Status of the "EPECURE" experiment (April 2009).
(PNPI – ITEP – ACU collaboration)

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Participants from PNPI and ITEP

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Contents.

Baryonic multiplets in the harmonic quark shell model.
(Inroductory remarks on baryon spectroscopy R. H. Dalitz, 1976)

A hadronic system of finite size can be expected to have at least two types of exited states:

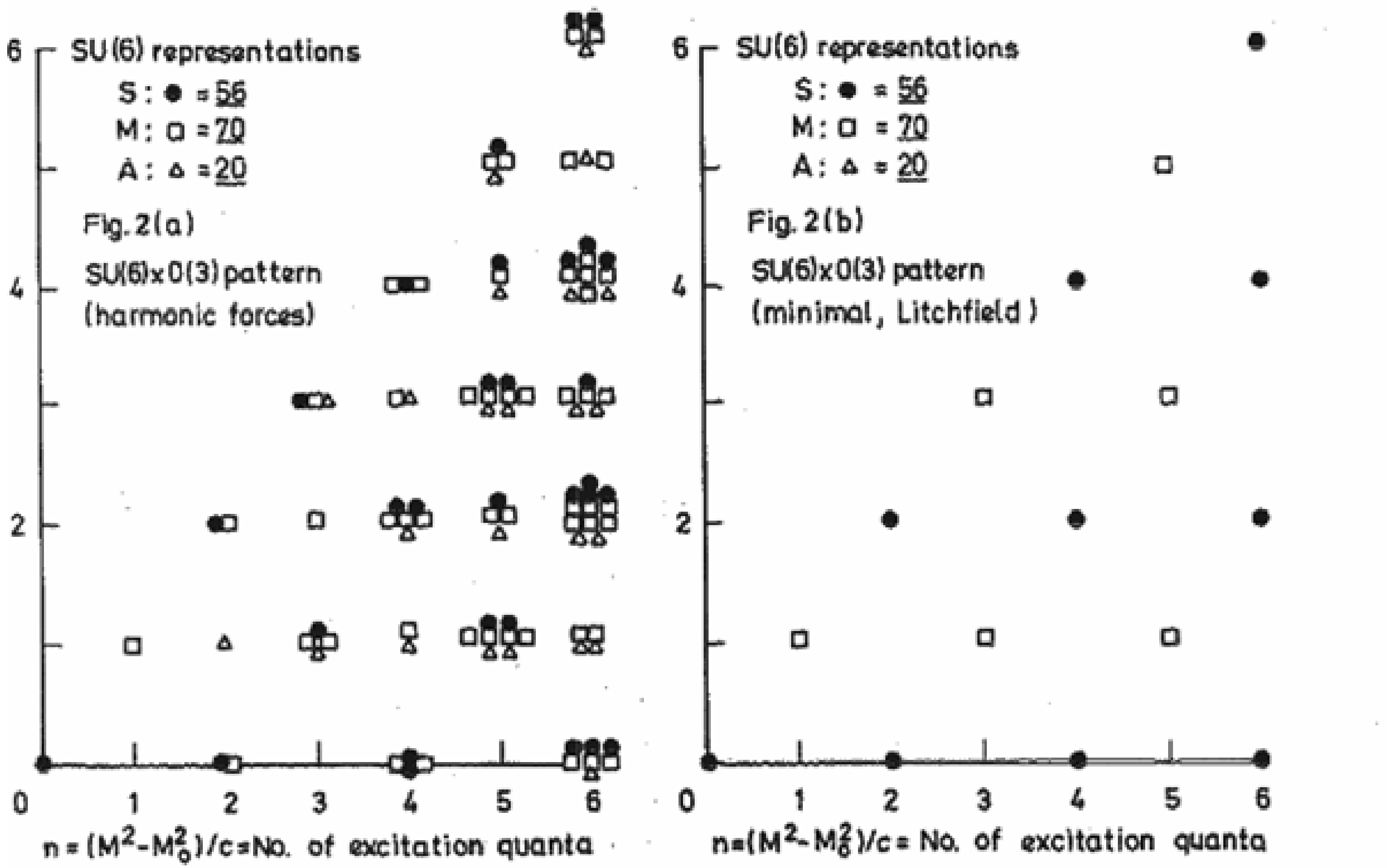
(a) rotational excitations (or Regge recurrences, in field theoretical language)

(b) radial vibrations (pulsations)

Following Greenberg's early shell-model proposal, the harmonic oscillator SU(6) x O(3) quark model has had much success in accounting for the low-lying multiplets observed for baryonic resonance states.

The SU(6) multiplets are best characterized by giving symmetry of the representation with respect to permutations of the labels of the three quarks. The 56 representation has complete symmetry (S), the 70 representation has mixed symmetry (M), and the 20 representation is antisymmetric (A). Taking together the SU(6) wave function and the internal space wave function, the excited SU(6) x O(3) supermultiplets may be specified by the notation $(\alpha , LP)_N$, where α denotes the SU(6) representation.

Model predictions { SU(6) x O(3) supermultiplets}, Dalitz (1976)



If n=4, it must be 1880 resonances.

If n=4, it must be 546 resonances.

Model predictions { SU(6) x O(3) supermultiplets}, Dalitz (1976) }

Let us summarize briefly the experimental situation concerning baryon spectroscopy and SU(6)xO(3), as it stood before this conference.

N=0. All eight isospin multiplets are known for the $(\underline{56}, 0+)_0$ supermultiplet.

N=1. The known states fit well the supermultiplet $(\underline{70}, 1-)_1$ predicted. Its SU(3) – singlet Λ states have been long well established, and the nucleonic member is now known for each of its (8) and (10) multiplets, together with more than half of the expected Λ^* and Σ^* states and several of the Ξ^* states. The gross features of the pattern of masses are given correctly, although many details about the spin-orbit splitting and mixing are not yet fully understood.The are no additional negative parity states known in this mass region, expect for Σ D13 (1940) and ΔD35 (1960), which lie rather high relative to the other masses in this supermultiplet and which may well belong to N=3 band.

N=2. The nucleonic members are known for four of the six SU(3) multiplets expected for $(\underline{56}, 2+)_2$ and for both of the SU(3) multiplets for $(\underline{56}, 0+)_2$, together with some Λ^* and Σ^* states and perhaps one or two Ξ^* states. Further positive parity states exist in this mass region, for example, NF17 (1990) and ΛF05 (2110) which would most naturally be assigned to $(\underline{70}, 2+)_2$, and NP (1780), for which a place exists in the $(\underline{70}, 0+)_2$ supermultiplet.

N=3. The well-established resonances NG17 (2190) and ΛG07 (2100) appear as rotational excitatiuns of ND03 (1520) and ΛD03 (1520) and are representative of $(\underline{70}, 3 -)_3$. Other negative parity states , not so well established, are known in this mass region and may be accommodated in this or other supermultiplets (8 supermultiplets in all !) of this band.

N=4. The well - established states NH19 (2220) and ΔH311 (2420) appear as double rotational excitations of NP11 (1940) and ΔP33 (1232) and are representative of $(\underline{56}, 4+)_4$.

We note that most of these supermultiplets lie within the minimal set based on $(\underline{56}, 0+)_0$ and $(\underline{70}, 1-)_1$, namely the supermultiplets $(\underline{56}, L +)_{L+2n}$ for L=even and n = 0, 1, 2… and $(\underline{70}, L -)_{L+2n}$ for L= odd and n=0,1,2…4

R.H.Dalitz and G.Hoehler comments.

" It is clear that we still need much more information about the existence and parameters of many baryon states, especially in the N=2 mass region, before this question of non-minimal SU(6) x O(3) supermultiplets can be settled."
(R.H.Dalitz, Introductory remarks on baryon spectroscopy, Oxford, 5-9 July, 1976.)

"The first problem is that the notion of a resonance is not well defined. The ideal case is a narrow resonance far away from the thresholds, superimposed on slowly varying background. It can be described by a Breit-Wigner formula and is characterized by a pole in the analytic continuation of the partial wave amplitude into the low half of the energy plane. The speed plot has a maximum at the resonance position and the resonance is seen in other channels, unless it is forbidden by a selection rule.

Unfortunately, in πN-scattering only the Δ(1232) resonance corresponds approximately to this picture. The other resonances occur frequently near thresholds of inelastic channels, and the background is not slowly varying. ………..

In this situation, the "Review of Particle Properties" can only give a collection of resonance-like phenomena. They show a continuous transition from textbook-type resonances to tiny wiggles on a large background."
(G.Hoehler, The πN Resonances in the Particle Data Table,
submitted at "Physics with light mesones and the Second International Workshop on πN Physics", December 1987)

SU(6) x O(3) classification of nucleon resonance by G.Hoeler at al. (from KH78).

SU(6)LP	Resonance from KH78	Σ
$(56,0^+)$	**P11(938),) P33(1233)**	2
$(56,2^+)$	**P13(1710), F15(1684), P31(1888), P33(1868), F35(1905), F37(1913)**	6
$(56,4^+)$	**F17(2005), H19(2205), F35(-), F37(2425), H39(2217), H3,11(2416)**	6
$(70,1^-)$	**S11(1526), D13(1519), S11(1670), D13(1731), D15(1679), S31(1610), D33(1680)**	7
$(70,3^-)$	**D15(-), G17(2140), D13(2081), D15(2228), G17(-), G19(2268), D35(2305), G37(2215)**	8
$(70,5^-)$	**G19(-), I 1,11(-), G17(-), G19(2792), I1,11(2577), I1,13(-), G39(2468), I3,11(-)**	8
$(70,7^-)$	**I1,13(-), L1,15(-), I1,11(-), I1,13(-), L1,15(-), L1,17(-), I3,13(2794), L3,15(-)**	8
$(70,2^+)$	**P13(-), F15(-), P11(1723), P13(-), F15(1882), F17(-), P33(-), F35(-)**	8
$(56,6^+)$	**H 1,11(-), K1,13(2612), H39(-), H3,11(-), K3,13(-), K3,15(2990)**	6
$(56,1^-)$	**S11(1880), D13(1920), S31(1908), D33(2070), D35(1901)**	5
Σ = 630	Σ = 39 (64)	Σ = 64

It would must be 630 baryon resonance, if all revealed 70-multiplets and 56-multiplets were filled in.

Comparison of the N* and Δ–resonance number predictions.

References	N* – resonance number	Δ – resonance number
Rev. of Part. Phys. (1980)	26	19
Rev. of Part. Phys. (2006)	21	22
KH80	21	18
KA84	18	16
CMB (Phys.Rev.D 20 1979)	16	13
T.P.Vrana et al.(nucl-th/9910012)	14	13
SM95 (Phys.Rev.C 52 1995)	13	8
FA02 (Phys.Rev.C 69, 2004)	10	7
SP06 (nucl-th/0605082)	13	9
S.Capstick et al.(Phys.Rev.D 49,1994)	40	27
U.Loring et al.(hep-ph/0103289)	99	82
Skyrme model (Phys.Rev.D31,1985)	10	13
J.Vijande et al.(hep-ph/0312165)	19	21

In the PDG 2008 Baryon summary table there are in general (N*, Δ, Λ, Σ and others) 135 baryons. n=4, three 70-plets and four 56-plets are given in summary tables. In general 434 baryons must be.

Phenomenology.

The pion-nucleon scattering amplitude can be written in general form as

$$F = f + ig(\sigma n).$$

Here f and g are the complex spin-non-flip and spin-flip amplitudes, accordingly; the **σ′**s are the Pauli spin operators, **n** is a unit vector normal to the scattering plane.

The relations connecting the observable - differential cross section dσ/δΩ, polarization parameter P, spin rotation parameters A and R - with the amplitudes f and g have the following form:

$$d\sigma/\delta\Omega = |\phi|^2 + |g|^2 \qquad \mathbf{P} = 2\mathrm{Im}(fg^*) / (|f|^2 + |g|^2)$$

$$\mathbf{A} = [1 / (|f|^2 + |g|^2)] \times [(|f|^2 - |g|^2)\sin(\theta\pi^{CM} - \theta\pi^{L}) - 2\mathrm{Re}(fg^*)\cos(\theta\pi^{CM} - \theta\pi^{L})]$$

$$\mathbf{R} = [1 / (|f|^2 + |g|^2)] \times [(|f|^2 - |g|^2)\cos(\theta\pi^{CM} - \theta\pi^{L}) - 2\mathrm{Re}(fg^*)\sin(\theta\pi^{CM} - \theta\pi^{L})]$$

Here $\theta\pi^{CM}$ and $\theta\pi^{L}$ are the angles of the recoil proton emission in the center-of-mass system and in the laboratory system, respectively.

