Physics Opportunities with Meson Beams

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To reap the full benefit of high-precision **EM** data, new high-statistics data from measurements with **meson beams**, with good **angle** and **energy coverage** for a **wide range of reactions**, are critically needed to advance our knowledge in **baryon** and **meson spectroscopy** and other related areas of **hadron** physics. To address this situation, a state-of-the-art **meson-beam facility** needs to be constructed.

Why We Need Meson Beams

- Great strides have been made over the last **two decades** to increase our knowledge of **baryon** and **meson Spectroscopy** with the 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**, and others.

- Regrettably, the **meson-beam data** for different final states are mostly **outdated** and **largely of poor quality**, or even **non-existent**, and thus limit us in fully exploiting the full potential of the **new EM data**.

- The center-of-mass energy range up to **2.5 GeV** is rich in opportunities for physics with **pion** and **Kaon beams** to study **baryon** and **meson spectroscopy** questions complementary to the **EM programs** underway at **EM facilities**.

- This talk **highlights some of these opportunities** and describes how facilities with **high-energy** and **high-intensity** **meson beams** can contribute to a full understanding of the 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 the **hadronic** complement of the ongoing **EM program**, to furnish the common ground for better and more reliable **phenomenological** and **theoretical** analyses based on **high-quality data**.

Partial-Wave Analysis

- Most of our current knowledge about the **bound states** of **three light quarks** has historically come from **PWAs** of **$\pi N \rightarrow \pi N$** scattering.

- Non-strange objects in the **PDG Listings** come mainly from:
  Karlsruhe-Helsinki,
  Carnegie-Mellon-Berkeley,
  and **GW**.



- The main source of **EM** couplings are **GW** and **BnGa** analyses.

- Measurements of **πN** elastic scattering are mandatory for determining absolute **πN** BRs.

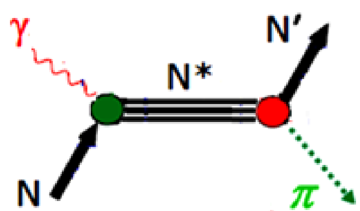
- The information on **resonance properties** obtained from analyses of experimental data provides fundamental information about **QCD** in the **non-perturbative** region.

Status of Data for Specific Reactions

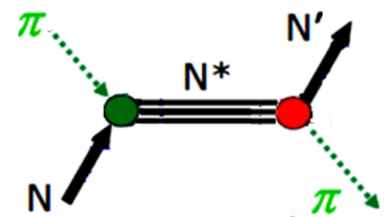
- Measurements of final states involving a single **pseudoscalar meson** and a spin-**1/2 baryon** are particularly important.

- *The reactions involving πN channels include:*

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



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



- The **πN** elastic scattering data allowed the establishment of the **4**-star resonances.

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

- Available data for **πN** elastic scattering are **incomplete**.

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

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

World Pion-Nucleon Elastic Data

W < 2.5 GeV

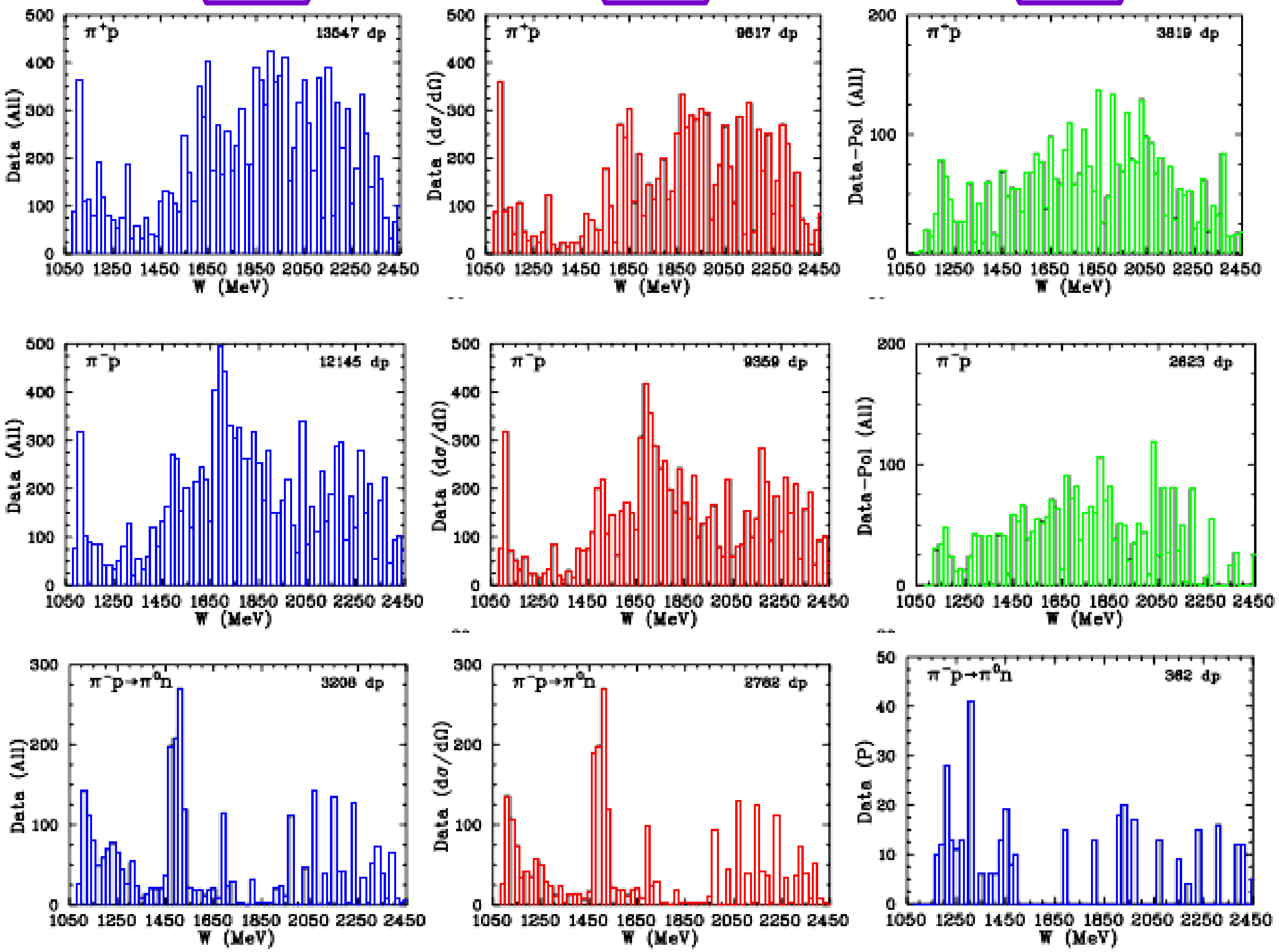
[SAID: http://gwdac.phys.gwu.edu/]

