Hadron Physics at EIC Facility

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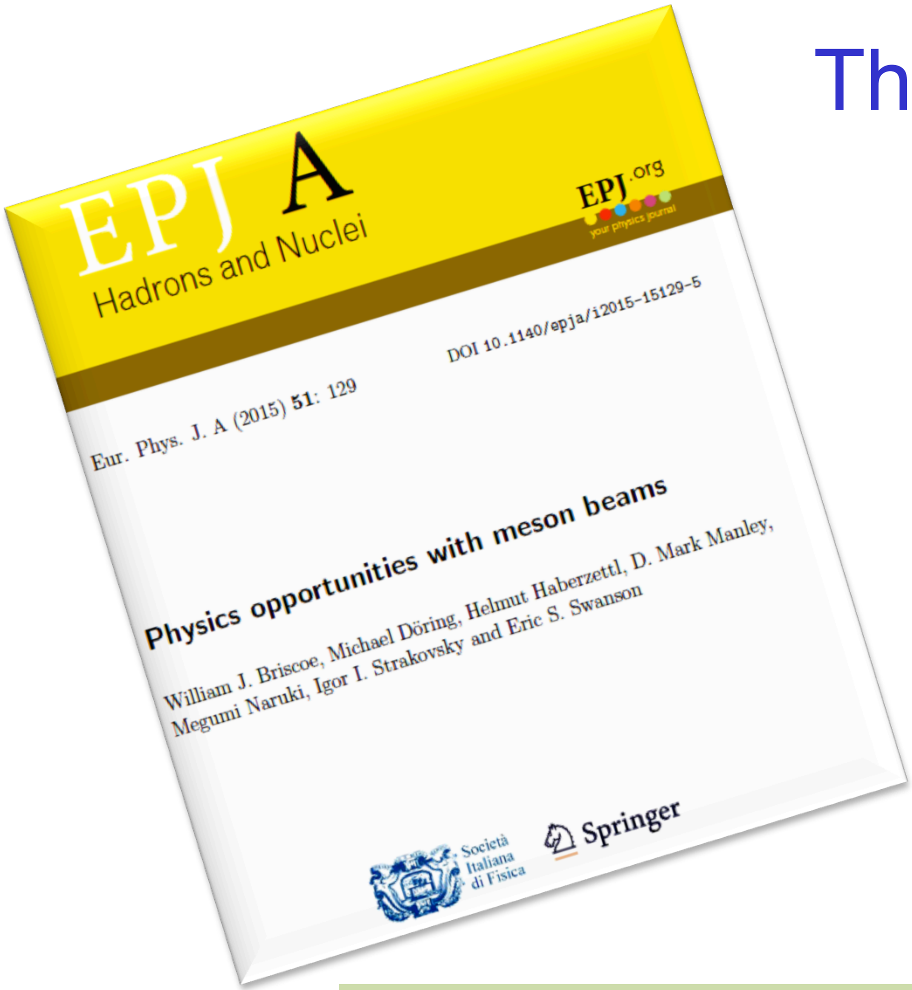
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Physics opportunities with meson beams

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Società Italiana di Fisica

Springer

- Hadron Spectroscopy.
- Opportunities with pion beams.
- Spectroscopy of hyperons.
- Meson spectroscopy.
- Physics opportunities.
- Summary.

135 endorsers from 77 institutes worldwide

* Supported by DOE DE-SC0014133

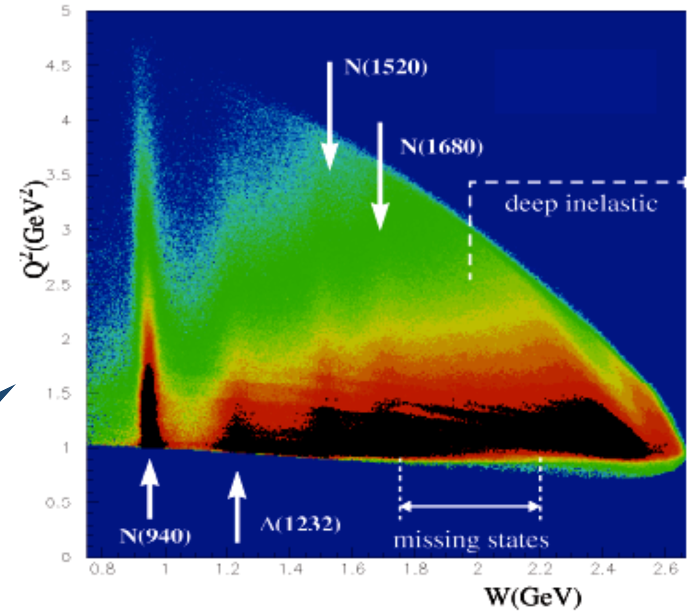
Hadron Spectroscopy

- To reap full benefit of high-precision studies and to advance our knowledge in **Baryon** and **Meson Spectroscopy**, 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 address this situation, we propose a state-of-the-art **Meson Facility**.

There are Many **Ways** to Study **N***

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

$\pi N \rightarrow \pi N$, $\pi\pi N$, ...
$\gamma N \rightarrow \pi N$, $\pi\pi N$, ...
$\gamma^* N \rightarrow \pi N$, $\pi\pi N$, ...
$pp \rightarrow pp\pi^0$, $pp\pi\pi$, ...
$J/\psi \rightarrow p\bar{p}\pi^0$, $p\bar{n}\pi^-$, ...



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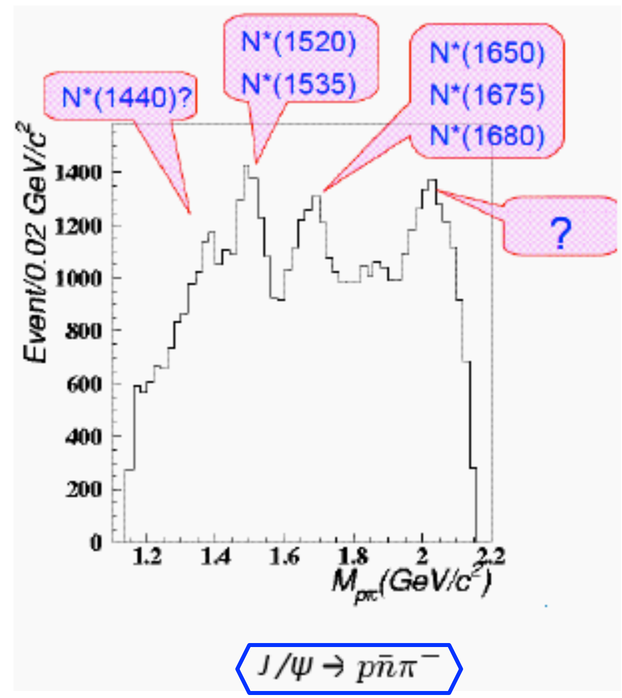
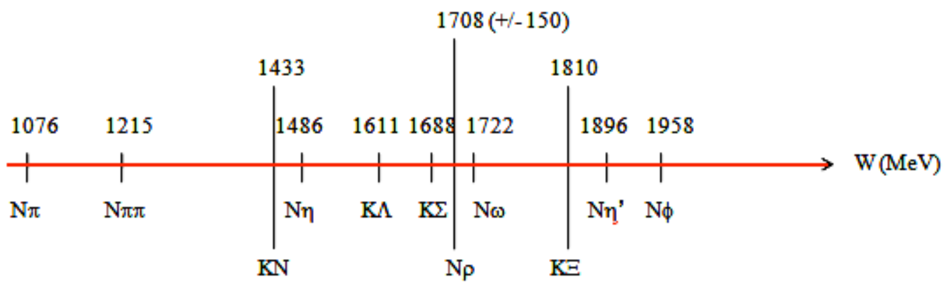


Most of **PDG Listings** info comes from **these sources**.