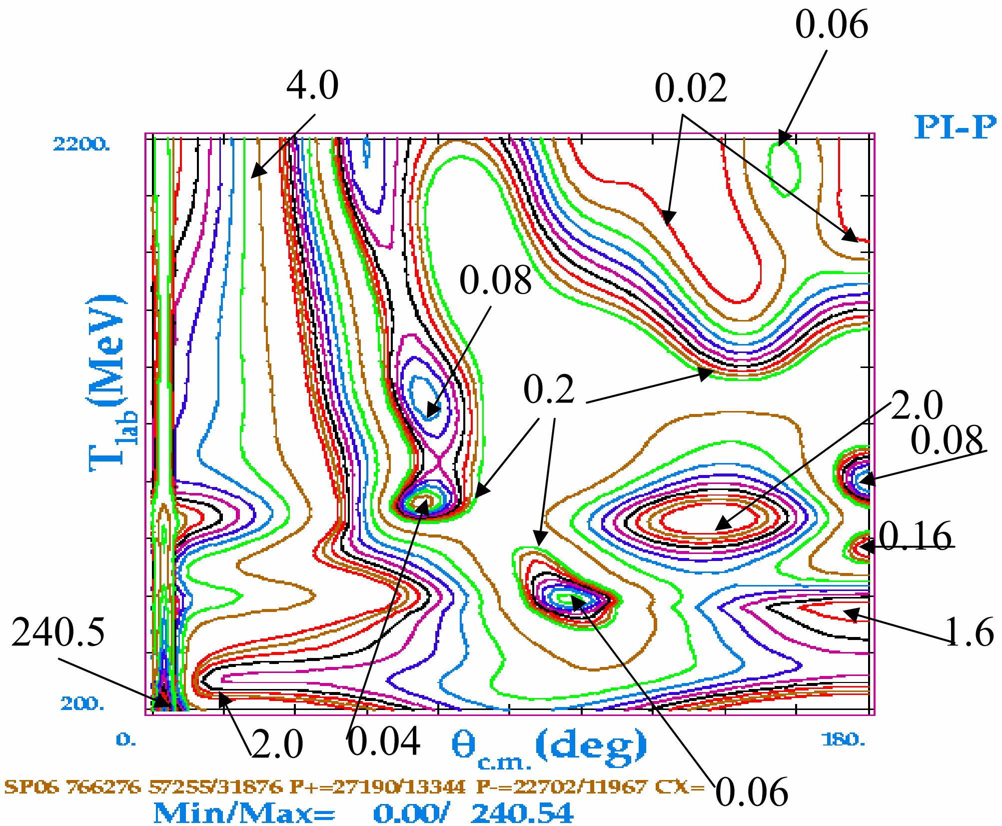
Everywhere $\mathbf{A}^2 + \mathbf{R}^2 + \mathbf{P}^2 = 1$ determine unambiguously f and g amplitudes.

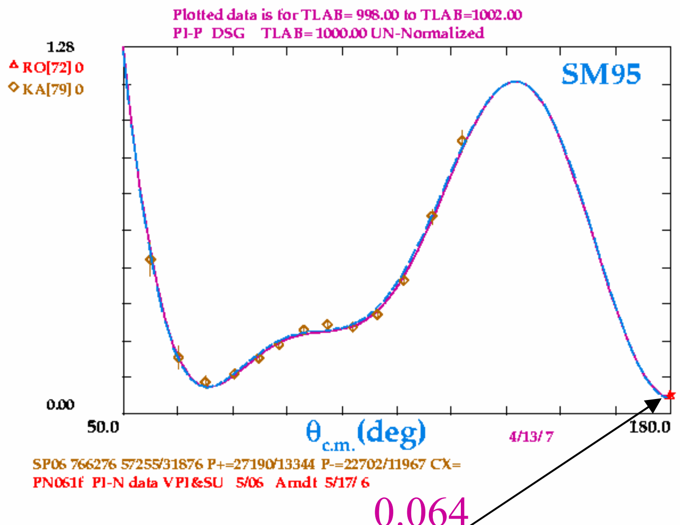
One and the same value of polarization parameter P can be obtained using different combinations of f and g. Only measurement in combination of parameter P and A (or P and R) removes these fundamental ambiguities (I.G.Alekseev et al., Phys.Rev.C55, 2049(1997)).

The minima in the elastic $\pi^{-}p$-scattering cross- section.

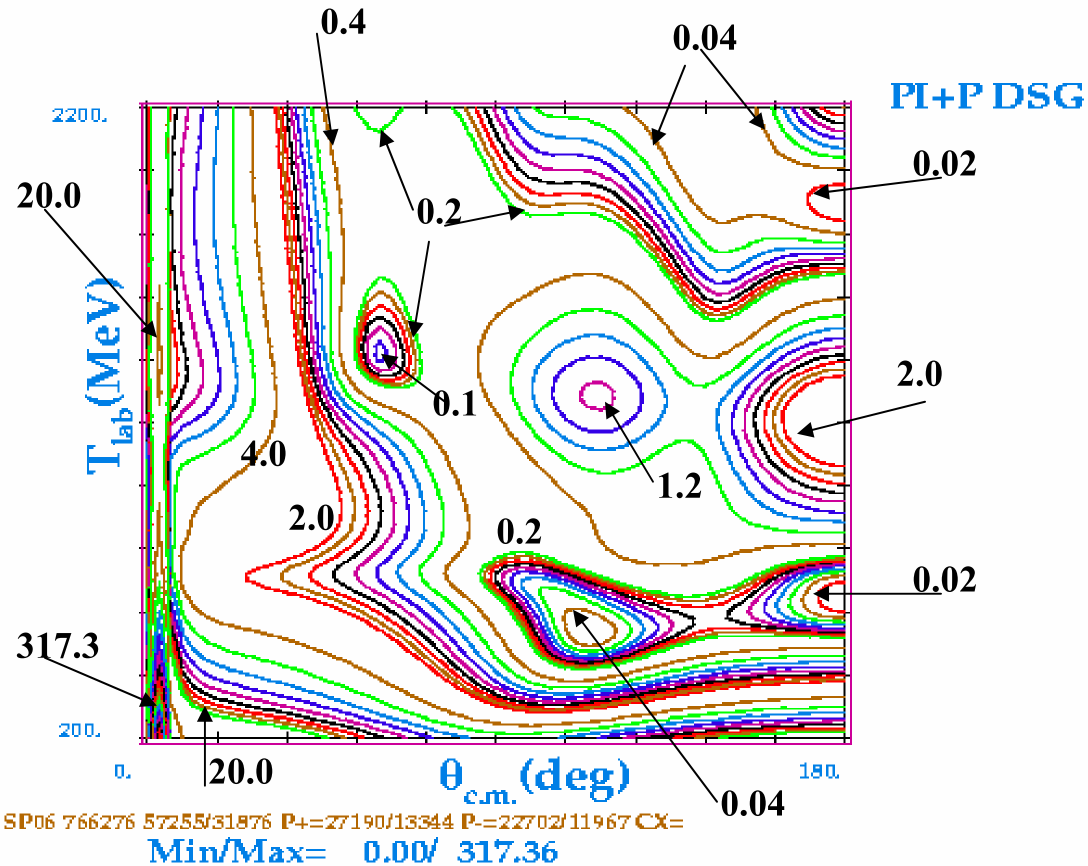
DSG steps between lines:

20.0	20.0	240.0	mb/sr
2.0	2.0	20.0	mb/sr
0.2	0.2	2.0	mb/sr
0.02	0.02	0.2	mb/sr





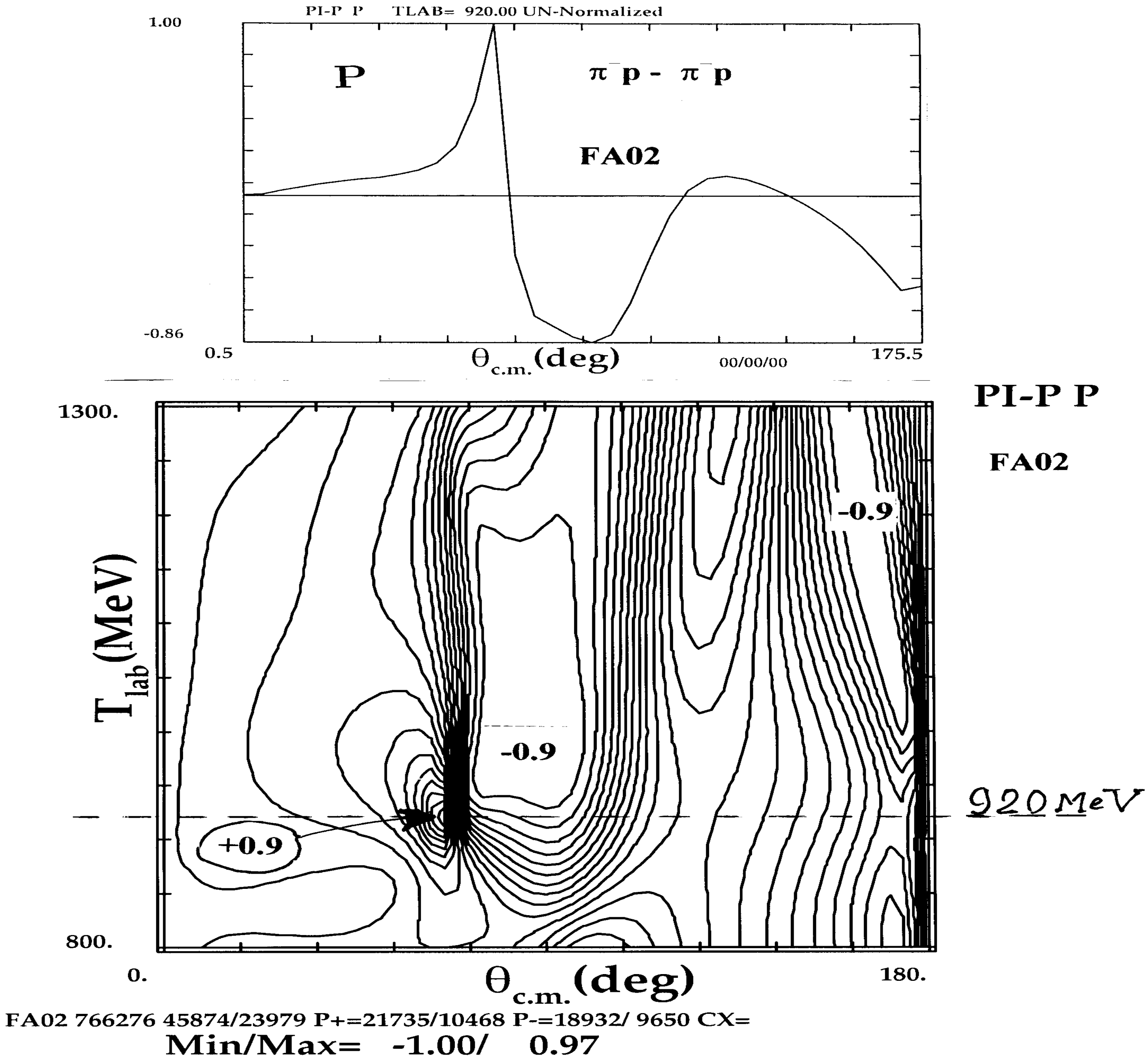
The minima in the elastic π^+p-scattering cross- section.



DSG steps between lines:

20.0	20.0	317.0	mb/sr
2.0	2.0	20.0	mb/sr
0.2	0.2	2.0	mb/sr
0.02	0.02	0.2	mb/sr

The polarisation in the elastic $\pi^- p$-scattering .



{ Barrelet method employment. }

The basic idea of the Barrelet methods is to represent the transverse amplitudes $F_{\pm}$ at fixed energy by the following ansatz, which exhibits the zeros in the complex $z = \cos\theta_{cm}$ – plane:

$$F(\pm;z)=F(1) \times \prod_{i=1}^{N} [(z-z_{\pm i})/(1-z_{\pm i})] \times R(\pm;z) \; ; \; R(\pm;1)=1.$$