Full **UnPol** **Pol**

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

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

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



GW INS

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WASHINGTON, DC

World Neutral and Charged PionPR Data

W < 2.5 GeV [SAID: http://gwdac.phys.gwu.edu/]

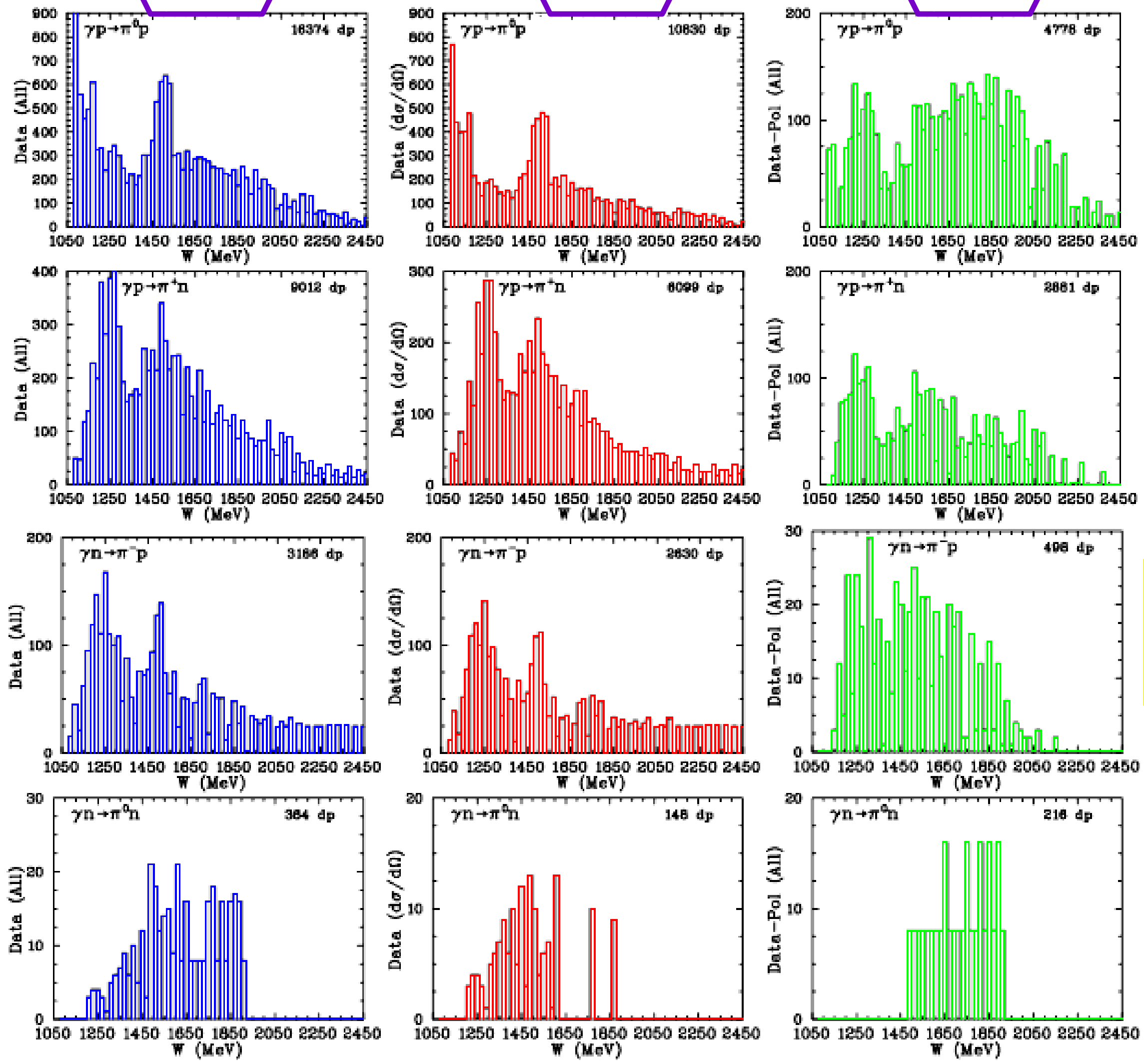
Full **UnPol** **Pol**

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

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

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

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



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

Status of Data for Specific Reactions

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

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

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

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

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

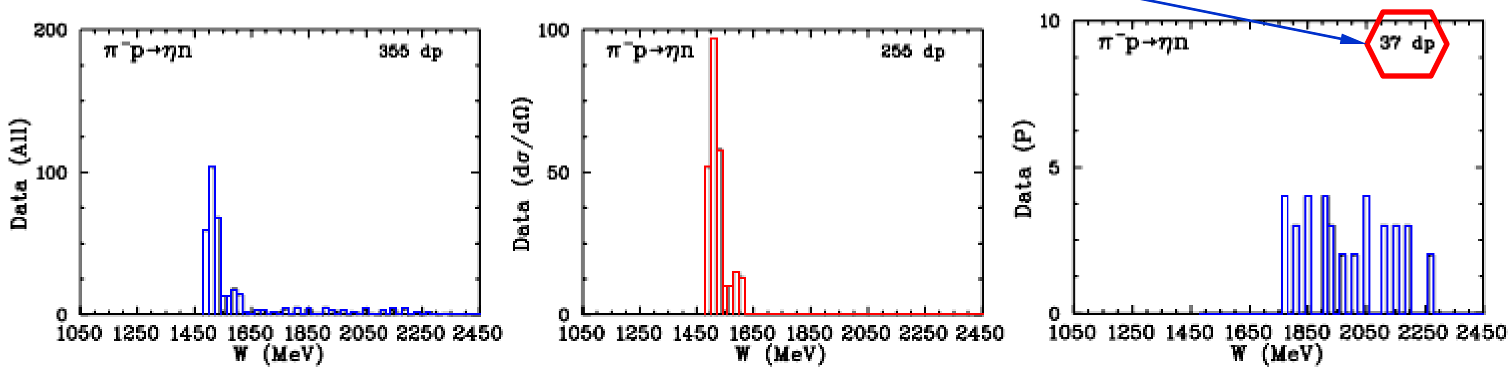
$\pi^- p \rightarrow \eta n$

- *$\gamma p \rightarrow \eta p$ is one of the **key reactions** for which colleagues in the **EM** community hope to do a ``**complete measurement**" and determine **PW** amplitudes **directly**.*
- Any coupled-channel analysis of those measurements will need precise data for **$\pi^- p \rightarrow \eta n$** .
- Most of the available data for that reaction come from measurements published in the **1970**s, which have been **evaluated** by **several groups** as being **unreliable** above **W** = **1620** MeV.

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

