Evidence for Formation of $K^0_s p$ Resonance's in (Anti)Neutrino Interactions

Further (preliminary) results of re-analysis of data of the Big Bubble Chamber Neutrino Collaboration: BEBC(CERN)+ 15'BC(FNAL)

by A. Asratyan, A. Dolgolenko

and

M. Kubantsev

(ITEP, Moscow)

Paying tribute for burial place of the 15' BC PentaQuark Detector (Fermilab)

The archeological site with one of the diggers.

Another of the BEBC, is by the CERN Theory Division

First result of the study:

Observation $\Theta^+ \rightarrow P + K^0_S$ in (Anti)Neutrino Interactions

has been published in hep-ex/0309042, Yad. Fiz. 67, 704 (2004) [Phys.At.Nucl.67,682(2004)]

$K^0_s p$ resonance's in neutrino interactions

We consider data from series of neutrino experiments with two big bubble chambers:

Fermilab 15' and CERN BEBC.

These were close to each other in geometry, fiducial volume and operation conditions. Data were collected and processed using very similar techniques and algorithms. It allowed us to merge these data in one big set.

$K^0_s p$ resonance's in neutrino interactions

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.

$K^0_S p$ resonance's in neutrino interactions

These experimental data compiled by A. Asratyan (ITEP) comprise some 120000 (Anti)neutrino charge current (CC) events*: $\nu_\mu (\bar{\nu}_\mu) + A \rightarrow \mu^- (\mu^+) + X$.

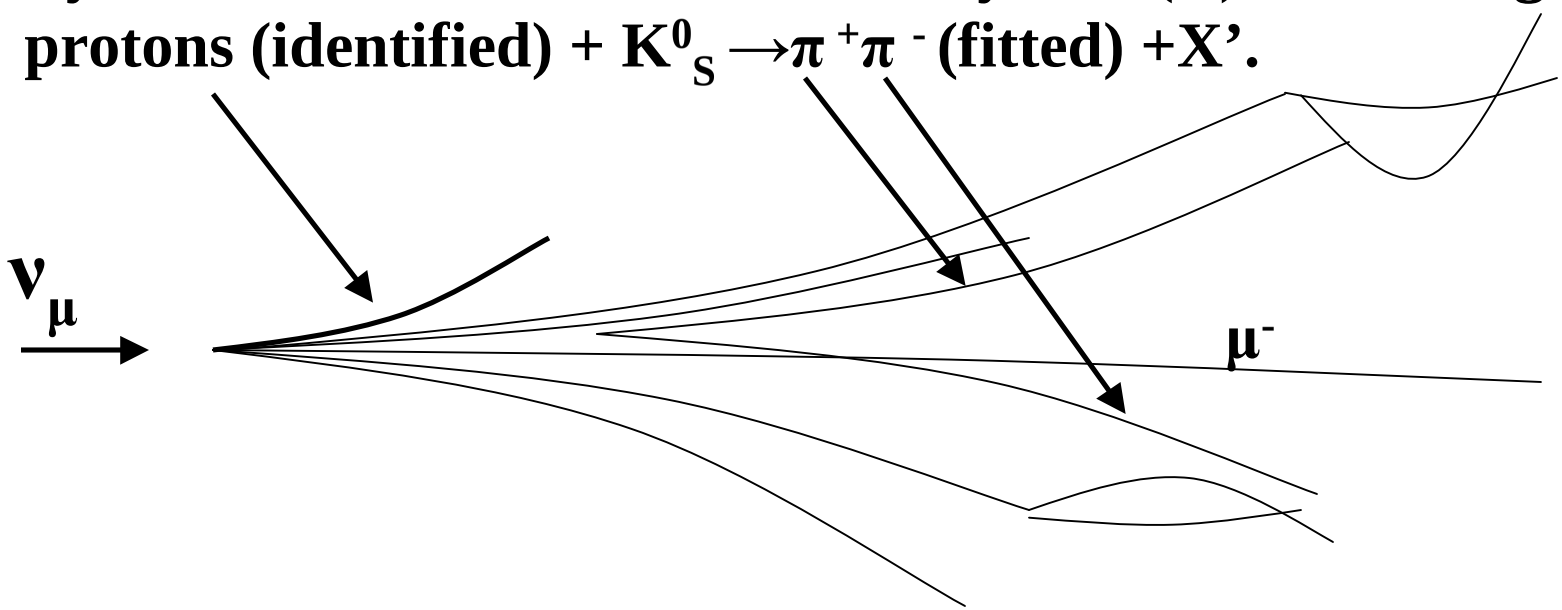
Neutral current events: $\nu_\mu(\bar{\nu}_\mu)+A \rightarrow \nu_\mu(\bar{\nu}_\mu) + X$ are not included (not measured systematically).