Here $R(\pm;1)$ is the remainder. It is more preferable in our case to work with a single analytic function of a variable ω, which is connected with z by a conformal mapping:

$$\omega = e^{i\theta} = z \pm (z^2-1)^{1/2}.$$

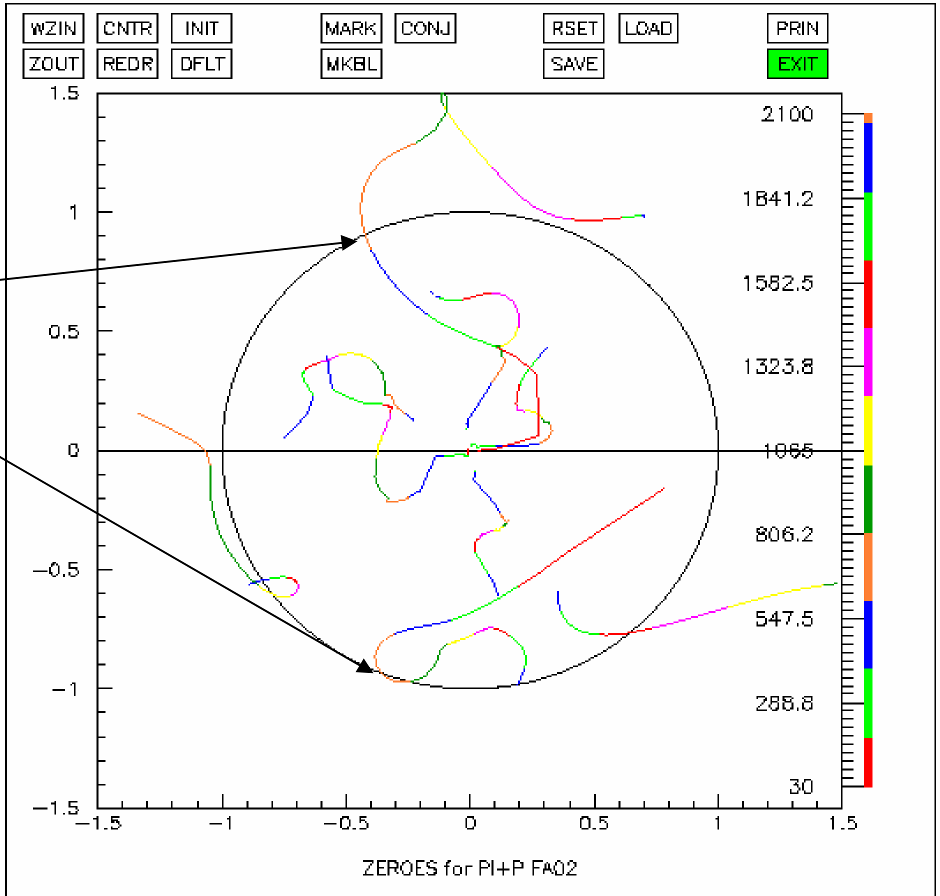
When θ is real, it corresponds to the center-of-mass scattering angle. This mapping has the property, that a physical value of z (i.e. z real and $|z| < 1$) is mapped onto two points in the ω-plane, which lies on the upper and lower halves of the unit circle, respectively. Here ω and ω^{-1} belong to the same value of z.. Transverse amplitudes have the advantage, that their modulus can be determined from dσ/dΩ and P data alone $|F_{\pm}| = d\sigma/d\Omega \times (1 \pm P)$. This equation shows that the zeros of the amplitude can be derived from the zeros of dσ/dΩ and P data but, unfortunately, there is a 2^{2N} fold ambiguity because for each pair of zeros z_i and z_i^* (or ω_i and $1/\omega_i^*$) one has the choice whether z_i or z_i^* belongs to the amplitude F.

The spin rotation parameters A and R measurements can help in such choice.

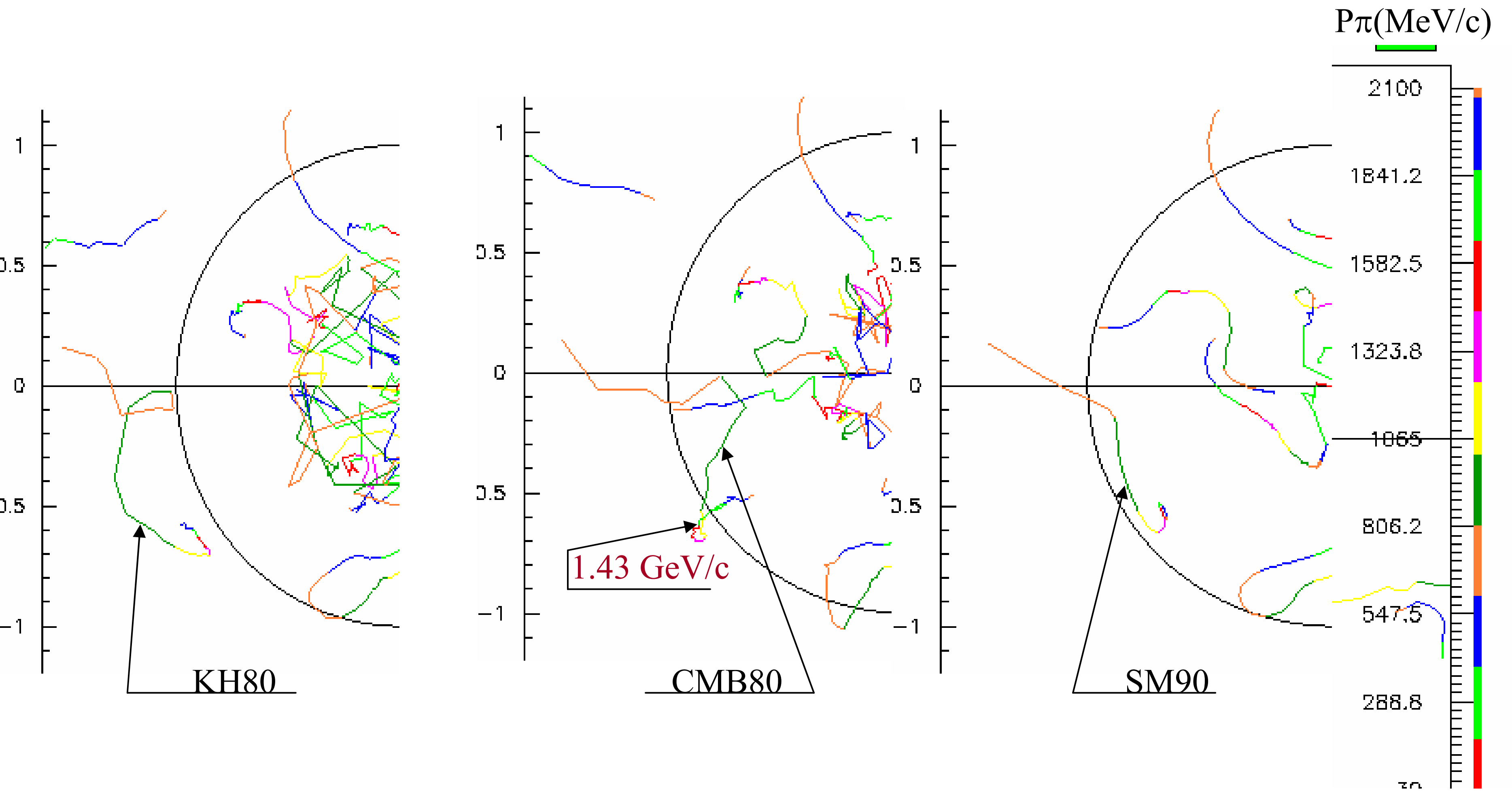
The positions of the zeros of $F_{\pm}$ depends of course on the incident pion beam momentum. This allows one to locate problems of the unknown PWA ambiguities simply by looking at the zero trajectories on the ω-planes which are near the physical region.

Zero trajectories for π^+p elastic scattering.

540 MeV,
115 deg

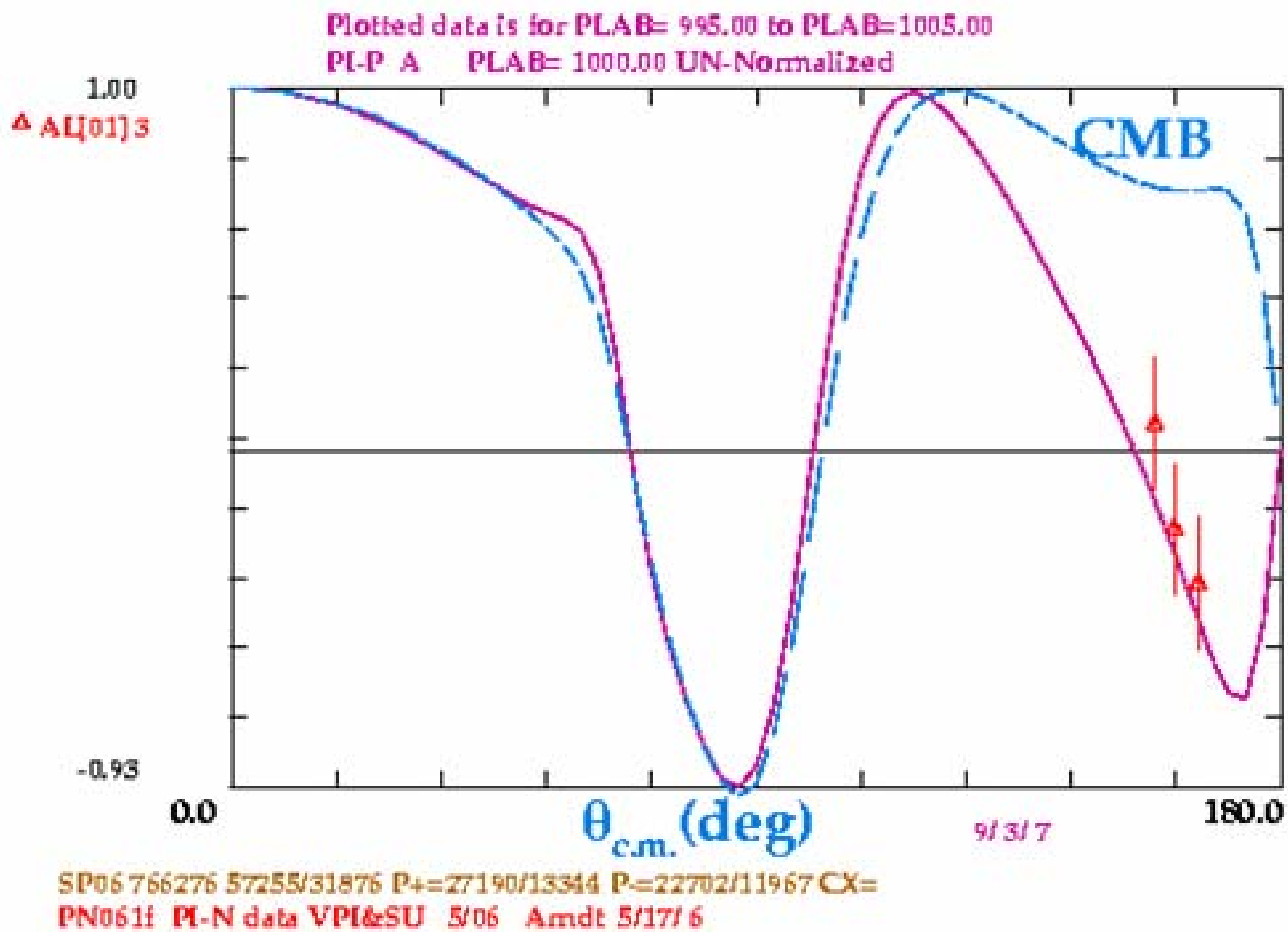


Twofold ambiguity example.

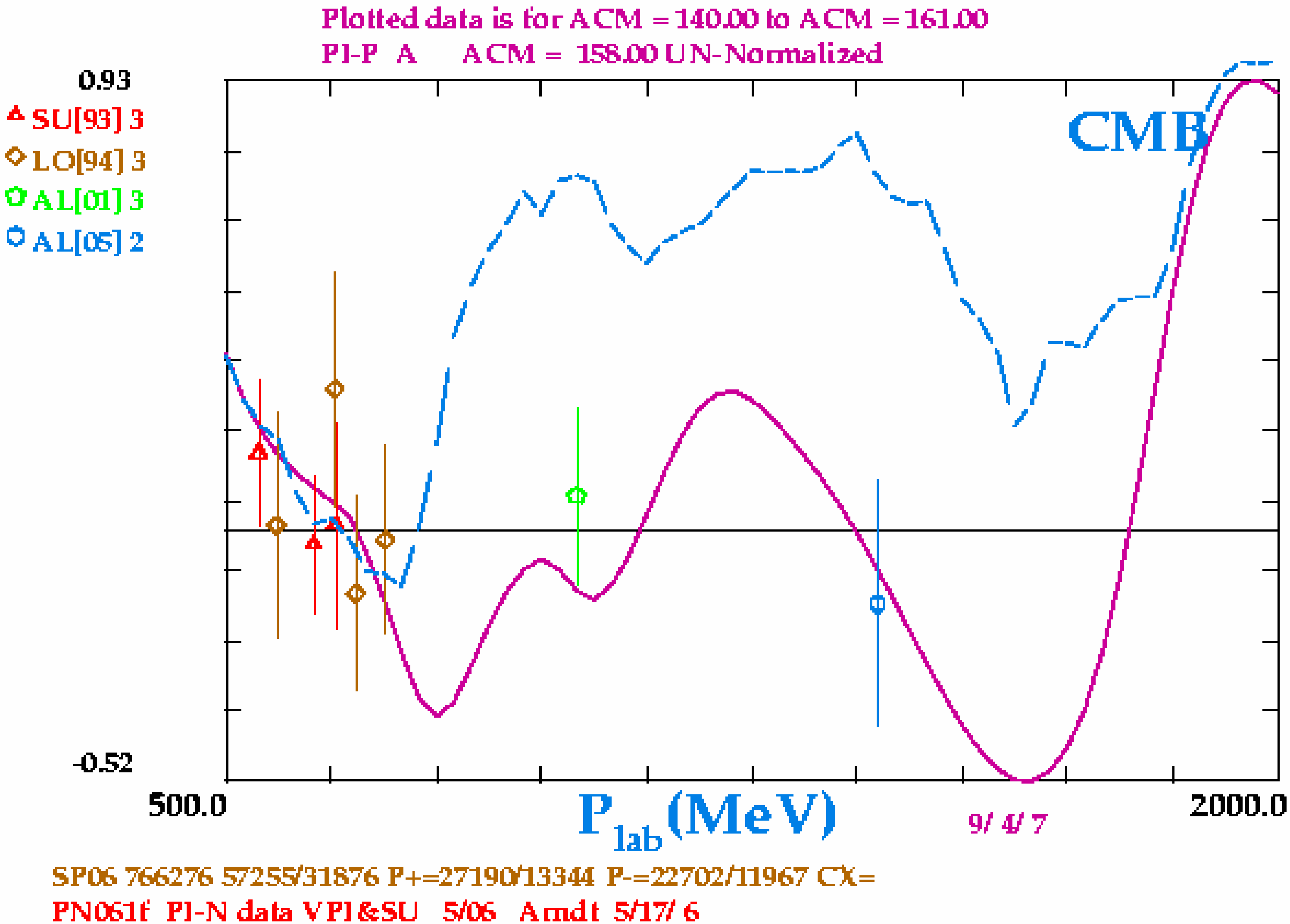


Comparison of the zero trajectories predictions in PWA KH80, CMB80 and SM90, which cross or reflect from the unit circle near 0.7 GeV/c.