- **πN** elastic scattering is simplified due to constraints.
- **Resonance** spectra are correlated.
- Two-body final states need **few amplitudes**.



Baryon Sector in PDG14

GW Contribution

p	$1/2^+$	****
n	$1/2^+$	****
$N(1440)$	$1/2^+$	****
$N(1520)$	$3/2^-$	****
$N(1535)$	$1/2^-$	****
$N(1650)$	$1/2^-$	****
$N(1675)$	$5/2^-$	****
$N(1680)$	$5/2^+$	****
$N(1685)$		*
$N(1700)$	$3/2^-$	***
$N(1710)$	$1/2^+$	***
$N(1720)$	$3/2^+$	****
$N(1860)$	[illegible]	[illegible]
$N(187$[illegible]$)$	[illegible]	[illegible]
$N(188$[illegible]$)$	[illegible]	[illegible]
$N(18$[illegible]$)$	1[illegible]	[illegible]
$N(19$[illegible]$)$	$3/$[illegible]	[illegible]
$N(19$[illegible]$)$	$7/2$[illegible]	[illegible]
$N(2000)$	$5/2^+$	**
$N(2040)$	$3/2^+$	*
$N(2060)$	$5/2^-$	**
$N(2100)$	$1/2^+$	*
$N(2120)$	$3/2^-$	**
$N(2190)$	$7/2^-$	****
$N(2220)$	$9/2^+$	****
$N(2250)$	$9/2^-$	****
$N(2600)$	$11/2^-$	***
$N(2700)$	$13/2^+$	**

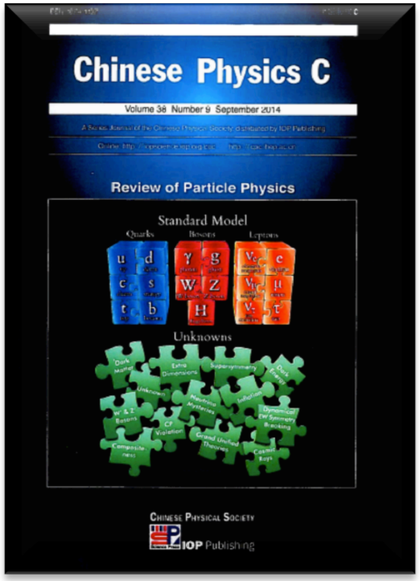
$\Delta(1232)$	$3/2^+$	****
$\Delta(1600)$	$3/2^+$	***
$\Delta(1620)$	$1/2^-$	****
$\Delta(1700)$	$3/2^-$	****
$\Delta(1750)$	$1/2^+$	*
$\Delta(1900)$	$1/2^-$	**
$\Delta(1905)$	$5/2^+$	****
$\Delta(1910)$	$1/2^+$	****
$\Delta(1920)$	$3/2^+$	***
$\Delta(1930)$	$5/$[illegible]	***
$\Delta(1940)$	[illegible]	[illegible]
$\Delta(1950)$	$7/2^+$	****
$\Delta(2000)$	$5/2^+$	[illegible]
$\Delta(215$[illegible]$)$	$1/2^-$	[illegible]
$\Delta(2$[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	$1/2^+$	****
$\Lambda(1405)$	$1/2^-$	****
$\Lambda(1520)$	$3/2^-$	****
$\Lambda(1600)$	$1/2^+$	***
$\Lambda(1670)$	$1/2$[illegible]	****
$\Lambda(1690)$	3[illegible]	****
$\Lambda(1800)$	[illegible]	***
$\Lambda(1810)$	$1/2$[illegible]	***
$\Lambda(1820)$	$5/2$[illegible]	****
$\Lambda(18$[illegible]$)$	$5/2^-$	***
$\Lambda($[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^-	$1/2^+$	****
$\Sigma(1385)$	$3/2^+$	****
$\Sigma(1480)$		*
$\Sigma(1560)$		**
$\Sigma(1580)$	$3/2^-$	*
$\Sigma(1620)$	$1/2^-$	**
$\Sigma(1660)$	$1/2^+$	***
$\Sigma(1670)$	$3/2^-$	****
$\Sigma(169$[illegible]$)$		[illegible]
$\Sigma(1750)$	$1/2^-$	[illegible]
$\Sigma(1770)$	[illegible]	*
$\Sigma(1775)$	[illegible]	****
$\Sigma(1840)$	[illegible]	*
$\Sigma(1880)$	$1/2^+$	**
$\Sigma($[illegible]$)$	[illegible]	****
$\Sigma(1940)$	$3/2$[illegible]	***
$\Sigma(2000)$	$1/2^-$	*
$\Sigma(2030)$	$7/2^+$	****
$\Sigma(2070)$	$5/2^+$	*
$\Sigma(2080)$	$3/2^+$	**
$\Sigma(2100)$	$7/2^-$	*
$\Sigma(2250)$		***
$\Sigma(2455)$		**
$\Sigma(2620)$		**
$\Sigma(3000)$		*
$\Sigma(3170)$		*

Ξ^0	$1/2^+$	****
Ξ^-	$1/2^+$	****
$\Xi(1530)$	[illegible]	****
$\Xi(162$[illegible]$)$	[illegible]	[illegible]
$\Xi(169$[illegible]$)$		***
$\Xi(1820)$	[illegible]	***
$\Xi(1950)$		***
$\Xi(2030)$	$\geq$ [illegible]	***
$\Xi($[illegible]$)$		[illegible]
$\Xi(2250)$		**
$\Xi(2370)$		**
$\Xi(2500)$		*
Ω^-	$3/2^+$	[illegible]
$\Omega($[illegible]$)^-$		[illegible]
$\Omega($[illegible]$)^-$		[illegible]
$\Omega($[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^-	$1/2^+$	***

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



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

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

Why We Need Meson Beams

- Much has been achieved over last **two decades** in increasing 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**, **ELPH**, **BEPC**, etc.

- **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**.

