Prospects for Experiments in Baryon Spectroscopy (Meson-Nucleon Reactions in the Resonance Region)

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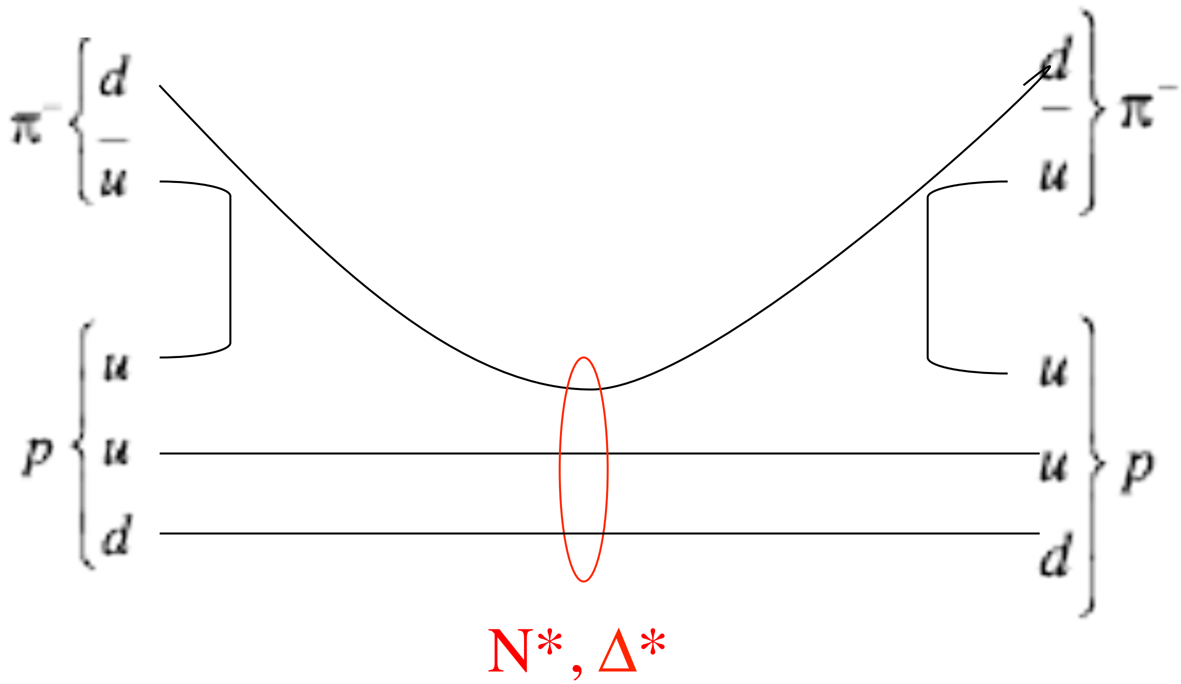
Outline

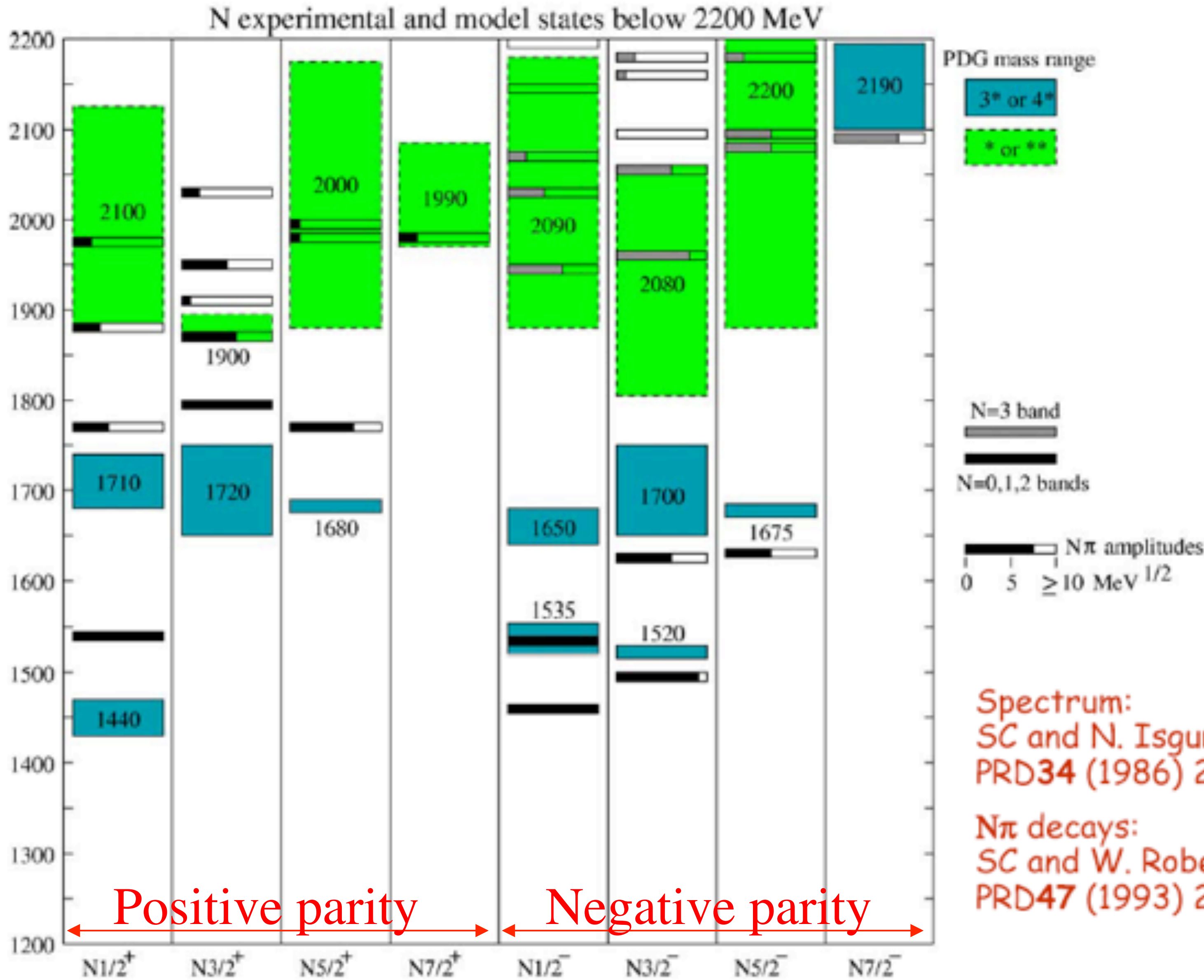
- Motivation for experiments using meson beams on nucleon targets to study resonances
- Summary of recent and present activity
  - Experimental programs
  - PWA efforts
- The MIPP Facility at Fermilab
- Collaboration to facilitate this program

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



Nucleon model states and Nπ couplings

BW Mass (MeV/c^2)



Spectrum:
SC and N. Isgur, PRD**34** (1986) 2809;

Nπ decays:
SC and W. Roberts, PRD**47** (1993) 2004

N(1440) summary in 2004 Review of Particle Physics

Citation: S. Eidelman *et al.* (Particle Data Group), Phys. Lett. B **592**, 1 (2004) (URL: http://pdg.lbl.gov)

$N(1440)\ P_{11}$

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$ Status: ∗∗∗∗

Most of the results published before 1975 are now obsolete and have been omitted. They may be found in our 1982 edition, Physics Letters **111B** (1982).

N(1440) BREIT-WIGNER MASS

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
1430 to 1470 (≈ 1440) OUR ESTIMATE				
1462±10	MANLEY	92	IPWA	$\pi N \to \pi N$ & $N\pi\pi$
1440±30	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
1410±12	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1518± 5	PENNER	02C	DPWA	Multichannel
1479±80	VRANA	00	DPWA	Multichannel
1463± 7	ARNDT	96	IPWA	$\gamma N \to \pi N$
1467	ARNDT	95	DPWA	$\pi N \to N\pi$
1421±18	BATINIC	95	DPWA	$\pi N \to N\pi, N\eta$
1465	LI	93	IPWA	$\gamma N \to \pi N$
1471	CUTKOSKY	90	IPWA	$\pi N \to \pi N$
1411	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
1472	[1] BAKER	79	DPWA	$\pi^- p \to n\eta$
1417	BARBOUR	78	DPWA	$\gamma N \to \pi N$
1460	BERENDS	77	IPWA	$\gamma N \to \pi N$
1380	[2] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

N(1440) summary in 2008 Review of Particle Physics

Citation: C. Amsler *et al.* (Particle Data Group), PL **B667**, 1 (2008) (URL: http://pdg.lbl.gov)

$N(1440)\ P_{11}$

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$ Status: ∗∗∗∗

Most of the results published before 1975 were last included in our 1982 edition, Physics Letters **111B** 1 (1982). Some further obsolete results published before 1984 were last included in our 2006 edition, Journal of Physics, G **33** 1 (2006).

N(1440) BREIT-WIGNER MASS

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
1420 to 1470 (≈ 1440) OUR ESTIMATE				
1485.0 ± 1.2	ARNDT	06	DPWA	$\pi N \to \pi N, \eta N$
1462 ±10	MANLEY	92	IPWA	$\pi N \to \pi N \ \& \ N\pi\pi$
1440 ±30	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
1410 ±12	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1436 ±15	SARANTSEV	08	DPWA	Multichannel
1468.0 ± 4.5	ARNDT	04	DPWA	$\pi N \to \pi N, \eta N$
1518 ± 5	PENNER	02C	DPWA	Multichannel
1479 ±80	VRANA	00	DPWA	Multichannel

N*(1710) summary in Review of Particle Physics

Citation: W.-M. Yao et al. (Particle Data Group), J. Phys. G 33, 1 (2006) and 2007 partial update for edition 2008 (URL: http://pdg.lbl.gov)

$N(1710)\ P_{11}$

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$ Status: ***

Most of the results published before 1975 were last included in our 1982 edition, Physics Letters **111B** 1 (1982). Some further obsolete results published before 1980 were last included in our 2006 edition, Journal of Physics, G **33** 1 (2006).

The latest GWU analysis (ARNDT 06) finds no evidence for this resonance.

N(1710) BREIT-WIGNER MASS

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
1680 to 1740 (≈ 1710) OUR ESTIMATE				
1717±28	MANLEY	92	IPWA	$\pi N \to \pi N$ & $N\pi\pi$
1700±50	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
1723± 9	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1752± 3	PENNER	02C	DPWA	Multichannel
1699±65	VRANA	00	DPWA	Multichannel
1720±10	ARNDT	96	IPWA	$\gamma N \to \pi N$
1766±34	[1] BATINIC	95	DPWA	$\pi N \to N\pi$, $N\eta$
1706	CUTKOSKY	90	IPWA	$\pi N \to \pi N$
1692	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
1730	SAXON	80	DPWA	$\pi^- p \to \Lambda K^0$
1720	[2] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
1710	[3] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

N*(1710) summary in Review of Particle Physics

N(1710) DECAY MODES

The following branching fractions are our estimates, not fits or averages.