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

- **Very few polarization data for these reactions exist out of range of dσ/dΩ.**



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

Status of Data for Specific Reactions

- *Another group of related reactions involve the* **KΣ** *channel:*

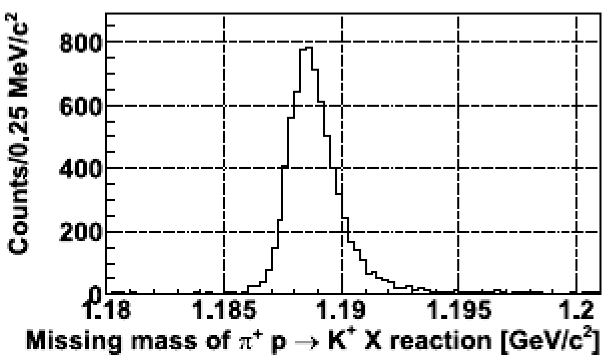
$$\gamma p \to K^+\Sigma^0$$
$$\gamma p \to K^0\Sigma^+$$
$$\gamma n \to K^+\Sigma^-$$
$$\gamma n \to K^0\Sigma^0$$

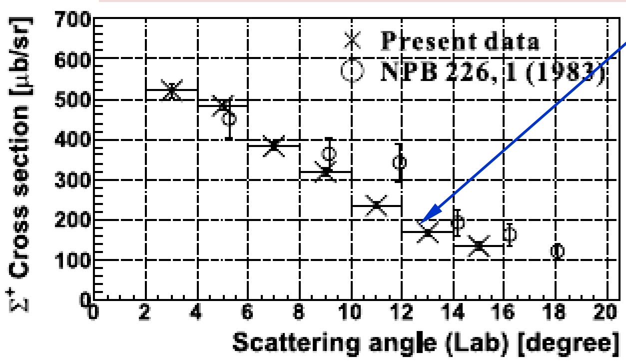
$$\pi^- p \to K^0\Sigma^0$$
$$\pi^- p \to K^+\Sigma^-$$
$$\pi^+ p \to K^+\Sigma^+$$

- Except for **$\pi^+p \to K^+\Sigma^+$,** these reactions involve a mixture of **isospin 1/2** and **3/2**.
- Although there have been a number of recent high-quality measurements involving **KΣ** photoproduction, the status of complementary reactions measured with **pion beams** is rather **dismal**.
- There are generally fewer available data for **π^-p** reactions with **KΣ**, **η'N**, **ωN**, and **ϕN** final states than for $\pi^- p \to \eta n$.

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

E19 at J-PARC



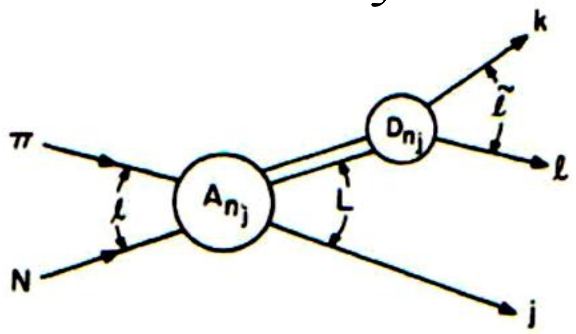


- Measurements like this, over a more comprehensive energy range, will greatly improve **PWA**s of the **KΣ** final state and, in return, help to extract the **S**-wave contribution needed, e.g., in approaches based on **unitarized chiral perturbation theory**.

Status of Data for Specific Reactions

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

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



- The analysis and interpretation of data from these reactions is more complicated because they involve **three-body** final states.