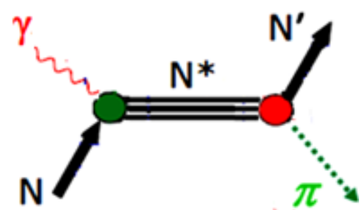
- We emphasize that what we advocate here is not a competing project, but **experimental program** that provides **hadronic** complement of ongoing **EM program**, to furnish common ground for better & more reliable **phenomenological** & **theoretical** analyses based on **high-quality data**.

Status of Data for Specific Reactions

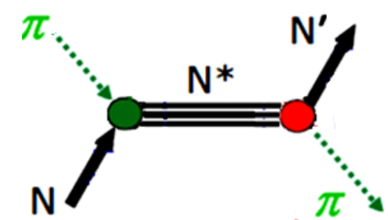
- Measurements of final states involving single **pseudoscalar meson** & **spin-1/2 baryon** are particularly interesting due to simple interpretation.

- The reactions involving **πN** channels include:

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



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



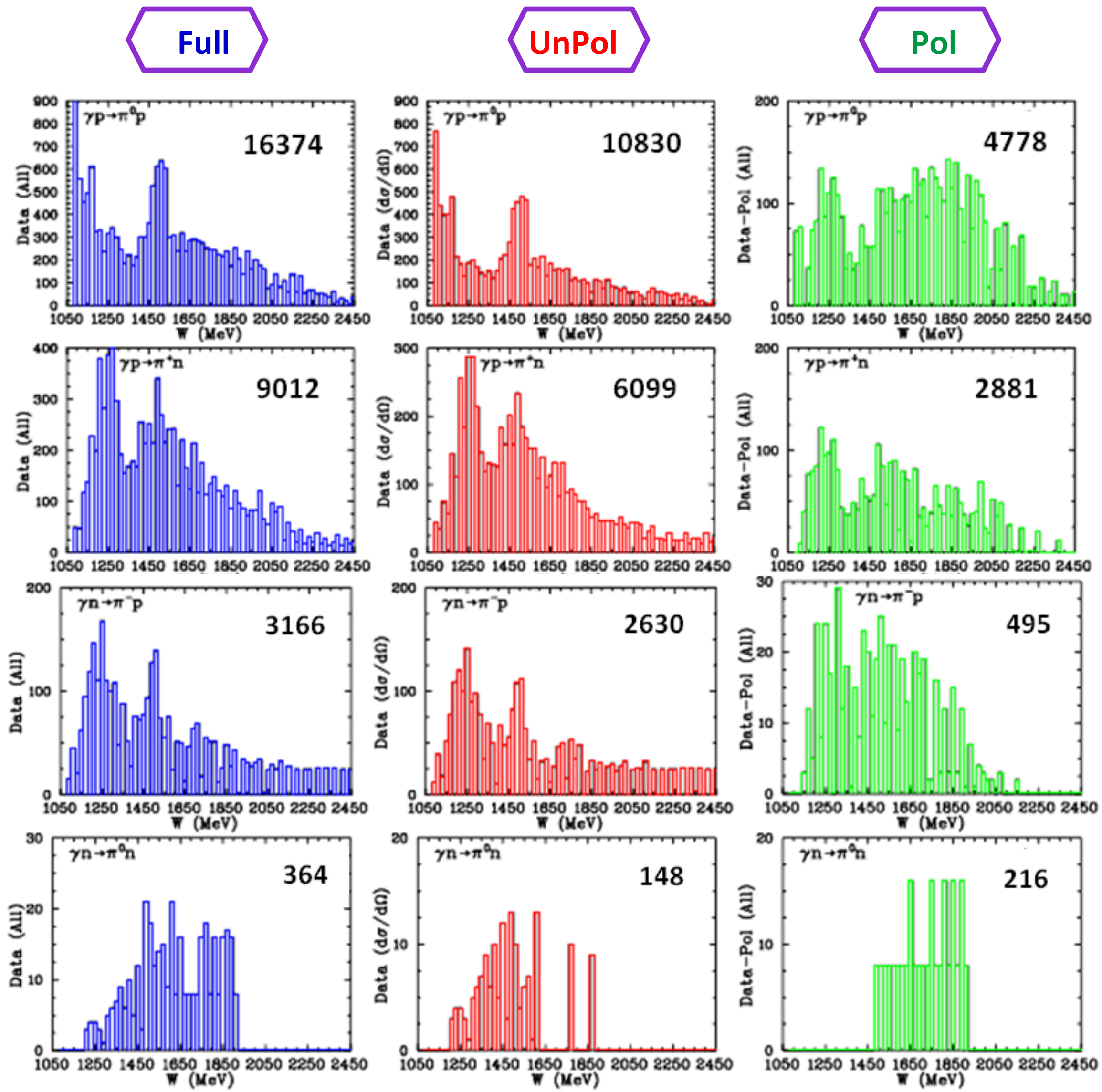
  - Only **$\pi^+ p \rightarrow \pi^+ p$** corresponds to **isospin 3/2** while rest of reactions is mixture of **isospins 1/2** & **3/2**.

  Data for **πN** elastic scattering are **incomplete**.

- Additional measurements of **P**, **A**, & **R** observables (limited data available) are needed to construct unbiased **PW amplitudes**.

World Neutral and Charged γN→πN Data

W < 2.5 GeV



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

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

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

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

$\gamma n \to \pi^- p$ data are mainly $d\sigma/d\Omega$, only 15% from polarized measurements.

