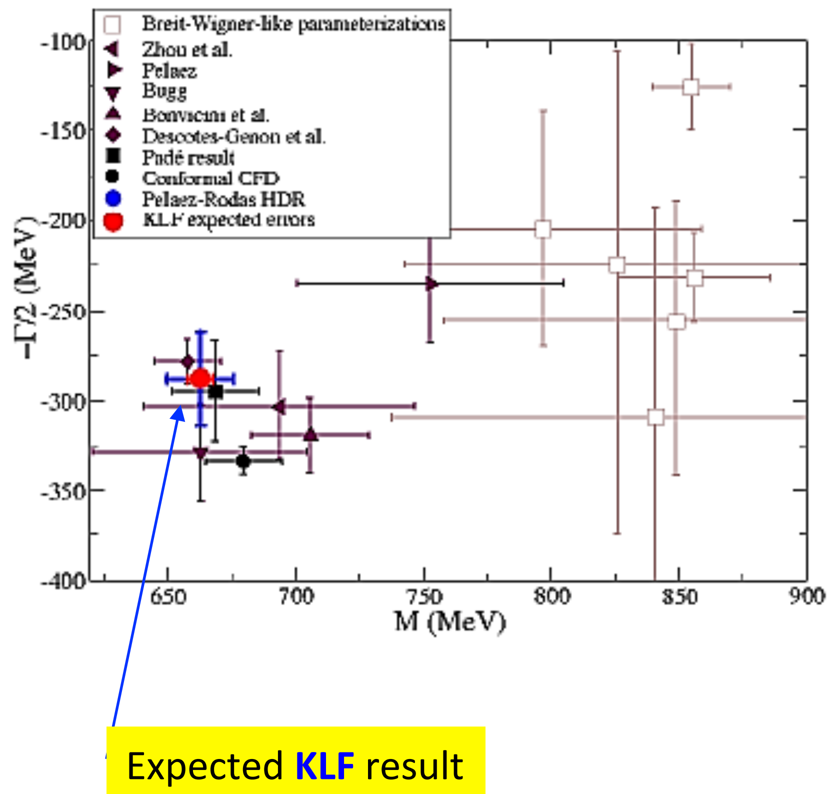
Courtesy of Dan-Olof Riska, 2017

Why We Have to Focus on Kπ Scattering with Regards to κ Meson in JLab

- **KLF** proposal will have very significant impact in our knowledge of **Kπ** scattering amplitudes in scalar **I = ½** channel.

- It will reduce by more than factor of **two** uncertainty in **mass** determination & by factor of **five** uncertainty on its **width** (& therefore on its coupling) of controversial **k(800).**

- Neutral kaon beam scattering on both **proton** & **neutron** targets at low t-Mandelstam will allow to produce & identify **all four isospin partners of κ(800)**.



Proposal for JLab PAC46

Strange Hadron Spectroscopy with Secondary K_L Beam at GlueX

A. Ali[18], M. B. Ali[47], M. J. Amaryan[45,*,†], E. G. Anassontzis[2], A. V. Anisovich[4,48],
A. Austregesilo[30], M. Baalouch[45], F. Barbosa[30], J. Barlow[13], A. Barnes[7], E. Barriga[13],
M. Bashkanov[10,†], A. Bazavov[29], T. D. Beattie[39], R. Bellwied[20], V. V. Berdnikov[8], V. Bernard[46],
T. Black[42], W. Boeglin[12], M. Boer[8], W. J. Briscoe[14], T. Britton[30], W. K. Brooks[53], B. E. Cannon[13],
N. Cao[22], E. Chudakov[30], G. Colangelo[3], P. L. Cole[21], S. Cole[1], O. Cortes-Becerra[14], V. Crede[13],
M. M. Dalton[30], T. Daniels[42], D. Day[58], P. Degtyarenko[30], A. Deur[30], S. Dobbs[13], G. Dodge[45],
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Hyperon & Strange Meson Spectroscopy

- Full **Proposal** was submitted for **JLab PAC46** .