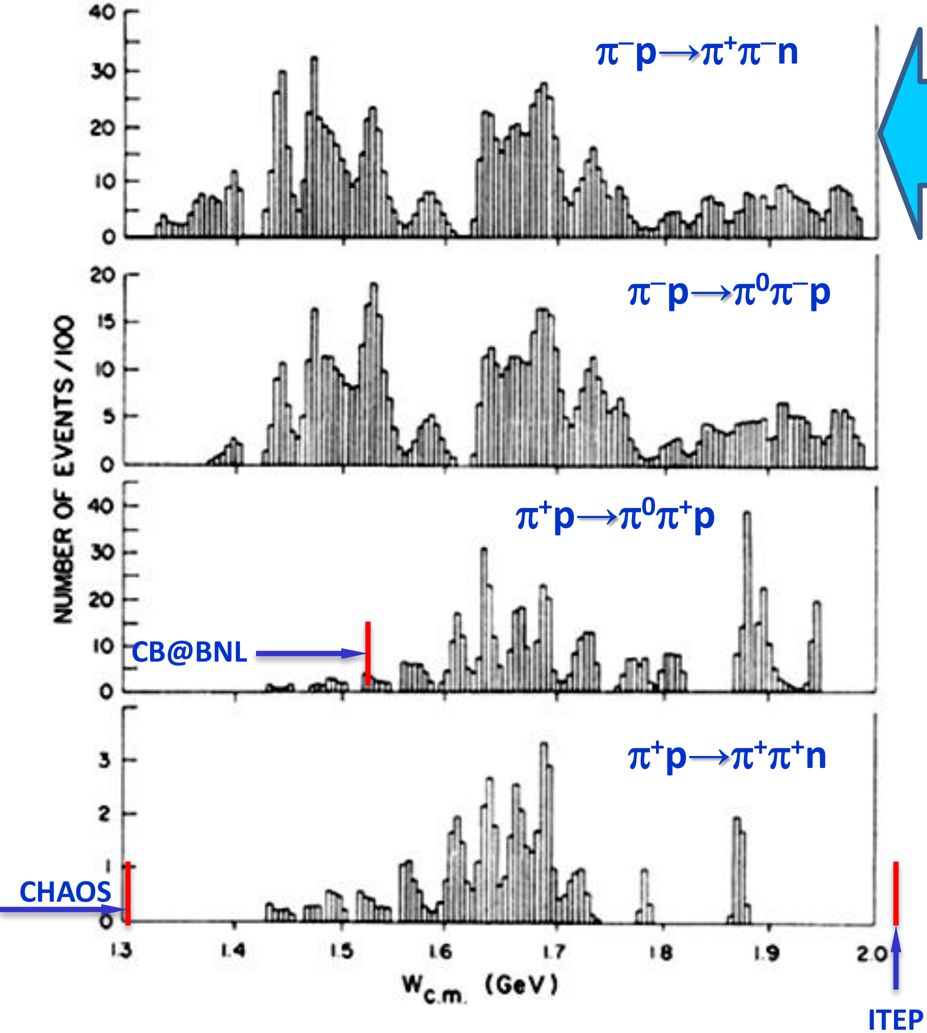
- However, **πN→ππN** reactions have the **lowest energy threshold** of any **inelastic hadronic** channel and some of the **largest cross sections**.

- For most established **N*** and **Δ*** resonances, the dominant inelastic decays are to **ππN** final states.

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

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

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



- **241,214** **Bubble Chamber** events for $\pi N \rightarrow \pi\pi N$ have been analyzed in **Isobar-model** **PWA** at **W** = **1320** to **1930** MeV.
  [Manley, Arndt *et al* Phys Rev D **30**, 904 (1984)]

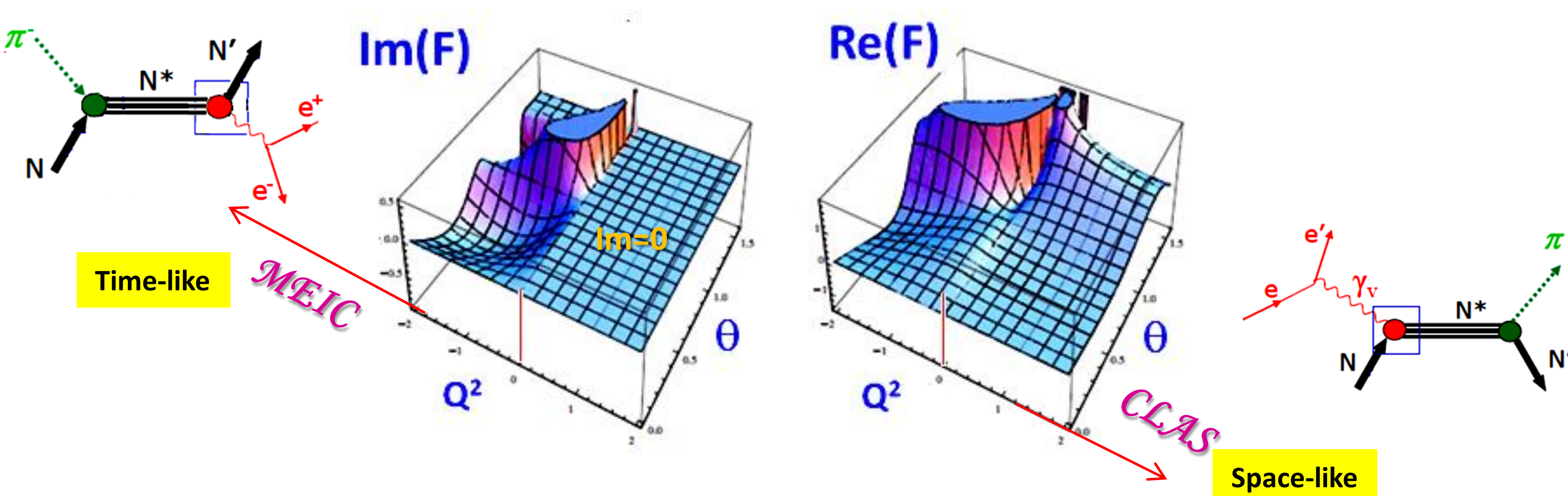
- **Post-Bubble Chamber** measurements:
  - **349,611** events for $\pi^- p \rightarrow \pi^0 \pi^0 n$ from **CB@BNL** at **W** = **1213** to **1527** MeV.
    [Prakhov *et al* Phys Rev C **69**, 045202 (2004)]
  - **20,000** events for $\pi^{+-} p \rightarrow \pi^{+-} \pi^{-+} n$ from **CHAOS@TRIUMF** at **W** = **1257** to **1302** MeV.
    TRIUMF [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.
    [Alekseev *et al* Phys At Nucl **61**, 174 (1998)]

