Status of πN Experiments at ITEP, FNAL and J-PARC

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

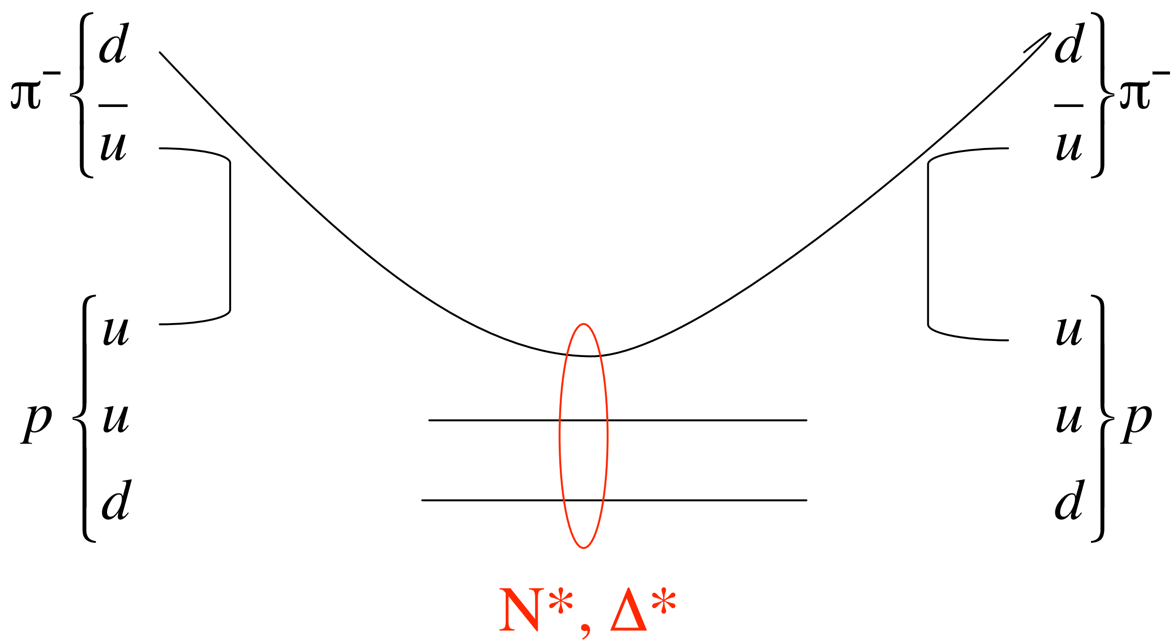
An Existing Facility for Measurements in Baryon Spectroscopy

Institute for Theoretical and Experimental Physics, Moscow, Russia

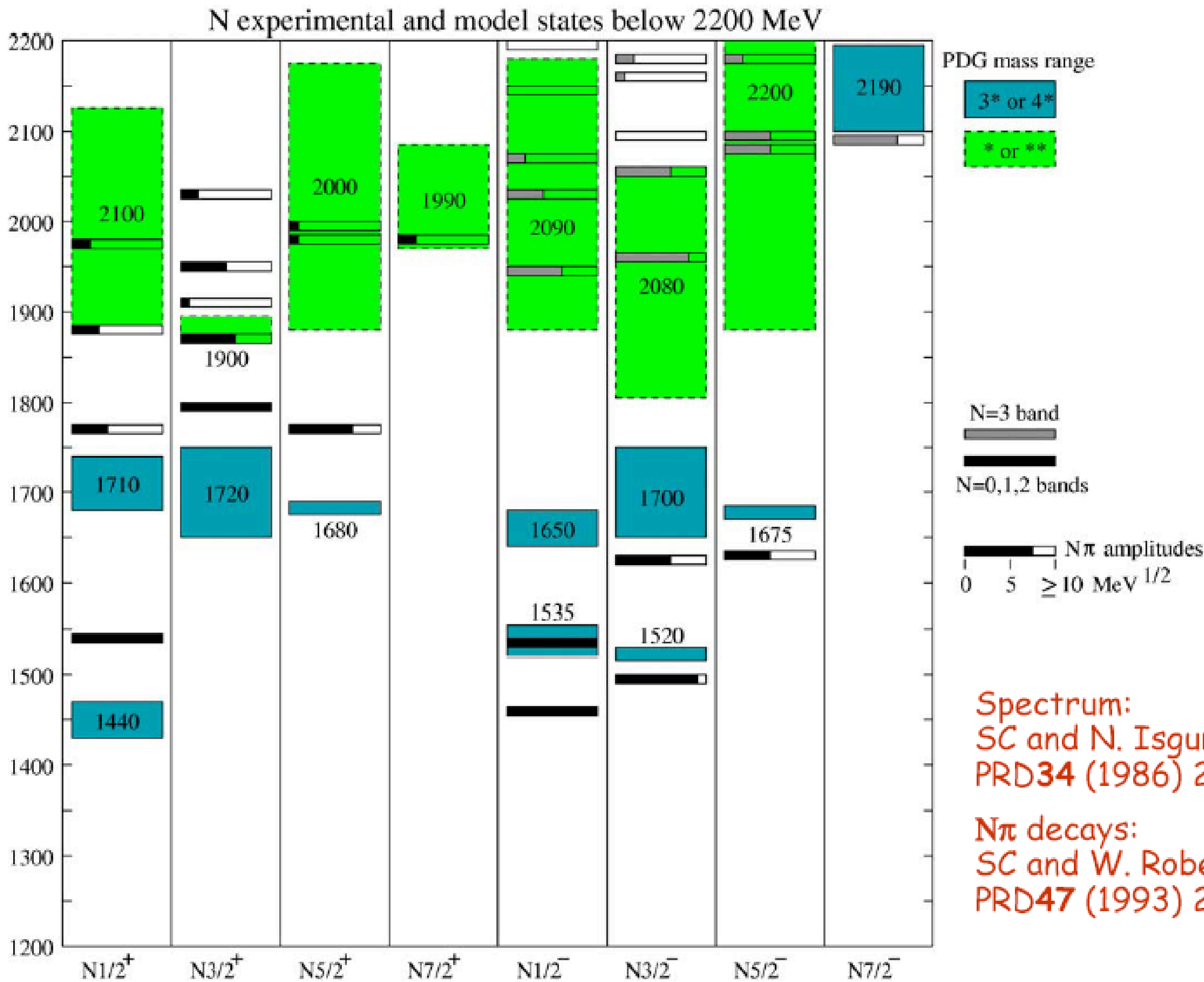
New Project at ITEP (EPECUR)

- Measurements of $\pi^- p \rightarrow \pi^- p$ and $\pi^- p \rightarrow K\Lambda$ at P_π = 900 - 1200 MeV/c $(\sqrt{s} = 1610 - 1770\ \mathrm{MeV})$
- Participating Institutions are ITEP, PNPI (Gatchina, Russia) 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

N* resonance formation ($\pi^- p \rightarrow \pi^- p$)



Nucleon model states and Nπ couplings



ITEP Meas.

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

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

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

• Differential cross sections at 40-120° CM as function of the invariant mass of π^-p-system.

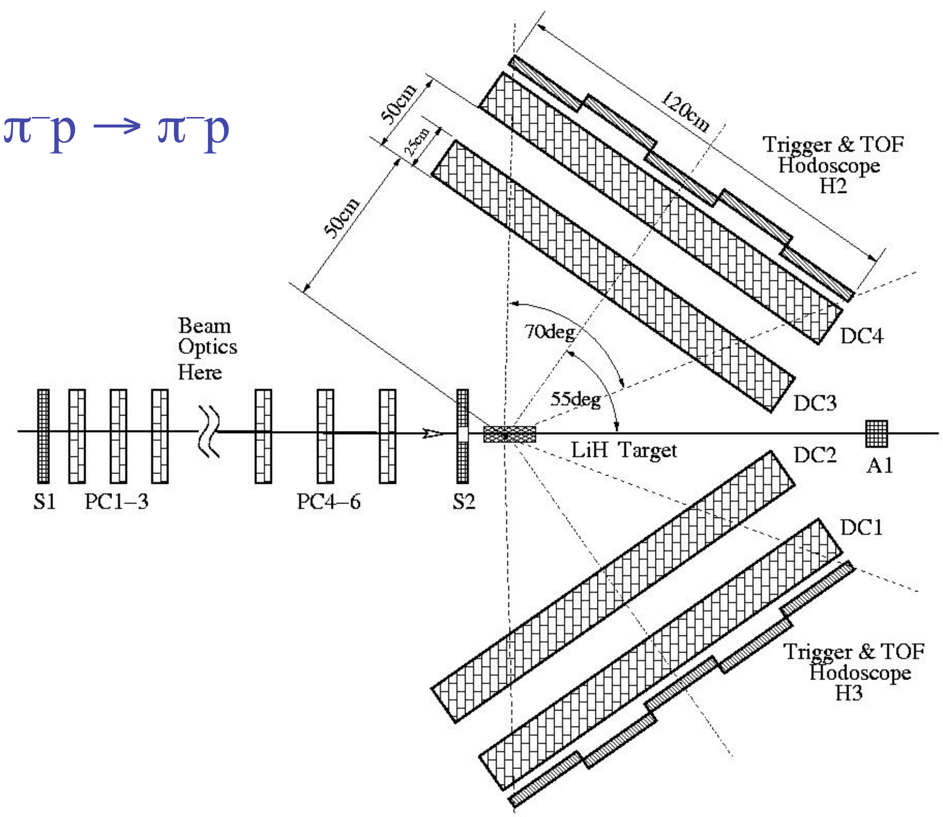
• "Formation"-type experiment: invariant mass resolution (0.7 MeV) is based on the high momentum resolution (0.1%) of the magneto-optic channel.

• Statistical resolution as high as 0.5 %

• Obtain clear evidence for a narrow (2-20 MeV) resonance even if its elasticity is only 1%.