World Pion-Nucleon Elastic (CEX) Data

2623

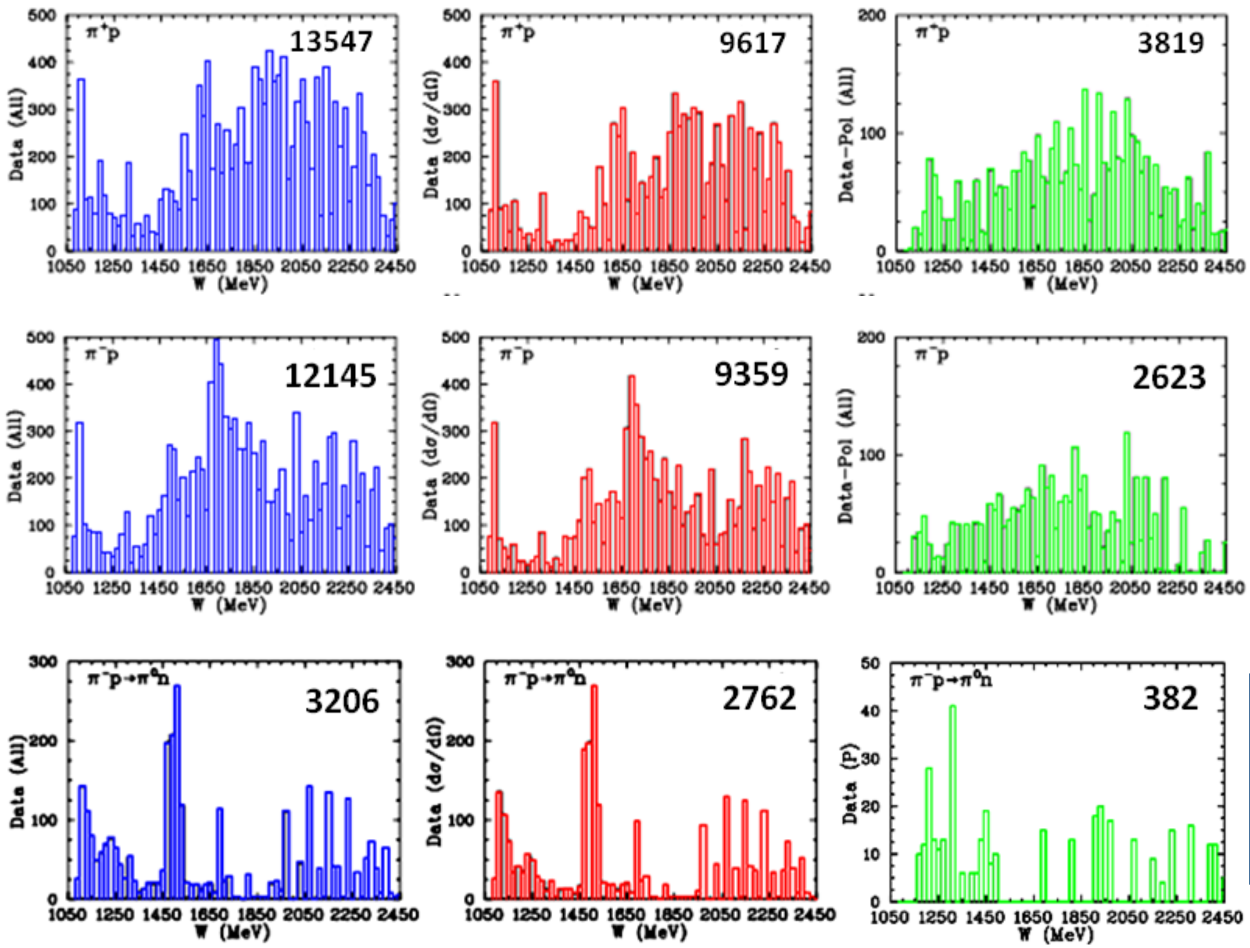
W < 2.5 GeV

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

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

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

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



CEX database is small fraction of measurements.

New Observables

- πN scattering data:

  $d\sigma/d\Omega$ (unpolarized)
  P (polarized target or recoil nucleon)
  R and A (polarized target and recoil measured)

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

PHYSICAL REVIEW C 74, 045205 (2006)

Extended partial-wave analysis of πN scattering data

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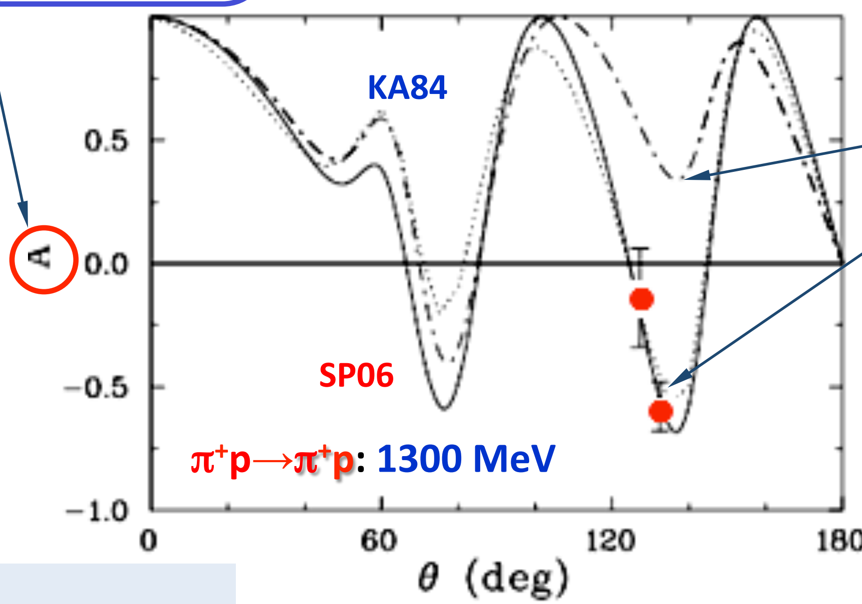
(Received 7 June 2006; published 23 October 2006)



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

Data:
ITEP: $\pi^+p \to \pi^+p$ @ 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 $\pi^{\mp}p \to \pi^{\mp}p$