The influence of the parameter A measurements
on the choice between PWA predictions.



The influence of the parameter A measurements on the choice between PWA predictions.



Summary of N* and Δ* finding (from I.I.Strakovsky)

- Standard PWA reveals only wide Resonances, but not too wide (Γ < 500 MeV) and possessing not too small BR (BR > 4%)
- PWA (by construction) tends to miss narrow Resonances with Γ < 30 MeV
- Our study does not support several N* and Δ* reported by PDG2006:

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

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

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

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

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

  *** $\Delta(1930)D_{35}$, $N(2600)I_{111}$ [no pole]

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

  new $N(2245)H_{111}$ [CLAS ?]

N(1710)P_{11} – What was Known.

(From I.I.Strakovsky.)

[W.-M. Yao *et al.* [RPP] J Phys G **33**, 1 (2006)]

PDG06=PDG04

χSA	DPP97	1710 [inp]	~40 [est]
PWA-BW	Ref	Mass(MeV)	Width(MeV)
	KH79	1723± 9	120± 15
	CMU80	1700±50	90± 30
	KSU92	1717±28	480±230
	GW06	not seen	
PWA-Pole		Re(MeV)	-2xIm(MeV)
	CMU80	1690±20	80± 20
	CMU90	1698	88
	KH93	1690	200
	GW06	not seen	

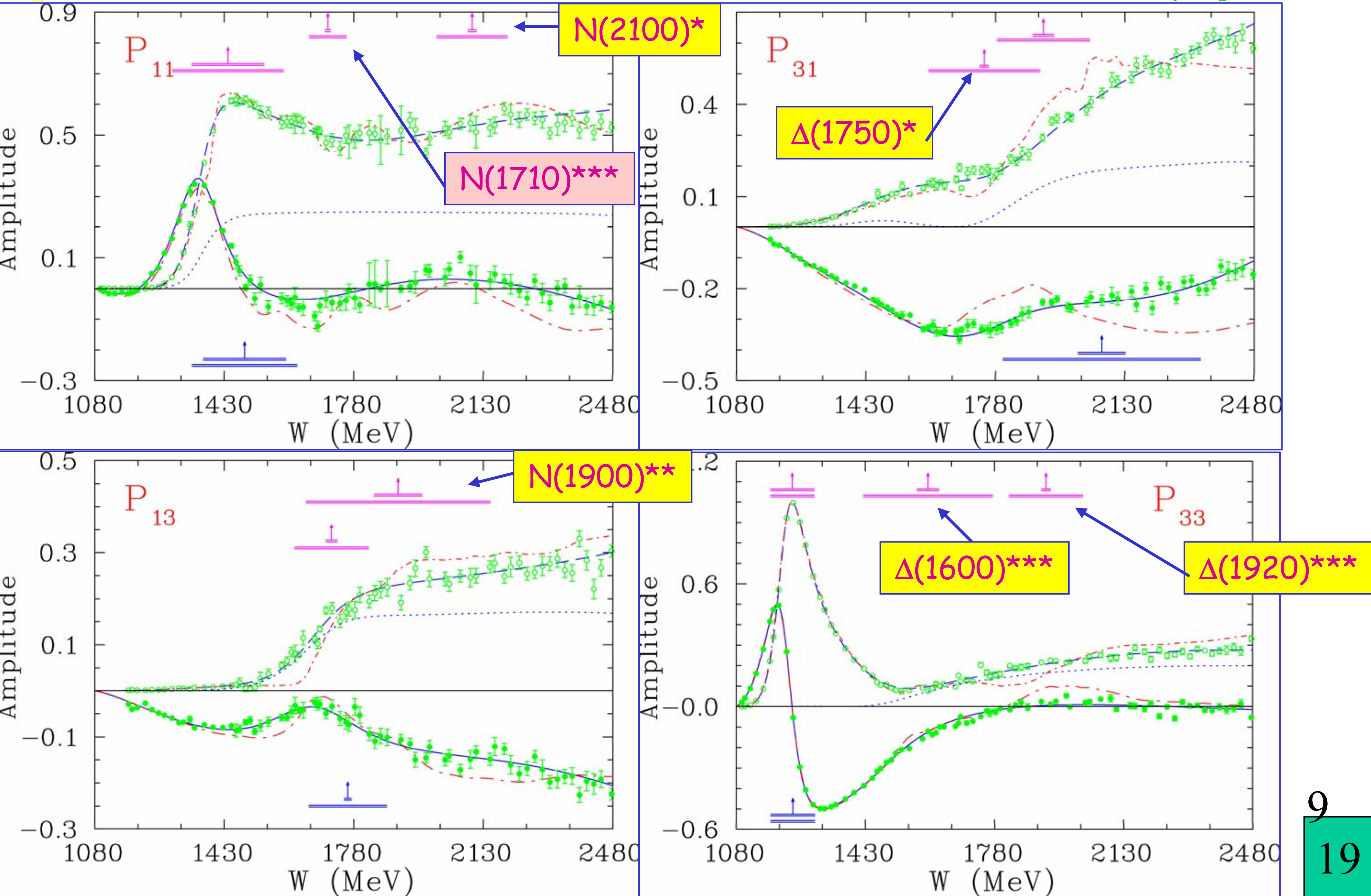
No BW, No pole, No Sp

[Sp(W)]

- The spread of Γ, selected by PDG, is very large
- It would be more natural for the same unitary multiplet (with Θ^+ and N*) to have comparable widths

P-waves from GWU PWA. (from I.I.Strakovsky)

From I.I.Strakovsky report



“Usual” resonance N(1710).

The following summary on the non-exotic P_{11} resonance N(1710) is taken mainly from the “Review of Particle Properties” (RPP, 2006). This resonance has a rating of three stars (***).

According to the results of the energy independent partial wave analyses (IPWA): KH80 – M_R=1723±9 MeV, Γ=120±15 MeV; CMB80 – M_R=1700±50 MeV, Γ=90±30 MeV.

Pion photoproduction IPWA gives M_R=1720±10 MeV, Γ=105±10 MeV, having the branching ratios for Nπ and KΛ channels (10-20)% and (5-25)% respectively.

The combined analysis of the πN→πN+Nππ processes (KSU) has two solutions, predicting either a wide resonance with Γ=480±230 MeV or a narrow one with Γ=50±40 MeV at the same mass of M_R=1717±28 MeV.

In the energy dependent (DPWA) analysis SP06 of GWU group the resonance N(1710) is not observed.

The quest for exotic hadron states.

Dramatic events in baryon spectroscopy took place during the last time. The narrow exotic baryon θ^+ with strangeness +1 and mass 1540 MeV (Fig.1) was discovered at ITEP and KEK , which was earlier predicted by the chiral soliton model. Then the exotic baryon $\Xi_{3/2}$ with strangeness –2 and mass 1860 MeV was clamed to be observed by NA49 collaboration.

The ITEP and KEK results were confirmed by several successive measurements. Due to their quantum numbers, θ^+ and $\Xi_{3/2}$ can contain four quark and one antiquark as a minimum, and this is why these particles were called pentaquarks.

In the chiral soliton model θ^+ and $\Xi_{3/2}$ belong to SU(3) baryon antidecuplet with the spin and parity equal $½^+$. This antidecuplet should also contain the cryptoexotic baryons with the quantum numbers of the nucleon and Σ-hyperon (Fig. 1).

No doubts that the discovery of these missing members of the antidecuplet would be a great step towards N_{10} the understanding of the strong interaction dynamics in the nonperturbative region.

The aim of PNPI-ITEP-ACU proposal is to perform the experimental search for the cryptoexotic non-strange neutral resonance in the reactions $\pi^- p \rightarrow \pi^- p$ and/or $\pi^- p \rightarrow K\Lambda$. According to the spin/parity of the antidecuplet ($½^+$) and to the isospin projection of (–1/2) the resonance effect should be searched in P_{11}-wave.

Pentaquark” antidecuplet.

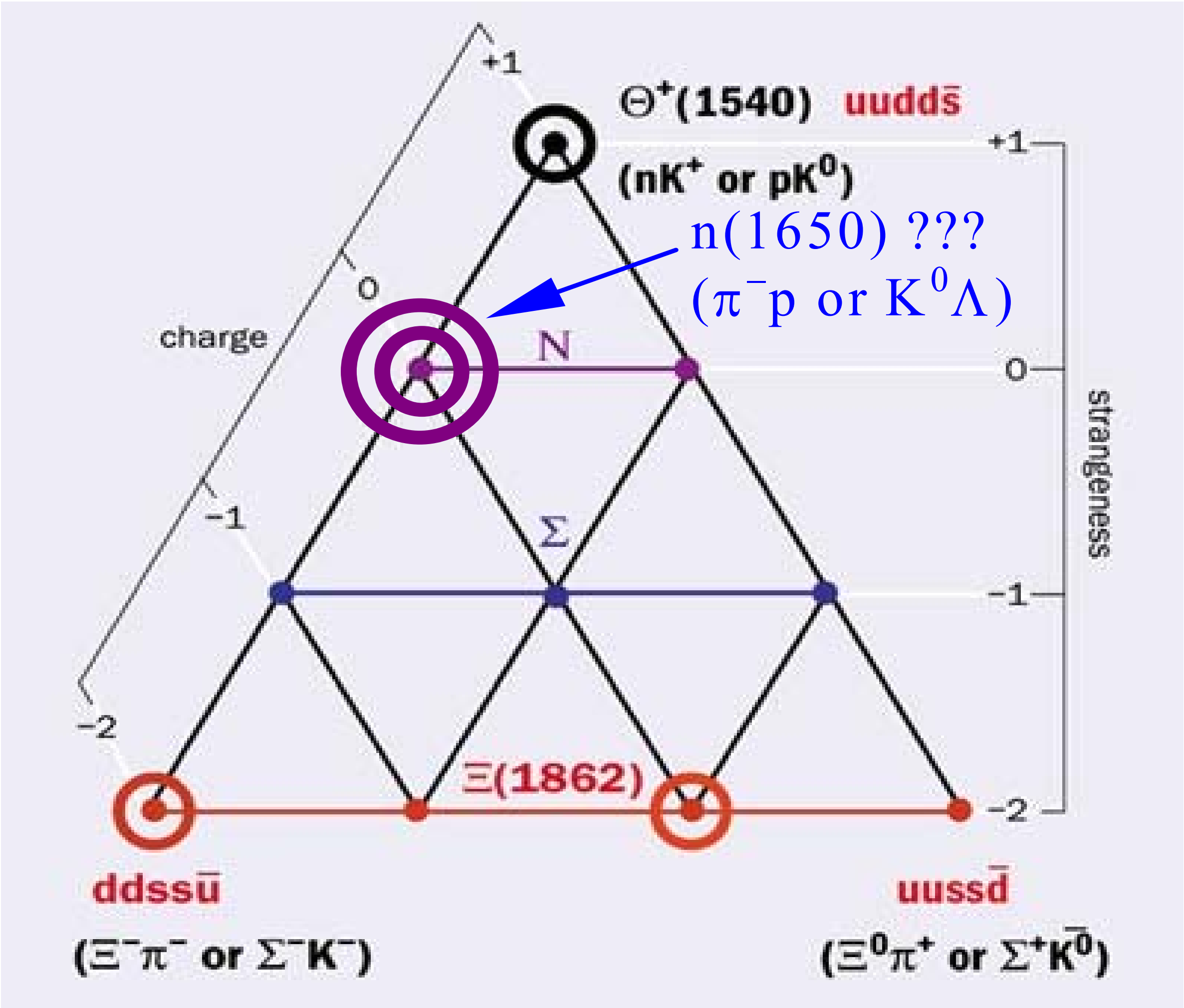


Figure 1. “Pentaquark” antidecuplet.

Experiment motivation and layout.

The general idea of the PNPI-ITEP-ACU collaboration proposal is to look for the effects in the cross-section in the "formation" type experiments using the elastic pion-nucleon scattering and reaction $\pi^- p \to K\Lambda$.