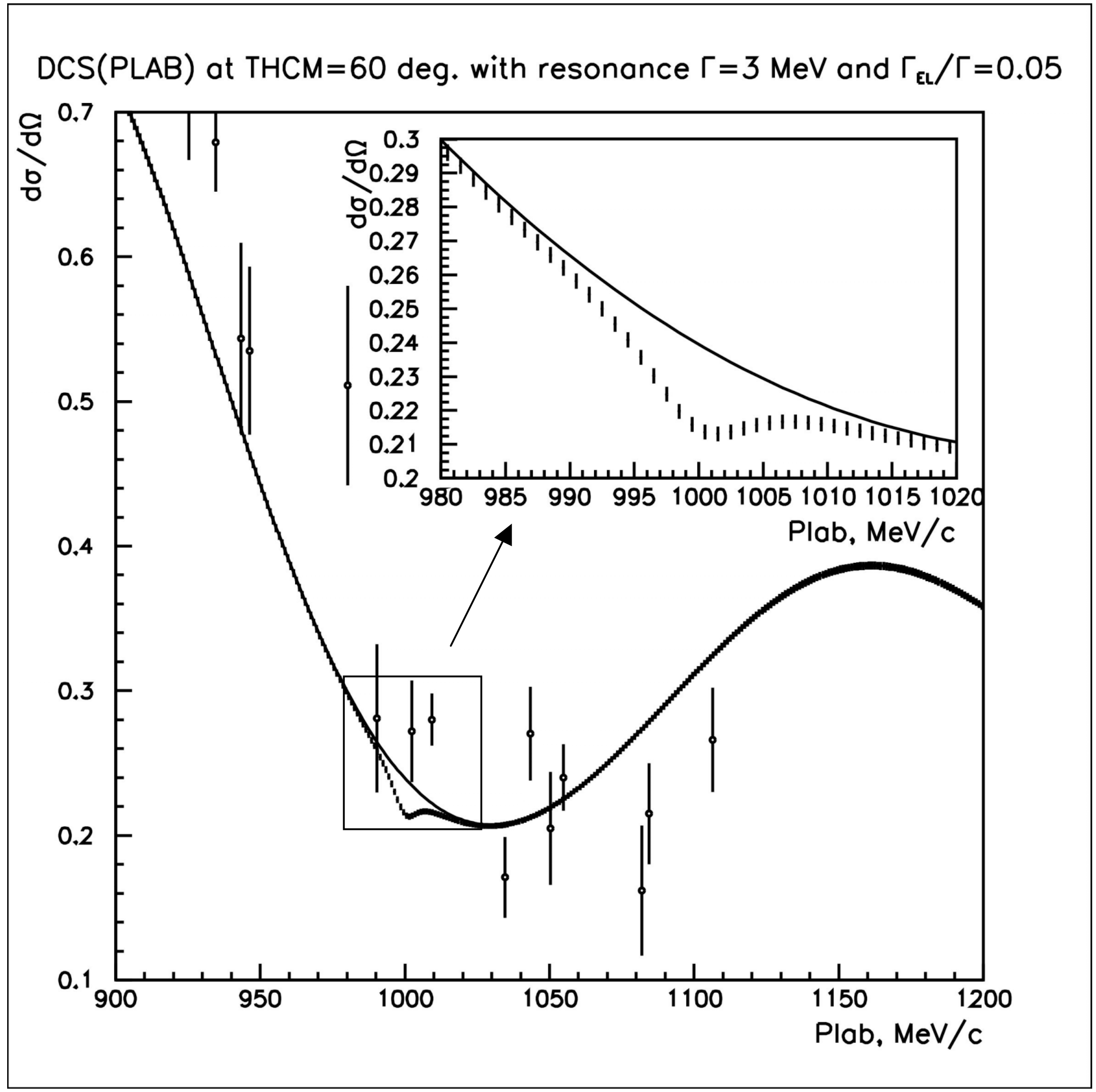
• Main parts of experimental setup are liquid hydrogen target and proportional and drift chambers.

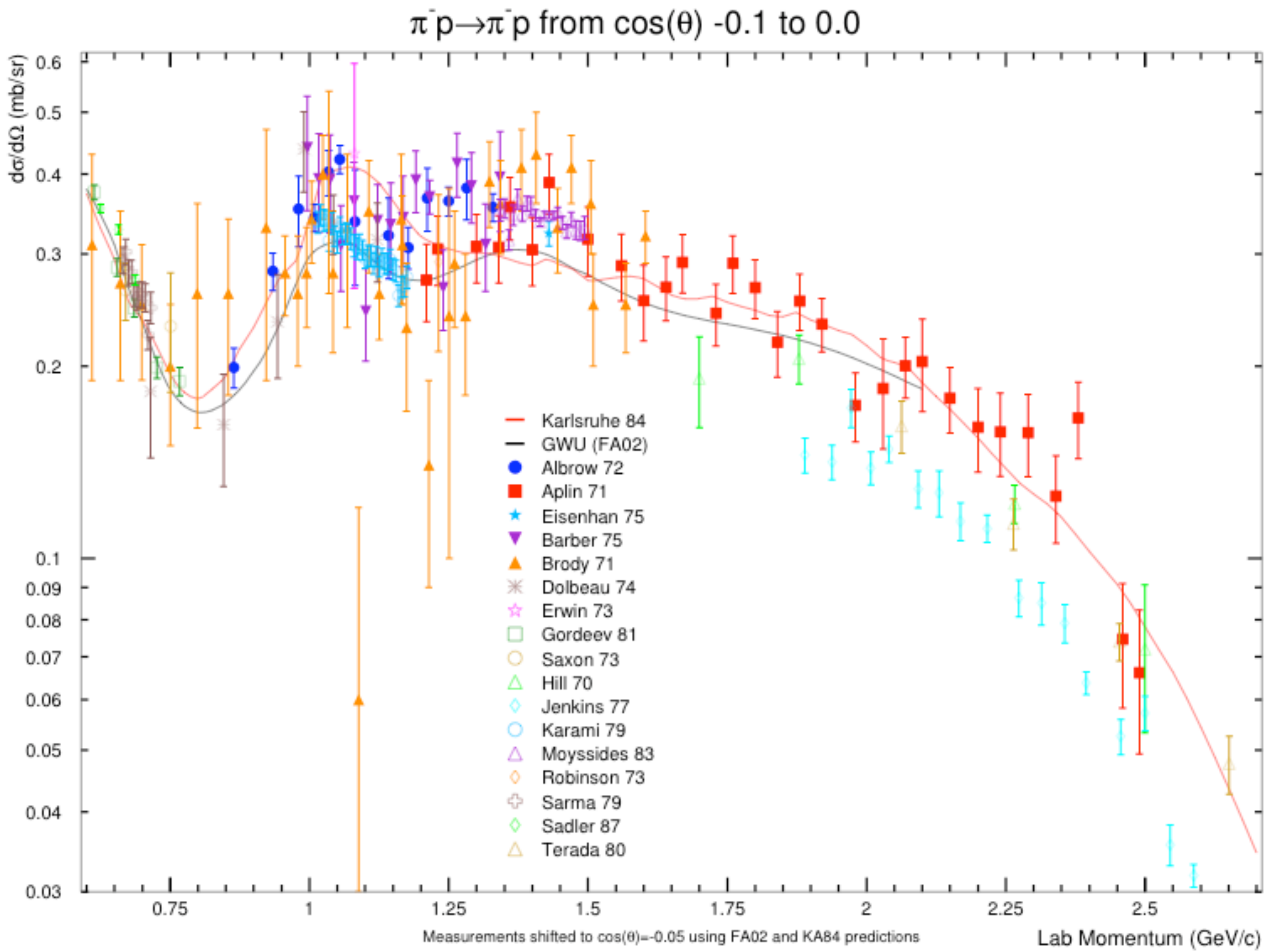
$\pi^- p \to \pi^- p$



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

- 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%
- Start data taking in early 2008
- ~20 days of running

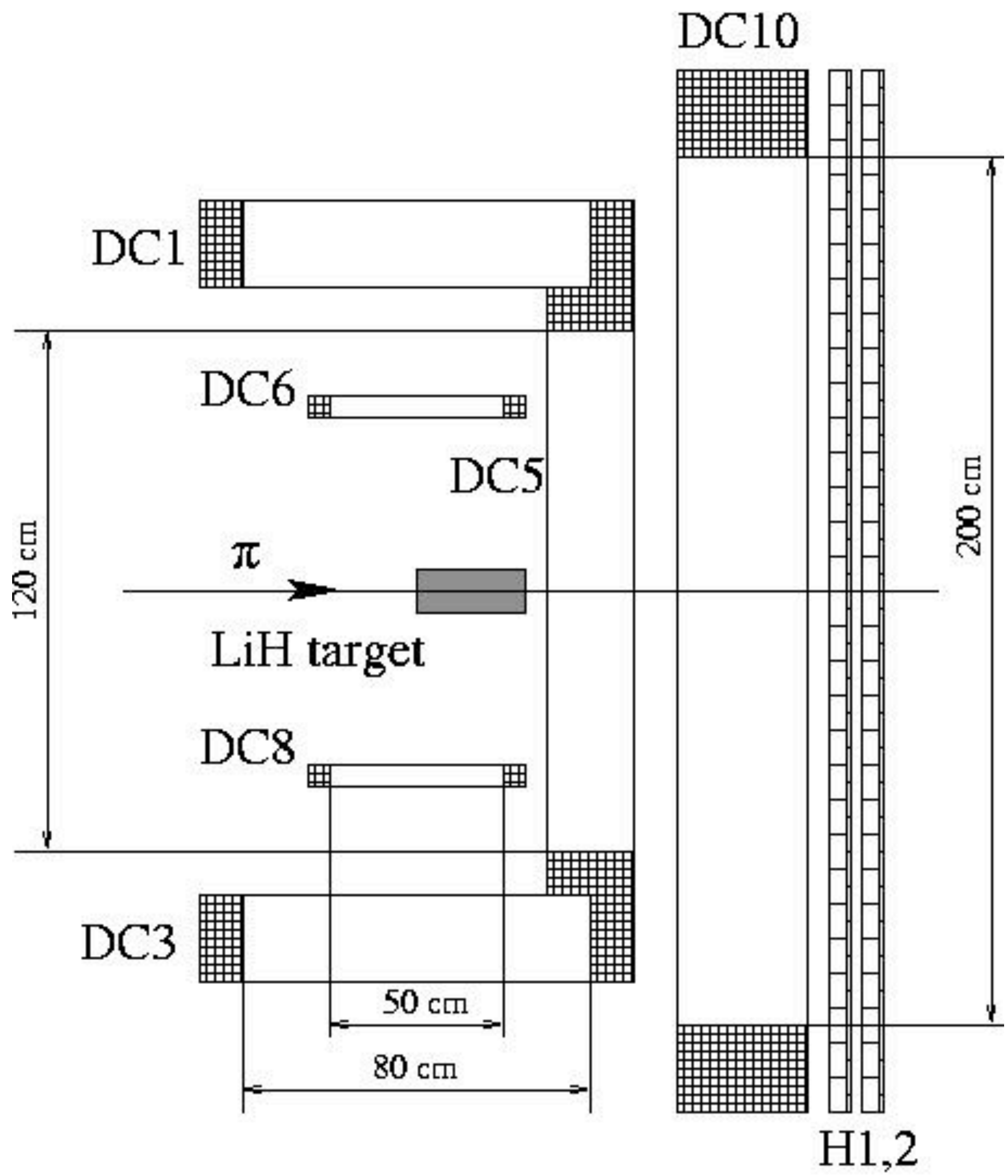




π⁻p→π⁻p from cos(θ) -0.1 to 0.0
dσ/dΩ (mb/sr)
0.6
0.5
0.4
0.3
0.2
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.75
1
1.25
1.5
1.75
2
2.25
2.5
Karlsruhe 84
GWU (FA02)
Albrow 72
Aplin 71
Eisenhan 75
Barber 75
Brody 71
Dolbeau 74
Erwin 73
Gordeev 81
Saxon 73
Hill 70
Jenkins 77
Karami 79
Moyssides 83
Robinson 73
Sarma 79
Sadler 87
Terada 80
Measurements shifted to cos(θ)=-0.05 using FA02 and KA84 predictions
Lab Momentum (GeV/c)