- 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

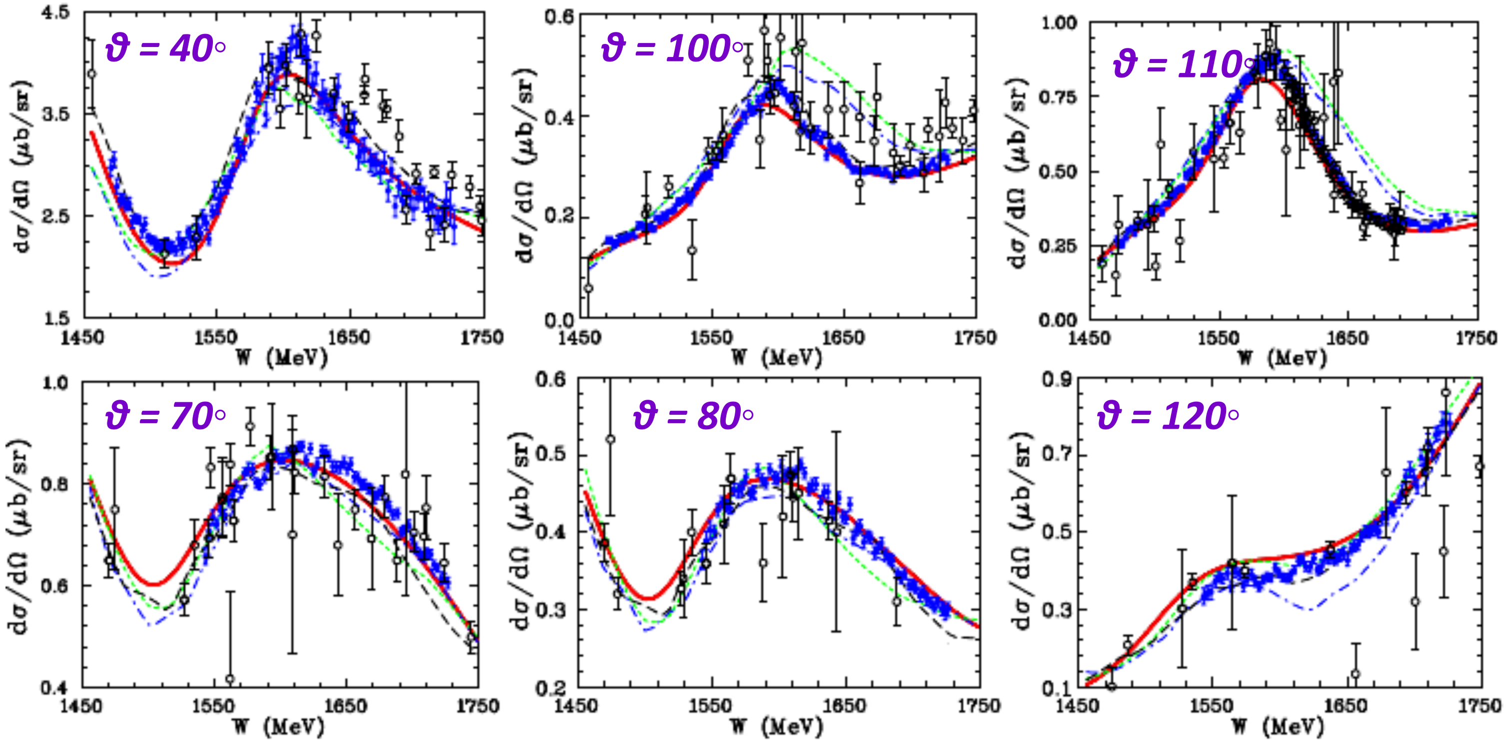
I. G. Alekseev,[1] V. A. Andreev,[3] I. G. Bordyuzhin,[1,5] W. J. Briscoe,[2] Ye. A. Filimonov,[3] V. V. Golubev,[3] A. B. Gridnev,[3] D. V. Kalinkin,[1] L. I. Koroleva,[1] N. G. Kozlenko,[3] V. S. Kozlov,[3] A. G. Krivshich,[3] B. V. Morozov,[1] V. M. Nesterov,[1] D. V. Novinsky,[3] V. V. Ryltsov,[1] 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)

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

4277 dσ/dΩ:
800 – 1243 MeV/c
40 – 122 deg

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

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



Predictions: WI08, KH80, KA84, CMB

- **CMB** analysis is here more **successful** compared to versions of **KH** analyses.

Status of Data for Specific Reactions

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

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

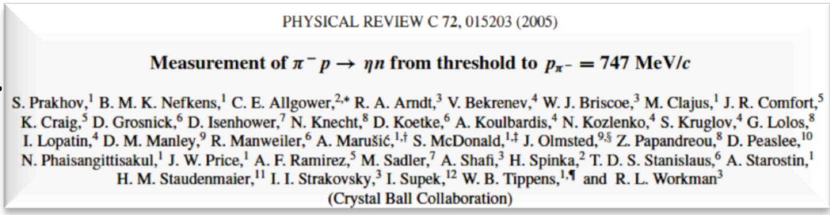
- Analyses of **photoproduction** combined with **pion-induced** reactions permit separating **EM** & **hadronic vertices**.

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

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

- $\gamma p \rightarrow \eta p$ is one of **key reactions** in which experimentalists hope to do ``*complete measurement*” and determine **PW** amplitudes **directly**.
- **Coupled-channel analysis** of those measurements need precise data for $\pi^- p \rightarrow \eta n$.

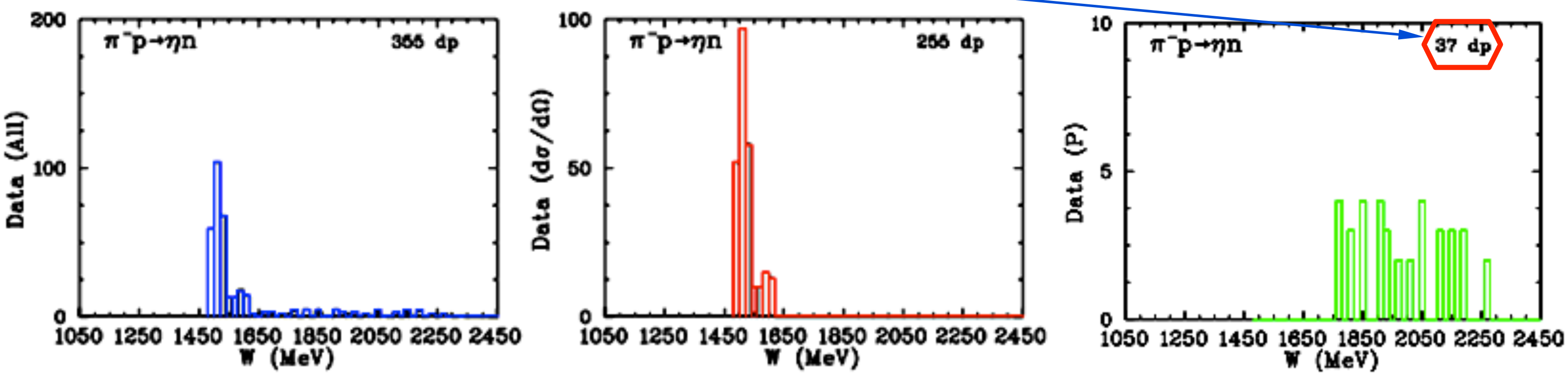
- Most of available data for $\pi^- p \rightarrow \eta n$ come from measurements published in **1970**s, which have been **evaluated** by **several groups** as being **unreliable** above **W** = **1620** MeV.
- Precise data were measured by **Crystal Ball** Collab, but these extend only up to peak of first S_{11}-resonance.


PHYSICAL REVIEW C 72, 015203 (2005)

Measurement of $\pi^- p \rightarrow \eta n$ from threshold to $p_{\pi^-} = 747$ MeV/c