The scan of the mass interval under investigation will be done by changing the initial pion momentum. Secondary pion beams with appropriate intensity and energy are available at ITEP from its 10 GeV proton synchrotron.

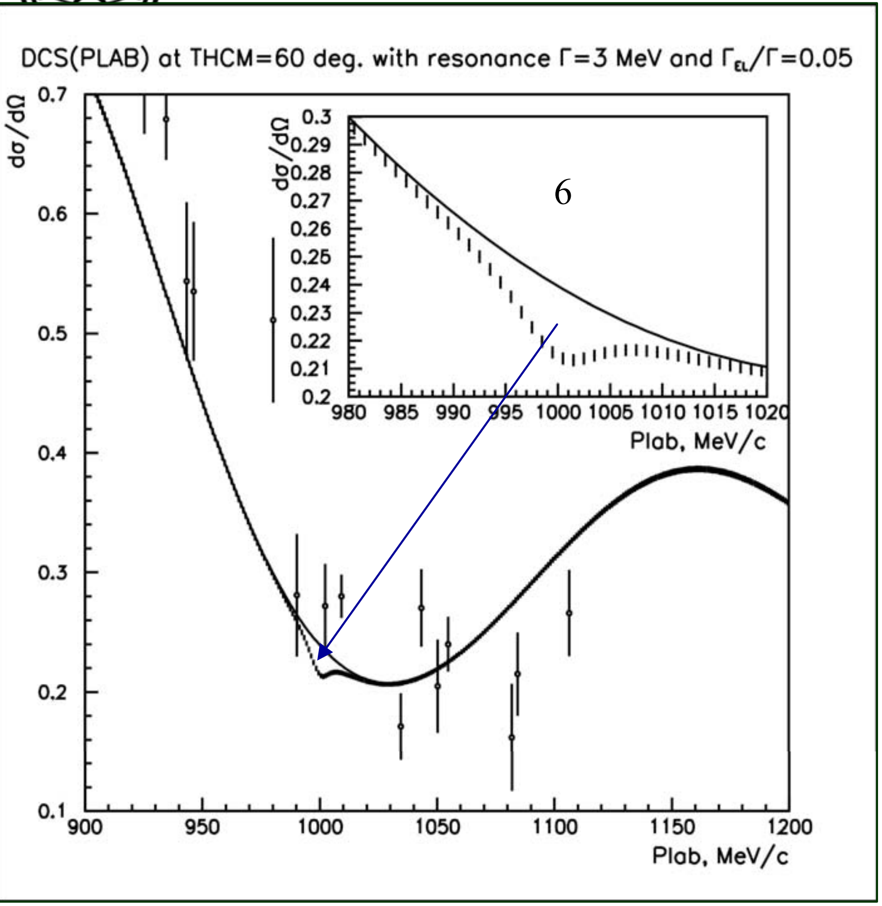
Two-focused beam line optics provides the possibility to analyses the individual momentum of the beam pion with the accuracy up to (0.06-0.15)%, having the total momentum range of $\Delta p/p = \pm 2\%$. Wide energy range of (0.8–2.5) GeV/c can be covered by changing of the magnetic elements currents.

$N_{\overline{10}}$ The results of the measurements may be analyzed by the standard procedure of the partial-wave (PWA) analysis, which is the important advantage of the "formation" type experiments.

In particular it means that all the quantum numbers of the resonance, if found, can be unambiguously determined. The results of the measurements in the two channels will be compared.

Next figure illustrates how could be seen in the elastic scattering assuming its full width equal 6 MeV, elasticity X=5% and mass 1671 MeV. The insertion in the top right corner is the zoom of the area around the resonance. Error bars and the point density correspond to the proposed statistical accuracy nd momentum resolution. It's worth mentioning that the effect of the resonance can be either a minimum (as in the figure), a maximum or a bipolar structure, dependent on its unpredictable pole residue phase.

Sensitivity of the elastic scattering measurements.



- Elastic scattering:
  - We measure differential cross-section with statistical precision 0.5 % and step in the invariant mass 0.5 MeV at the angles 40-120^o CM.
  - Momentum range 900-1200 MeV/c ⇒ 1610-1770 MeV
  - ~20 days of running
- KΛ:
  - Differential cross-section with statistical precision 1% and step in the invariant mass 0.5 MeV at the angles 0-180^o CM.
  - Momentum range 900-1200 MeV/c ⇒ 1610-1770 MeV
  - ~24 days of running

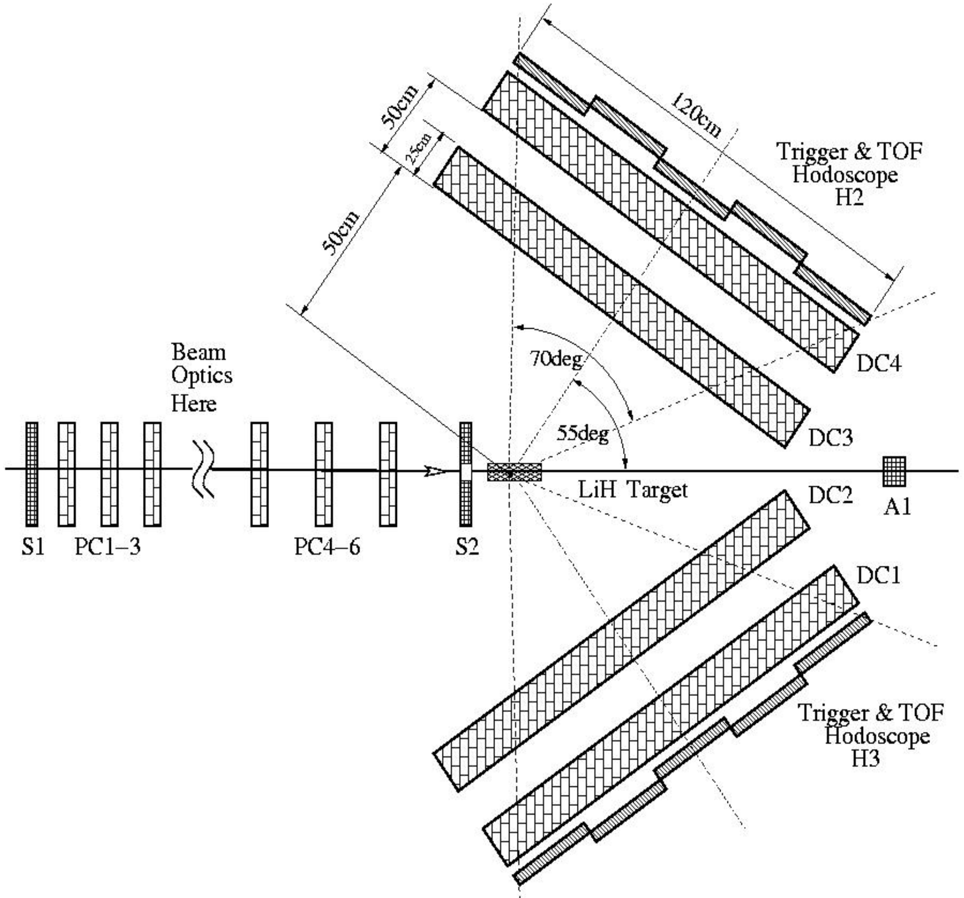
	Elastic scattering	KΛ
Width	(2-20) MeV	(2-20) MeV
Elastic width, Γ_{el}	>0.1 MeV	>0.02 MeV
Elasticity, X	>0.05	>0.01

EPECURE – elastic scattering.

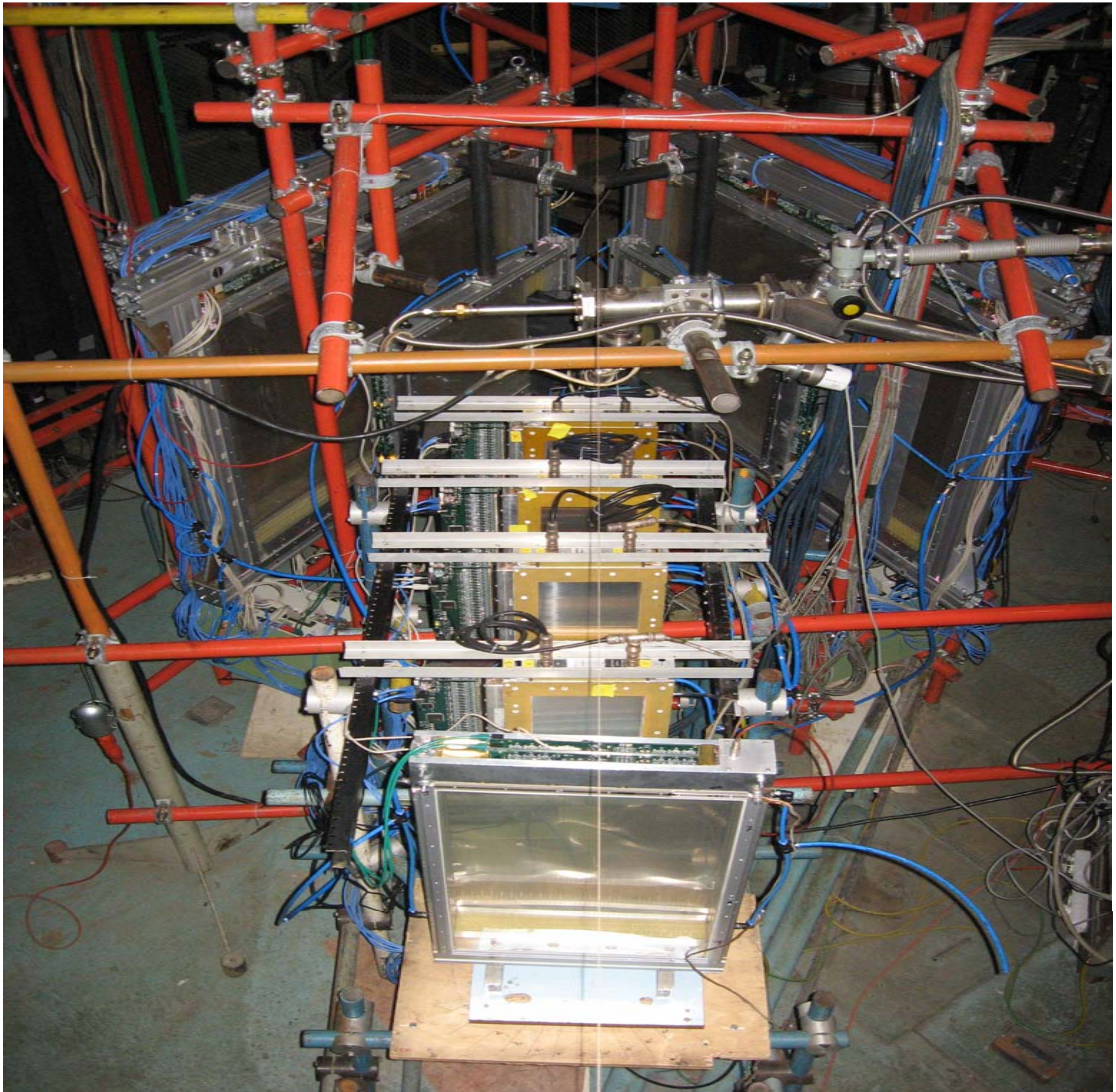
•Method: measure differential cross-section at the angles 40-120° CM as function of the invariant mass of π^-p-system. Main parts of experimental setup are liquid hydrogen target and proportional and drift chambers.

•"Formation"-type experiment: invariant mass resolution (0.7 MeV) is based on the high momentum resolution (0.1%) of the magneto-optic channel.We want to reach statistic resolution as high as 0.5 %. We can get clear evidence for a narrow (2-20 MeV) resonance even if its elastisity is only 1%.