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

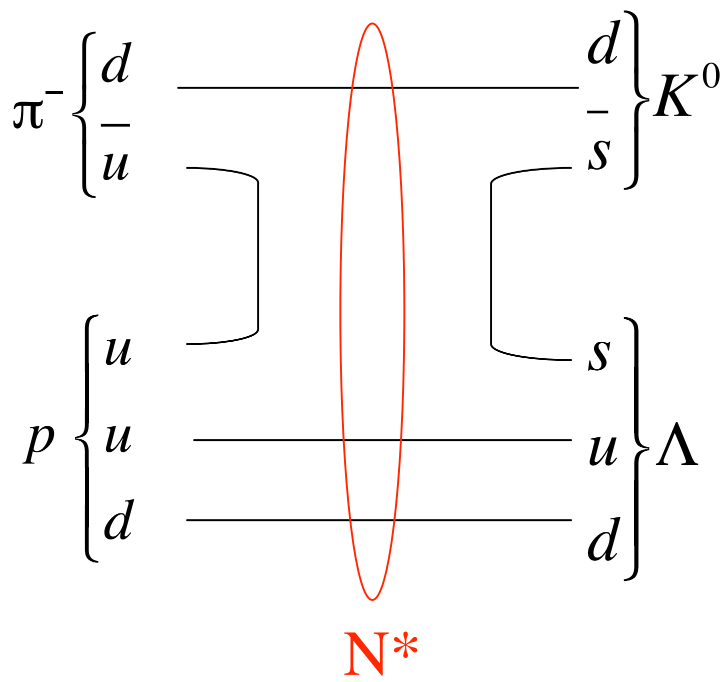
- Differential cross-section with statistical precision 1% and step in the invariant mass 0.5 MeV at the angles 0-180° CM.
- Momentum range 900-1200 MeV/c ⇒ 1610-1770 MeV
- ~24 days of running, after $\pi^- p \rightarrow \pi^- p$ measurements



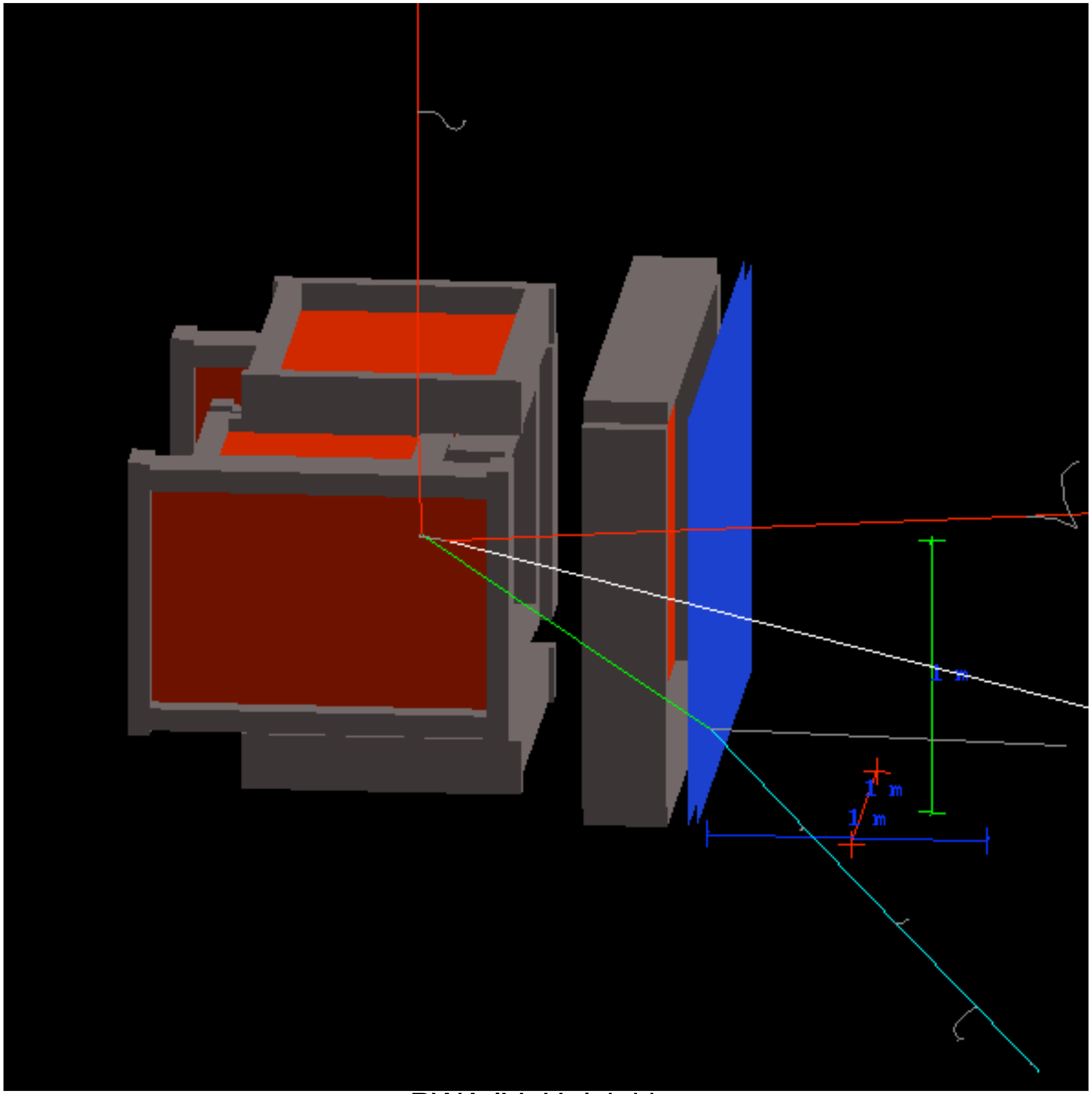
Strangeness Production (Λ^0)

- $\pi^- p \rightarrow K^0 \Lambda$
  - $\Lambda \rightarrow \pi^- p$
  - $K^0 \rightarrow K_S \rightarrow \pi^+ \pi^-$
- 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 $\pi^- p \rightarrow K^0 \Lambda$ should be straightforward to analyze with a PWA.

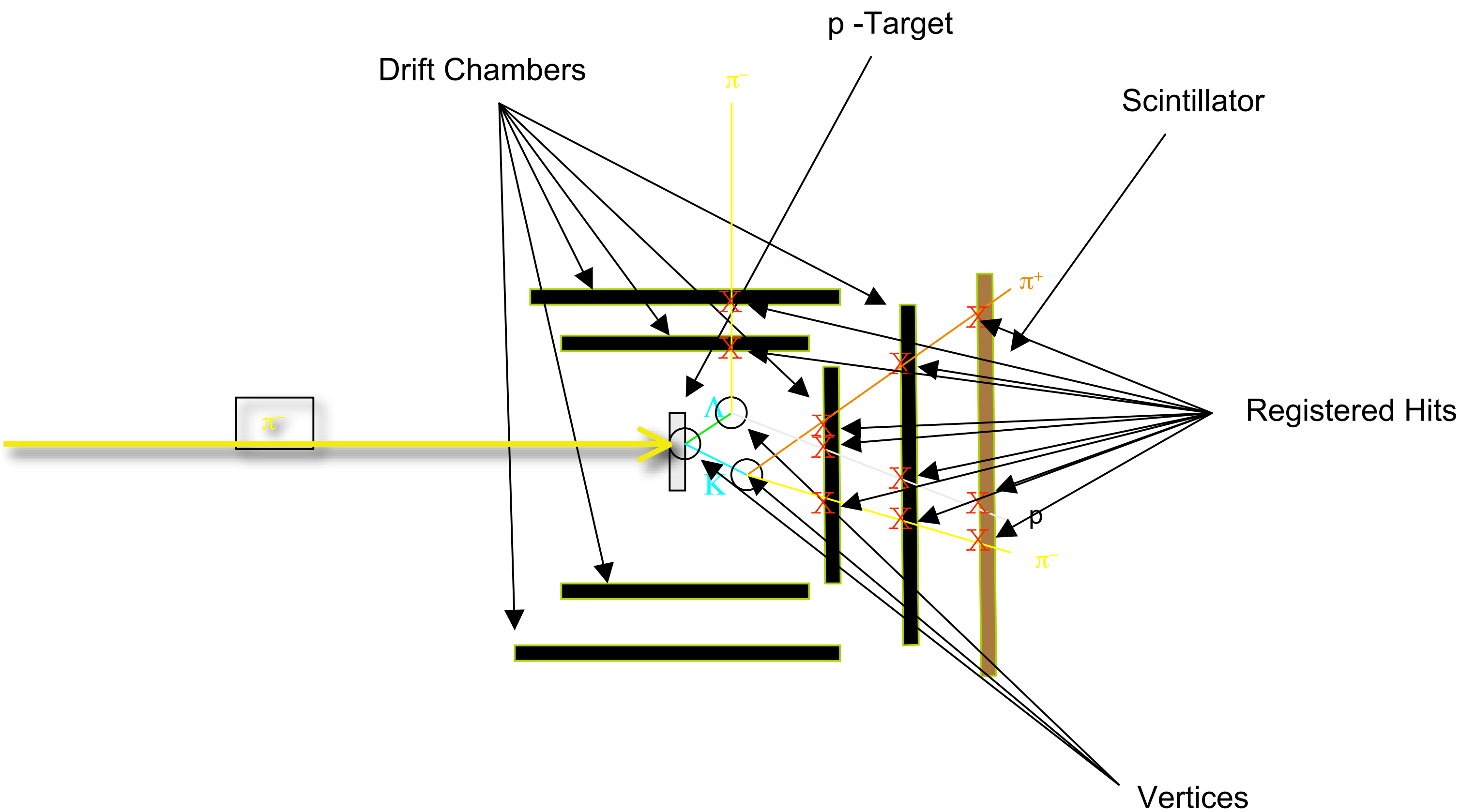
Resonance formation and decay for $\pi^- p \rightarrow K^0 \Lambda$