Even after several decades the bubble chamber neutrino data are superb in quality and completeness of physics information (see below about NOMAD experiment).

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

$K^0_S p$ resonance's in neutrino interactions

We analysed CC events with the hadron system (X) containing protons (identified) + $K^0_S \rightarrow \pi^+\pi^-$ (fitted) +X'.



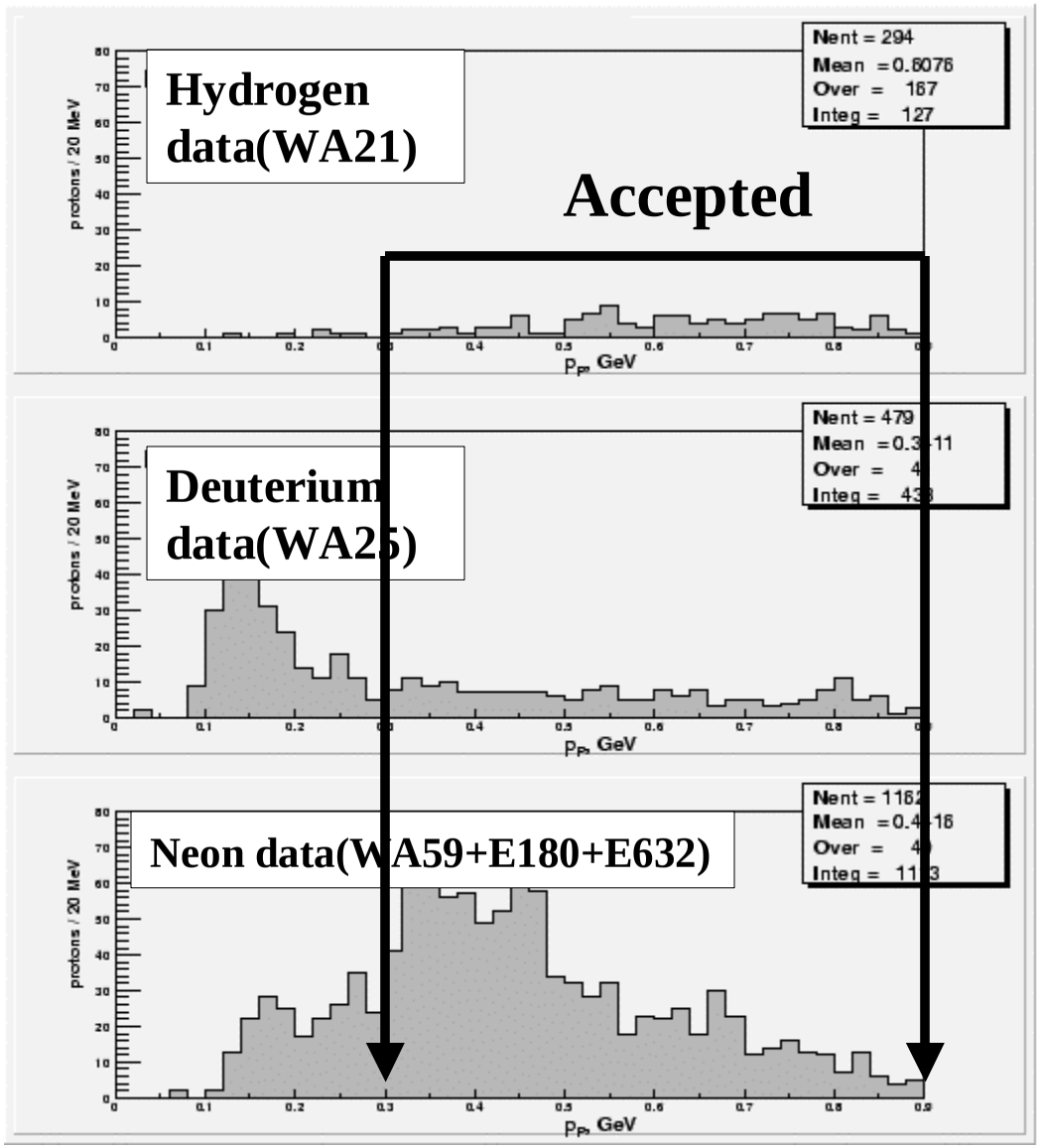
Sketch of the neutrino event in the bubble chamber