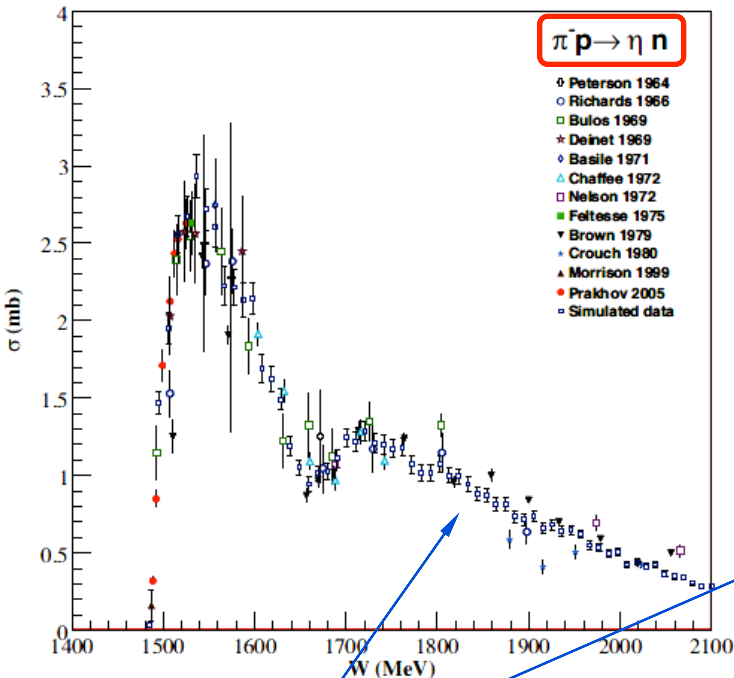
S. Prakhov,[1] B. M. K. Nefkens,[1] C. E. Allgower,[2,*] R. A. Arndt,[3] V. Bekrenev,[4] W. J. Briscoe,[3] M. Clajus,[1] J. R. Comfort,[5] K. Craig,[5] D. Grosnick,[6] D. Isenhower,[7] N. Knecht,[8] D. Koetke,[6] A. Koulbardis,[4] N. Kozlenko,[4] S. Kruglov,[4] G. Lolos,[8] I. Lopatin,[4] D. M. Manley,[9] R. Manweiler,[6] A. Marušić,[1,†] S. McDonald,[1,‡] J. Olmsted,[9,§] Z. Papandreou,[8] D. Peaslee,[10] N. Phaisangittisakul,[1] J. W. Price,[1] A. F. Ramirez,[5] M. Sadler,[7] A. Shafi,[3] H. Spinka,[2] T. D. S. Stanislaus,[6] A. Starostin,[1] H. M. Staudenmaier,[11] I. I. Strakovsky,[3] I. Supek,[12] W. B. Tippens,[1,¶] and R. L. Workman[3]
(Crystal Ball Collaboration)

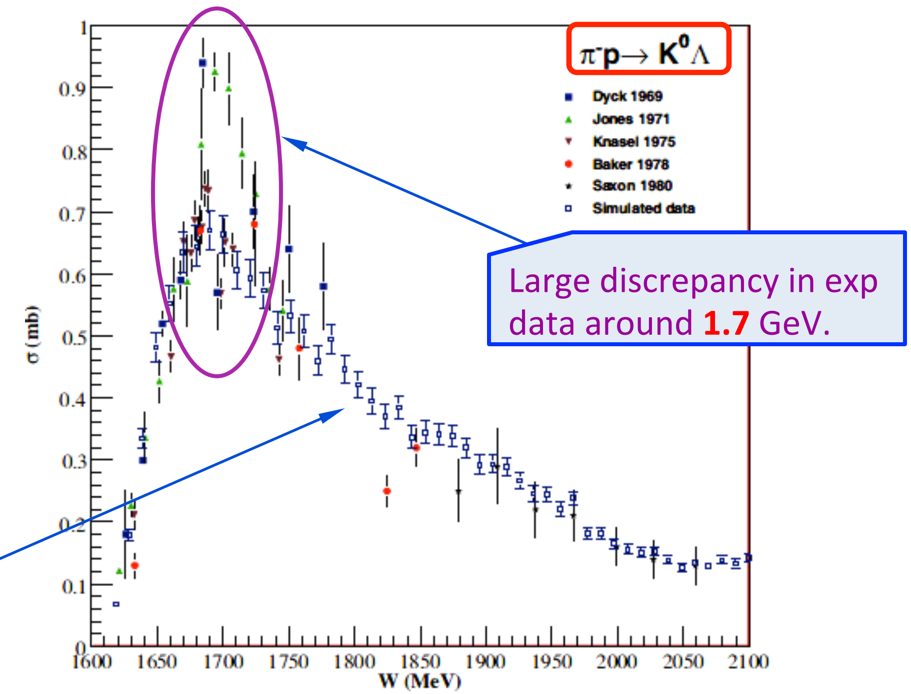
Very few polarized data for this reaction exist.
dσ/dΩ and **P** are taken at different energies .



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

Improvement of $\pi^- p \to \eta n$ and $\pi^- p \to K^0 \Lambda$ Data





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

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

Status of Data with Strangeness Production

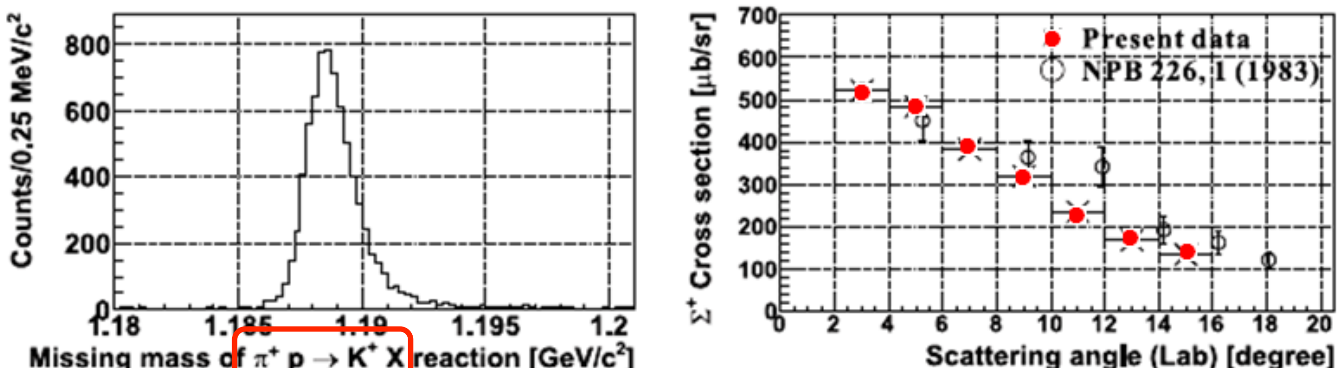
$\gamma p \to K^+\Sigma^0$
$\gamma p \to K^0\Sigma^+$
$\gamma n \to K^+\Sigma^-$
$\gamma n \to K^0\Sigma^0$

- Group of related reactions involve **KΣ** channel:

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

- Except for **$\pi^+ p \to K^+\Sigma^+$**, these reactions involve mixture of **isospins 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 **bleak**.

[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 and, in return, help to extract **S**-wave contribution needed, e.g., in approaches based on **unitarized chiral perturbation theory**.

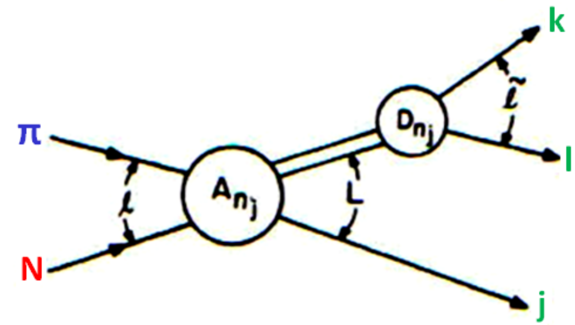
The Durham HepData Project

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

Status of Data for Multi-Pion Reactions

- Important reactions that can be studied are those with **$\pi\pi N$** final states:

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



- **$\pi N \to \pi\pi N$** reactions have the **lowest energy threshold** of all **inelastic hadronic** reactions & some of **largest cross sections**.