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

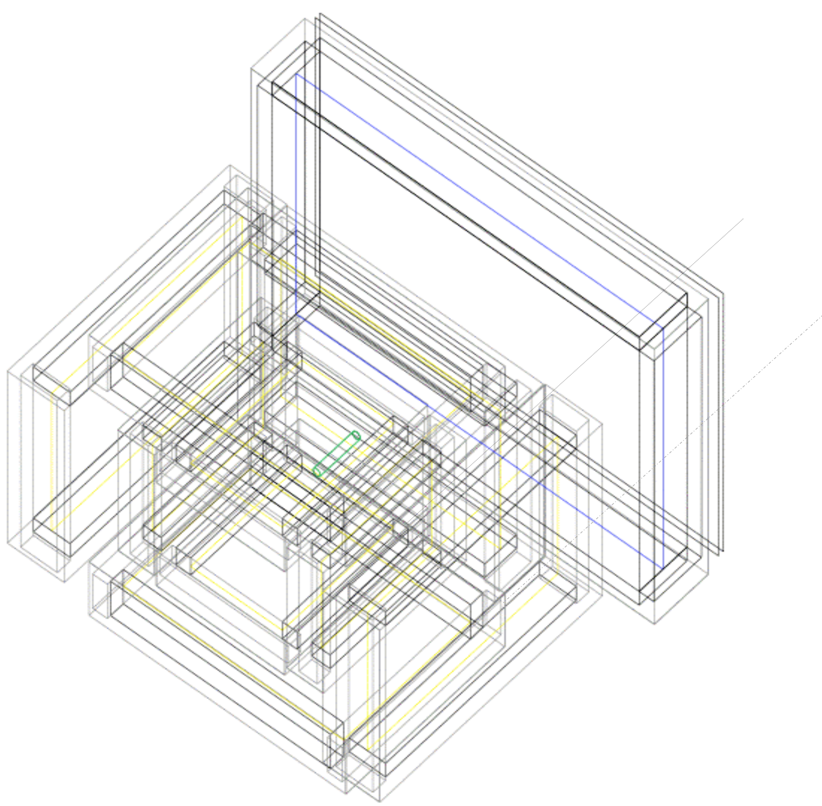


Experimental Geometry for $\pi^{-}p \rightarrow K\Lambda$

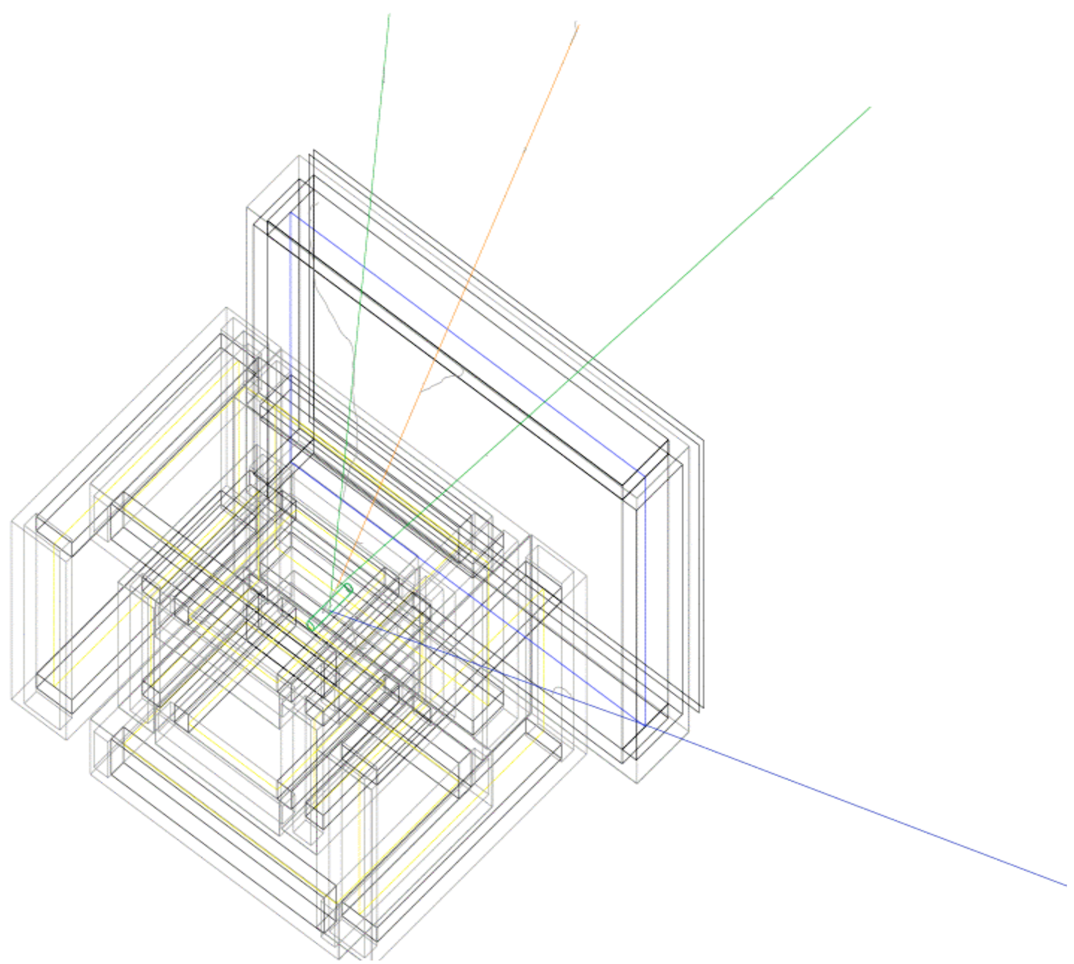


MC (GEANT4) Simulation of $\pi^- p \rightarrow K \Lambda$

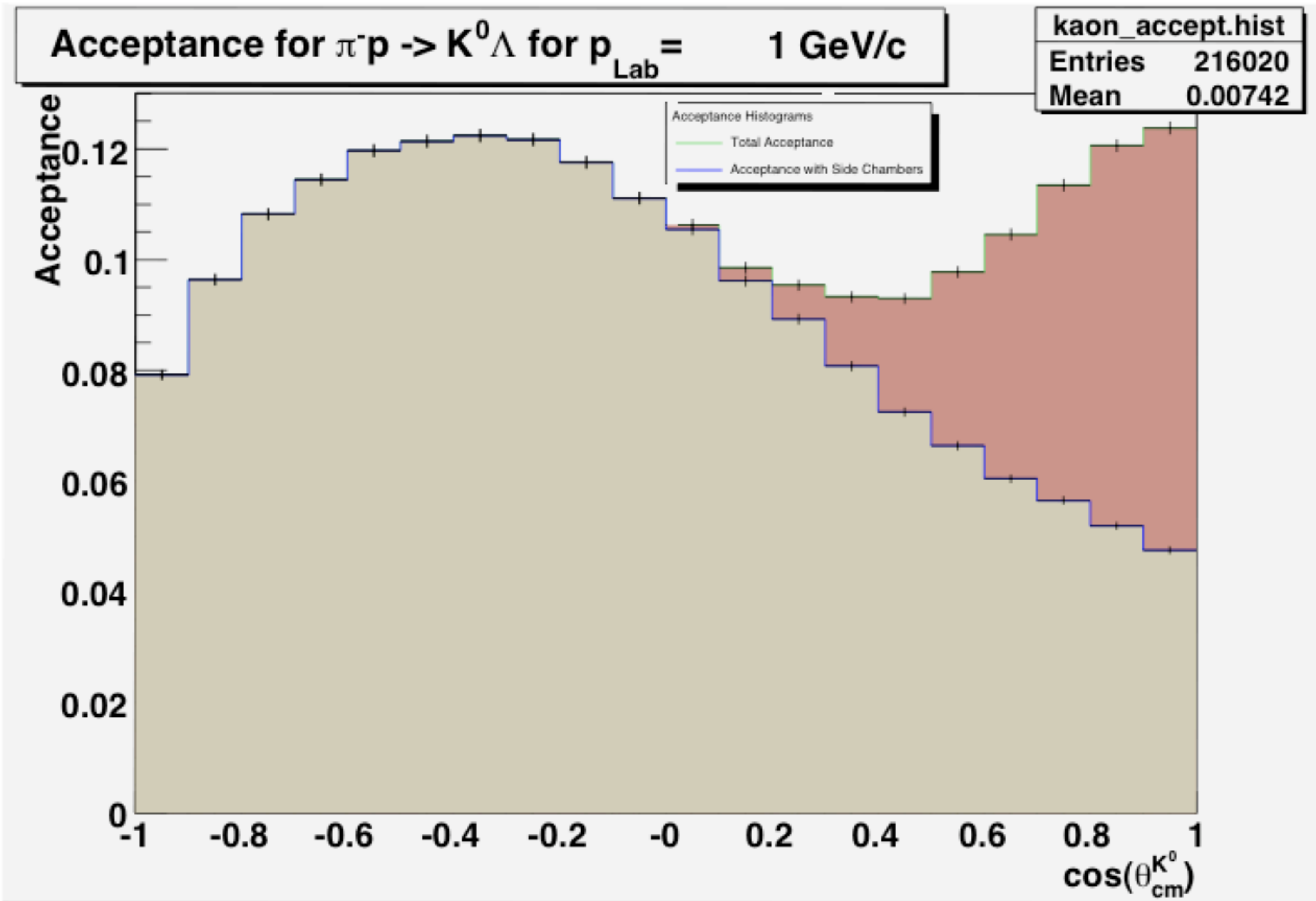
Another VIew:
Without Tracks



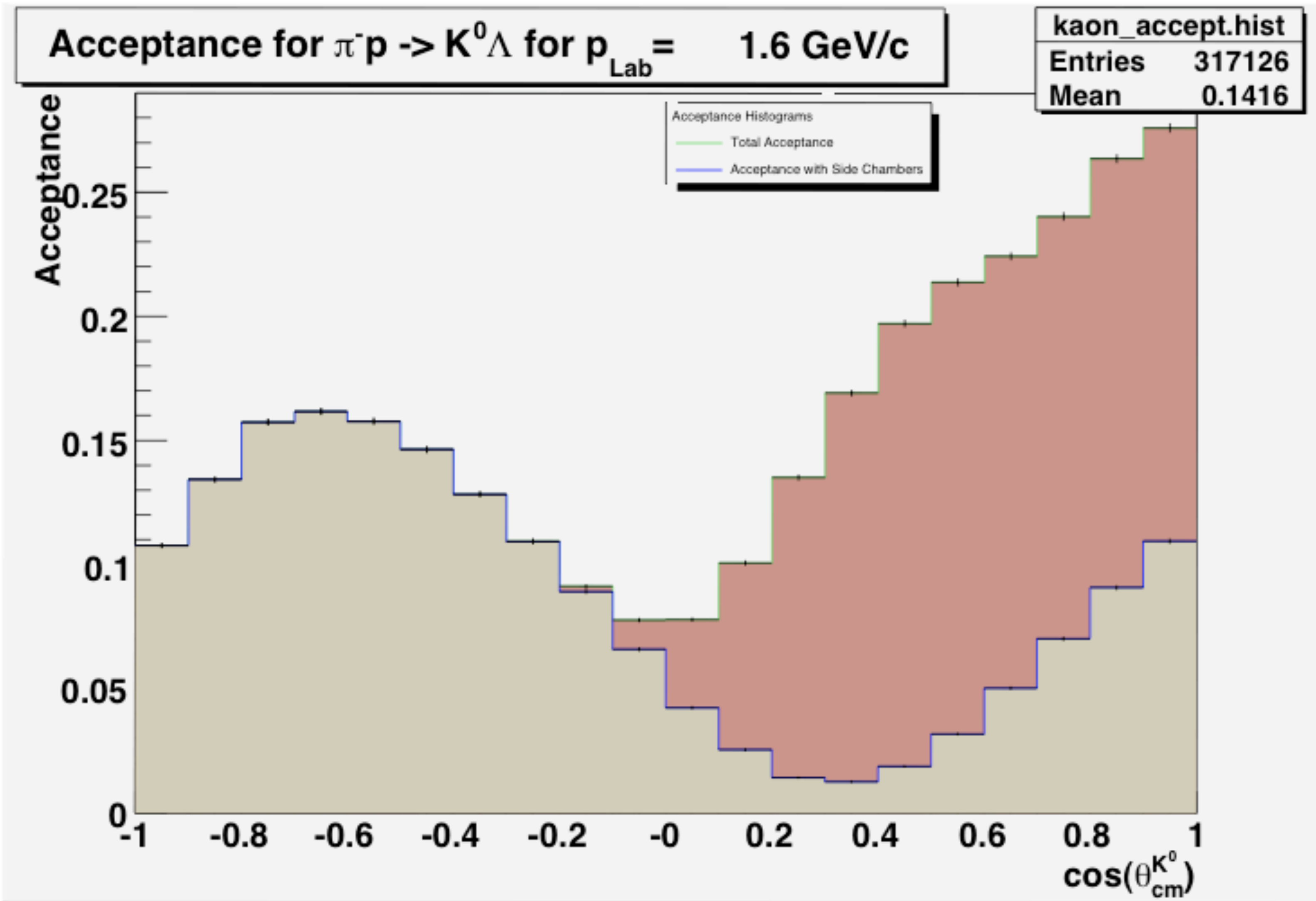
With Tracks



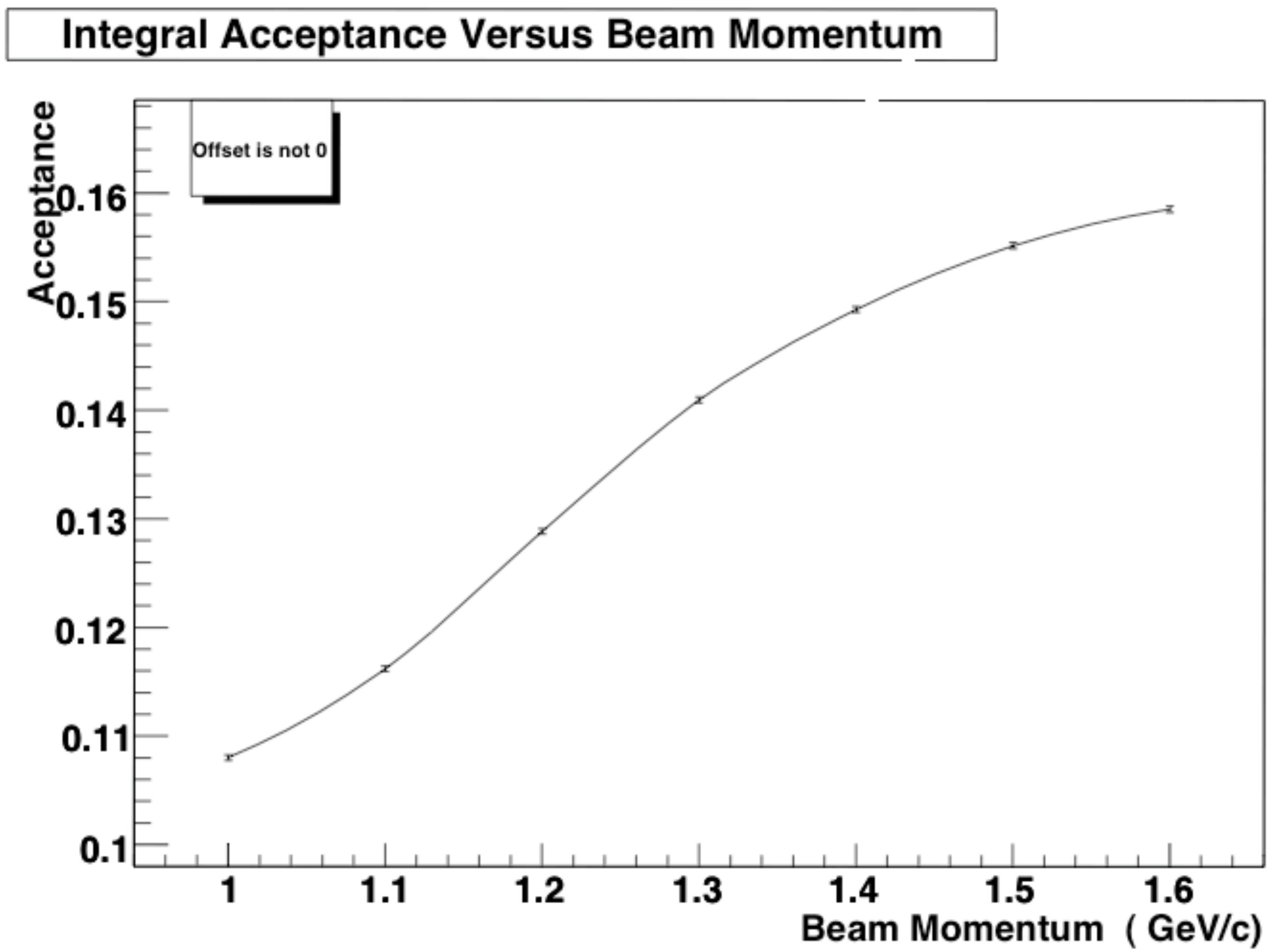
MC (GEANT4) Simulation of $\pi^- p \rightarrow K\Lambda$



MC (GEANT4) Simulation of $\pi^{-}p \rightarrow K\Lambda$



MC (GEANT4) Simulation of $\pi^- p \rightarrow K\Lambda$



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

$N(1710)$ BREIT-WIGNER WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
50 to 250 (≈ 100) OUR ESTIMATE				
480±230	MANLEY	92	IPWA	$\pi N \to \pi N$ & $N\pi\pi$
93± 30	CUTKOSKY	90	IPWA	$\pi N \to \pi N$
90± 30	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