$K^0_S p$ resonance's in neutrino interactions

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

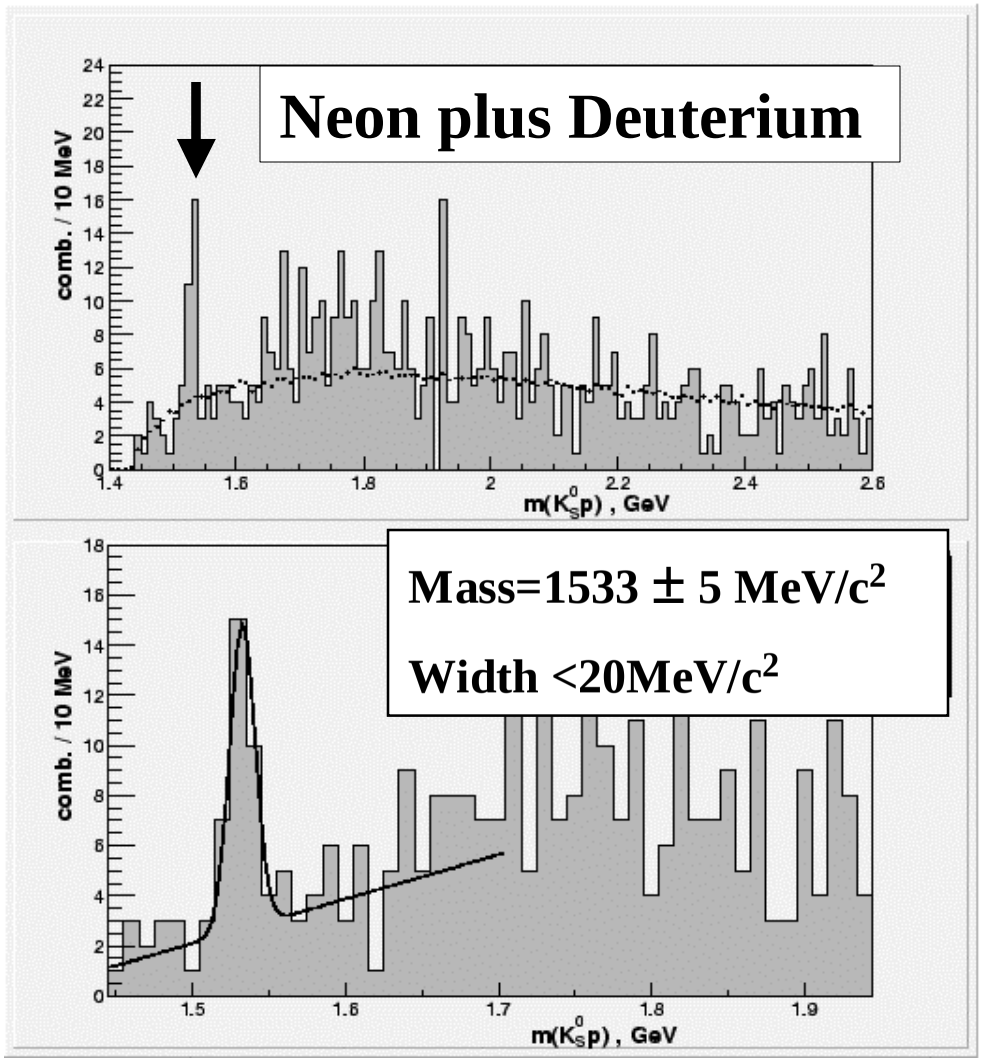
Neutrino (D+Ne) 42579,(Ne) 22810; Antineutrino (D+Ne) 39124,(Ne) 16256 events

$K^0_s p$ resonance's in neutrino interactions



Published analysis: Identified protons emitted in momentum range of 300<P<900 MeV/c in association with K^0_S in ν_μCC and $\bar{\nu}_\mu$CC collisions with Hydrogen, Deuterium, and Neon are used.

$K^0_S p$ resonance's in neutrino interactions



K^0_S p (identified) invariant mass for ν_μCC and $\bar{\nu}_\mu$CC events combined with the random star background:

26 events with ~8 events of the background; significance of 6.7 σ.

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.