Form-Factor Measurements

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

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

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



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

Spectroscopy of Hyperon Resonances

- Our current experimental knowledge of **Λ^*** and **Σ^*** resonances is far worse than our knowledge of **N*** and **Δ^*** resonances; however, within the 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)

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

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

- The line shape of **$\Lambda(1405)1/2^-$** can be studied in **K^-p** and **K^-d** (**K^-n**) reactions. A comparison between pion- and kaon-induced reactions together with photoprod is important.
- The **H-dibaryon**, which has a **quark** configuration of **uuddss**, will be searched for in the (**K^-**, **K^+**).
- The measured $\pi\Sigma/\pi\pi\Sigma$ **BR** for the **Σ(1670)** produced in the reaction **$K^-p\to\pi^-\Sigma(1670)^+$** depends strongly on momentum transfer, and it has been suggested that there exist two **Σ(1670)** resonances with the same mass and quantum numbers, one with a large $\pi\pi\Sigma$ branching fraction and the other with a large $\pi\Sigma$ BR.
- This **Σ(1670)** puzzle could be solved using future production experiments with **Kaon** beams.

Status of Data for Specific Reactions

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

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

- 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** and modern **multi particle spectrometers**.

- The lack of appropriate beams and detectors in the **past** greatly **limited** our **knowledge**.

- Currently only the **cascade** ground states of **spin-1/2** and **spin-3/2** are well identified.

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

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

Meson Spectroscopy

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

- The **availability** of **pion** and **Kaon** beams provide an important opportunity to improve this situation.

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

- The **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 the properties of **hybrids** with a photon beam.

Summary

- In this talk, we have **outlined** some of the **physics programs** that could be advanced with a **hadron-beam facility**.
- These include studies of **baryon spectroscopy**, particularly the search for ``**missing resonances**" with **hadronic beam data** that would be analyzed together with **photo**- and **electroproduction** data using modern **coupled-channel analysis** methods.
- A **hadron beam facility** would also advance **hyperon spectroscopy** and the study of **strangeness** in **nuclear** and **hadronic** physics.

- Furthermore, searches for highly anticipated, but never unambiguously observed, **exotic states** such as **multiquarks**, **glueballs**, and **hybrids**, would be greatly enhanced by the availability of a **hadron beam facility**.
- Simply observing many of the **missing low-lying meson states** would also assist in constructing new models of the emergent properties of **QCD**, thereby improving our understanding of this strongly coupled quantum field theory.

- An **electron-pion collider** would open exciting new opportunities to measure the **pion EM form factor directly**, while a pion beam alone would allow detailed studies of inverse pion electroproduction, which is the only process that allows the determination of **EM nucleon** and **pion form factors** in the case of **time-like virtual photons**.

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Back Up Slides

ITEP for $\pi^{-+}p \to \pi^{-+}p$

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

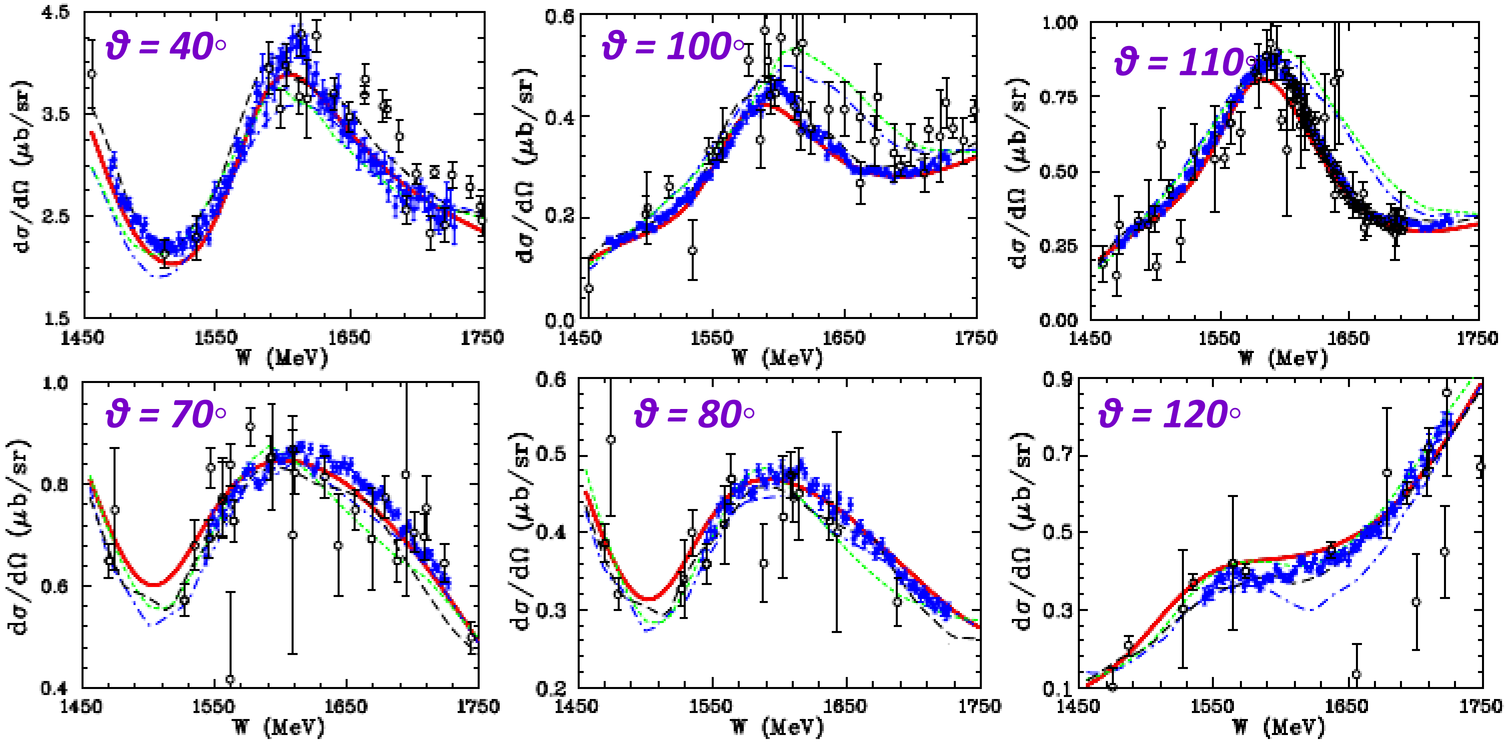
I. G. Alekseev *et al*. Phys Rev C **91**, 025205 (2015).