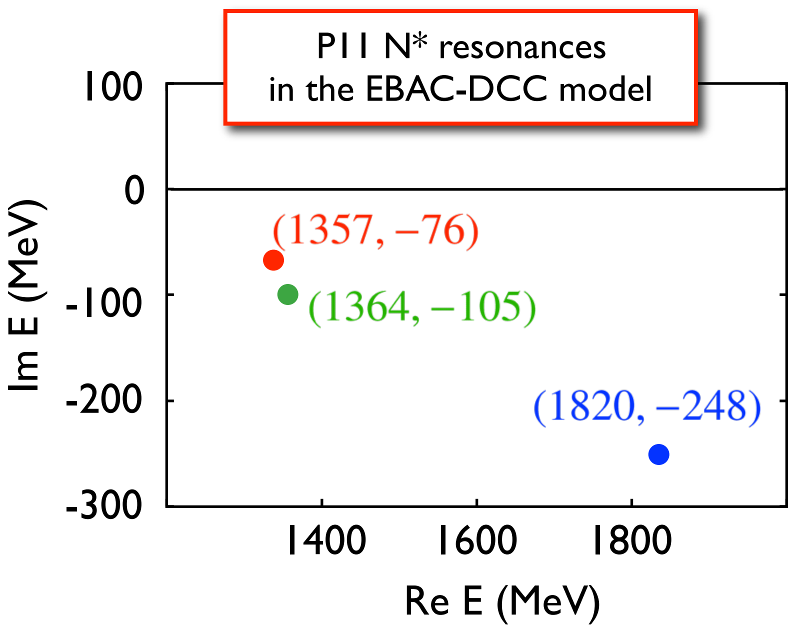
	Mode	Fraction (Γ_i/Γ)
Γ_1	$N\pi$	10–20 %
Γ_2	$N\eta$	(6.2±1.0) %
Γ_3	$N\omega$	(13.0±2.0) %
Γ_4	ΛK	5–25 %
Γ_5	ΣK	
Γ_6	$N\pi\pi$	40–90 %
Γ_7	$\Delta\pi$	15–40 %
Γ_8	$\Delta(1232)\pi$, P-wave	
Γ_9	$N\rho$	5–25 %
Γ_{10}	$N\rho$, S=1/2, P-wave	
Γ_{11}	$N\rho$, S=3/2, P-wave	
Γ_{12}	$N(\pi\pi)^{I=0}_{S\text{-wave}}$	10–40 %
Γ_{13}	$p\gamma$	0.002–0.05%
Γ_{14}	$p\gamma$, helicity=1/2	0.002–0.05%
Γ_{15}	$n\gamma$	0.0–0.02%
Γ_{16}	$n\gamma$, helicity=1/2	0.0–0.02%

Slide courtesy Hiroyuki Kamano (EBAC), GHP2011, April 27-29, 2011, Anaheim, California

Dynamical origin of P11 resonances

Suzuki, Julia-Diaz, Kamano, Lee, Matsuyama, Sato, PRL104 042302 (2010)

All three P11 poles below 2 GeV are generated from a *same, single* bare state!



Multi-channel reactions can generate many resonance poles from a single bare state

Eden, Taylor, Phys. Rev. 133 B1575 (1964)

Evidences in hadron and nuclear physics are summarized e.g., in Morgan, Pennington PRL59 2818 (1987)

(This slide courtesy of Igor Strakovsky)

N* and Δ* States Coupled to πN

- One of the most convincing ways to study Spectroscopy of N^* & Δ^* is πN PWA

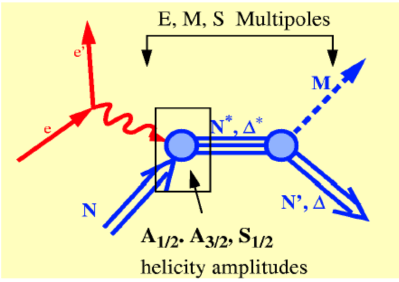
- Main objects in the PDG Listings [http://pdg.lbl.gov/] come from:
  Karlsruhe-Helsinki, Carnegie-Mellon-Berkeley, and GW/VPI

- GW DAC SAID program: $\pi N \to \pi N \Rightarrow \gamma N \to \pi N \Rightarrow \gamma^* N \to \pi N$

  - πN elastic amplitudes from fits to the observables:
    σ^{tot}, $d\sigma/d\Omega$, and P plus a few R and A measurements, 0.4 %

  - Contains resonances contributing to $\gamma^* N \to \pi N$
  - Assuming dominance of 2 hadronic channels, can parametrize $\gamma^* N \to \pi N$ in terms of $\pi N \to \pi N$ amplitudes alone
  - Resulting multipoles can be re-fitted in terms of Res/Bckgr contributions or used as input to multi-channel fits with more elaborate constraints

  - Comparison of various resonance-extraction methods gives a more reliable estimate of systematic (model) errors



(This slide courtesy of Igor Strakovsky)

Summary of N* and Δ* from GWU08 Analysis

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

- Standard PWA reveals only wide Resonances, but not too wide (Γ < 500 MeV) and possessing not too small BR (BR > 4%)
- Standard PWA (by construction) tends to miss narrow Resonances with Γ < 30 MeV

- Our study does not support several N* and Δ* reported by PDG2008:
  - *** $\Delta(1600)P_{33}$, $N(1700)D_{13}$, $N(1710)P_{11}$, $\Delta(1920)P_{33}$
  - ** $N(1900)P_{13}$, $\Delta(1900)S_{31}$, $N(1990)F_{17}$, $\Delta(2000)F_{35}$, $N(2080)D_{13}$, $N(2200)D_{15}$, $\Delta(2300)H_{39}$, $\Delta(2750)I_{313}$
  - * $\Delta(1750)P_{31}$, $\Delta(1940)D_{33}$, $N(2090)S_{11}$, $N(2100)P_{11}$, $\Delta(2150)S_{31}$, $\Delta(2200)G_{37}$, $\Delta(2350)D_{35}$, $\Delta(2390)F_{37}$

- Our study does suggest several 'new' N* and Δ*:
  - **** $\Delta(2420)H_{311}$
  - *** $\Delta(1930)D_{35}$, $N(2600)I_{111}$ [BW, no Pole]
  - ** $N(2000)F_{15}$, $\Delta(2400)G_{39}$
  - new $N(2245)H_{111}$ [CLAS ?]

Summary of Pion-Nucleon Reactions and πN Experiments at LAMPF and BNL

Reactions

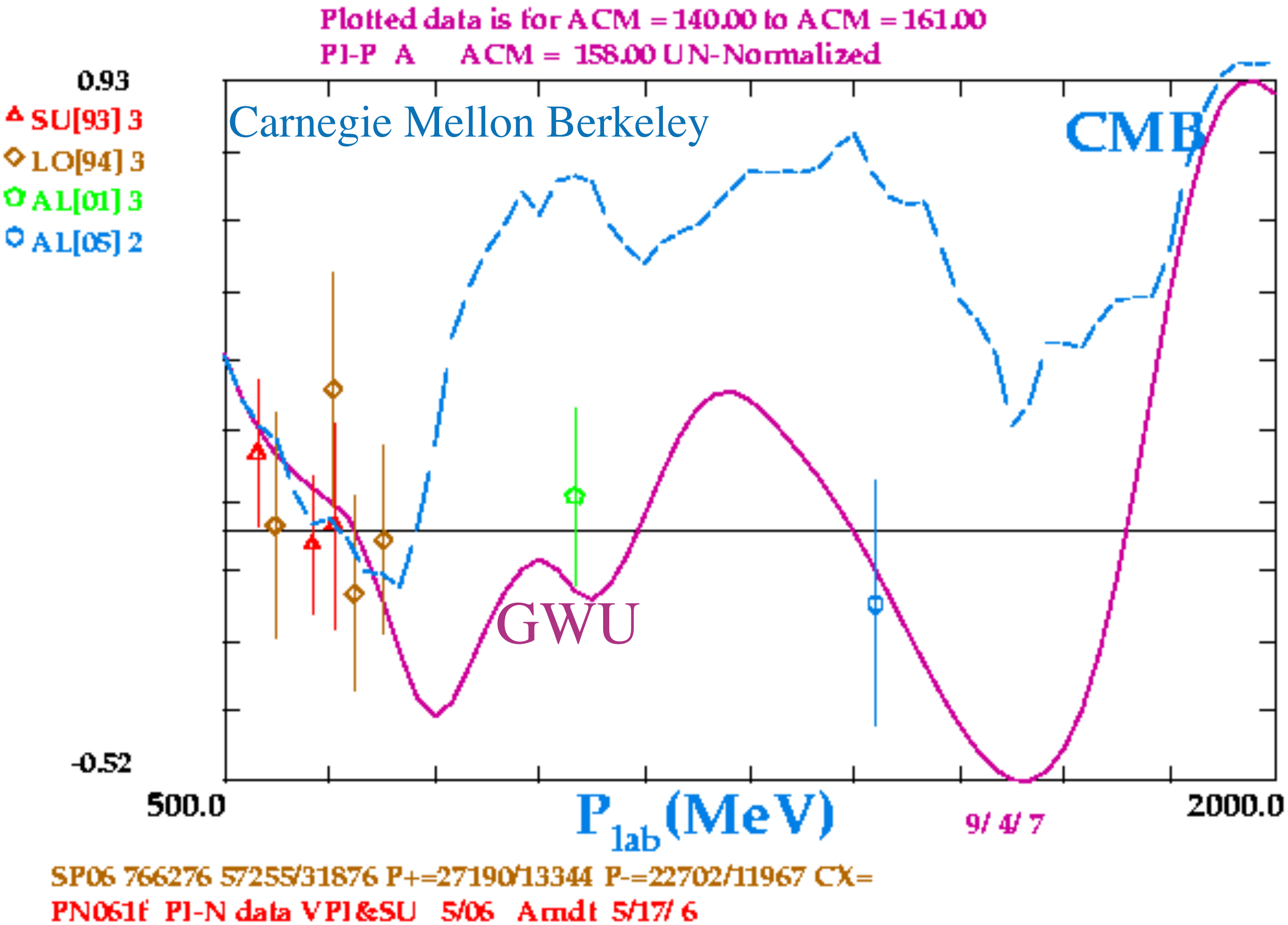
$\pi^+ p \rightarrow \pi^+ p$
$\pi^- p \rightarrow \pi^- p$
$\pi^- p \rightarrow \pi^o n$

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

Observables

$d\sigma/d\Omega$
P $(=A_N)$
A and R

Comparison of the spin rotation parameter A with PWA predictions



Summary of Present PWA Efforts

πN→ γN→	πN	ππN	ηN	KΛ, KΣ
SAID	🔴 🔵	🔴	🔴 🔵	
Bonn-Gatchina	🔴 🔵	🔴 🔵	🔴 🔵	🔴 🔵
EBAC	🔴 🔵	🔴 🔵	🔴 ★	★ ★
Juelich-UGA	🔴 🔵	🔴 ★	🔴	🔴 ★
Zagreb	🔴 ★	🔴 ★	🔴 ★	🔴 ★
Giessen	🔴 🔵	🔴 🔵	🔴 🔵	🔴 🔵

★ In progress

Adapted from T. Sato review talk, “EBAC meeting”, Jefferson Laboratory, May 2010,
and B. Julia-Diaz, MENU2010, College of William and Mary, June 2010.