$K^0_s p$ resonance $\Theta^+(1530)$: confirmation

Neutrino 2004
Paris
June 13th-19th, 2004

Precision Measurements in Neutrino Interactions

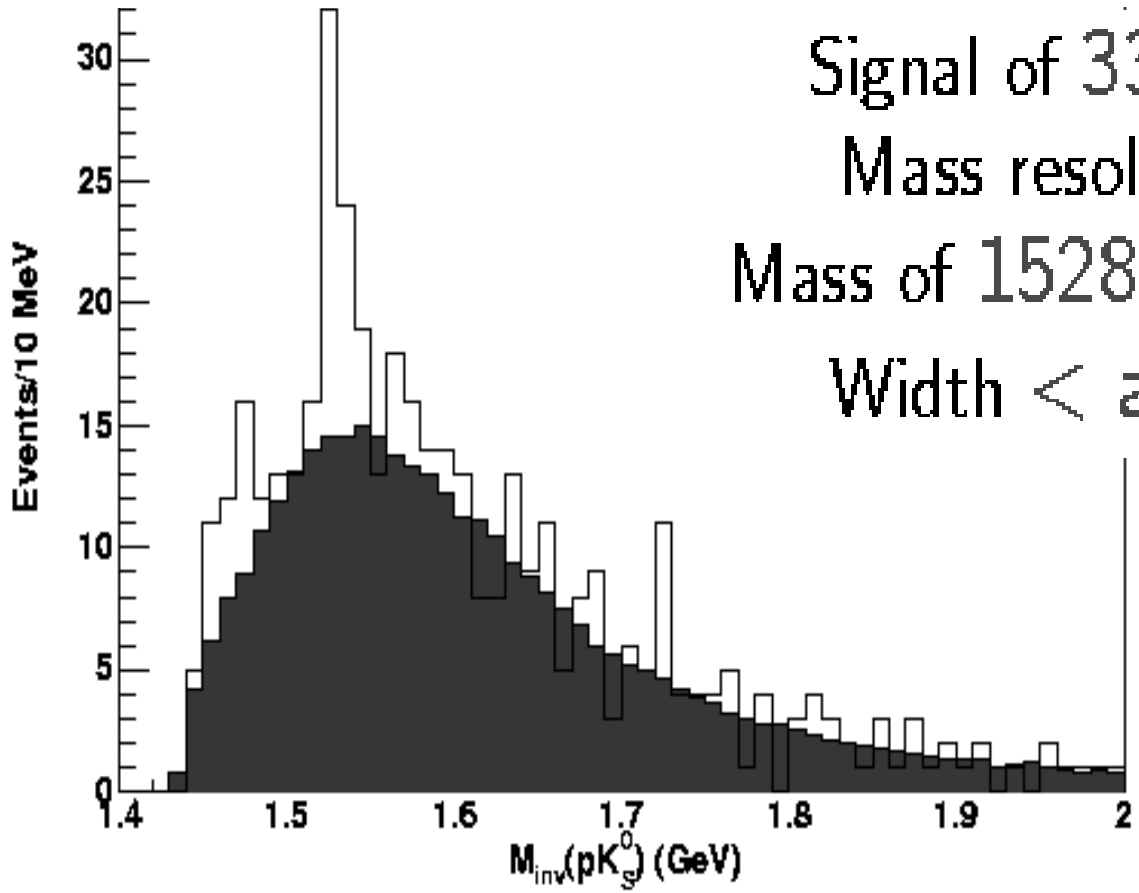
Leslie Camilleri
CERN

NOMAD searched for the Θ^+ in $K^0_s p$ in CC and NC.
NOMAD can reconstruct individual particles
and, in particular, 25000 K^0_s's. **(P>0.9 GeV/c)**
(Nucl. Phys. B621 (2002) 3)
High purity K^0_s sample and 60% purity proton sample.

$K^0_S p$ resonance $\Theta^+(1530)$: confirmation

Neutrino 2004
Paris
June 13th-19th, 2004

Leslie Camilleri
CERN



Signal of 33 events $\rightarrow$ 4.3 σ.