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

4277 dσ/dΩ:
800 – 1243 MeV/c

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

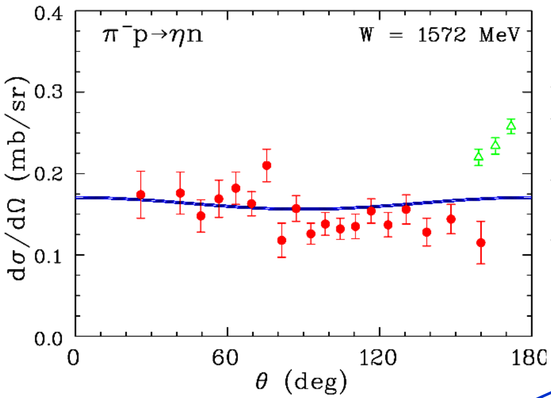
2638 dσ/dΩ:
918 – 1240 MeV/c

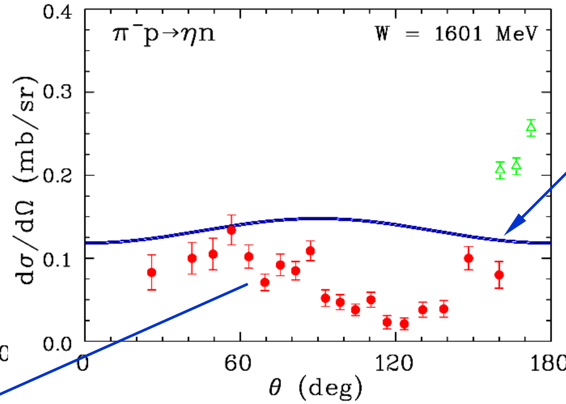


- **CMB** analysis is significantly more **predictive** when compared to versions of the **KH** analyses

Predictions: WI08, KH80, KA84, CMB

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

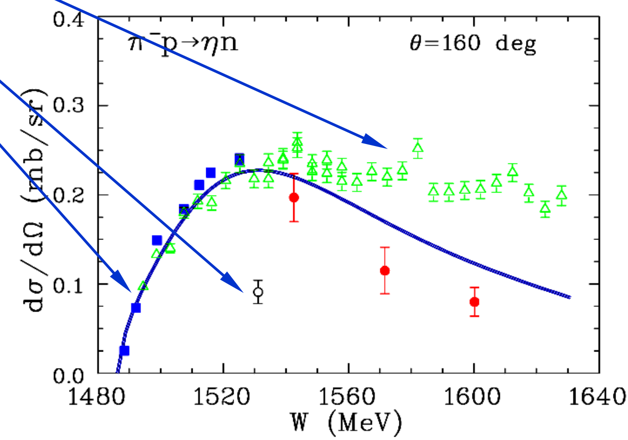




- **There are several independent evaluations:**
  - Arndt *et al* Phys Rev C **69**, 035213 (2004)
  - Clajus & Nefkens, πN News Lett **7**, 76 (1992)
  - Wighman *et al* Phys Rev D **38**, 3365 (1988)
  - Koch & Pietarinen, Nucl Phys **A336**, 331 (1980)
  - Cutkosky *et al* Phys Rev D **20**, 2804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

- The **evaluation** for reactions with **KY**, **η'N**, **ωN**, **ϕN**, and so on final states are **not possible now** because of small databases.

Baryon Sector at PDG

[K.A. Olive *et al* [PDG] Chin. Phys *C* **38**, 090001 (2014)]

p	$1/2^+$	****
n	$1/2^+$	****
$N(1440)$	$1/2^+$	****
$N(1520)$	$3/2^-$	****
$N(1535)$	$1/2^-$	****
$N(1650)$	$1/2^-$	****
$N(1675)$	$5/2^-$	****
$N(1680)$	$5/2^+$	****
$N(1685)$		*
$N(1700)$	$3/2^-$	***
$N(1710)$	$1/2^+$	***
$N(1720$[illegible]	[illegible]$/2^+$	*[illegible]*
$N(186$[illegible]	[illegible]$/2^+$	[illegible]
$N(187$[illegible]	[illegible]2^-	[illegible]*
$N(18$[illegible]	1[illegible]$^+$	[illegible]
$N(18$[illegible]	1[illegible]	[illegible]*
$N(1$[illegible]$)$	$3/$[illegible]	[illegible]**
$N(1990)$	$7/2^+$	**
$N(2000)$	$5/2^+$	**
$N(2040)$	$3/2^+$	*
$N(2060)$	$5/2^-$	**
$N(2100)$	$1/2^+$	*
$N(2120)$	$3/2^-$	**
$N(2190)$	$7/2^-$	****
$N(2220)$	$9/2^+$	****
$N(2250)$	$9/2^-$	****
$N(2600)$	$11/2^-$	***
$N(2700)$	$13/2^+$	**