Summary of Present PWA Status

- Listings in Review of Particle Properties rely primarily on Karlsruhe-Helsinki and Carnegie Mellon-Berkeley PWAs from 1980.
- GWU (formerly VPI) PWA includes recent data, but differs significantly in prediction of resonances.
- New efforts by EBAC, Bonn-Gatchina, Juelich, Zagreb and Giessen are producing results but are ignored in RPP.
- To date, no "missing resonances" found! Indeed, have we 'lost' the $P_{11}(1710)$?
- Analyses should include $\pi p \rightarrow \pi\pi N$, new data are needed.
- **Hadronic data are needed to analyze data from photo- and electro-production of resonances.**

$\pi^- p \to \pi^- p$ and $\pi^- p \to K\Lambda$ at ITEP

An Existing Facility for Measurements in Baryon Spectroscopy

Institute for Theoretical and Experimental Physics, Moscow, Russia

I.G.Alekseev, P.Ye. Budkovsky, V.P. Kanavets, M.M. Kats, L.I. Koroleva, V.V. Kulikov, B.V. Morozov, V.M. Nesterov, V.V. Ryltsov, V.A. Sakharov, A.D. Sulimov, D.N. Svirida, **ITEP**

A.I. Kovalev, N.G. Kozlenko, V.S. Kozlov, A.G. Krivshich, D.V. Novinsky, V.V. Sumachev, V.Yu. Trautman, Ye.A. Filimonov, **PNPI**

M.E. Sadler, J. Kish, D. Soboyede, E. Walker, S. Watson **ACU**

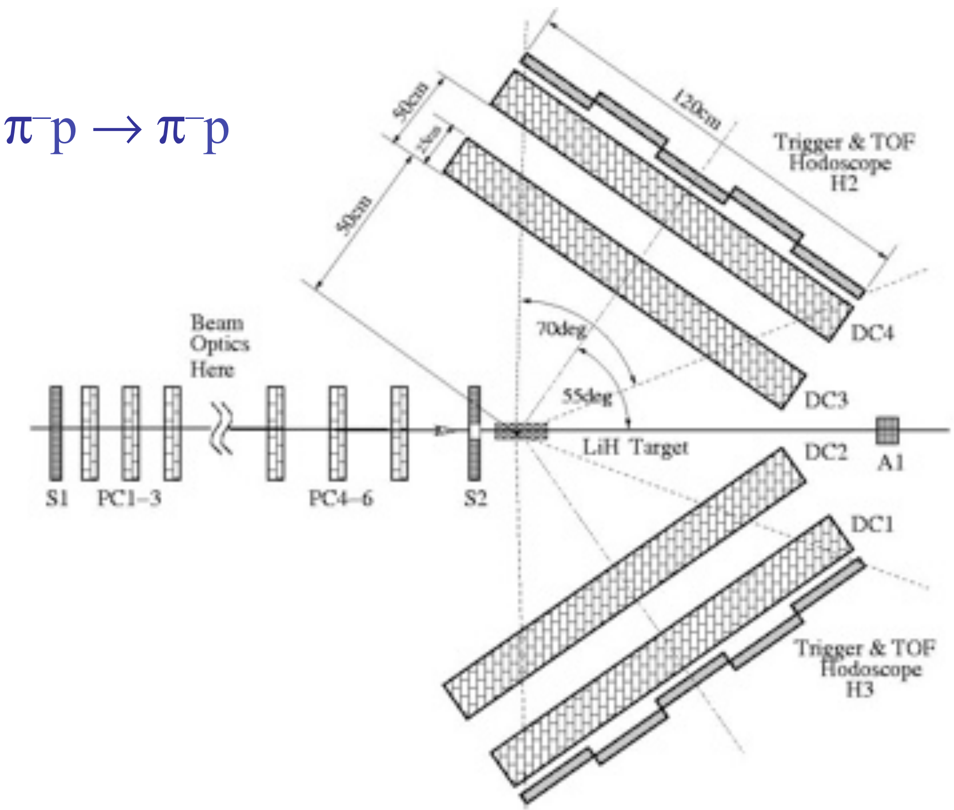
Project at ITEP (EPECUR)

- Measurements of $\pi^- p \rightarrow \pi^- p$ and $\pi^- p \rightarrow K\Lambda$ at P_π = 900 - 1200 MeV/c $(\sqrt{s} = 1610 - 1770\ \text{MeV})$
- Participating Institutions are ITEP, PNPI and ACU
- Emphasis on narrow resonance search and N*(1710) (second P_{11})
- Natural extension of LAMPF, PNPI and BNL (Crystal Ball) programs
- Preparation for experiments at J-PARC or FAIR?

$\pi^- p \rightarrow \pi^- p$ at ITEP

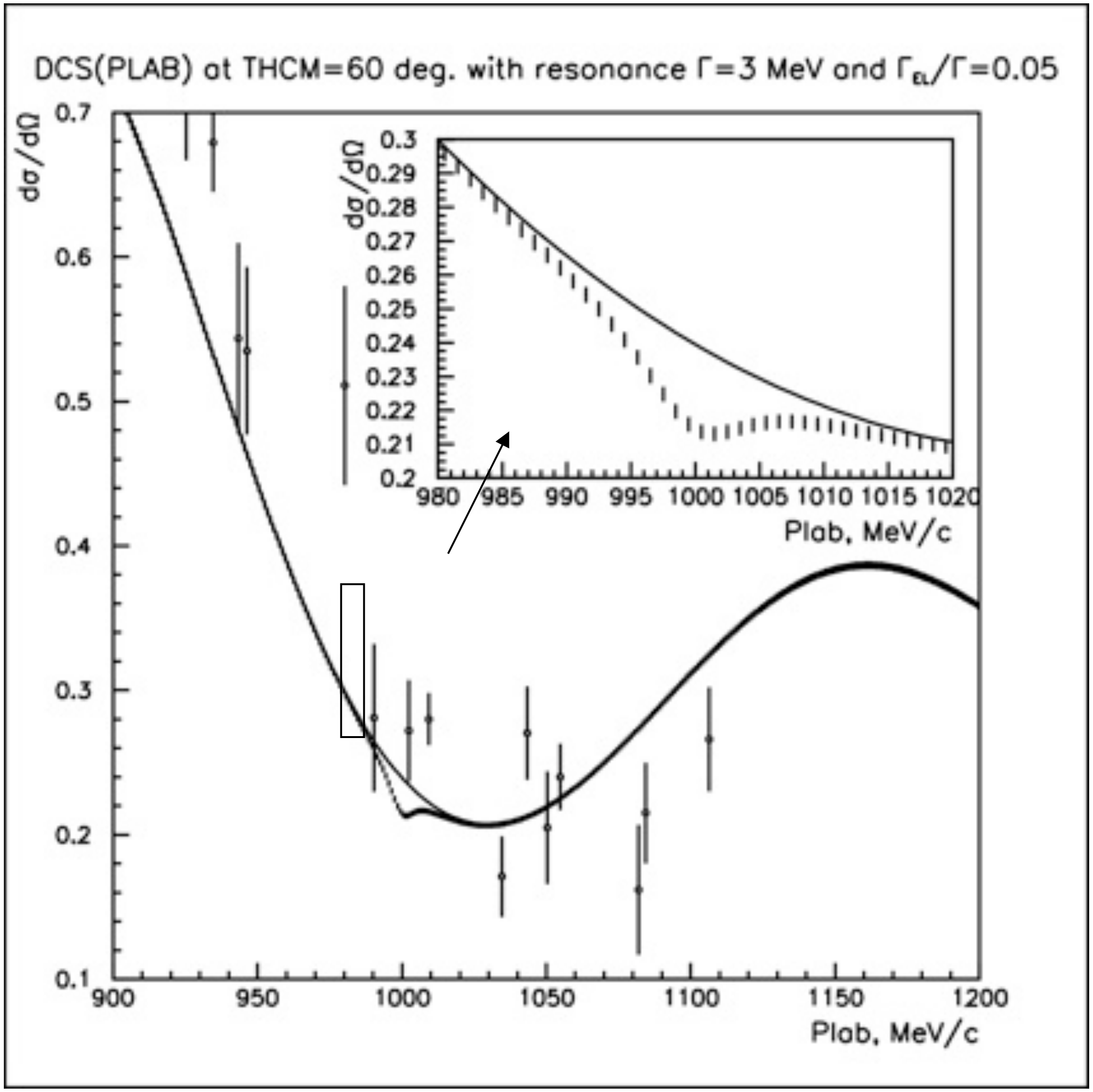
- Differential cross sections at 40-120° CM as function of the invariant mass of π^-p-system.
- "Formation"-type experiment: invariant mass resolution (0.7 MeV) is based on the high momentum resolution (0.1%) of the magneto-optic channel.
- Statistical resolution as high as 0.5 %
- Obtain clear evidence for a narrow (2-20 MeV) resonance even if its elasticity is only 1%.
- Main parts of experimental setup are liquid hydrogen target and proportional and drift chambers.

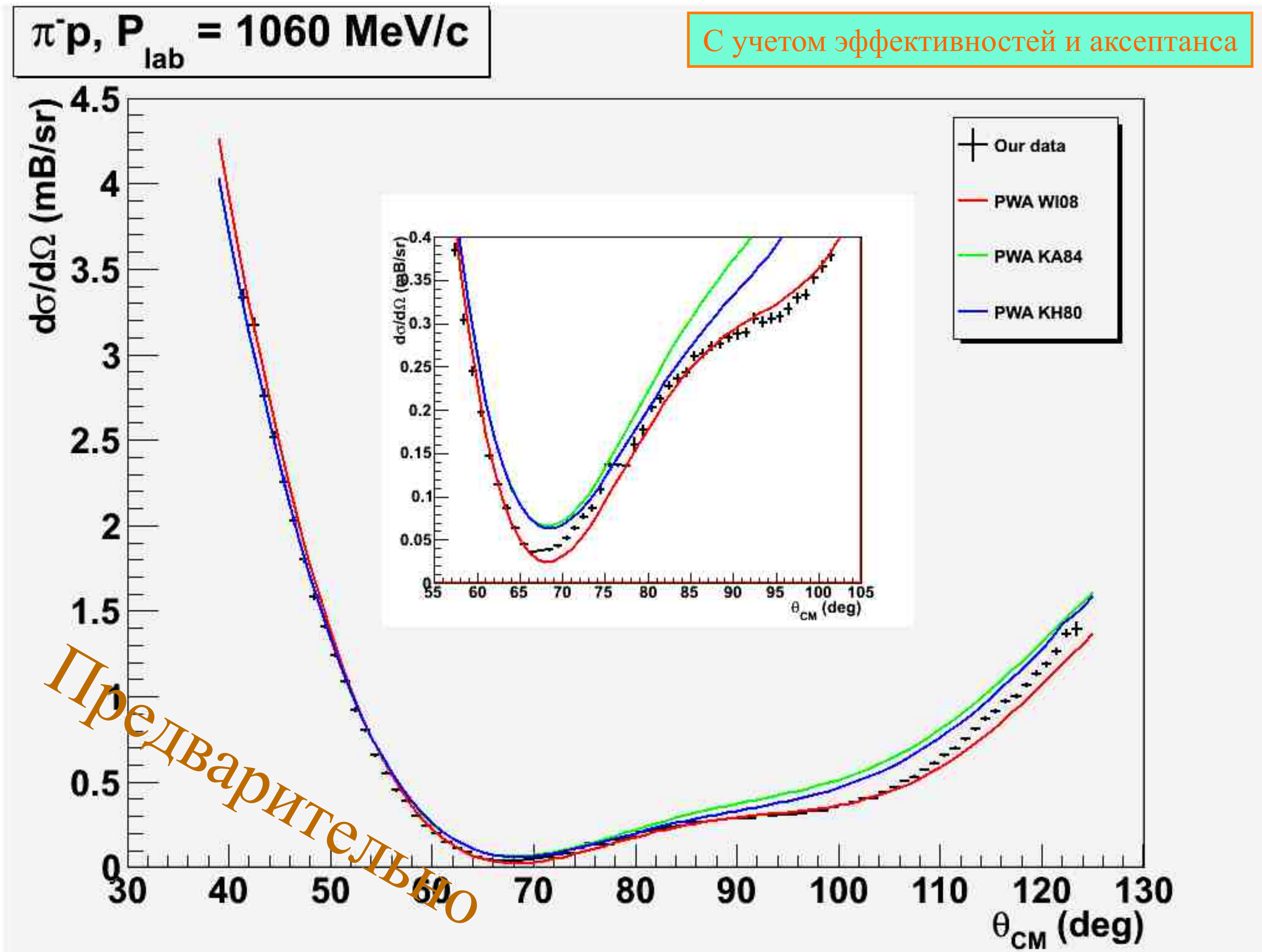
$\pi^- p \rightarrow \pi^- p$



Sensitivity for $\pi^- p \to \pi^- p$

- Momentum range 900-1200 MeV/c, 40-120^o CM
- $\sqrt{s}$ = 1610-1770 MeV
- Invariant mass intervals of 0.5 MeV
- Statistical precision of 0.5%
- Started data taking in 2009





π⁻p, P lab = 1060 MeV/c
С учетом эффективностей и аксептанса
dσ/dΩ (mB/sr)
θCM (deg)
Our data
PWA WI08
PWA KA84
PWA KH80
Предварительно

Strangeness Production (Λ^0)