Mass resolution: 9 MeV/c^2

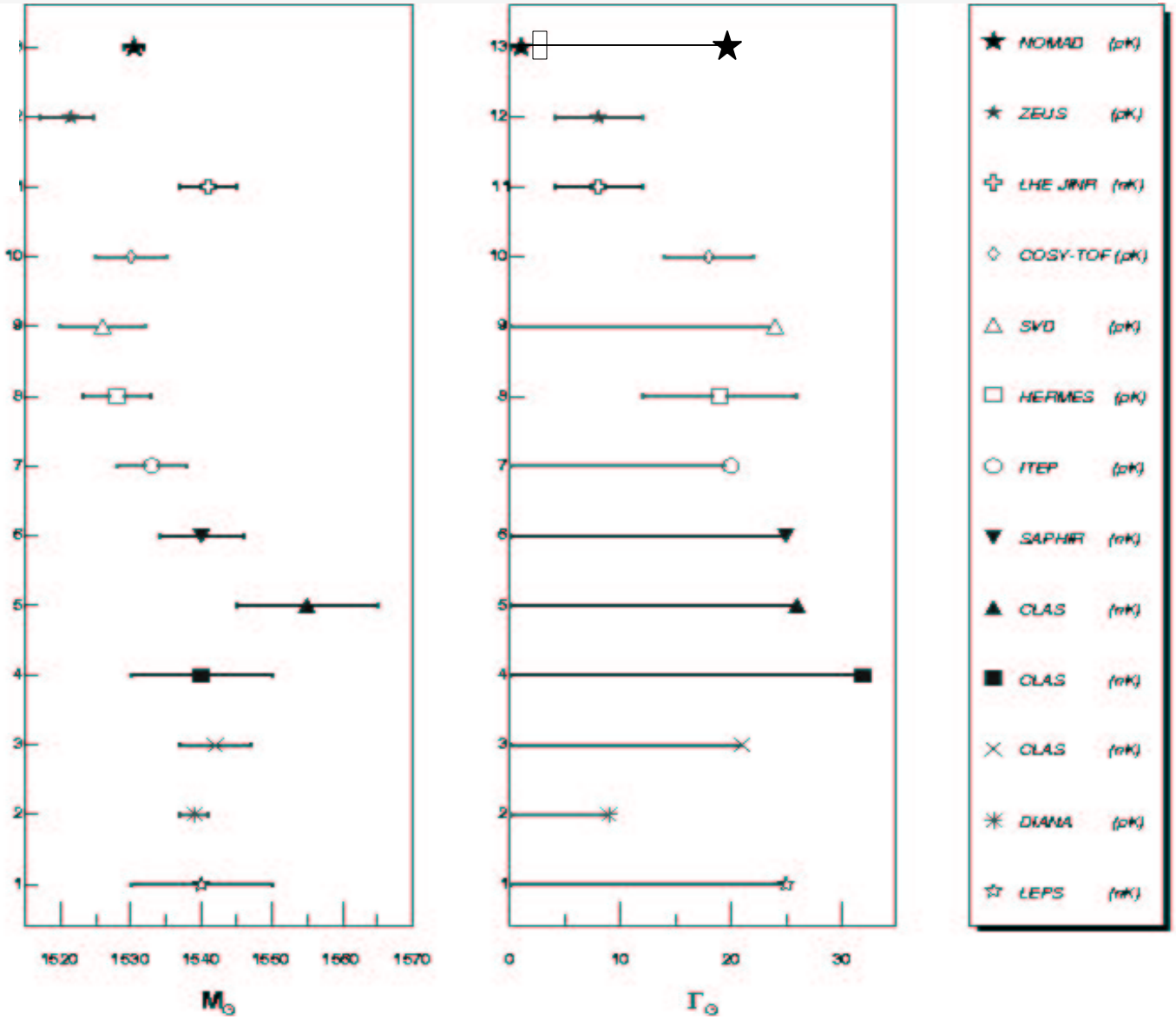
Mass of 1528.7 ± 2.5 MeV/c^2

Width $<$ a few MeV/c^2

$\Theta^+(1530)$ Mass and Width Summary:

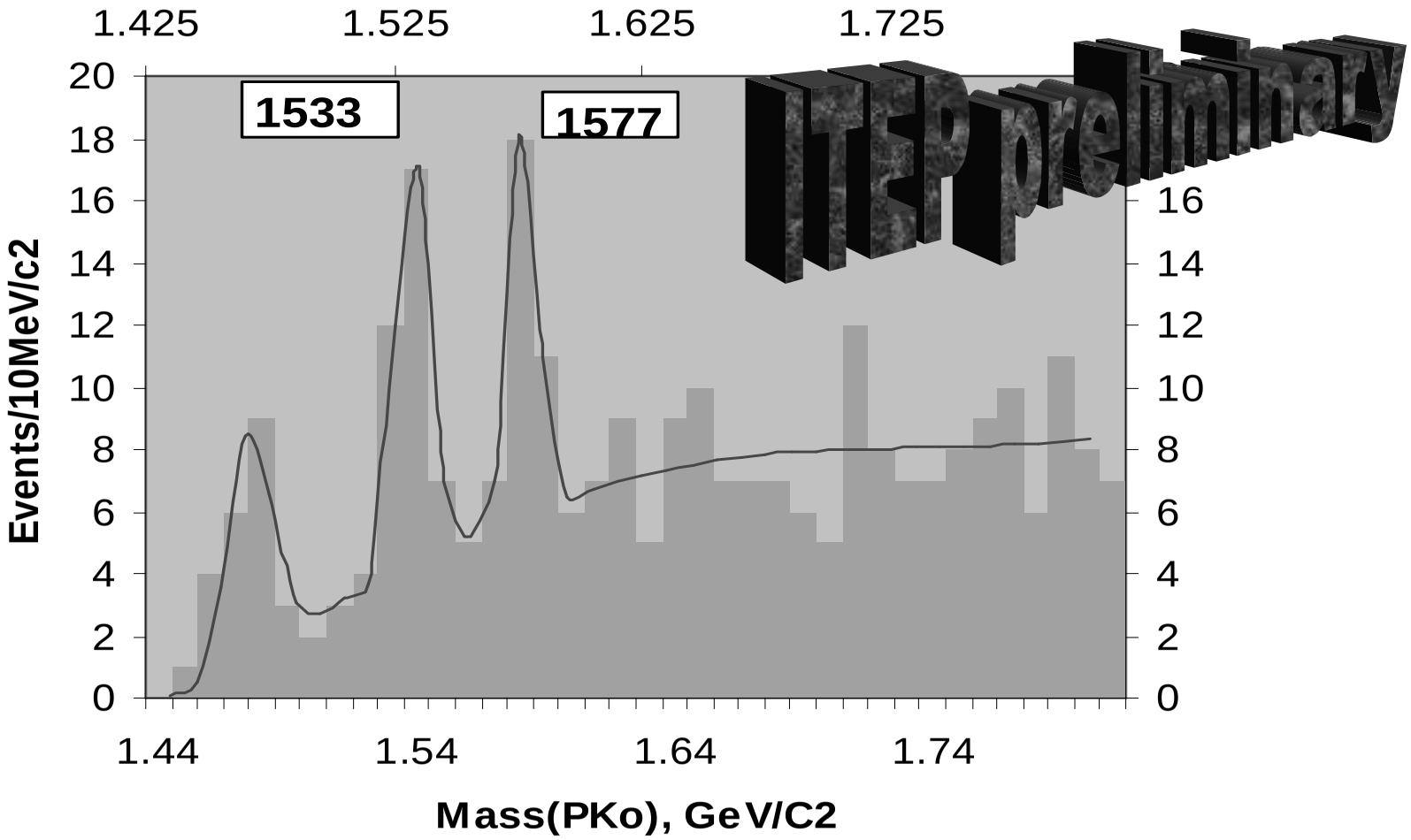
Neutrino 2004
Paris
June 13th-19th, 2004

