Observation of a Θ^+ -Baryon decay to pK⁰_S in K⁺ and neutrino interactions with nuclei

DIANA collaboration of ITEP, Moscow & Frascati: V.V. Barmin, V.S. Borisov, G.V. Davidenko, A.G. Dolgolenko, C. Guaraldo, I.F. Larin, V.A. Matveev, C.Petrascu,V.A.Shebanov, N.N. Shishov, L.I. Sokolov, G.K. Tumanov and re-analysis of data of Big Bubble Chamber Neutrino Collaboration by A. Asratyan, A. Dolgolenko, M. Kubantsev

M. Kubantsev, ITEP/NWU

Observation of \Theta^+ in the DIANA bubble chamber



Separated beam of K⁺ mesons with momentum of 750 MeV/c from ITEP **10 GeV proton accelerator** irradiates **DIANA** chamber filled with liquid Xenon: density: 2.2 g/cm³ Rad. length: 3.7 cm Volume: 700 liters Viewed with 4 cameras No magnetic field

The DIANA chamber under preparation

M. Kubantsev, ITEP/NWU



Charged particles: identified by ionization; momentum measured by range. Interaction energy is determined by range of the kaon before interaction: K⁺+N→ ⊕⁺→ P+ K⁰ (+1 strangeness!)

Protons are identified by range. K_{S}^{0} are fitted to the vertex. About 25000 events with visible K_{S}^{0} decays: $K_{S}^{0} \rightarrow \pi^{+}\pi^{-}$ and $K_{S}^{0} \rightarrow \pi^{0}\pi^{0}$ have been found.

M. Kubantsev, ITEP/NWU



K⁺ range distributions:

(1) all incoming K⁺ : peak at 945 mm corresponds to decays of stopping kaons;

(2) K⁺ decays (mostly in rest);
all kaon decays are uniquely
identified (+branching ratios are
verified);

(3) charge exchange reaction events: $K^+Xe \rightarrow K^0 X$.



K⁺ with range more than 550 mm are selected:

K⁺ momentum distribution has a peak at 470 MeV/c for events of reaction: K⁺Xe →K⁰ pX

M. Kubantsev, ITEP/NWU



Estimation of K⁰ p effective mass reconstruction accuracy was made with observed decays $\Lambda^0 \rightarrow p \pi^$ observed value of mass (p π^-) 1116 ±1 MeV/c²

and instrumental width : $\sigma = 3.3 \pm 1.0 \text{ MeV/c}^2$

(in similar momentum range as in K⁰ p reaction !)



Pentaquark Workshop 2003, Nov 6-8,

Observation of \Theta^+ in the DIANA bubble chamber



Effective mass of K⁰p system fitted by linear combination of **Monte-Carlo simulated and** random star background distributions. Qualitatively, there is a narrow enhancement at $M \sim 1530-1540 \text{ MeV/c}^2$ of 107 events over background of 84 (significance of 2.6 σ)







- Above we presented direct approach to search for Θ^+ analyzing effective mass of K⁰ p system.
- Another approach is to measure cross sections for formation of $K^0\,p$, K^+n and $K^+\,p$ final states as function of $\sqrt{\,s}$:



Work on the K⁺ Xe cross section data continues.

M. Kubantsev, ITEP/NWU



PDG 2002 tables show very scarce cross section data in region of K⁺ momenta below 600 MeV/c.

M. Kubantsev, ITEP/NWU Pentaquark Workshop 2003, Nov 6-8, Jlab 11



M. Kubantsev, ITEP/NWU Pentaquark Workshop 2003, Nov 6-8, Jlab 12

Observation Θ⁺ → P+ K⁰_S in (Anti)Neutrino Interactions (strangeness is unidentified)

re-analysis of data of the Big Bubble Chamber Neutrino Collaboration are analysed by A. Asratyan, A. Dolgolenko and M. <u>Kubantsev</u> (ITEP, Moscow)

M. Kubantsev, ITEP/NWU

Two big bubble chambers: Fermilab 15' and CERN BEBC, were close to each other in geometry, fiducial volume and operation conditions.Data were collected and processed using very similar techniques and algorithms.

Neutrino interactions were recorded in wide band neutrino beams of Fermilab 400 GeV accelerator (E180) and 800 GeV Tevatron (E632) with Neon-Hydrogen fill of 15' BC and CERN 450 GeV accelerator with Hydrogen (WA21), Deuterium (WA25) and Neon (WA59) fills of BEBC.

These experimental data compiled by A. Asratyan (ITEP) comprise some 120000 (Anti)Neutrino charge current (CC) events*:

 $v_{\mu}(\overline{v_{\mu}}) + A \rightarrow \mu^{-}(\mu^{+}) + X.$

Neutral current events: $\overline{v}_{\mu}(v_{\mu}) + A \rightarrow \overline{v}_{\mu}(v_{\mu}) + X$ are not included (not measured systematically).

Even after several decades the bubble chamber neutrino data are still unrivaled in quality and completeness of physics information. We analysed CC events with the hadron system (X) containing protons (identified) + $K_s^0 \rightarrow \pi^+\pi^-$ (fitted) +X'.