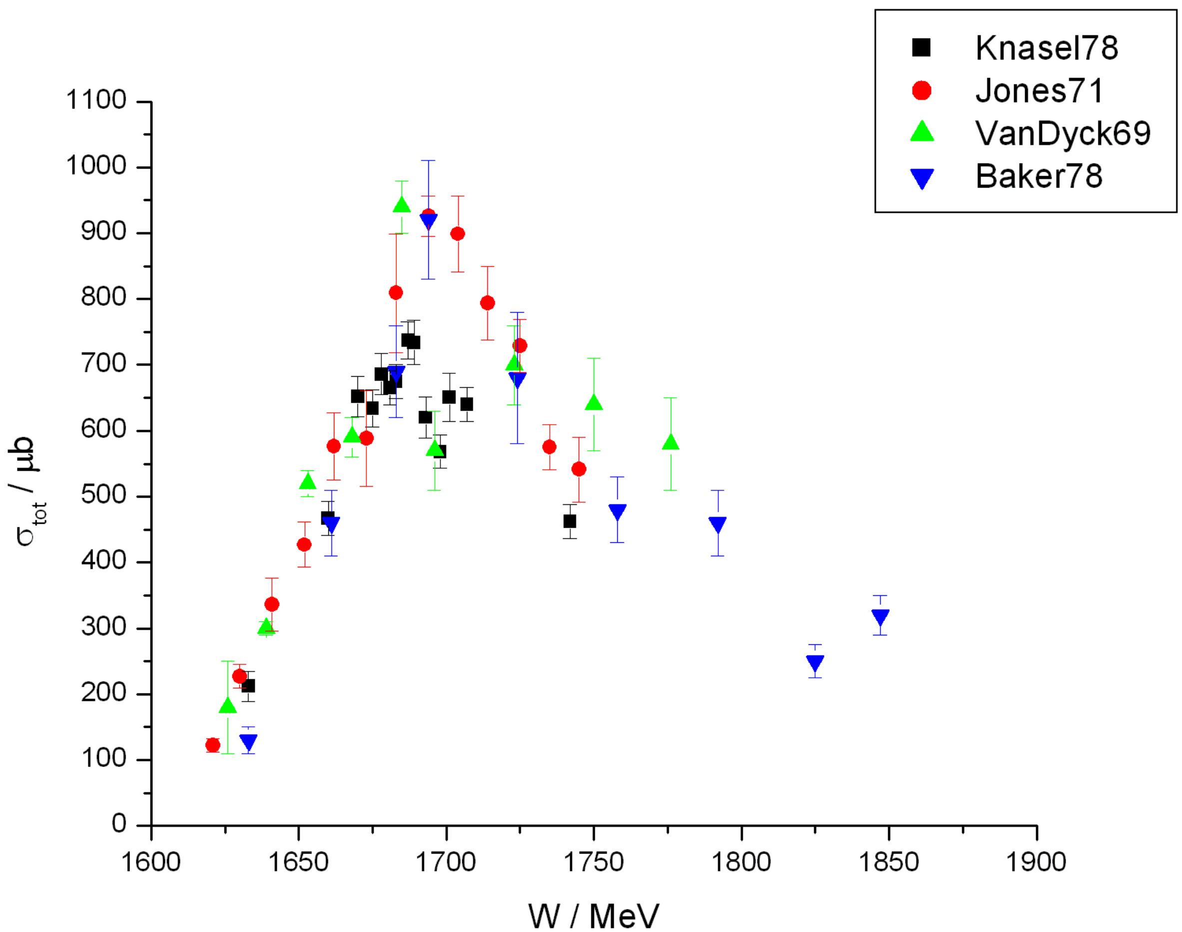
- $\pi^- p \to K^0 \Lambda$

  $\Lambda \to \pi^- p$

  $K^0 \to K_S \to \pi^+ \pi^-$

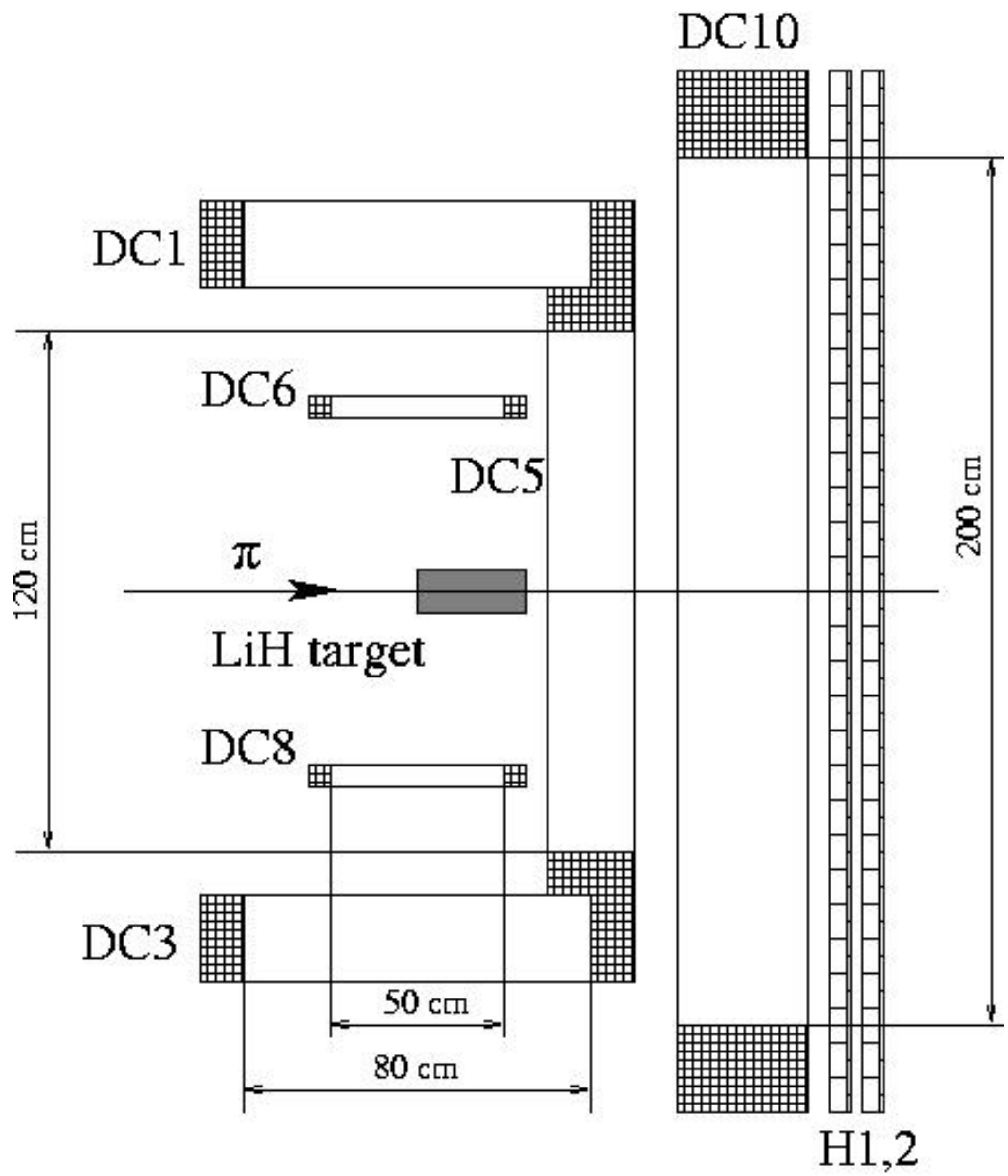
- Important reaction because:
  - Sizable cross section.
  - Pure I = 1/2 selects only N* resonances.
- Little is known about resonances that decay to K Λ.
- Will also be able to determine the final-state Λ polarization, since it is self-analyzing (two observables).
- Precise differential cross section and polarization data for $\pi^- p \to K^0 \Lambda$ should be straightforward to analyze with a PWA.

Current situation – experimental data for $\pi^- p \to K^0 \Lambda$

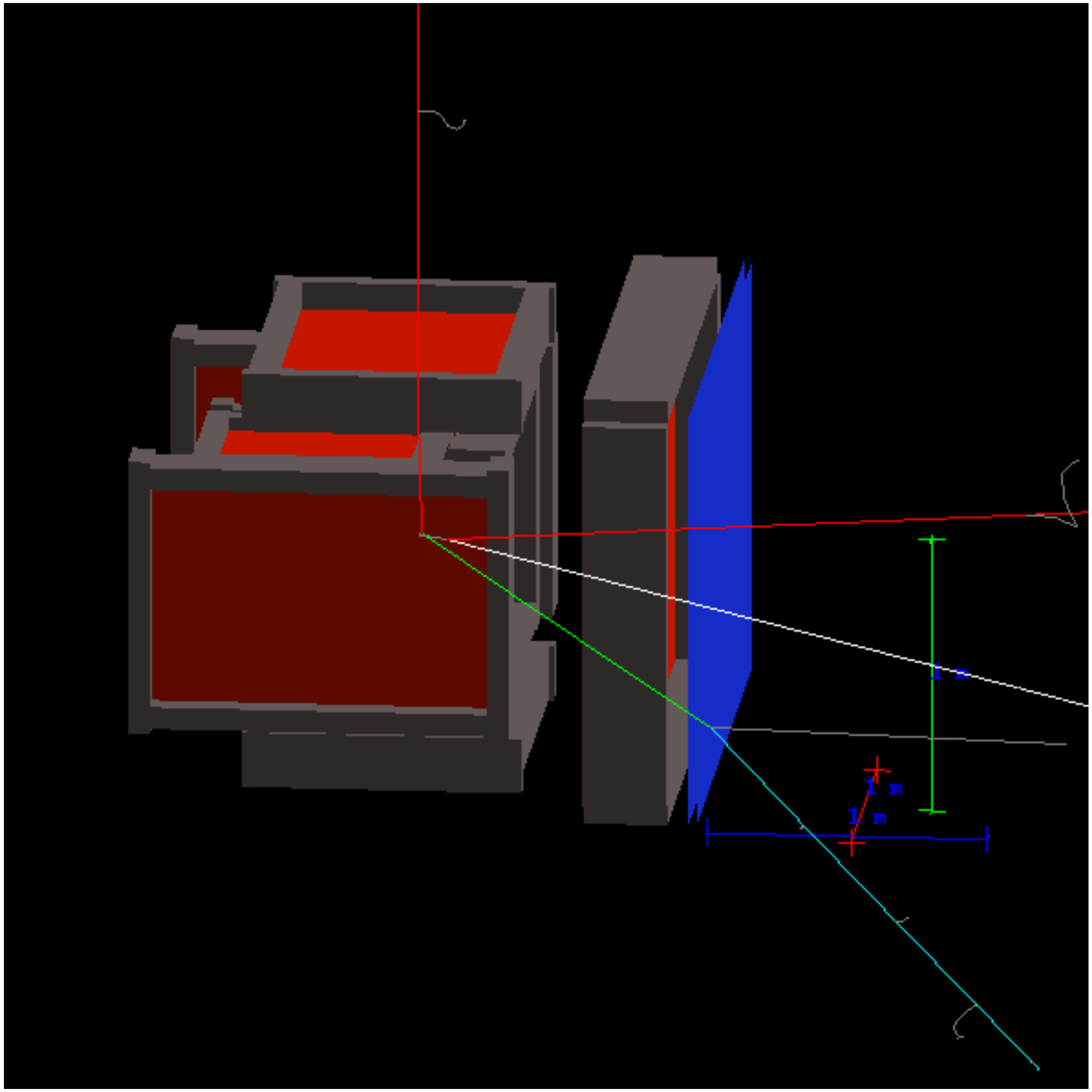


$\pi^- p \to K\Lambda$ at ITEP

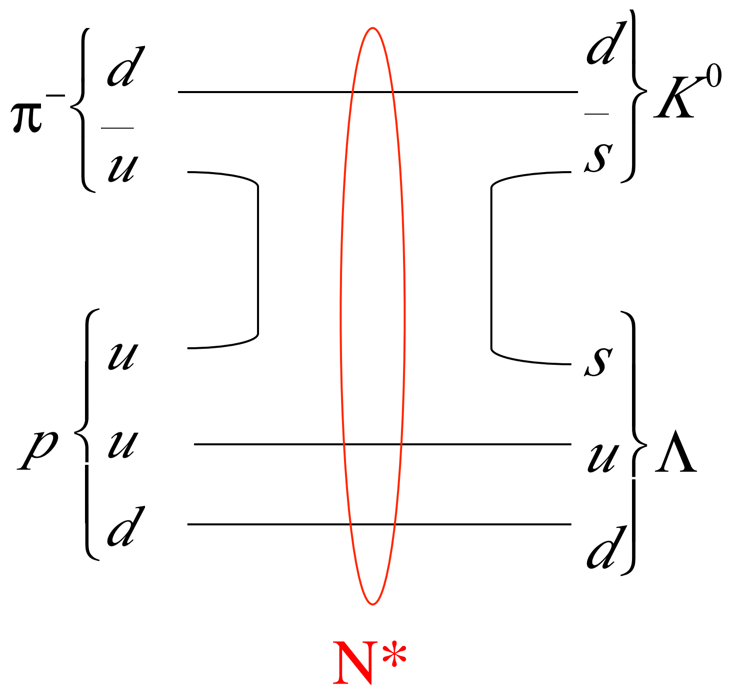
- Differential cross-section with statistical precision 1% and step in the invariant mass 0.5 MeV at the angles 0-180° CM.
- Momentum range 900-1200 MeV/c ⇒ 1610-1770 MeV
- ~24 days of running, after $\pi^- p \to \pi^- p$ measurements