120± 15	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
386± 59	PENNER	02C	DPWA	Multichannel
143±100	VRANA	00	DPWA	Multichannel
105± 10	ARNDT	96	IPWA	$\gamma N \to \pi N$
185± 61	BATINIC	95	DPWA	$\pi N \to N\pi$, $N\eta$
540	BELL	83	DPWA	$\pi^- p \to \Lambda K^0$
200	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
550	SAXON	80	DPWA	$\pi^- p \to \Lambda K^0$
120	[2] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
75	[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%

New Possibility for Measurements in Baryon Spectroscopy

The Main Injector Particle Production Experiment
(MIPP-FNAL-E907) at Fermilab

MIPP collaboration list

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Petersburg Nuclear Physics Institute, Gatchina, Russia
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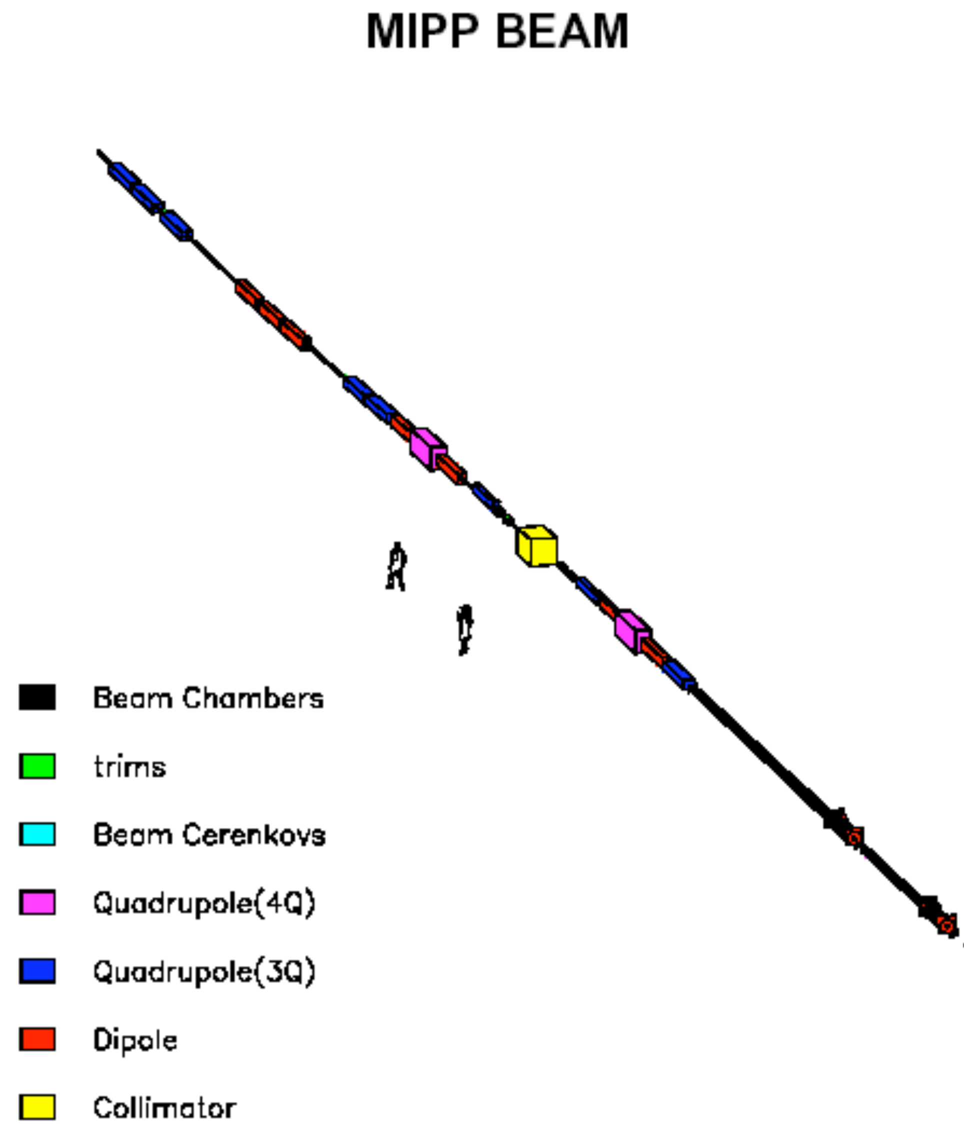
University of Virginia