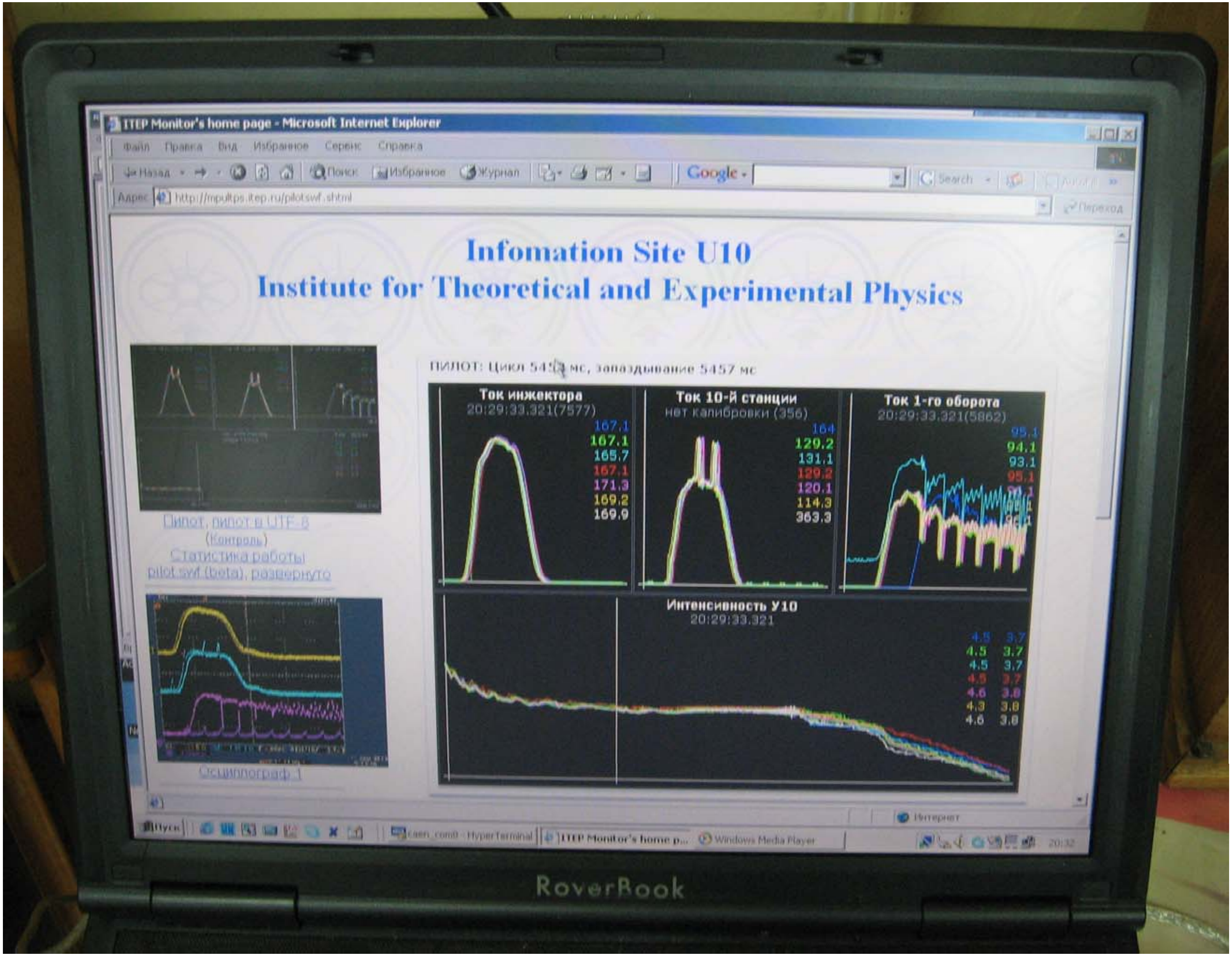
$\pi^-p \rightarrow \pi^-p$



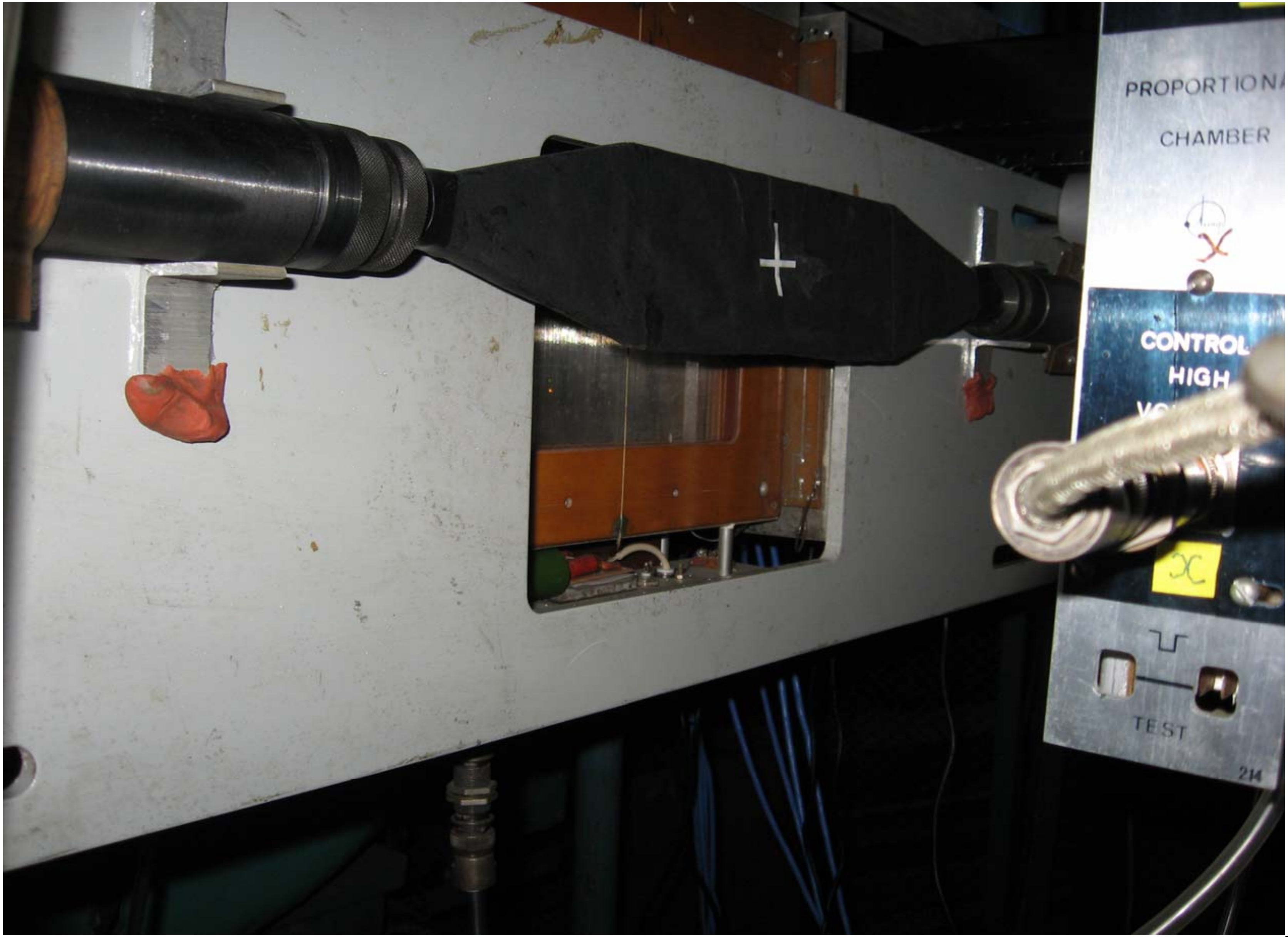
EPECURE – current status.



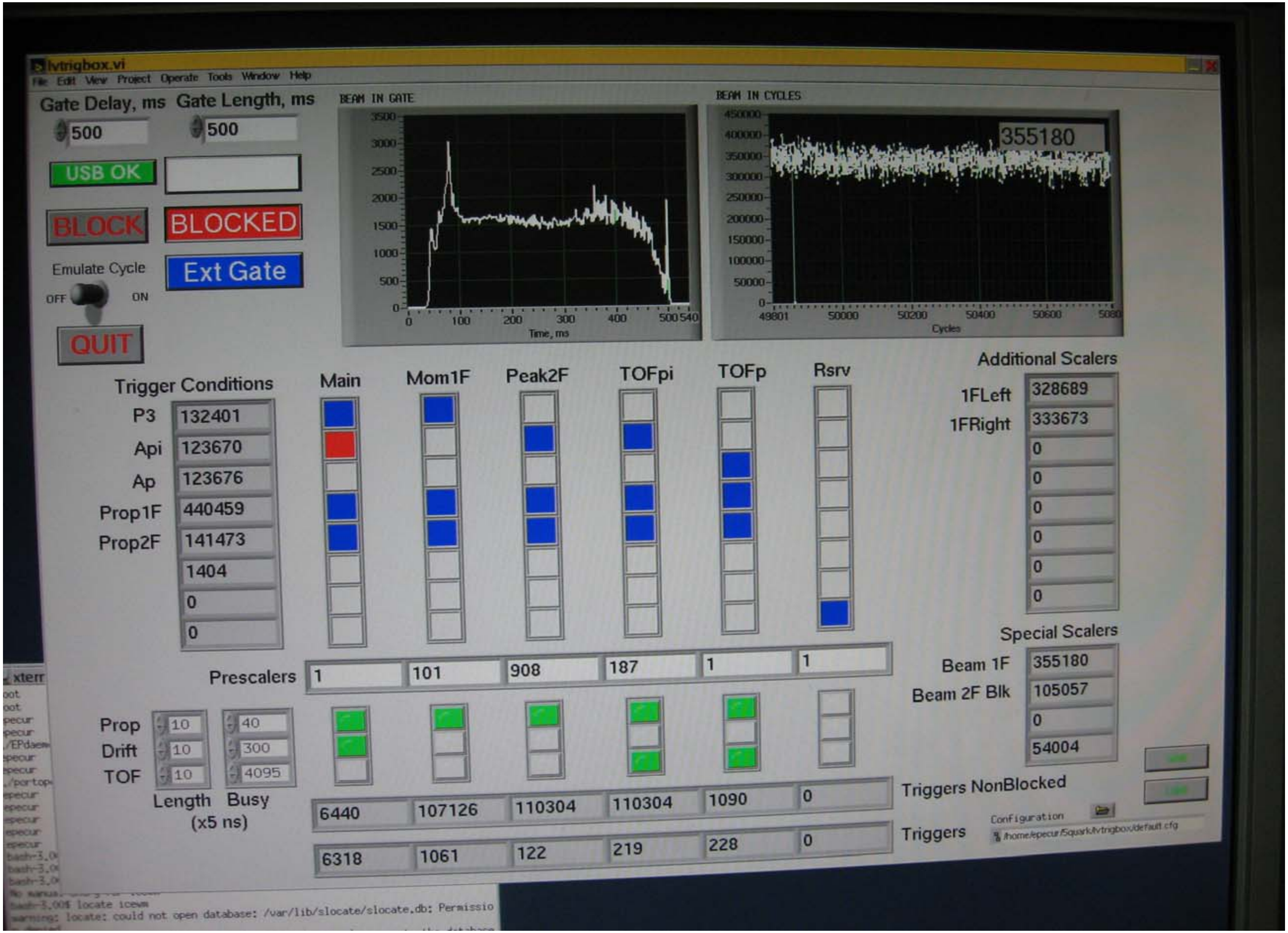
U 10 - proton beam.



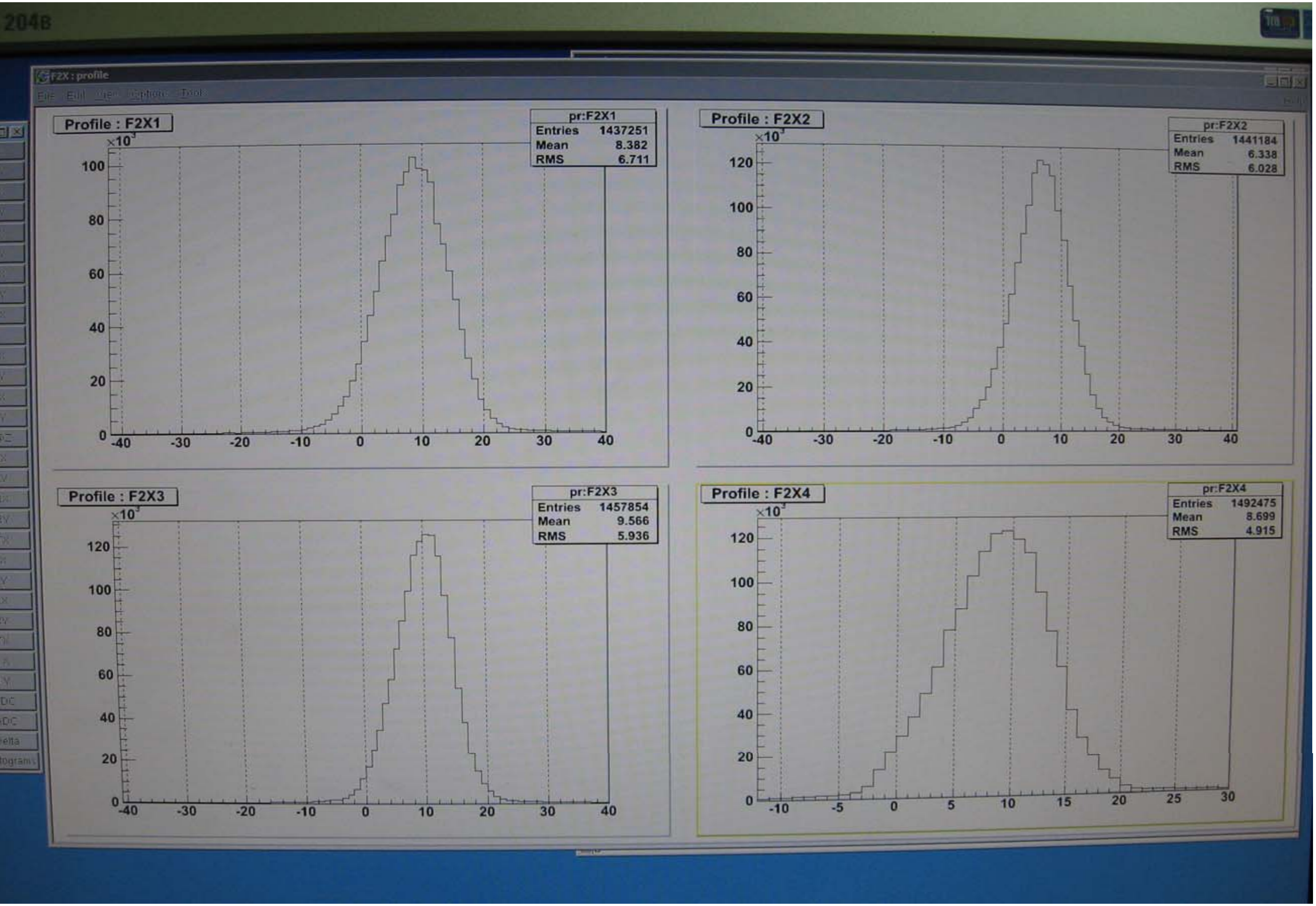
Pion beam counter – first focus.