$\Delta(1232)$	$3/2^+$	****
$\Delta(1600)$	$3/2^+$	***
$\Delta(1620)$	$1/2^-$	****
$\Delta(1700)$	$3/2^-$	****
$\Delta(1750)$	$1/2^+$	*
$\Delta(1900)$	$1/2^-$	**
$\Delta(1905)$	$5/2^+$	****
$\Delta(1910)$	$1/2^+$	****
$\Delta(1920)$	$3/2^+$	[illegible]**
$\Delta(1930)$	$5/$[illegible]	[illegible]**
$\Delta(1940)$	[illegible]$/2^-$	[illegible]
$\Delta(1950)$	$7/2^+$	[illegible]**
$\Delta(2000)$	$5/2^+$	[illegible]
$\Delta(21$[illegible]$)$	$1/2^-$	[illegible]
$\Delta($[illegible]$)$	[illegible]	[illegible]
$\Delta(2300)$	$9/2^+$	**
$\Delta(2350)$	$5/2^-$	*
$\Delta(2390)$	$7/2^+$	*
$\Delta(2400)$	$9/2^-$	**
$\Delta(2420)$	$11/2^+$	****
$\Delta(2750)$	$13/2^-$	**
$\Delta(2950)$	$15/2^+$	**
Λ	$1/2^+$	****
$\Lambda(1405)$	$1/2^-$	****
$\Lambda(1520)$	$3/2^-$	****
$\Lambda(1600)$	$1/2^+$	***
$\Lambda(1670)$	$1/2^-$	****
$\Lambda(1690)$	$3/$[illegible]	****
$\Lambda(1800)$	[illegible]$/2^-$	[illegible]***
$\Lambda(1810)$	$1/2^+$	[illegible]**
$\Lambda(1820)$	$5/2^+$	[illegible]***
$\Lambda(183$[illegible]$)$	$5/2^-$	[illegible]***
$\Lambda($[illegible]$)$	$3/2^+$	[illegible]***
$\Lambda(2000)$		*
$\Lambda(2020)$	$7/2^+$	*
$\Lambda(2100)$	$7/2^-$	****
$\Lambda(2110)$	$5/2^+$	***
$\Lambda(2325)$	$3/2^-$	*
$\Lambda(2350)$	$9/2^+$	***
$\Lambda(2585)$		**

Σ^+	$1/2^+$	****
Σ^0	$1/2^+$	****
Σ^-	$1/2^+$	****
$\Sigma(1385)$	$3/2^+$	****
$\Sigma(1480)$		*
$\Sigma(1560)$		**
$\Sigma(1580)$	$3/2^-$	*
$\Sigma(1620)$	$1/2^-$	**
$\Sigma(1660)$	$1/2^+$	***
$\Sigma(1670)$	$3/2^-$	****
$\Sigma(1690)$	[illegible]	[illegible]
$\Sigma(1750)$	[illegible]$/2^-$	***
$\Sigma(1770)$	[illegible]2^+	*
$\Sigma(1775)$	5[illegible]	****
$\Sigma(1840)$	$3/2^+$	*
$\Sigma(1880)$	$1/2^+$	[illegible]*
$\Sigma($[illegible]$)$	[illegible]	****
$\Sigma(1940)$	$3/2^-$	***
$\Sigma(2000)$	$1/2^-$	*
$\Sigma(2030)$	$7/2^+$	****
$\Sigma(2070)$	$5/2^+$	*
$\Sigma(2080)$	$3/2^+$	**
$\Sigma(2100)$	$7/2^-$	*
$\Sigma(2250)$		***
$\Sigma(2455)$		**
$\Sigma(2620)$		**
$\Sigma(3000)$		*
$\Sigma(3170)$		*

Ξ^0	$1/2^+$	****
Ξ^-	$1/2^+$	****
$\Xi(1530)$	[illegible]	[illegible]
$\Xi(1620)$		*
$\Xi(1690)$		***
$\Xi(1820)$	[illegible]	[illegible]**
$\Xi(1950)$		[illegible]**
$\Xi(2030)$	$\geq \frac{5}{2}^?$	***
$\Xi($[illegible]$)$		[illegible]
$\Xi(2250)$		**
$\Xi(2370)$		**
$\Xi(2500)$		*
Ω^-	$3/2^+$	[illegible]
$\Omega($[illegible]$)^-$		[illegible]
$\Omega($[illegible]$80)^-$		[illegible]
$\Omega($[illegible]$70)^-$		[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^-	$1/2^+$	***

- **PDG14** has **112** Baryon Resonances (**58** are **4*** & **3*** of them).
- For example for **SU(6) x O(3)**, it would be **434** resonances, if all revealed **three 70**– and **four 56**– multiplets were filled in.

- There are many **more states** in the **QCD** inspired models than currently observed.

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

Resonance $\rightarrow N\rho$ Branching Ratios

	GiBUU12	UrQMD09	KSU12	KSU92	BnGa12	CLAS12	PDG14	
$N(1520)3/2^-$	21	15	20.9(7)	21(4)	10(3)	12.7(4.3)	**20(5)**	D_{13}
$N(1720)3/2^+$	87	73	1.4(5)	87(5)	10(13)	47.5(21.5)	**77.5(7.5)**	P_{13}
$\Delta(1620)1/2^-$	29	5	26(2)	25(6)	12(9)	37(12)	**16(9)**	S_{31}
$\Delta(1905)5/2^+$	87	80	<6	86(3)	42(8)		**>60**	F_{35}