Brief Description of Experiment

- Situated in Meson Center 7
- Uses 120 GeV Main Injector Primary protons to produce secondary beams of $\pi^{\pm}$, $K^{\pm}$, $p^{\pm}$ from 5 GeV/c to 100 GeV/c to measure particle production cross sections of various nuclei including hydrogen.
- Uses a TPC we measure momenta of ~all charged particles produced in the interaction and identify the charged particles in the final state using a combination of dE/dx, ToF, differential Cherenkov and RICH technologies.
- Open Geometry- Lower systematics. TPC gives high statistics.

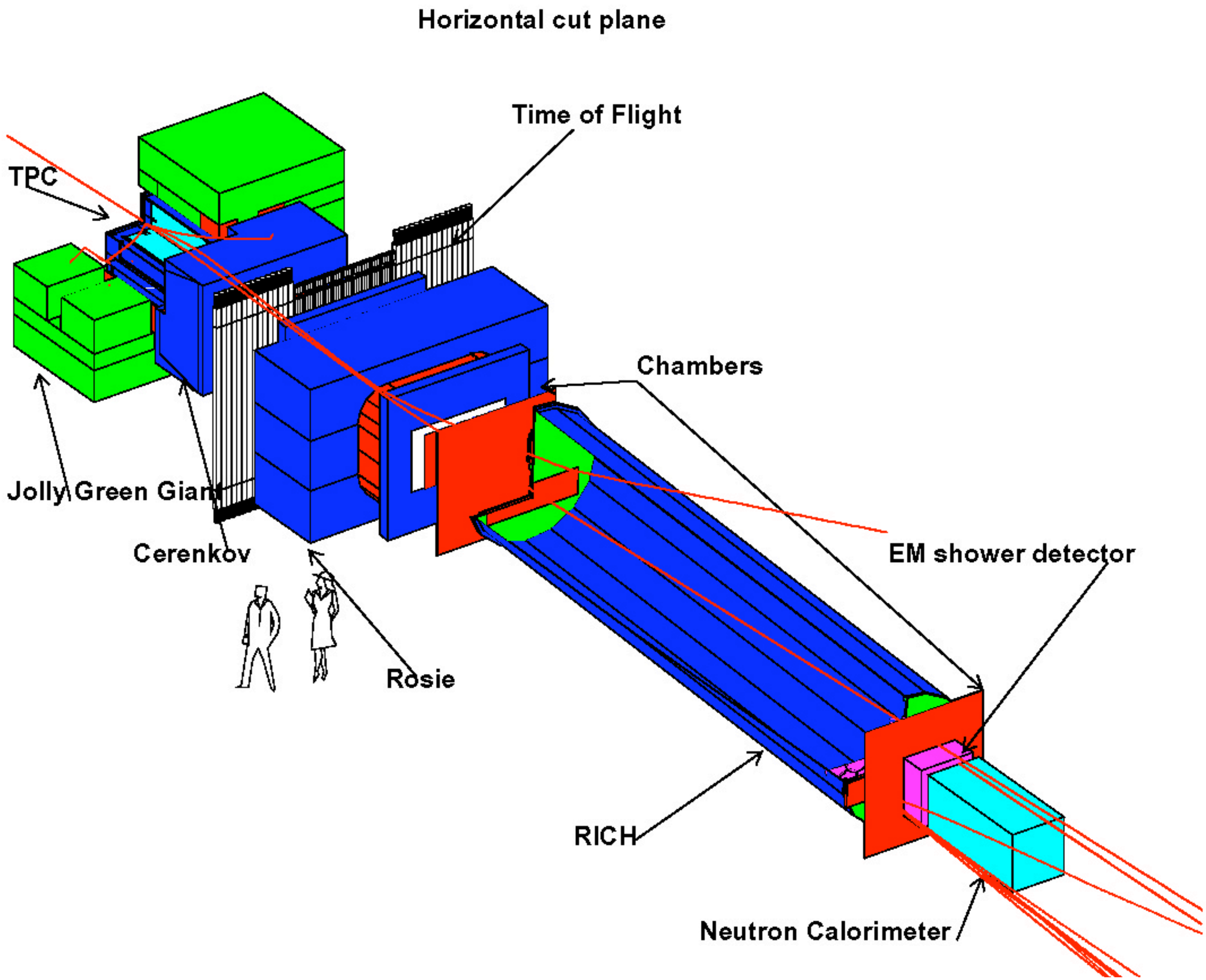
MIPP Secondary Beam

Installed in 2003. Has delivered slow-spill positive beam since February, 2004.



MIPP

Main Injector Particle Production Experiment (FNAL-E907)



MIPP Collision Hall

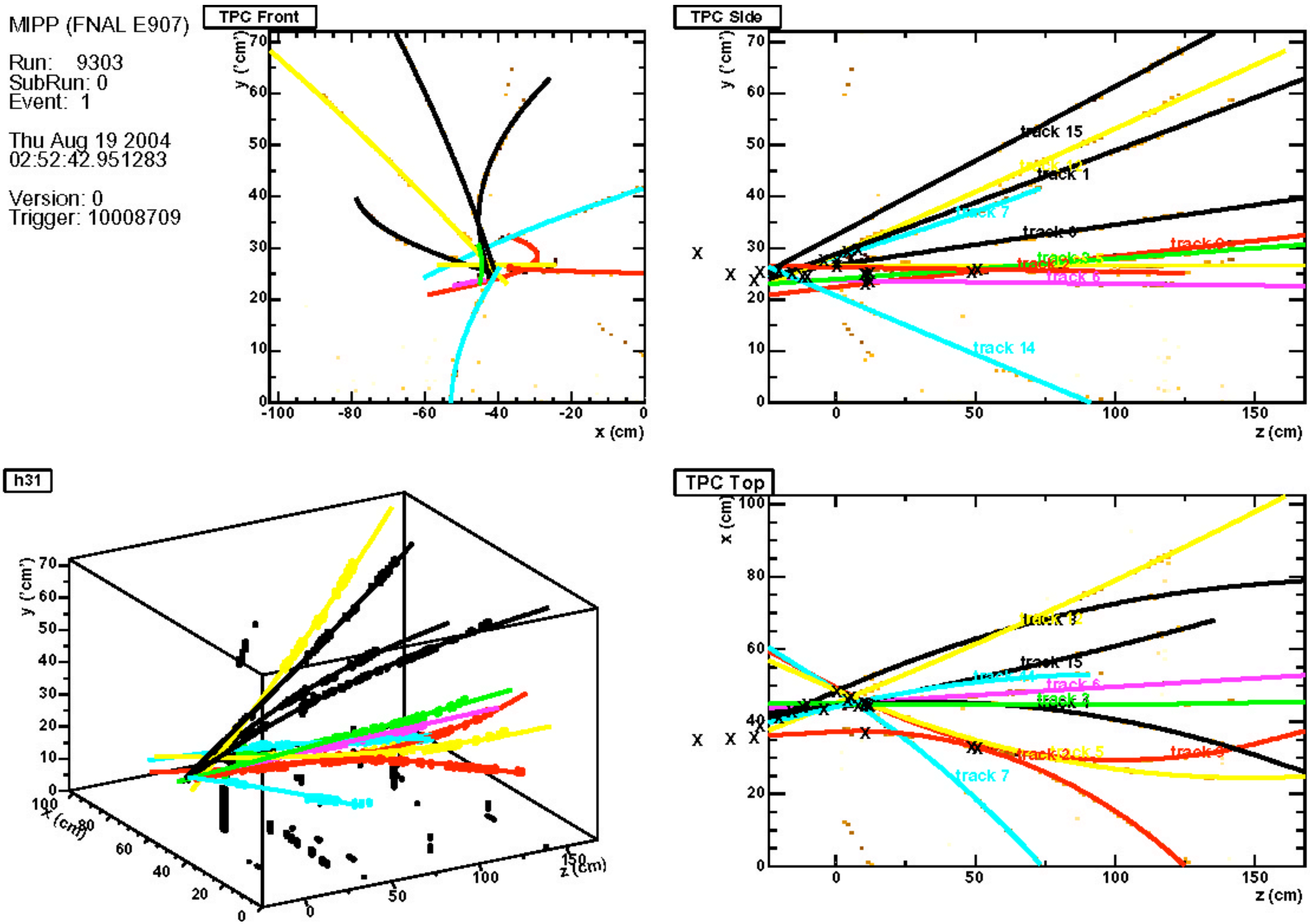
MIPP Collision Hall

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 16μs. Unreacted beam swept out in 8μs. Can tolerate 10^5 particles per second going through it.
- Can handle data taking rate ~60Hz with current electronics. Can increase this to ~1000 Hz with an upgrade.
- TPC dimensions 96 x 75 x 150 cm.