GEANT4 Simulation for $\pi^- p \to K\Lambda$



Resonance formation and decay for $\pi^- p \rightarrow K^0 \Lambda$



New Possibility for Measurements in Baryon Spectroscopy

The Main Injector Particle Production Experiment (MIPP-FNAL-P960) at Fermilab

MIPP Upgrade collaboration list

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University of Iowa

MIPP Upgrade collaboration list

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Purdue University
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Rutgers University
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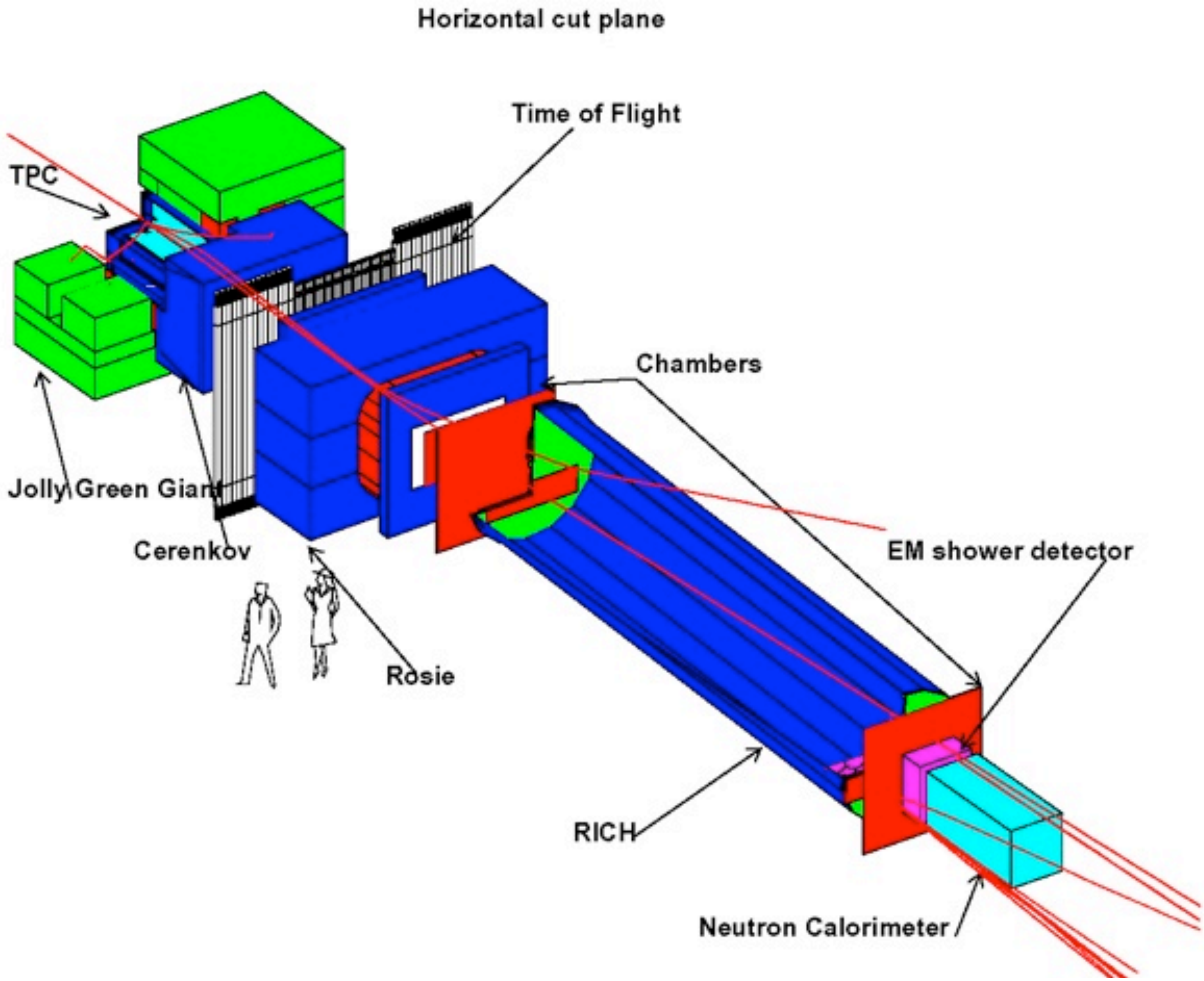
University of South Carolina
C.Dukes,C.Materniak,K.Nelson,A.Norman
University of Virginia
P.Desiati, F.Halzen, T.Montaruli,
University of Wisconsin, Madison
P.Sokolsky, W.Springer
University of Utah
H.Meyer, N.Solomey,
Wichita State University, Kansas

18 new institutions have joined. 6 from India.
New Collaborators in color cyan

MIPP

Main Injector Particle Production Experiment (FNAL-E907)

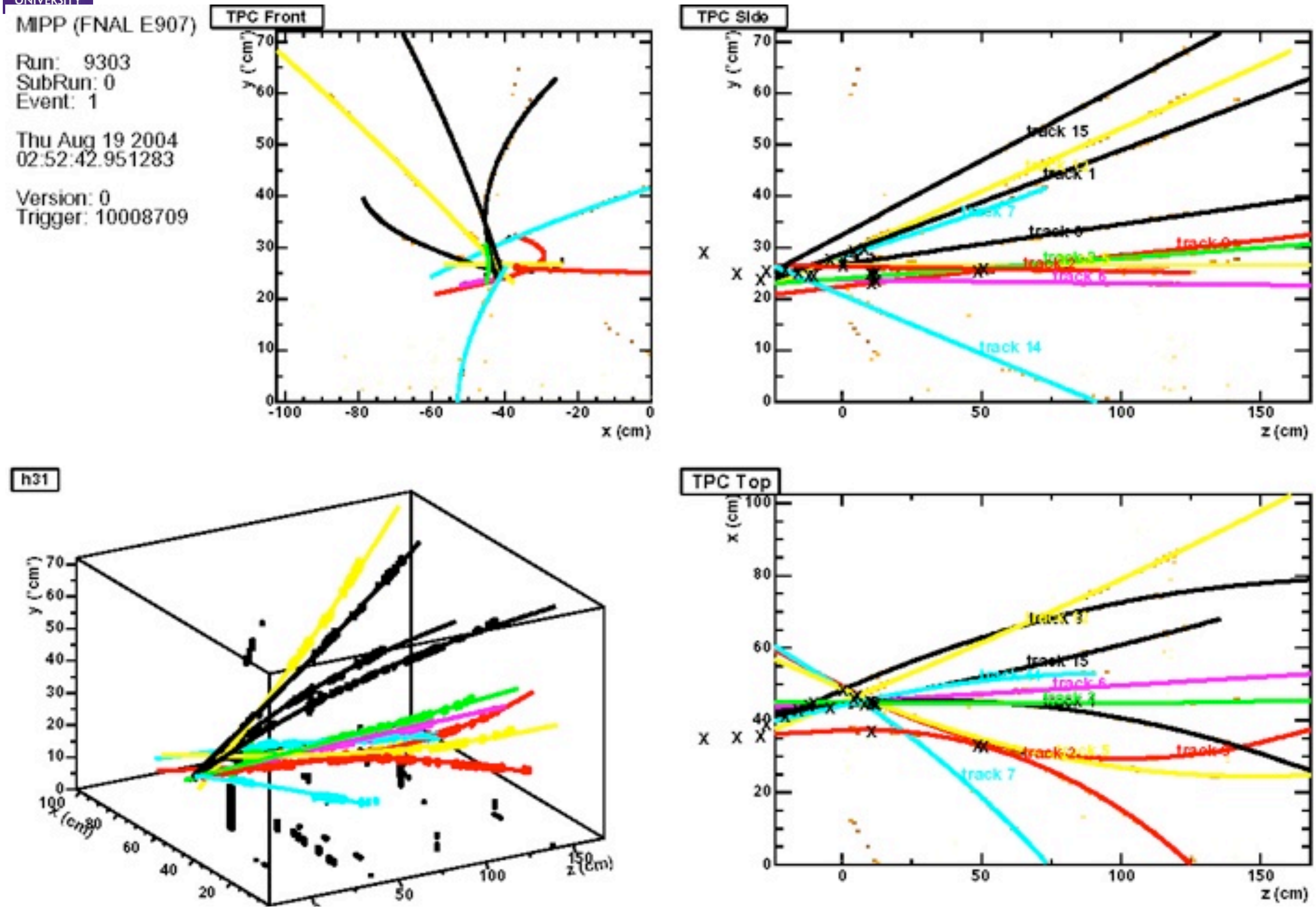


TPC installation

MIPP-TPC

- The Time Projection Chamber was built by the BEVALAC group at LBL for heavy ion studies in 1990’s. Donated to Fermilab after usage at BNL. It took approximately $3 million to construct.
- Can handle high multiplicity events. Time to drift across TPC=16 μs.
- Electronic equivalent of bubble chamber, high acceptance, with dE/dx capabilities. Dead time 16ms. Unreacted beam swept out in 8ms. Can tolerate 10^5 particles per second going through it.
- TPC dimensions 96 x 75 x 150 cm.
- Previous data taking rate was ~60 Hz. Electronics upgraded to increase rate to ~1000 Hz.