Partial courtesy of Piotr Salabura, Sept 2013

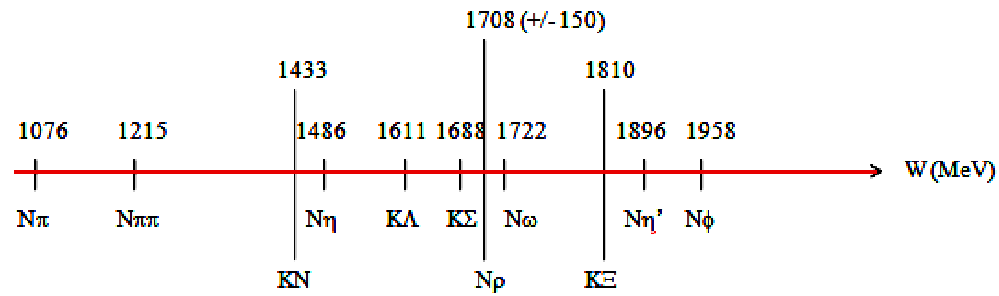
CLAS12: V. Mokeev *et al*, Phys Rev C **86**, 035203 (2012); V. Mokeev, PC 2013
BnGa12: A.V, Anisovich *et al*, Eur Phys J A **48**, 15 (2012)
GiBUU12: J. Weil *et al*, Eur Phys J A **48**, 111 (2012); J. Weil, PC
KSU92: D.M. Manley and E.M. Saleski, Phys Rev D **45**, 055203 (1992)
KSU12: M. Shrestha and D.M. Manley, Phys Rev D **86**, 055203 (2012)
PDG14: K.A. Olive *et al* [RPP] Chin. Phys C **38**, 090001 (2014)
UrQMD09: K. Schmidt *et al*, Phys Rev C **79**, 4002 (2009)

Why We Need Meson Beams

White Paper: arXiv:1503:07763 [hep-ph]

A **state-of-the-art hadron beam facility** could be used to investigate a much wider range of physics than baryon and meson spectroscopy alone. For example, it could be used for studies of

- pion diffractive dissociation to two jets (**$\pi A \to 2$ jets X**),
- pion double-charge exchange **$A(\pi^+, \pi^-)$** at high energies,
- **hypernuclear** spectroscopy,
- inelastic scattering of mesons on nuclei to study **in-medium** effects,
- neutrino physics using **neutrinos** from the decays of pions and kaons,
- physics with **muons** produced from the decays of pions and kaons (e.g., for studies of lepton number violation using **$\mu^+ \to e^+\gamma$** or **$\mu^+e^- \to \mu^-e^+$**,
- physics with **K^+** and **K^0_L** beams,
- **meson-A** interactions of mesons with nuclei outside of the valley of stability.

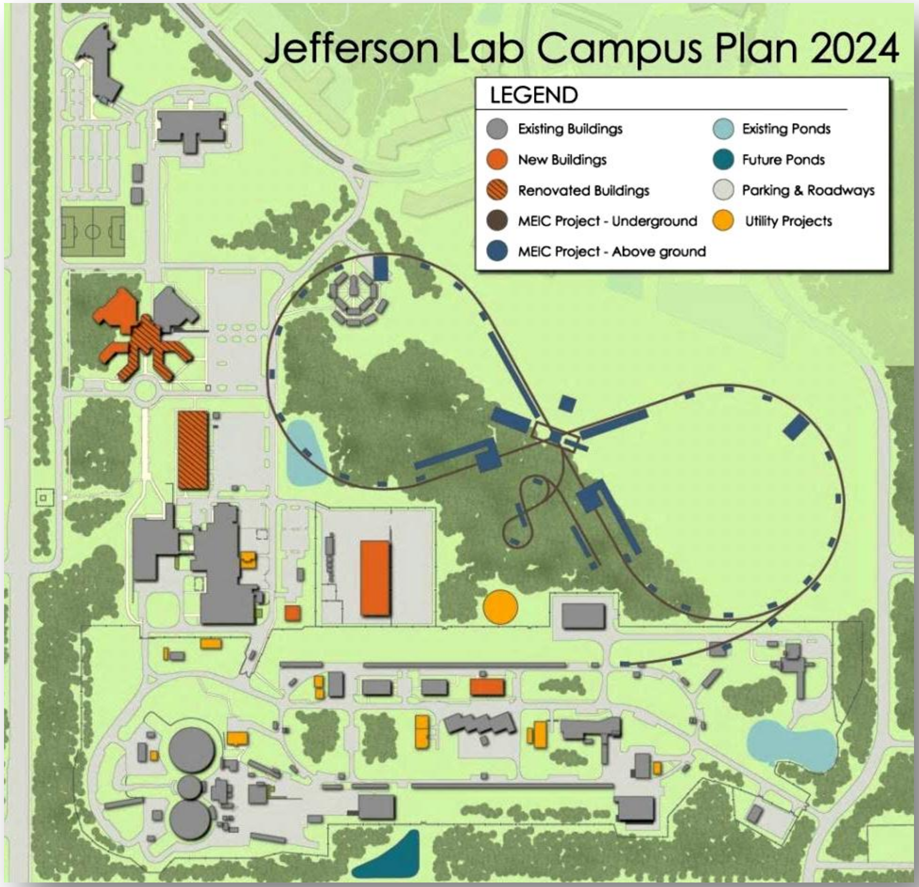


Jefferson Lab: MEIC

JLab MEIC Figure 8 Concept

- **Initial configuration**:
  - 3-10 GeV on 20-100 GeV ep/eA collider
  - Optimized for high ion beam polarization:
    - polarized deuterons
  - Luminosity:
    - up to few x 10^{34} e-nucleons cm^{-2} s^{-1}
- **Low technical risk**
- **Upgradable to higher energies**
  250 GeV protons + 20 GeV electrons
- **Flexible timeframe for Construction**
  consistent w/running 12 GeV CEBAF
- **Thorough cost estimate completed**
  presented to NSAC EIC Review
- **Cost effective operations**

→ **Fulfills White Paper Requirements**



Courtesy of Hugh Montgomery

Current Hadronic Projects

EPECURE @ ITEP [2009-2011], Then JINR or IHEP

HADES @ GSI [2014], Then 2017-2020

& **J-PARC** [2016+]

$\pi^- p \to \pi^- p$, $K\Lambda$
$\pi^+ p \to \pi^+ p$

Igor Alekseev

$\pi^- p \to \pi^- p, \pi^0 n, 2\pi N$, KY, γn, $e^+ e^- n$

Piotr Salabura

$\pi^\pm p \to \pi^\pm p$, $2\pi N$, KY

Ken Hicks
H. Sako

That is Not Enough

- *In particular, no **plan** for pol target measurements now*

Phenomenology for Baryon & Meson Resonances

Do you have any questions to the speaker?