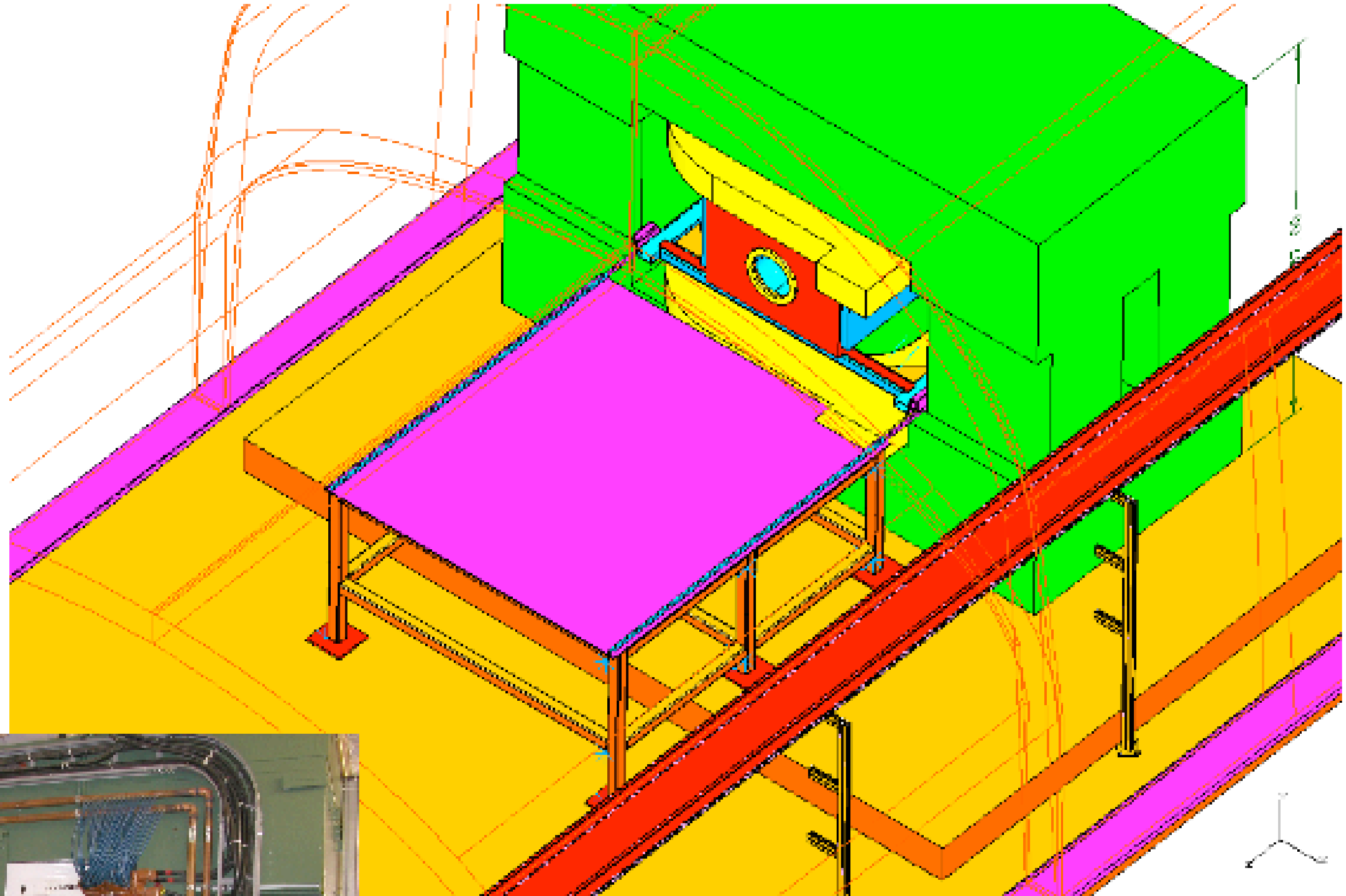
TPC processed event



Baryon Spectroscopy at MIPP

- Pion beams as low as 1 GeV/c possible with new magnet controls.
- Was proposed to PAC in April 2005.
- Approval was deferred, awaiting analysis of previous data.
- If approved (eventually), opens possibility of making measurements in the πN resonance region.

Jolly Green Giant Magnet

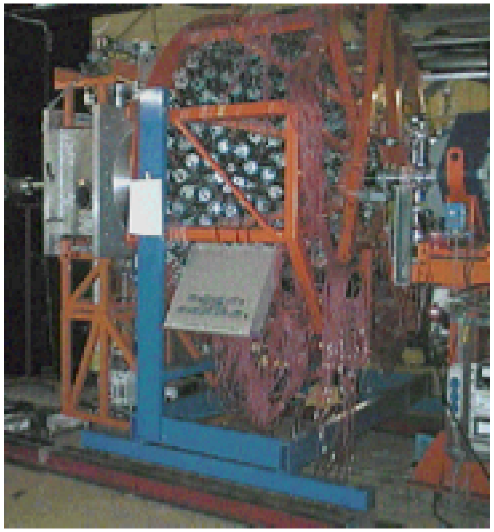


Overall view of the current M-center Jolly Green Giant Magnet area

2

Plastic Ball Recoil detector

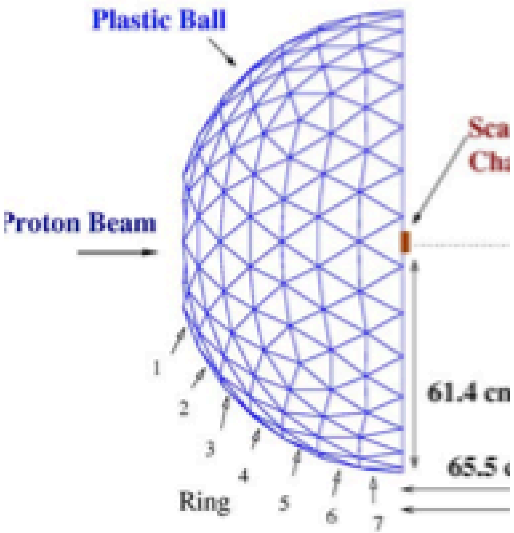
- Plastic ball detector is avaliable. GSI/KVI have joined MIPP. We will install a hemisphere in MIPP. Mounting details to be worked out. Need the ability to remove the detector to repair it and the TPC.
- Transportation to Fermilab.
- GSI/KVI will play a lead role in making this happen
- Detector will help in all aspects of MIPP data including tagged neutral beams, missing baryon resonances and hadronic shower simulation data.
- New electronics--Baldin