*Unfortunately E53 data are not included (61800 CC v_u Ne events)

M. Kubantsev, ITEP/NWU

Experiment	WA21	WA25	WA59	E180	E632	Total
Chamber	BEBC	BEBC	BEBC	15' B.C.	15' B.C.	
Fill	Hydrogen	Deuterium	Neon-H2	Neon-H2	Neon-H2	
Neutrinos:						
Mean ,GeV	48.8	51.8	56.8	52.2	136.8	59.5
Mean momentum						
of detected K0S, GeV/c	5.7	5.7	4.5	3.4	7.7	5.8
All measured CC events	18746	26323	9753	882	5621	61325
CC events with K0S	1050	1279	561	21	587	3498
CC events with K0S and						
identified protons						
(900>P>300 MeV/c)	78	128	193	8	157	564
Antineutrinos:						
Mean ,GeV	37.5	37.9	39.5	33.8	110	39.5
Mean momentum						
of detected K, GeV/c	4.2	4.2	3.5	3.4	7.6	4.1
All measured CC events	13155	16314	15693	5927	1190	52279
CC events with K0S	702	761	631	231	123	2448
CC events with K0S and						
identified protons						
(900>P>300 MeV/c)	43	57	185	54	28	367

M. Kubantsev, ITEP/NWU Pentaquark Workshop 2003, Nov 6-8,



Identified protons emitted in momentum range of 300<P<900 MeV/c in association with K_{S}^{0} in $v_{\mu}CC$ and $\overline{\mathbf{v}}_{\mathbf{u}}\mathbf{C}\mathbf{C}$ collisions with Hydrogen, Deuterium, and Neon are used in the analysis.

17

ITEP/NWU



M. Kubantsev, ITEP/NWU Pentaquark Workshop 2003, Nov 6-8,



K⁰_S p (identified) invariant mass distributions for $v_{\mu}CC + \overline{v}_{\mu}CC$ events: random star background is shown by dots; open histogram is for Neon events with one identified proton only. Note: no events enter in the peak region twice.

M. Kubantsev, ITEP/NWU Pentaquark Workshop 2003, Nov 6-8,



K⁰_S p (identified) invariant mass for $v_{\mu}CC$ and $\overline{v}_{\mu}CC$ events combined with the random star background: 27 events with ~8 events of the background; significance of 6.7σ . The same distribution with bins shifted by 5Mev is fitted to get mass and width of the peak. Width of the peak is compatible with instrumental resolution.

M. Kubantsev, ITEP/NWU Pentaquark Workshop 2003, Nov 6-8,

Peak events mean values of

- neutrino energy of E_v (57±10 GeV) and transverse 4-momentum $Q^2(12.5\pm3.3 \text{ GeV}^2)$
- are consistent with those for all events with K⁰_{S.}
- No strangeness determined ! But
- there are no known Σ^+ states in this region. We interpret the peak at 1533 MeV/c² a signal of formation of the Θ^+ . Further observations:
- (1) Θ^+ production cross section by neutrinos appears to increase with atomic number of the target nucleus;
- (2) Relative v and \overline{v} yields of Θ^+ are close;
- (3) Associated production of neutral strange particles is not different from other events with K_{S}^{0} (specially no excess of Λ^{0}).

M. Kubantsev, ITEP/NWU Pentaquark Workshop 2003, Nov 6-8,

Comparison of Θ^+ and $\Sigma^+(1385) \rightarrow \Lambda^0 + \pi^+$ in (anti)neutrino interactions



M. Kubantsev, ITEP/NWU Pentaquark Workshop 2003, Nov 6-8,

Comparison of Θ^+ and $\Sigma^+(1385)$ in (anti)neutrino interactions

- Qualitatively we see most of Θ^+ signal on Ne and small one on H_2 and D_2 with roughly the same luminosity.
- At the same conditions $\Sigma^+(1385)$ signal is seen on H₂ and D₂ and it is not seen on neon.
- **Observed v** and \overline{v} yields of Θ^+ are about the same.
- Σ^+ (1385) is mostly produced in v, not v beam.
- Observed Θ^+ are produced slow moving in lab system: may speculate that it is produced by re-scattering of secondary kaons(?) in nuclei.
- Σ^+ (1385) are produced at higher momenta and charge of interacting quark (+2/3 for v and -1/3 for \overline{v}) is important. Re-interactions in nuclei apparently destroy Σ^+ (1385) peak.

M. Kubantsev,	
ITEP/NWU	

Conclusions

A signal of Θ⁺→pK⁰_S is observed on level of 4.4 σ in K ⁺ Xe and

 6.7σ in neutrino interactions with Neon and Deuterium. Mass values and widths are found:

M = 1539 \pm 2 MeV/c² and Γ (observed)<9MeV/c²(K⁺Xe)

 $M = 1533 \pm 5 \text{ MeV/c}^2$ and $\Gamma(\text{observed}) \leq 20 \text{MeV/c}^2(\text{vNe+vD}_2)$

Low energy K⁺ cross sections with nucleons and nuclei are not well known, there are some hints of cross section enhancement at

 \sqrt{s} ~ 1530-1540 MeV from old and not so old data.

Work on the K⁺ Xe cross section data continues.

The cross section of Θ^+ production by neutrinos appears to increase with atomic number of the target nucleus.

M. Kubantsev,	
ITEP/NWU	