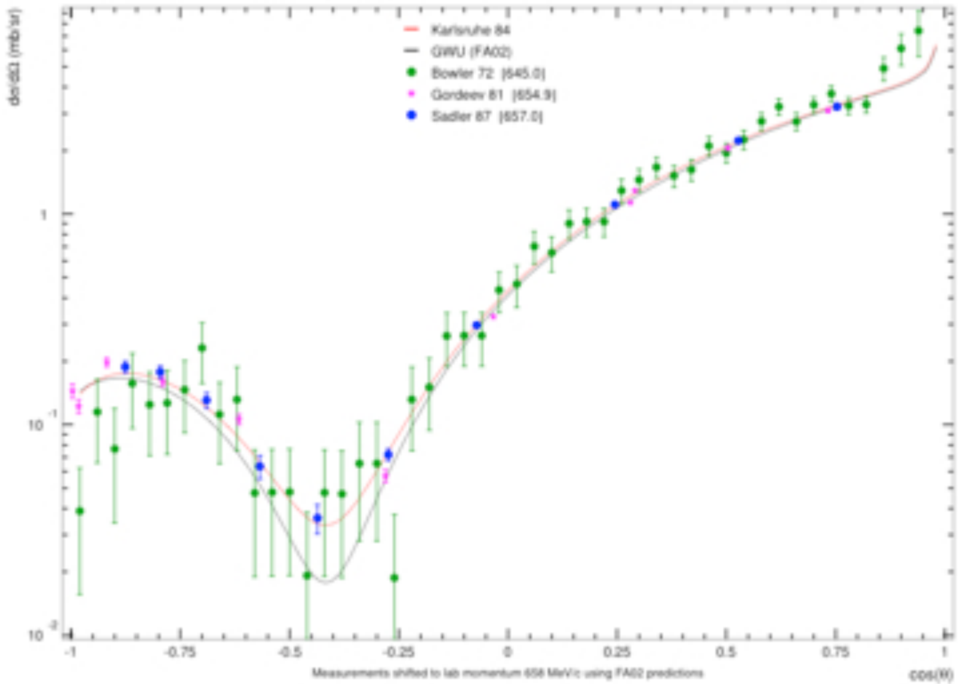
TPC processed event



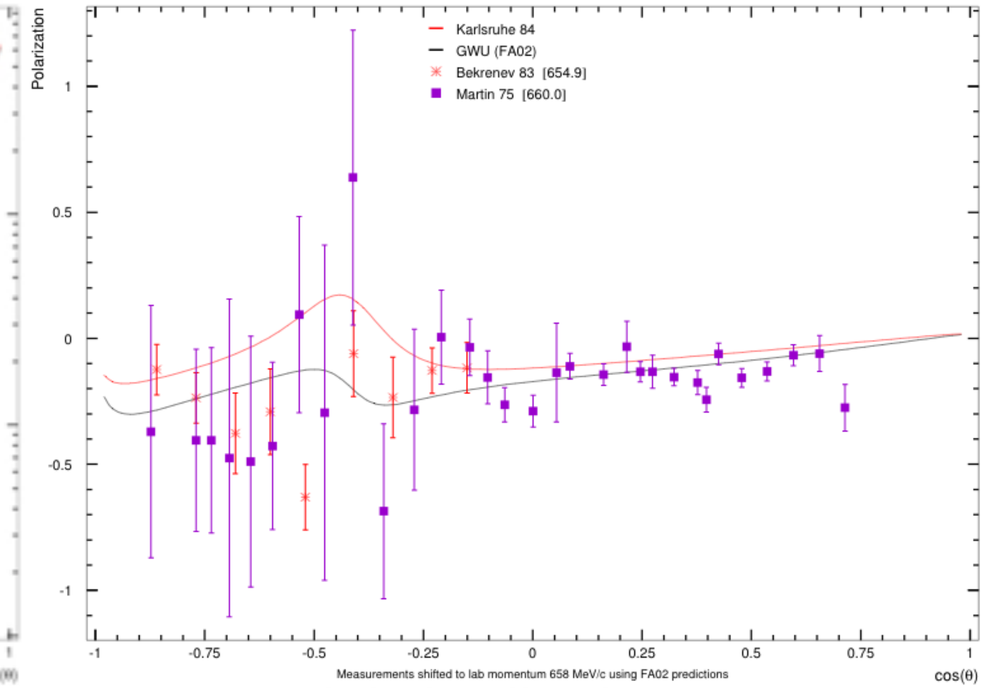
Extension of MIPP

- Pion beams as low as 1 GeV/c possible with new magnet controls.
- Was proposed to Fermilab PAC in 2006. Approval was deferred until data analysis of first run is completed and running in collider mode is ended. Was rejected in November 2010. To be submitted again in June 2013.
- If eventually approved, opens possibility of making measurements in the πN resonance region.
- ACU (M. E. Sadler), Kent State University (M. Manley), and PNPI (V. V. Sumachev, S. P. Kruglov, I. V. Lopatin, N. G. Kozlenko, A. A. Kulbardis, and D. V. Nowinsky) have agreed to participate in new proposal.
- Additional collaborators are invited!

$\pi^+p \to \pi^+p$ from 636 to 667 MeV/c



$\pi^+p \to \pi^+p$ from 636 to 667 MeV/c



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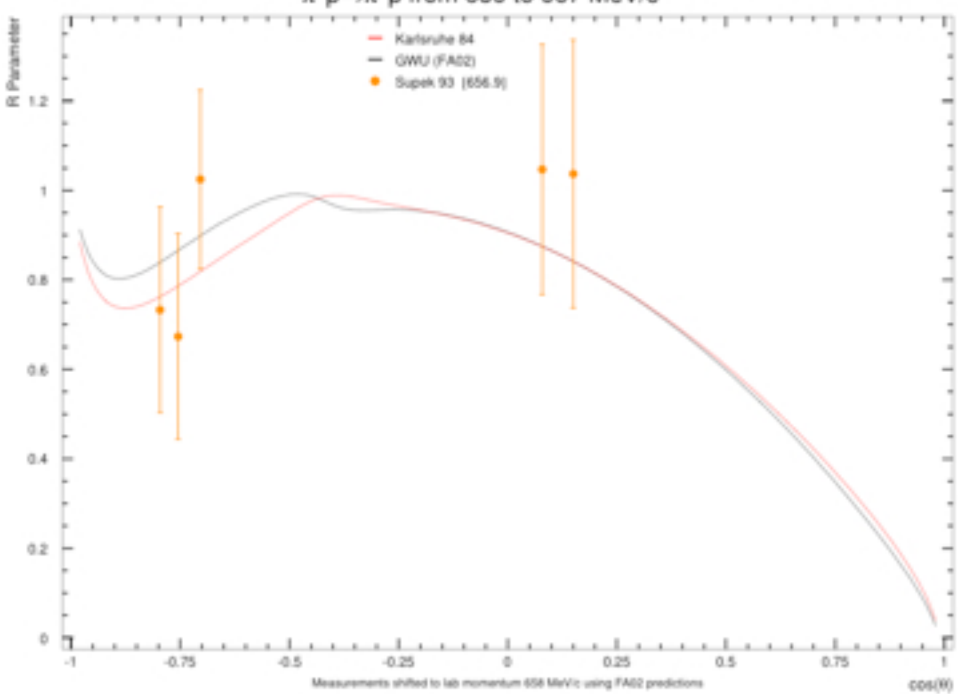
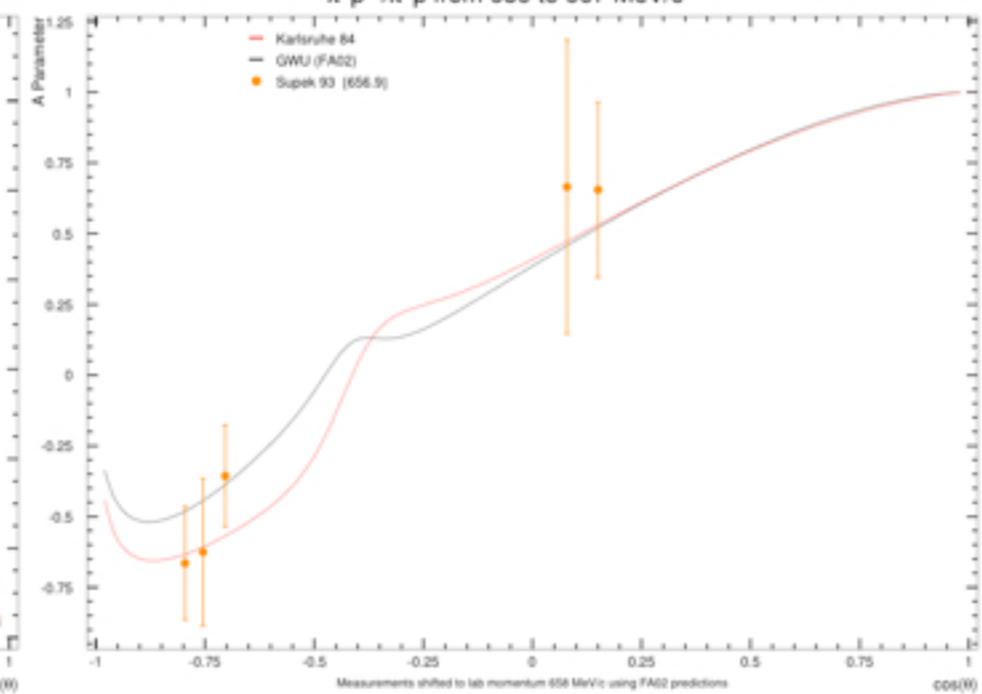
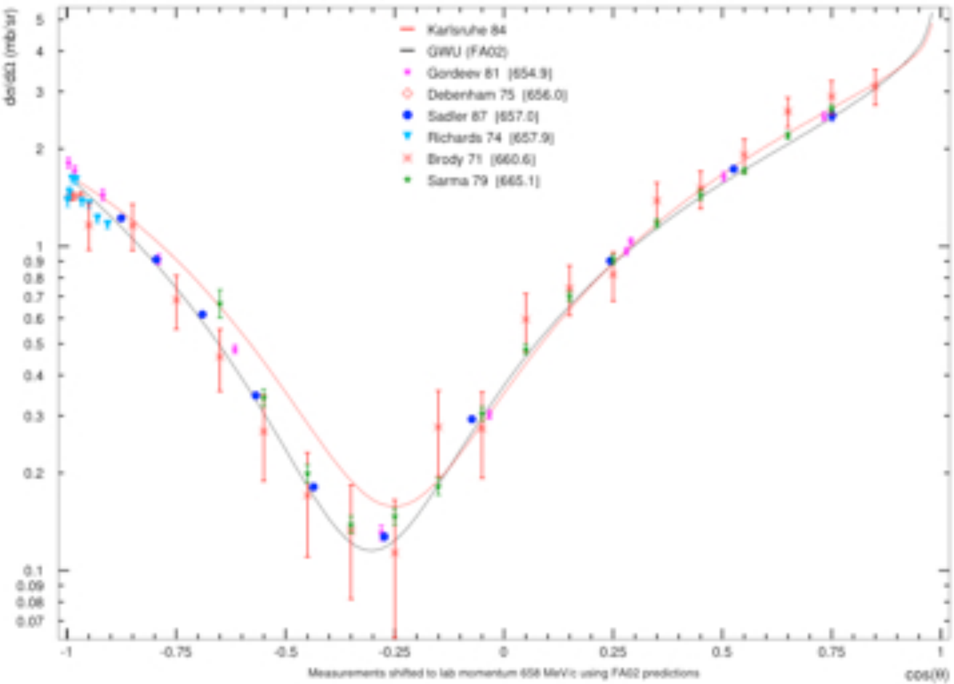


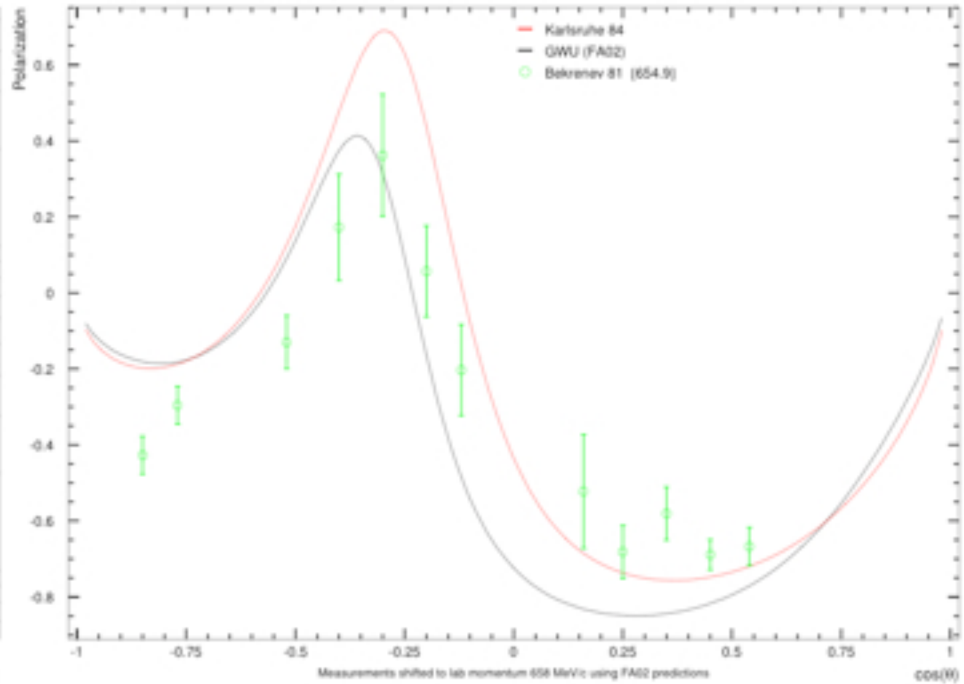
$\pi^+p \to \pi^+p$ from 636 to 667 MeV/c