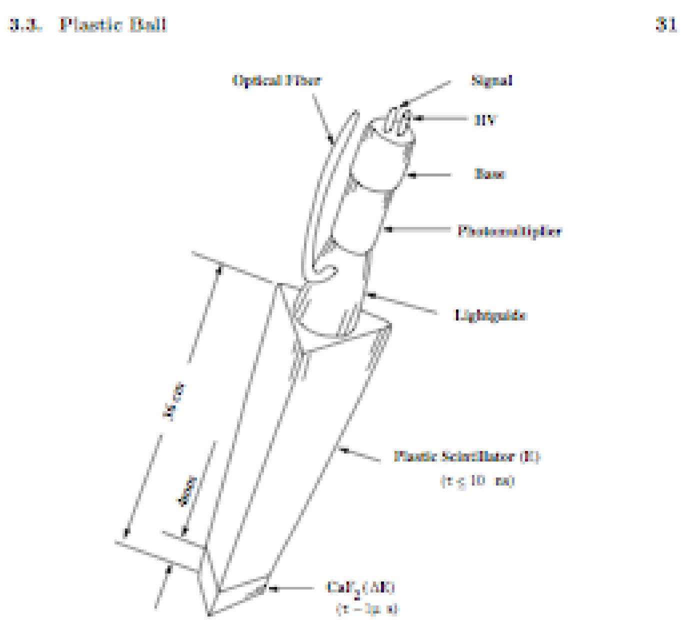


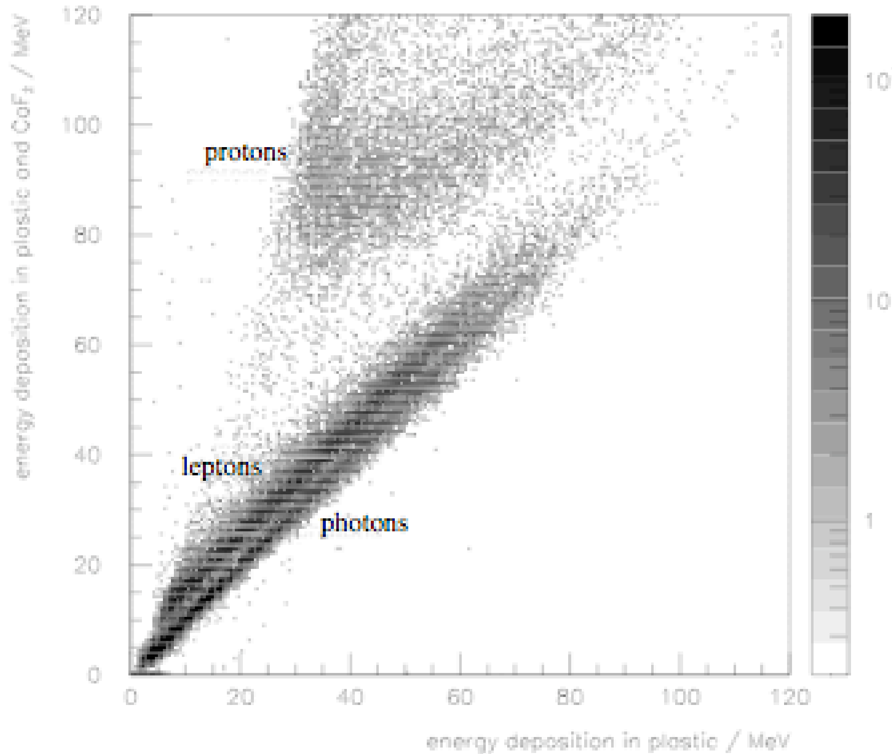
Picture of the full plastic ball at KVI

Plastic Ball for MIPP Upgrade

The recoil detector



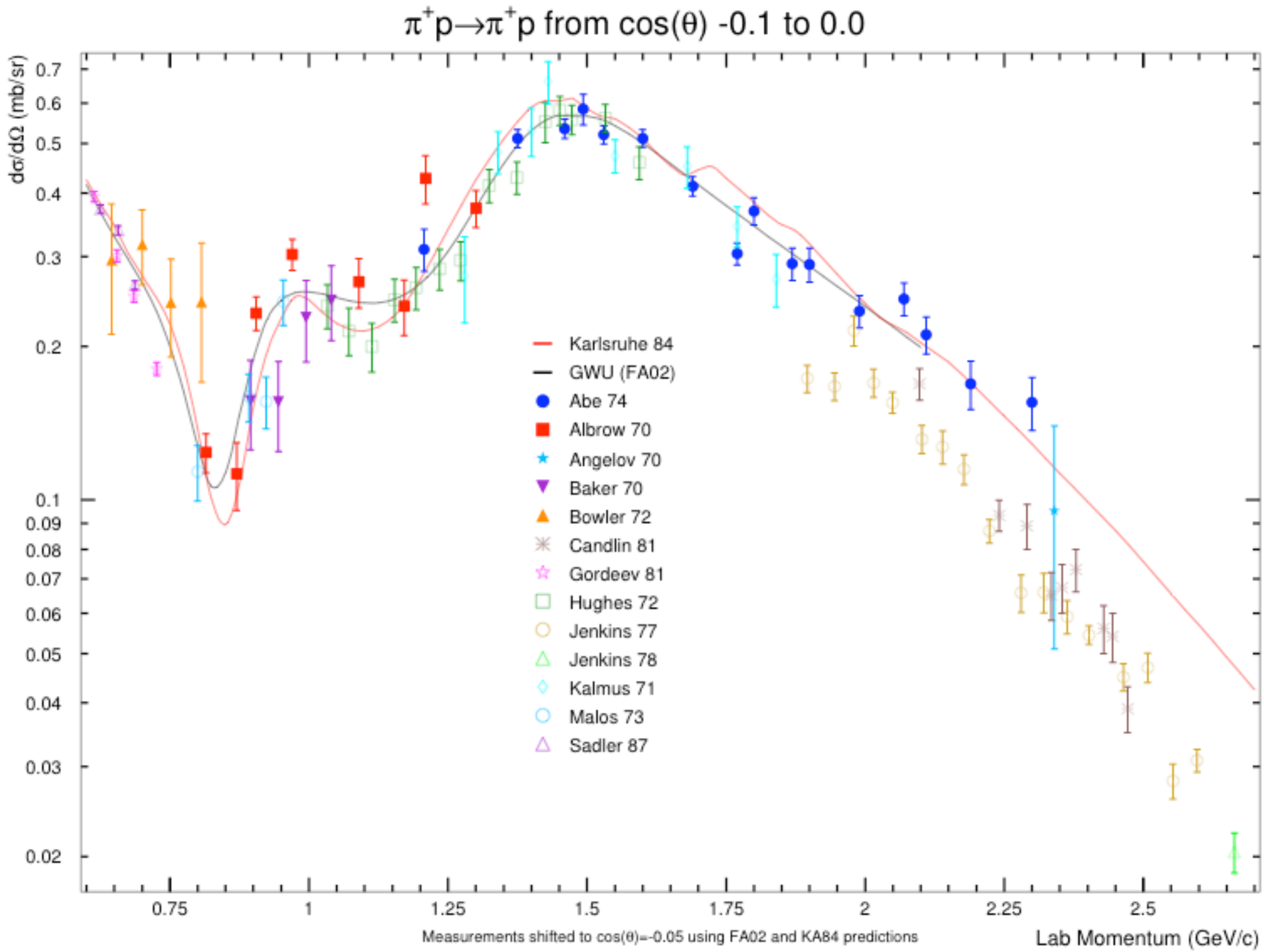




Detect recoil protons, neutrons, pizeros and charged pions,kaons

$\pi^{\pm}p \rightarrow N^{*} \rightarrow \pi^{\pm}p$

- Baryon spectroscopy through partial-wave analysis (PWA).
- GWU data analysis group maintains database and regularly updates their partial wave analyses of pion nucleon elastic scattering and single pion photoproduction.
- Needs other rejuvenated groups participating in ongoing PWA.
- Precise data needed to make a coupled channel analysis with the precise single pion photoproduction data from Jefferson Laboratory and other electromagnetic facilities.
- No new data at energies above the Roper resonance in about 3 decades.
- Some of the old data sets are inconsistent with each other.


$\pi^+p \to \pi^+p$ from cos(θ) -0.1 to 0.0
dσ/dΩ (mb/sr)
Karlsruhe 84
GWU (FA02)
Abe 74
Albrow 70
Angelov 70
Baker 70
Bowler 72
Candlin 81
Gordeev 81
Hughes 72
Jenkins 77
Jenkins 78
Kalmus 71
Malos 73
Sadler 87
Measurements shifted to cos(θ)=-0.05 using FA02 and KA84 predictions
Lab Momentum (GeV/c)

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.
- $\pi^- p \rightarrow K^+ \Sigma^- \rightarrow K^+ \pi^- n$

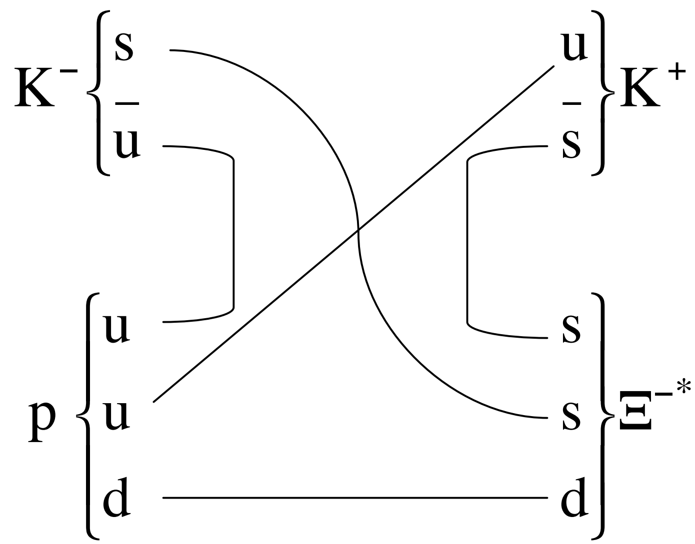
  Detect neutron by missing mass and reconstruct Σ^- by its invariant mass.
- $\pi^- p \rightarrow K^0 \Sigma^0$
  - $\Sigma^0 \rightarrow \gamma \Lambda \rightarrow \gamma \pi^- p$
  - $K^0 \rightarrow K_S \rightarrow \pi^+ \pi^-$

  Detect γ by missing mass, reconstruct Λ from π^-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).

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



- Strangeness -2 baryons accessible with hadronic beams.
- ssd baryon spectrum similar to uud and udd by flavor symmetry.
- Production (as opposed to formation) experiment.
- Signal is missing mass from $K^- p \to K^+ + MM$.
- Charged decay products of Ξ^{-*} will also be observed.
- 44 predicted Ξ^{-*}, 8 seen.

Nucleon structure experiments planned at J-PARC (near Tokyo)

Nuclear and Particle Physics Facility
原子核・素粒子物理実験施設
J-PARC
High Intensity Proton Accelerator Project

- Measurements of the spin rotation parameters A & R in the resonance region (PNPI, ITEP, and KEK).
- Systematic program in baryon spectroscopy (ANL, ACU, GWU, KSU, KEK, PNPI).
- Measurement of u and d antiquark distributions in the nucleon (Illinois, Duke, MIT, ACU, LANL, ANL, Kyoto, KEK, Tokyo).

N(1440) summary in Review of Particle Physics (2004)

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	$\pi N \to N\pi\pi$
1390	[3] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

N(1440) summary in Review of Particle Physics (2006)

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)

$N(1440)\ P_{11}$

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$ 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 1980 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. • • •				
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
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	$\gamma N \to \pi N$
1380	[1] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
1390	[2] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

N(1440) summary in Review of Particle Physics

N(1440) BREIT-WIGNER WIDTH

VALUE (MeV)		DOCUMENT ID		TECN	COMMENT
250 to 450 (≈ 350) OUR ESTIMATE					
391±34		MANLEY	92	IPWA	$\pi N \rightarrow \pi N$ & $N\pi\pi$
545±170		CUTKOSKY	90	IPWA	$\pi N \rightarrow \pi N$
340±70		CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$
135±10		HOEHLER	79	IPWA	$\pi N \rightarrow \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
668±41		PENNER	02C	DPWA	Multichannel
490±120		VRANA	00	DPWA	Multichannel
360±20		ARNDT	96	IPWA	$\gamma N \rightarrow \pi N$
440		ARNDT	95	DPWA	$\pi N \rightarrow N\pi$
250±63		BATINIC	95	DPWA	$\pi N \rightarrow N\pi$, $N\eta$
315		LI	93	IPWA	$\gamma N \rightarrow \pi N$
334		CRAWFORD	80	DPWA	$\gamma N \rightarrow \pi N$
113	1	BAKER	79	DPWA	$\pi^- p \rightarrow n\eta$
331		BARBOUR	78	DPWA	$\gamma N \rightarrow \pi N$
279		BERENDS	77	IPWA	$\gamma N \rightarrow \pi N$
200	2	LONGACRE	77	IPWA	$\pi N \rightarrow N\pi\pi$
200	3	LONGACRE	75	IPWA	$\pi N \rightarrow N\pi\pi$

N(1440) summary in 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) DECAY MODES

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

	Mode	Fraction (Γ_i/Γ)
Γ_1	$N\pi$	60–70 %
Γ_2	$N\eta$	
Γ_3	$N\pi\pi$	30–40 %
Γ_4	$\Delta\pi$	20–30 %
Γ_5	$\Delta(1232)\pi$, P-wave	
Γ_6	$N\rho$	<8 %
Γ_7	$N\rho$, S=1/2, P-wave	
Γ_8	$N\rho$, S=3/2, P-wave	
Γ_9	$N(\pi\pi)^{I=0}_{S\text{-wave}}$	5–10 %
Γ_{10}	$p\gamma$	0.035–0.048 %
Γ_{11}	$p\gamma$, helicity=1/2	0.035–0.048 %
Γ_{12}	$n\gamma$	0.009–0.032 %
Γ_{13}	$n\gamma$, helicity=1/2	0.009–0.032 %

Considerations for future πN experiments

- Pion beams from 0.7 to 3.0 GeV/c.
- Large acceptance detectors.
- Polarized targets (transverse for P measurements, longitudinal plus polarimeter for A and R measurements).
- Ability to detect and analyze inelastic channels.
- Ongoing PWA.

An active πN experimental/PWA program is needed to complement electro- and photo-production data from Jefferson Laboratory, Mainz, …

Conclusions

- New PWA efforts are needed to determine properties of the $P_{11}(1440)$ resonance.
- Complete data sets now available.
- KH and CMB analyses completed in 1980.
- These analyses can be extended to higher resonances when (if?) data become available from new facilities.
- An experiment on non-strange resonances near 1710 MeV is being prepared at ITEP (Moscow).
- MIPP at FNAL presents a new possibility (if eventually approved) to make measurements in the πN resonance region (1-3 GeV/c) and with kaon beams higher than 3 GeV/c.
- J-PARC (near Tokyo) is a future hadron facility. No baryon spectroscopy or nucleon structure experiments included in Phase I experiments.