- Analysis & interpretation of data from these reactions are **more complex** because of **3-body** final states.

- **Dominant inelastic decays** for most established **N*** & **Δ*** resonances are to **$\pi\pi N$** final states.

- Our knowledge of **πΔ**, **ρN**, & other quasi-two-body **$\pi\pi N$** channels comes mainly from **Isobar-model** analyses of **$\pi N \to \pi\pi N$** data.

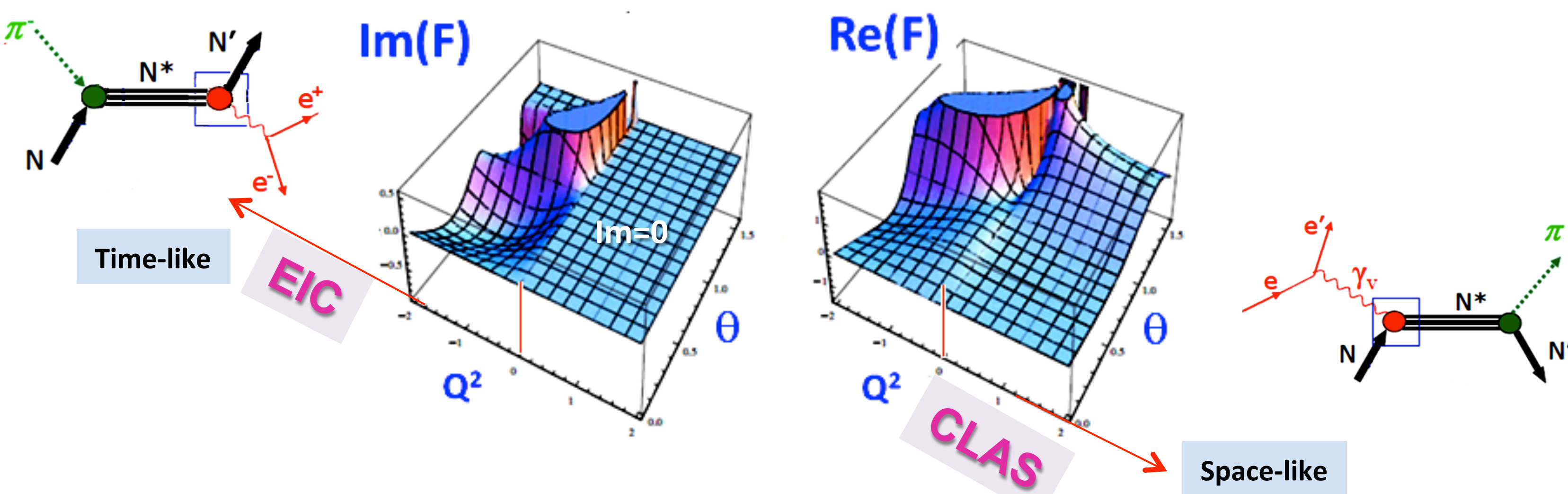
- Larger **experimental database** (including **pol** measurements) is **needed** to determine precisely the **PW** amplitudes because so many amplitudes are **required** to describe **3-body** final states.

Form-Factor Measurements

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

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

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



- **$\pi^- p \rightarrow e^+e^- n$** measurements will significantly complement current studies of the evolution of **baryon** properties with increasing momentum transfer in **electroproduction** by investigating the case of ***time-like virtual photon***.

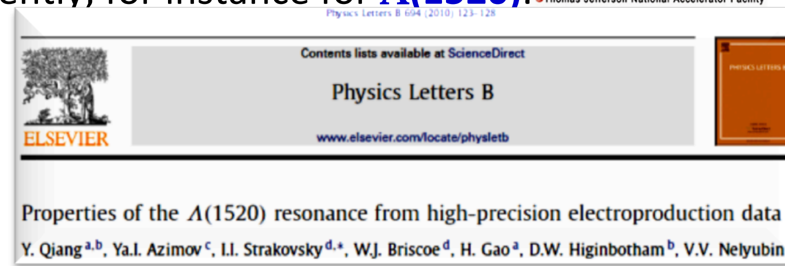
Spectroscopy of Hyperons

- Our current experimental knowledge of Λ^* and Σ^* resonances is far **worse** than our knowledge of **N*** and Δ^* resonances, but they are **equally fundamental**.

- **Pole** position for hyperons began to be studies only recently, for instance for **Λ(1520)**.

- Clearly, complete understanding of **three-quark bound** states requires to learn baryon resonances in ``**strange sector**".

Jefferson Lab
Thomas Jefferson National Accelerator Facility


Physics Letters B 694 (2010) 123–128
Contents lists available at ScienceDirect
Physics Letters B
www.elsevier.com/locate/physletb
Properties of the $\Lambda(1520)$ 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]

- One of secondary beam problems is that **Kaon yield** is less than **pion one** by factor of about **500**.
- This is main reason why there are limited exp data for **Kaon** induced measurements & there are negligible **polarized** measurements.

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

Status of Data for Kaon Induced Reactions

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

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

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

$$K^- n \to \pi^- \Lambda$$
$$K^- n \to \pi^0 \Sigma^-$$
$$K^- n \to \pi^- \Sigma^0$$

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

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

- **Cascade hyperon resonances** could be studied with high-momentum **Kaon beams** and modern **multi particle spectrometers**.

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

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

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

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

Meson Spectroscopy

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

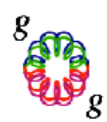
- **Availability** of **pion** & **Kaon** beams provide important opportunity to improve situation.

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

- The **chief areas** of interest in **Meson Spectroscopy** are

scalar mesons,

multiquark states,



glueballs, &

hybrids.

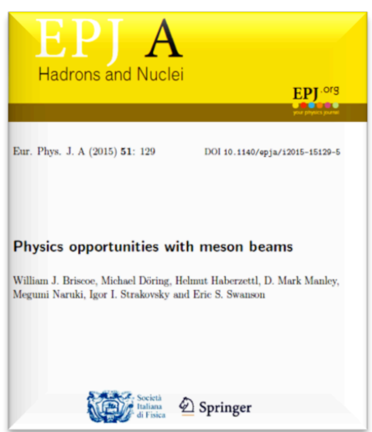
- Experimental effort with **meson beams** will complement **GlueX** experiment at **JLab**, which seeks to explore properties of **hybrids** with photon beam.

Physics Opportunities

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

- New **Meson Facility** would need large-acceptance **detector** and availability of **polarized** target.