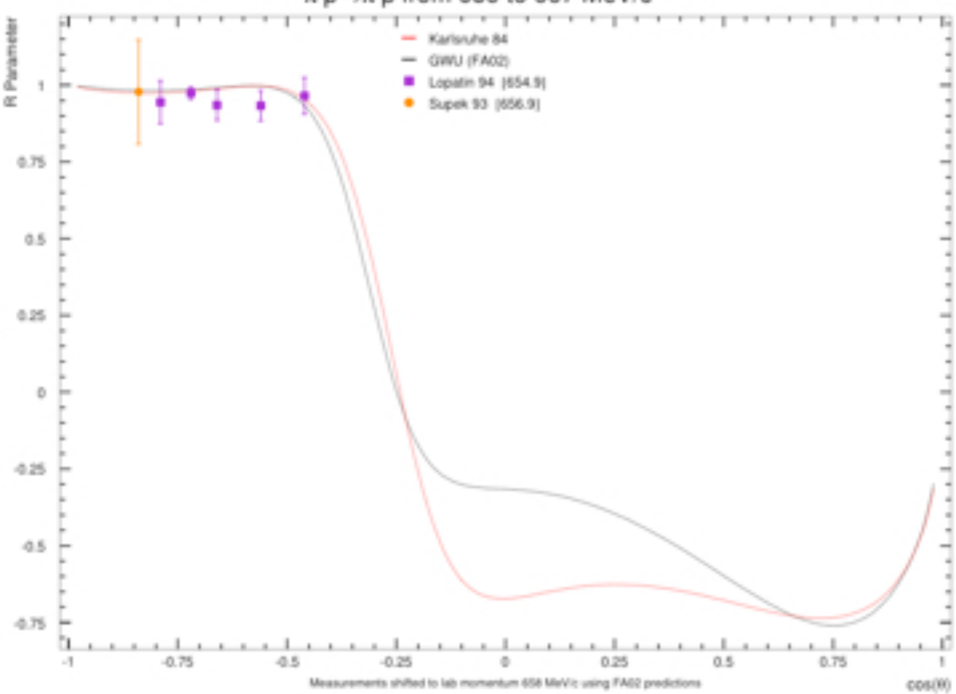
π⁻p→π⁻p from 636 to 667 MeV/c



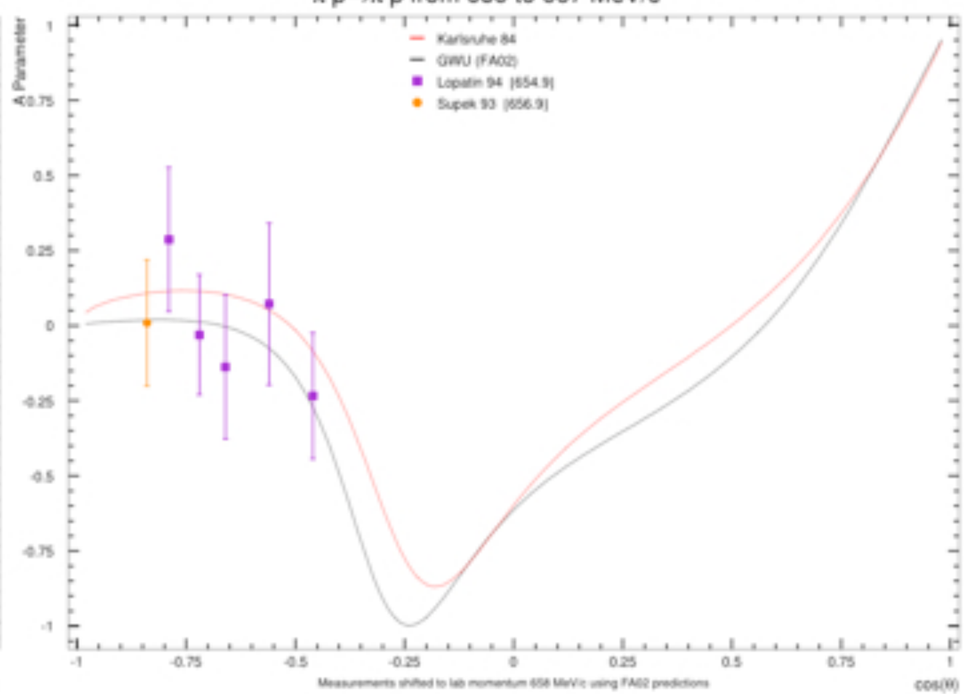
π⁻p→π⁻p from 636 to 667 MeV/c



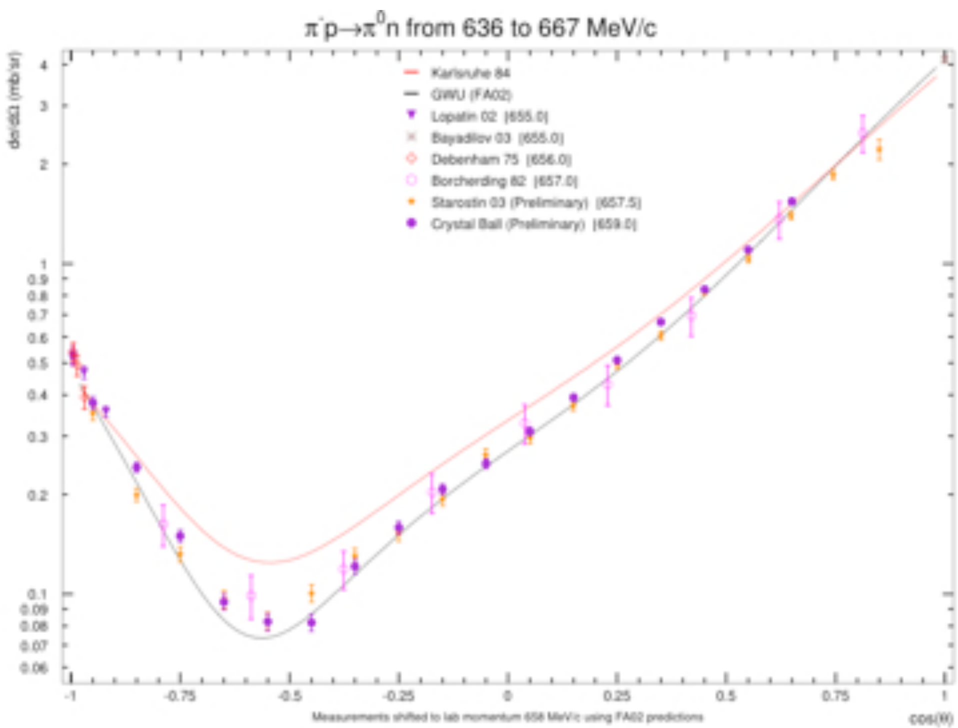
π⁻p→π⁻p from 636 to 667 MeV/c

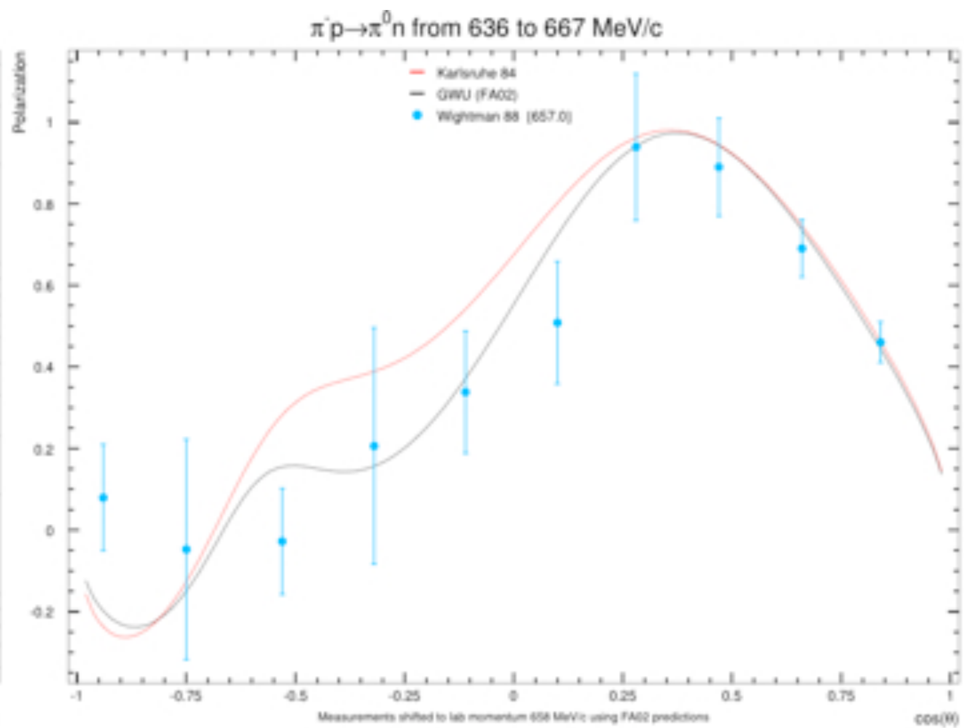


π⁻p→π⁻p from 636 to 667 MeV/c



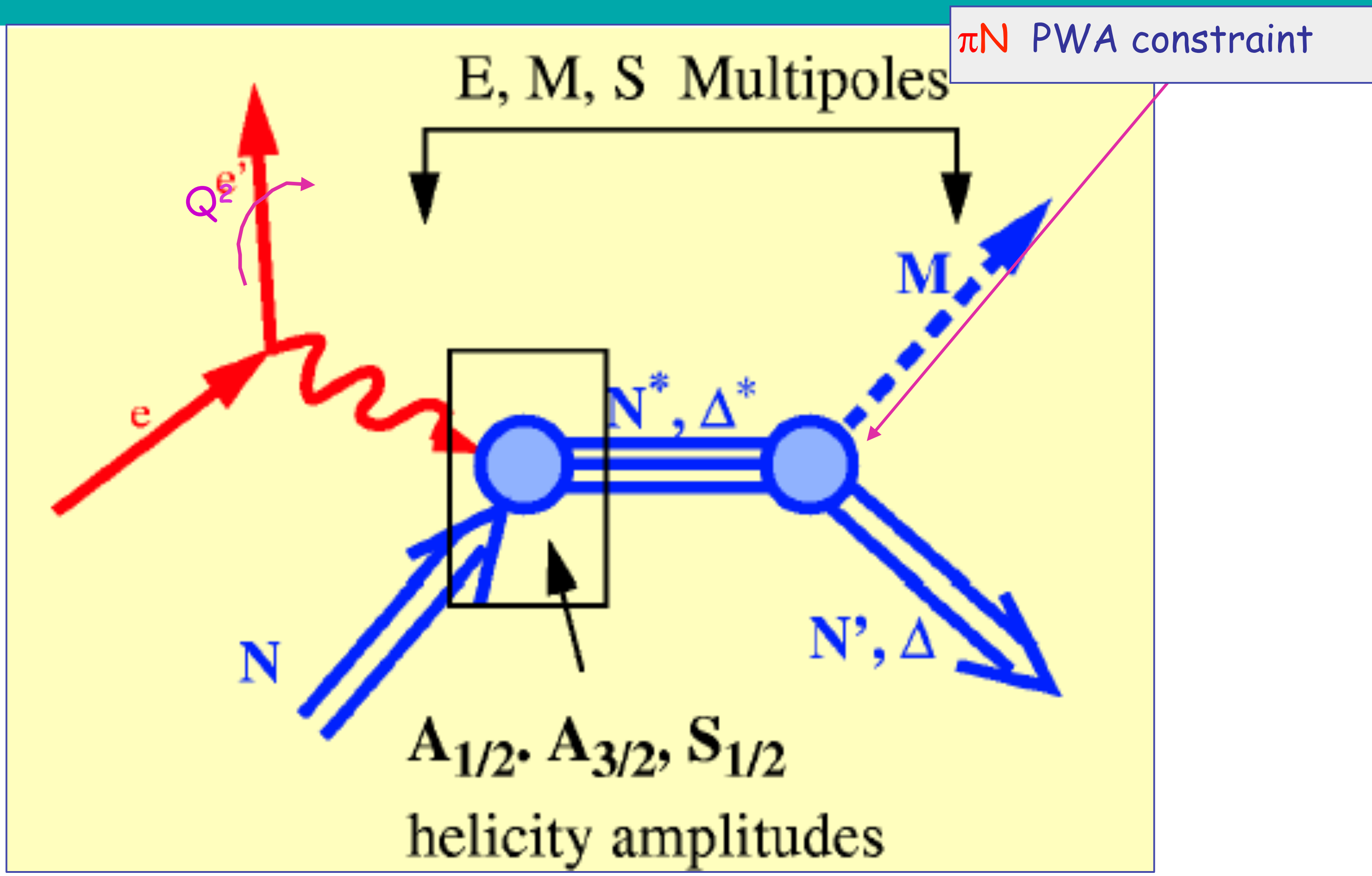
657 MeV/c $\pi^- p \rightarrow \pi^0 n$





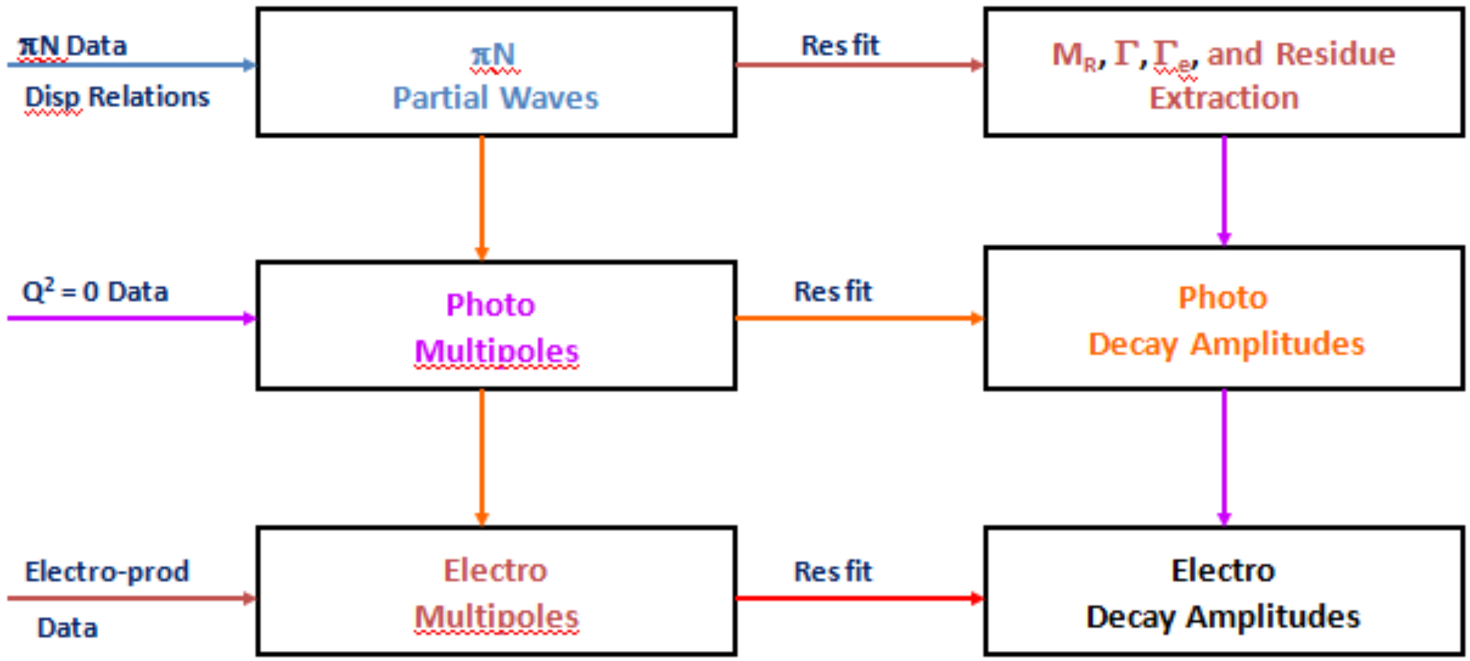
(This slide courtesy of Igor Strakovsky)

Electromagnetic Probe for Resonance Physics



GWUπN PWA provides the base for Spectroscopy studies for *non-strange* baryons in all other processes

(This slide courtesy of Bill Briscoe)



- PWA - as model-independent as possible, so as to avoid bias when used in resonance extraction or Coupled-channel analysis

N*s and Δ*s in GWU Analysis

(This slide courtesy of Bill Briscoe, GWU)

- We consider a resonance as a Pole in the complex plane - not far from the physical axis

- <u>Applied</u> directly to the data via Breit-Wigner + Background

- <u>Assume</u>: $S \rightarrow S_R S_B$ $\quad S_R = 1 + 2iT_R$

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

$$\Gamma = \Gamma_e + \Gamma_I \qquad \Gamma_e = r_e \Gamma R \qquad \Gamma_I = r_i \Gamma (1 - R)$$

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

- <u>Map</u> $c^2[W_R, \Gamma]$ while searching all other PW parameters
  Look for significant improvement

- <u>Subjective variables are</u>
  - Energy binning
  - Strength of constraints
  - Which PW to be searched

- <u>Standard PWA</u>
  - Tends (by construction) to miss narrow Resonances with $\Gamma < 30$ MeV
  - Reveals only wide Resonances, but not too wide [$\Gamma < 500$ MeV]
    and possessing not too small BR [BR > 0.04]

- <u>Modified PWA</u>
  - Allows one to put a resonance by hand then the search allows us to see how "necessary" it is

Summary of N* and Δ* Finding from GW πN PWA

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

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

- PDG10 states

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

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

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

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

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

PDG10 * $\Delta(1930)D_{35}$**

PDG10 ** $N(2000)F_{15}$, $\Delta(2400)G_{39}$

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

N.B. : New, high-quality, high-statistics Pion-Nucleon Data are needed!

(This slide courtesy of Bill Briscoe)

Single pion production
$\pi^{\pm}p \rightarrow \pi N^* \rightarrow \pi^{\pm}\pi^0 p$ or $\pi^{\pm}p \rightarrow \pi N^* \rightarrow \pi^{\pm}\pi^+ n$

- Single pion production is an important reaction to search for missing resonances that couple weakly to πN.
- With a TPC, one can measure 4 of the 5 reactions amenable to $\pi^{\pm}$p scattering:
  - $\pi^+ p \rightarrow \pi^+ \pi^0 p$ and $\pi^- p \rightarrow \pi^- \pi^0 p$ (detect π^0 by missing mass)
  - $\pi^+ p \rightarrow \pi^+ \pi^+ n$ and $\pi^- p \rightarrow \pi^- \pi^+ n$ (detect n by missing mass)
- Manley and Salesky performed an isobar-model partial-wave analysis of the world's available set of bubble-chamber data for these reactions many years ago [PRD **45**, 4002 (1992)]. Data set consisted of about 241,000 events (very low statistics by modern standards).
- Biggest problems began around 1600 MeV, where the number of important partial waves became greater than the data available to determine them. The amplitudes for quasi-two-body reactions as $\pi N \rightarrow \pi\Delta$ and $\pi N \rightarrow \rho N$ become quite noisy. A new isobar model analysis could be performed to determine the $\pi\Delta$ and ρN couplings of N* and Δ* resonances more precisely.