Leslie Camilleri
CERN



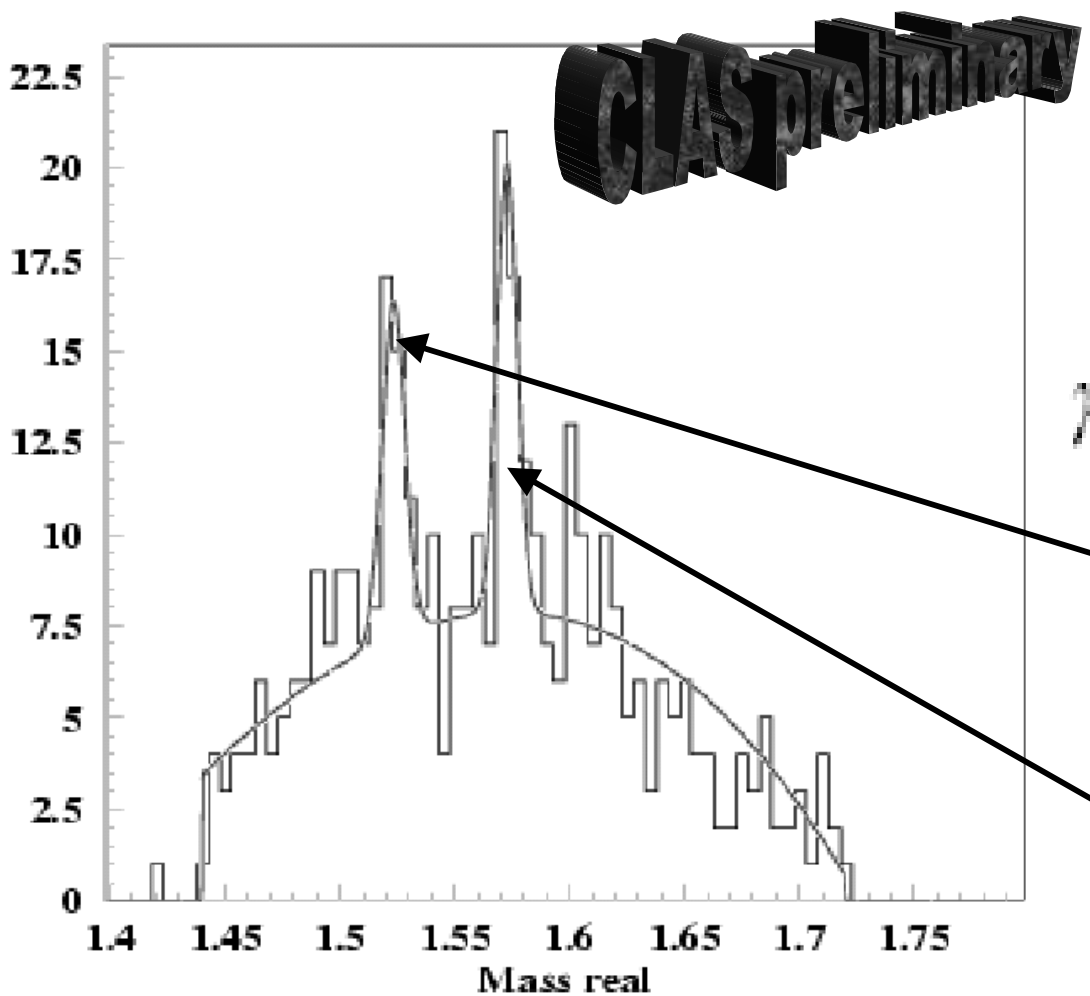
Possible partners of $\Theta^+(1530)$?