- In particular, such dedicated facility should be able to provide features listed in our recent **White Paper**:


EPJ A
Hadrons and Nuclei
EPJ .org

Eur. Phys. J. A (2015) 51: 129 DOI 10.1140/epja/i2015-15129-5

Physics opportunities with meson beams

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

Società Italiana di Fisica Springer

Electron Ion Collider

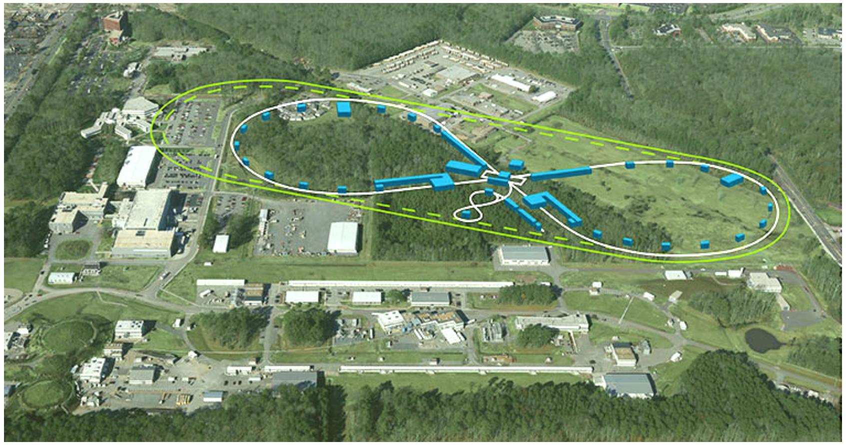
NSAC LRP 2015:

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**’…*
*The **experimental data** are, therefore, suggestive of a more intricate manifestation of **QCD** in baryons…“*

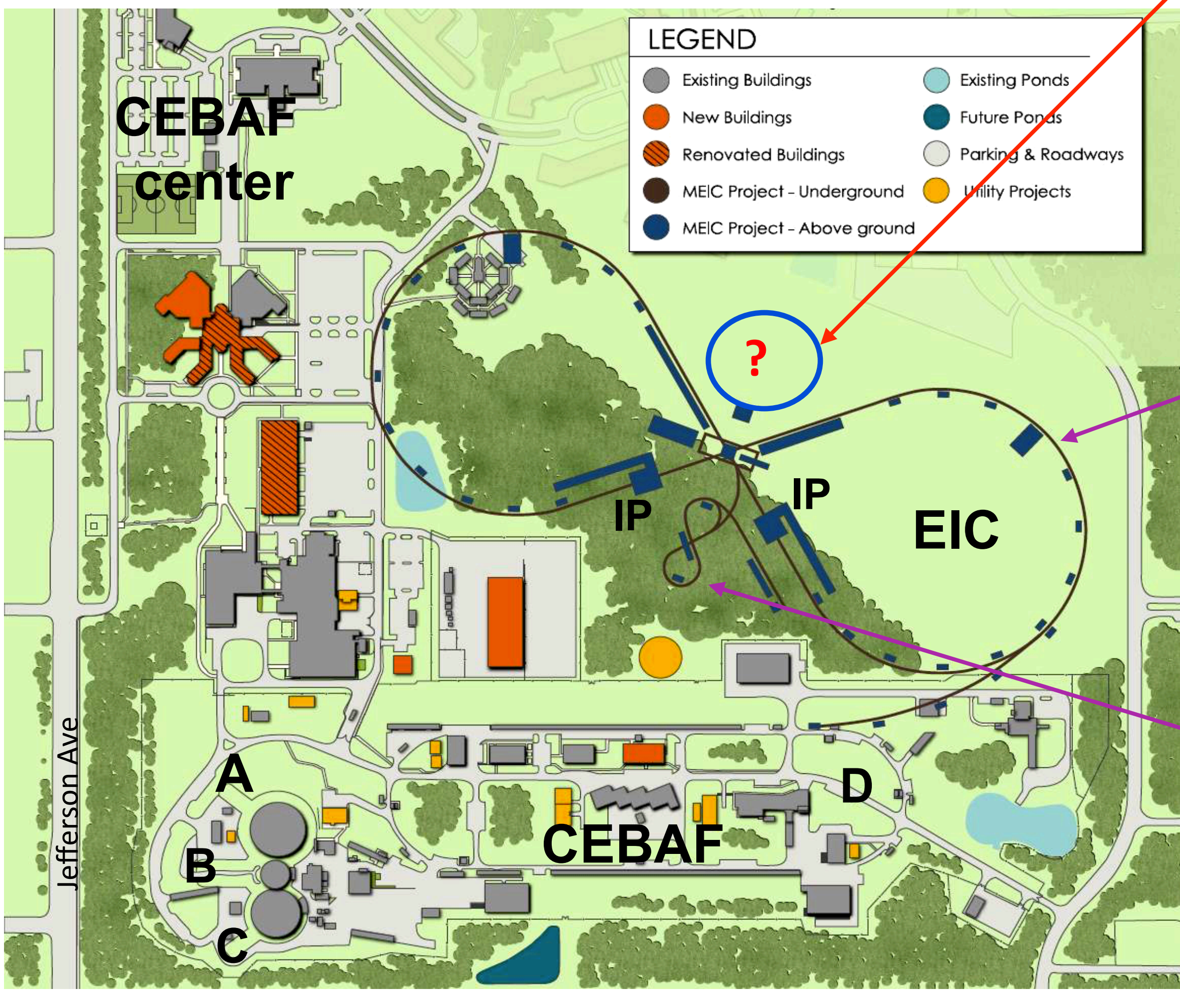
*``For many years, there were both theoretical and experimental reasons to believe that the **strange sea quarks** might play a significant role in the nucleon's structure; a better understanding of the role of **strange quarks** became an important priority.”*

Why EIC and Why at Jefferson Lab ?



- ***EIC 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.
- Large established **user community** at **JLab**.
- ***Meson Facility*** would keep **JLab Ion Booster** busy longer (to use much more than ``**several minutes**" a day), which would be much more effective use of ***EIC Facility***, **without significant increase of the cost of JLab Ion Booster**.

JLab Campus Layout



Meson Facility [good to have]:

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

EIC Facility:

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

Ion Booster:

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

JLab for Hyperon Spectroscopy

Summary

- We have outlined some of **physics programs** that could be advanced with **EIC** especially appended by **Meson Facility**.

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

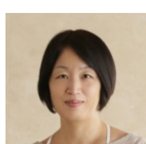
- Searches for **exotic states** (highly anticipated, but never observed unambiguously), such as **multiquarks**, **glueballs**, & **hybrids** would be greatly enhanced by availability of **Meson Facility**.

- Simply discovering of missing **low-lying meson states** would also assist in constructing new models for apparent **properties** of **QCD**, thereby improving our understanding of this strongly coupled **non-linear quantum field theory.**

Thank You







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