- Such an analysis could incorporate the new data for $\pi^- p \rightarrow \pi^0 \pi^0 n$, which were measured at BNL by the Crystal Ball Collaboration.
- Needed to analyze data from Jefferson Lab in the reaction $e\, p \rightarrow e' \pi^- \pi^+ p$.
- An isobar model analysis is nontrivial, but can be done with new data.

New baryons in the $\eta\Delta$ and $\omega\Delta$ channels

- The $\eta\Delta$ channel is pure I=3/2 and presents an opportunity to discover new Δ^* resonances in these final states. The $\eta\Delta$ channel could be studied by the reactions
  - $\pi^- p \rightarrow \pi^- \eta p$ (identify η by missing mass; select Δ^0 events by invariant mass of $\pi^- p$)
  - $\pi^+ p \rightarrow \pi^+ \eta p$ (identify η by missing mass; select Δ^{++} events by invariant mass of $\pi^+ p$)
  - Isospin invariance of the strong interactions means that these two reactions must give consistent results for $\eta\Delta$ couplings. This presents a tight constraint to make sure that the couplings are determined consistently.

- Similarly, $\omega\Delta$ couplings are also pure I=3/2 and could be studied by
  - $\pi^- p \rightarrow \pi^- \omega p$ (identify ω by missing mass; select Δ^0 events by invariant mass of $\pi^- p$)
  - $\pi^+ p \rightarrow \pi^+ \omega p$ (identify ω by missing mass; select Δ^{++} events by invariant mass of $\pi^+ p$)

- These reactions present a good opportunity to search for new and missing Δ^* resonances. Quark-model predictions have been made by Simon Capstick and Winston Roberts (PRD **57**, 4301 (1998)).

Strangeness Production (Σ's)

- $\pi^+ p \rightarrow K^+ \Sigma^+ \rightarrow K^+ \pi^+ n$
  - Detect neutron by missing mass, and reconstruct Σ^+ by its invariant mass.
  - This reaction is especially important because it is pure I=3/2 and will excite only Δ^* resonances.
- $\pi^- p \rightarrow K^+ \Sigma^- \rightarrow K^+ \pi^- n$
  - Detect neutron by missing mass and reconstruct Σ^- by its invariant mass.
- $\pi^- p \rightarrow K^0 \Sigma^0$

  $\Sigma^0 \rightarrow \gamma\Lambda \rightarrow \gamma\pi^- p$

  $K^0 \rightarrow K_S \rightarrow \pi^+ \pi^-$
  - Detect γ by missing mass, reconstruct Λ from $\pi^- p$ invariant mass, then reconstruct Σ from $\gamma\Lambda$.
- Previous two reactions are complementary, since they are a mixture of I=1/2 and I=3/2. Both are needed.

Strangeness Production

- Resonance couplings determined for K Λ and K Σ can be compared with quark model calculations, such as those of Simon Capstick and Winston Roberts (PRD **58**, 074011 (1998)).
- Quark-model predictions have also been made for other channels involving strange particles, such as K* Λ, K Λ (1405), and K Λ (1520).

Recent Progress

New veto wall constructed

DAQ electronics upgraded

Magnet, TPC winding completed

Zip tracking hardware improved

What is needed

Zip tracking of magnet

DAQ expertise

Electronics expertise

Hall probes, beam calibration

Install Plastic Ball as a back angle detector

Commissioning of new experiment

Invitation

Additional collaborators are welcome!

Contact me (sadler@physics.acu.edu)

Or Rajendran Raja (raja@fnal.gov)

Full MIPP proposal:

http://ppd.fnal.gov/experiments/e907/notes/MIPPnotes/public/pdf/MIPP0138/MIPP0138.pdf

Summary of Present Status

- Listings in Review of Particle Properties rely on PWA's from 1980.
- GWU (formerly VPI) analyses fit data well, but other analyses using different approaches are also needed.
- Analyses should include $\pi^- p \rightarrow K\Lambda$, $\pi p \rightarrow \pi\pi N$ and other inelastic channels. New efforts by EBAC, Bonn, Zagreb and other groups are now in place. Effect on PDG?
- PWA for hadronic channels is needed to analyze data from photo- and electro-production of resonances.
- MIPP is a unique (existing!) experimental facility that can be used for baryon spectroscopy (1-3 GeV/c π's).