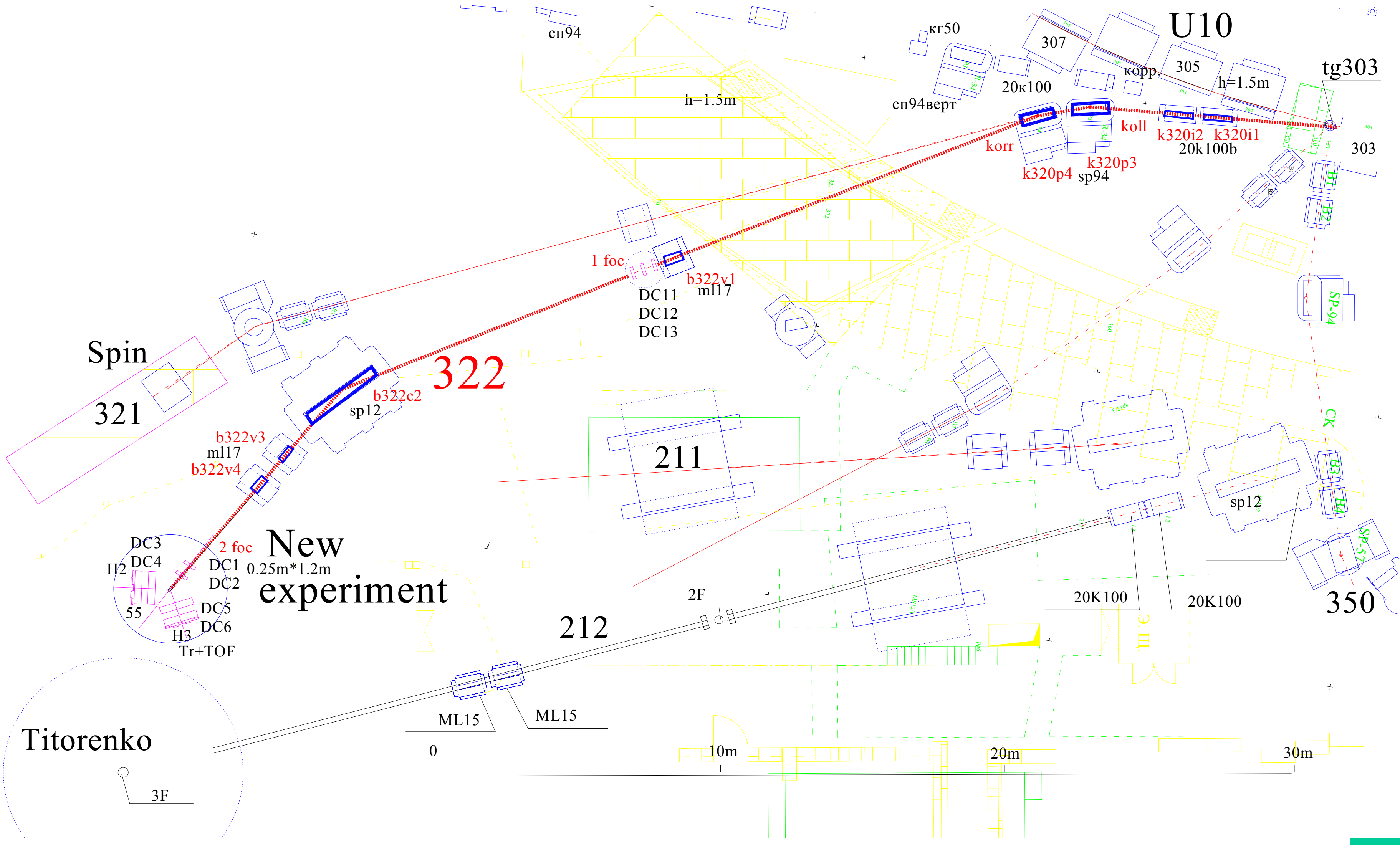
U 10 - pion beam.



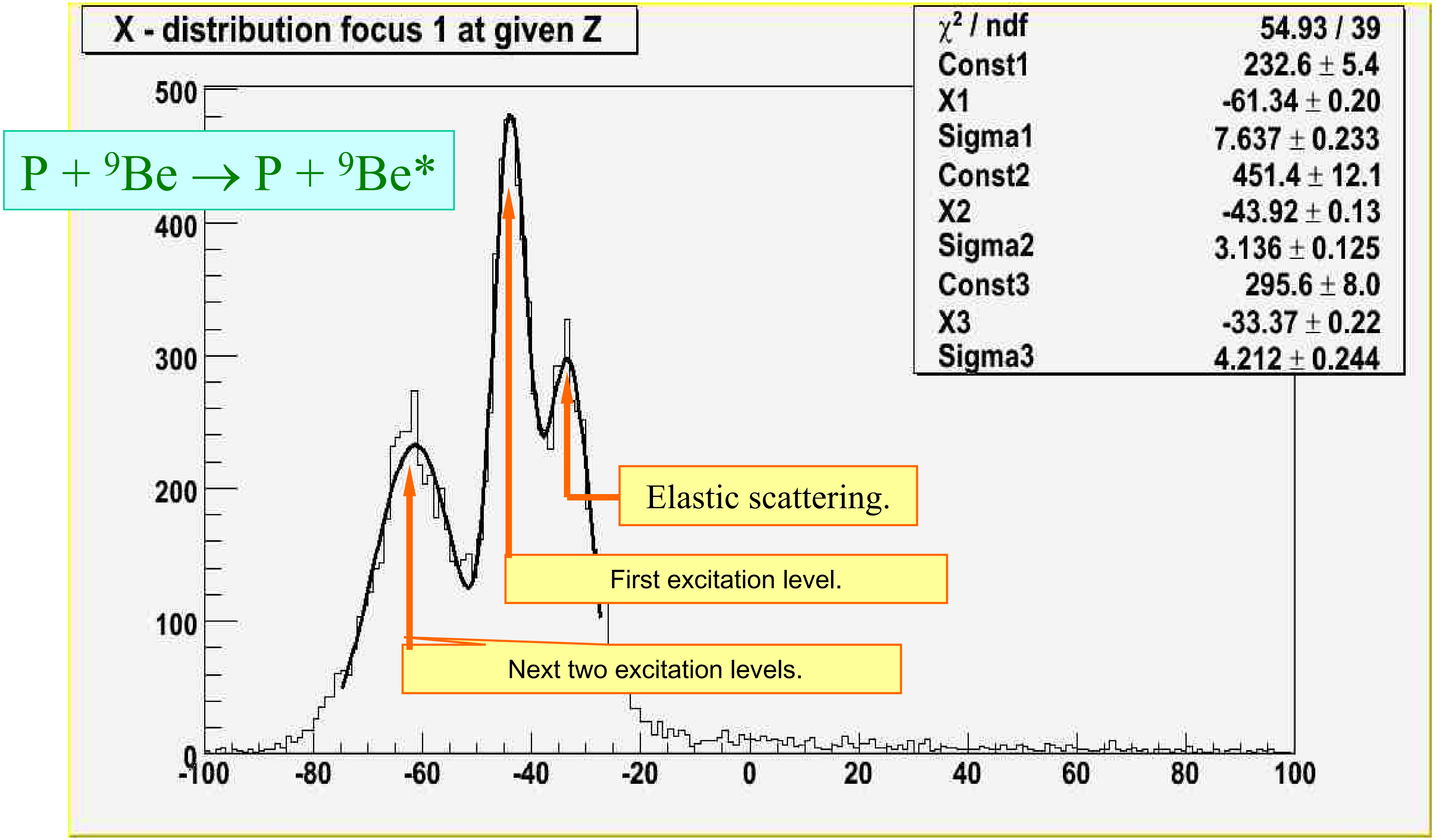
Pion beam in 2 focus.



Pion channel № 322.

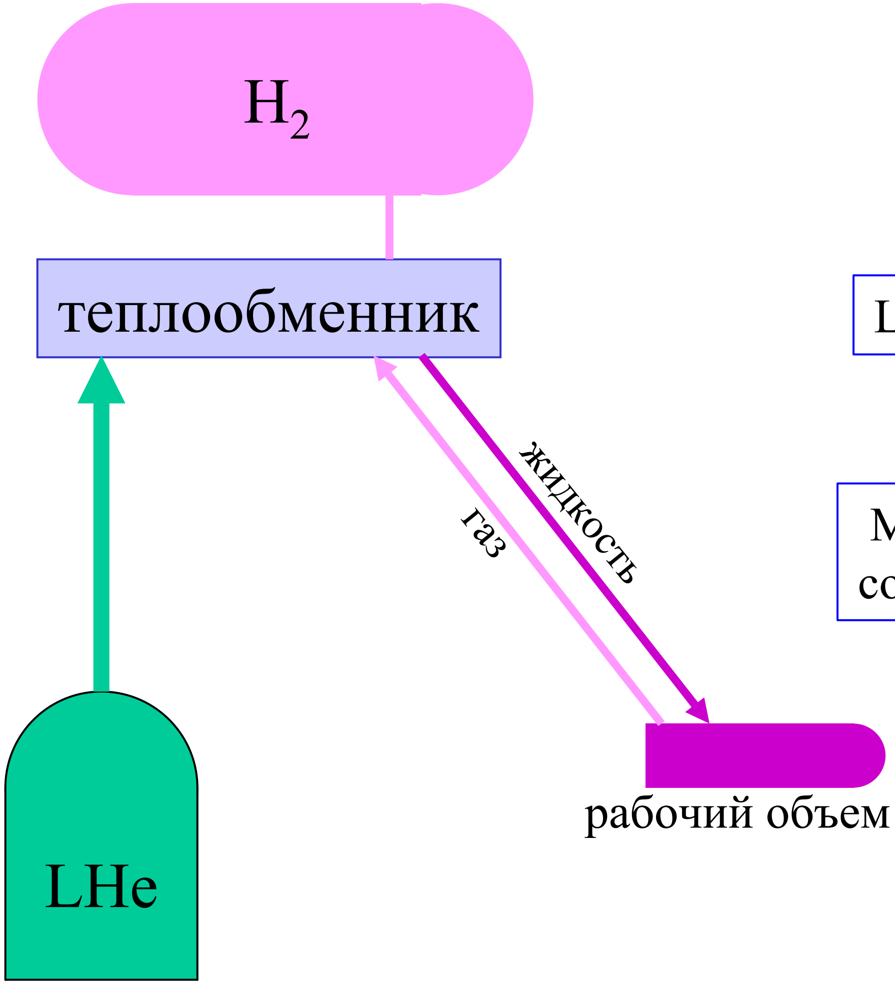


Pion channel resolution.