ITEP group @ PentaQuark 2003, Jlab, Nov 8, 2003



Possible partners of $\Theta^+(1530)$?

M. Battaglieri et al for CLAS collaboration at Trento, Feb 10-12 2004



Preliminary result about observations in :

$$\gamma p \rightarrow K_s^0 \Theta^+ \rightarrow K_s^0 K^+ n$$

$N_{peak} \pm sqrt(N_{bg})$
$22 \pm sqrt(30)$
stat. sig. = $(3.9 \pm 0.2)\sigma$
Mass = 1523 +/- 5 MeV

$N_{peak} \pm sqrt(N_{bg})$
$27 \pm sqrt(26)$
stat. sig. = $(6.0 \pm 0.2)\sigma$
Mass = 1573 +/- 5 MeV

$K^0_s p$ resonance's in neutrino interactions

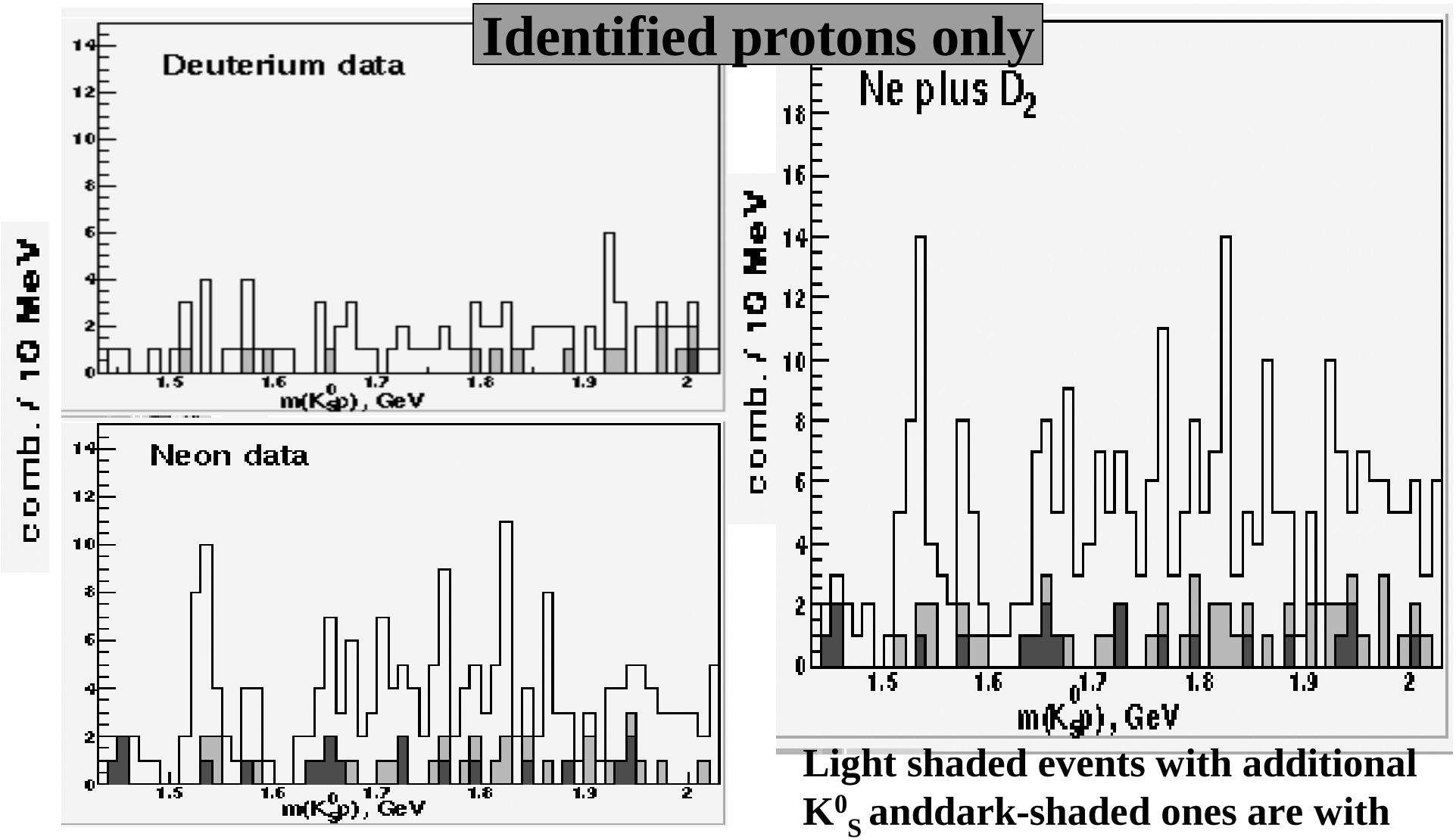
We expand the proton sample for a new study:

First step, use events with ALL identified protons (no 400<P<900 MeV/c requirement). However, we keep only events with any ADDITIONAL proton of momentum below 400 MeV/c to avoid events of hard nucleon re-scattering and break-up.