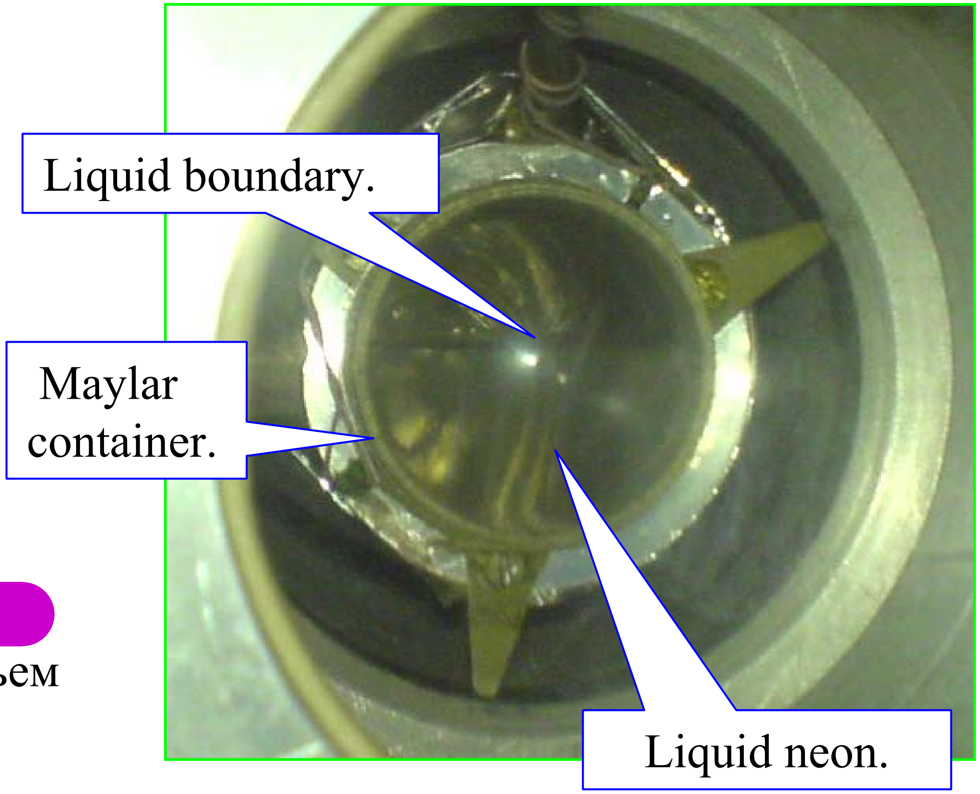


$\Delta P/P = 0.06\%$

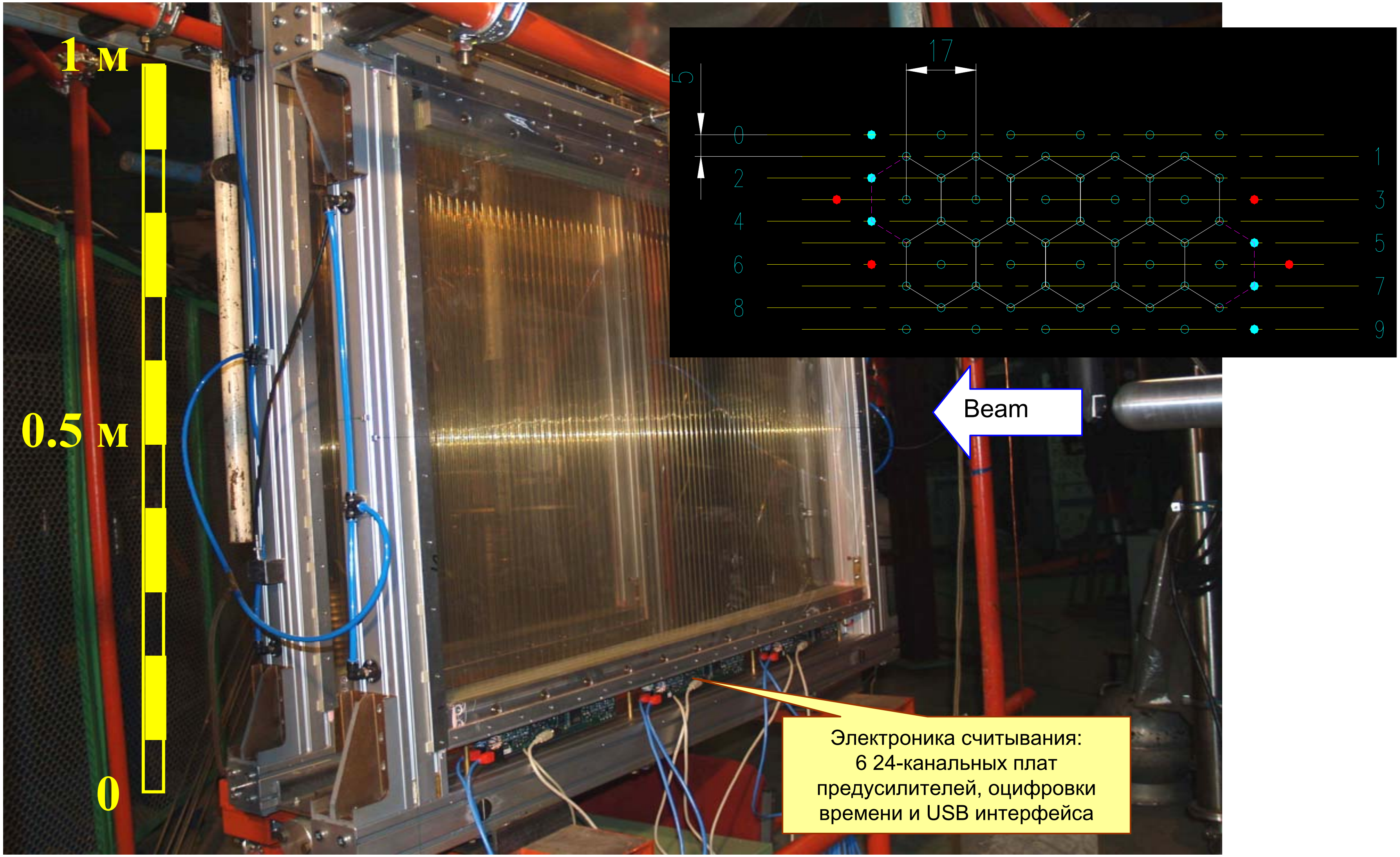
Liquid hydrogen target.



Neon test.



Drift chambers.

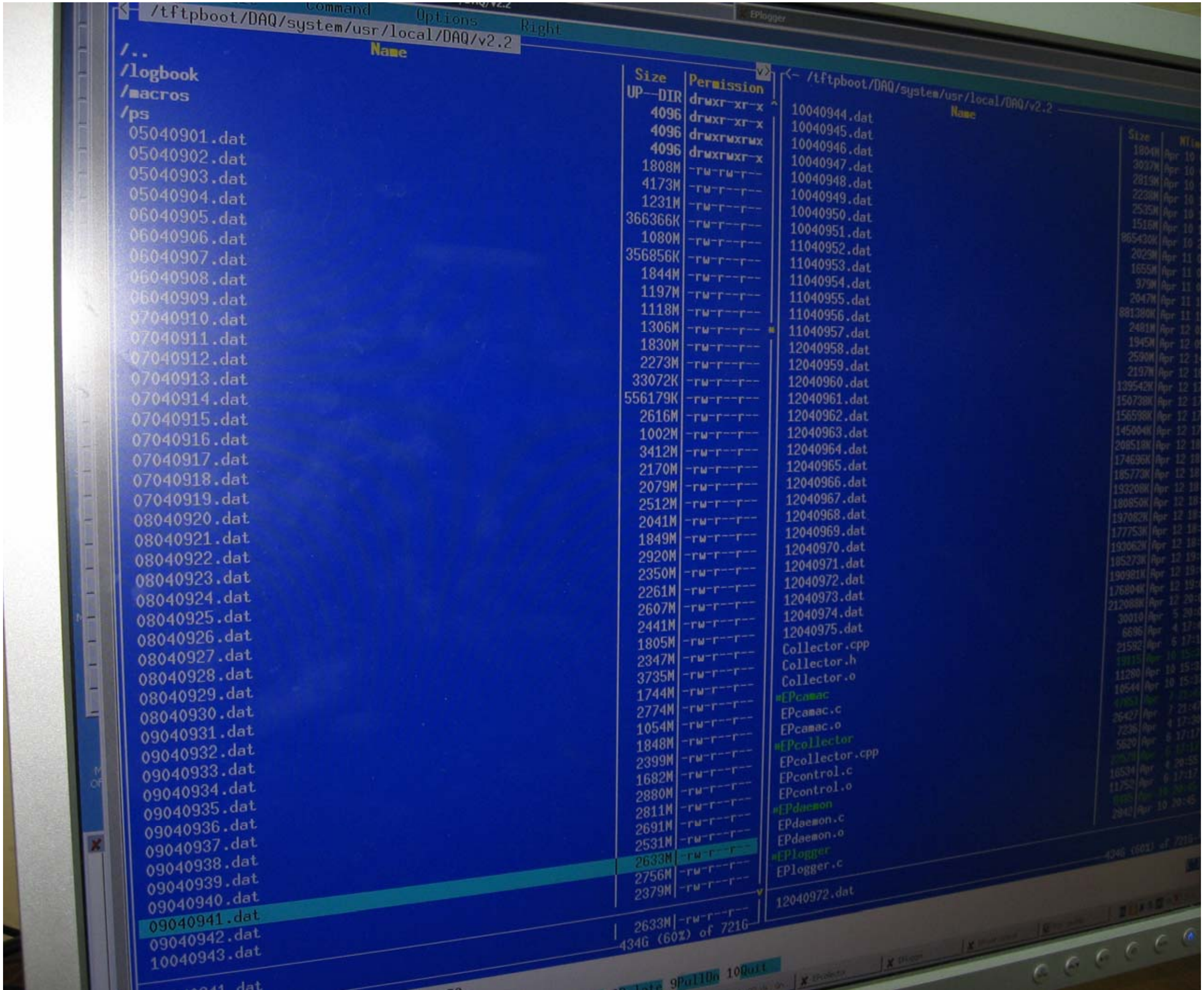


Information from drift chambers

Information about statistics from run March-April 2009

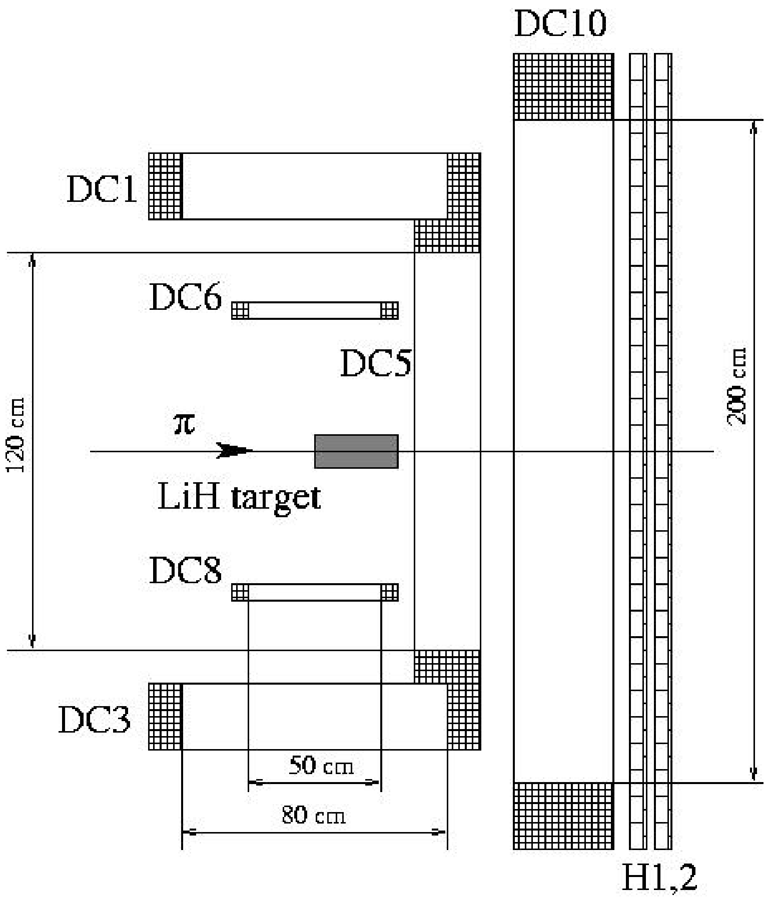
Momentum (MeV/c)	Triggers	Size (Mb)
940	28471194	7354
955	31040346	8062
970	34621416	9881
985	39099209	10299
1000	38293063	10060
1015	36900000	9818
1030	39782780	10348
1045	38293817	10135
1060	40700000	10642
1075	38262212	9859
1090	34642196	8732
1105	27291091	7578
1120	35061766	9059
1135	10772000	2775

Information at screen.



Setup for $N_{\overline{10}}$ search in $\pi^- p \rightarrow K\Lambda$ reaction.

The proposed setup included:
5 drift chambers with sensitive area 800x1200 mm^2;
4 inner drift chambers with sensitive area 500x700 mm^2;
4 drift chambers with sensitive area 1600x2400 mm^2;
The two-coordinate segmented hodoscope with cell size 100x100 mm^2;
The beam part of setup is exactly the same as in the elastic setup.



Setup for Baryon Resonance Study in the Reaction $\pi^- p \to K\Lambda$

The reaction $\pi^- p \to K\Lambda$ has several properties attractive for the baryon spectroscopy studies in general and for the proposed experiment in particular:

- ❖ Pure isotopic state with isospin ½
- ❖ Sizeable threshold of $K\Lambda$ production facilitating the study of resonances with small spin and large mass
- ❖ High analyzing power of $\Lambda \to \pi^- p$ weak decay with the asymmetry $\alpha=0.642$
- ❖ The threshold of $K\Lambda$ production is lower than the threshold of competitive process with $K^0\Sigma^0$ production
- ❖ Significant fraction of the charged mode (22% of the total reaction cross-section)
- ❖ Large total cross-section (~0.9 mb, [25]) in the considered energy interval

These arguments along with the ones from Sec. 1.1.3 and 1.1.4 makes $\pi^- p \to K\Lambda$ reaction extremely attractive for the search of the cryptoexotic state $N_{\overline{10}}$

Conclusions.

The "missing" resonance problem is one of the radical problem of the modern physics.
It is clear today, that the problem of the "missing" baryon resonances can't be resolved without of additional investigation of the pion-nucleon interactions.
The problem of the narrow resonances must be resolved.
The inelastic channels must be systematically investigated for pion-nucleon interaction in the whole resonance region.