Second step , use other positive particles and assign proton mass.

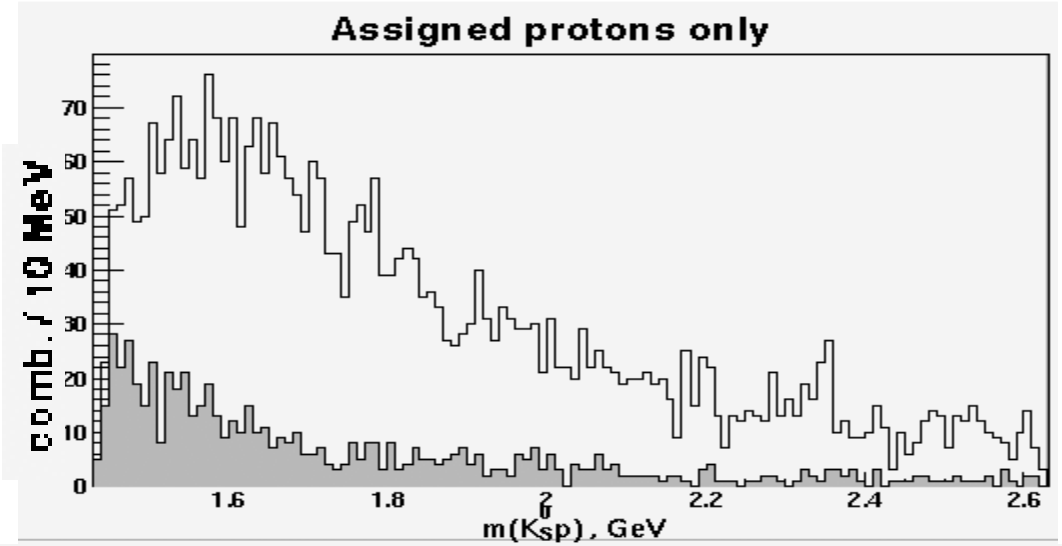
$K^0_s p$ resonance's in neutrino interactions

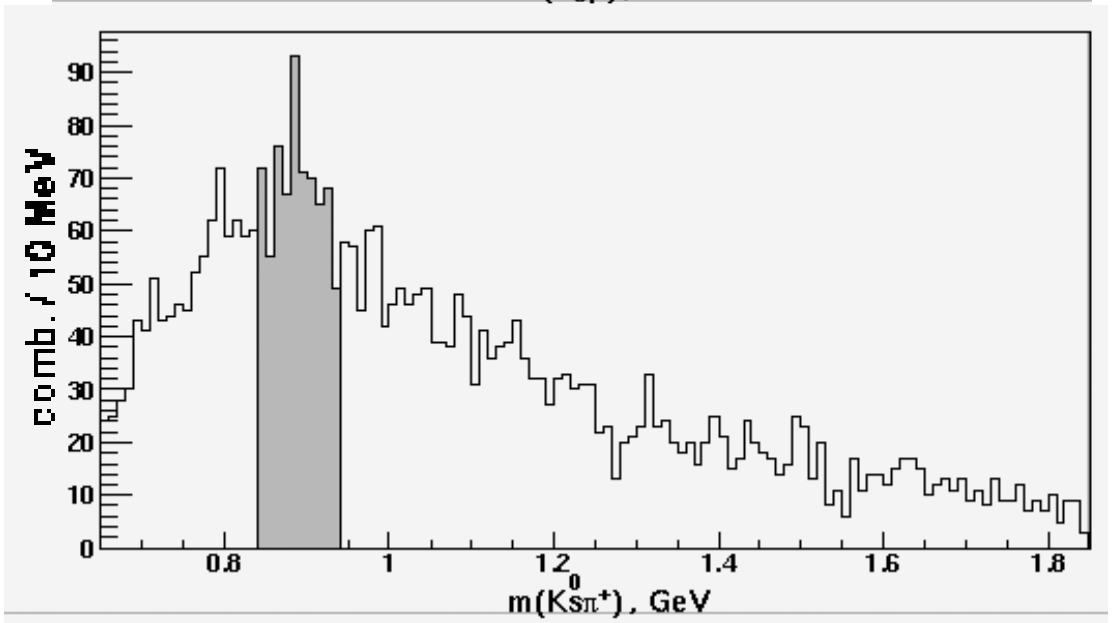
Identified protons only



Light shaded events with additional K^0_S anddark-shaded ones are with additional Λ^0

$K^0_s p$ resonance's in neutrino interactions





Add possible protons: positive tracks with momentum > 1 GeV

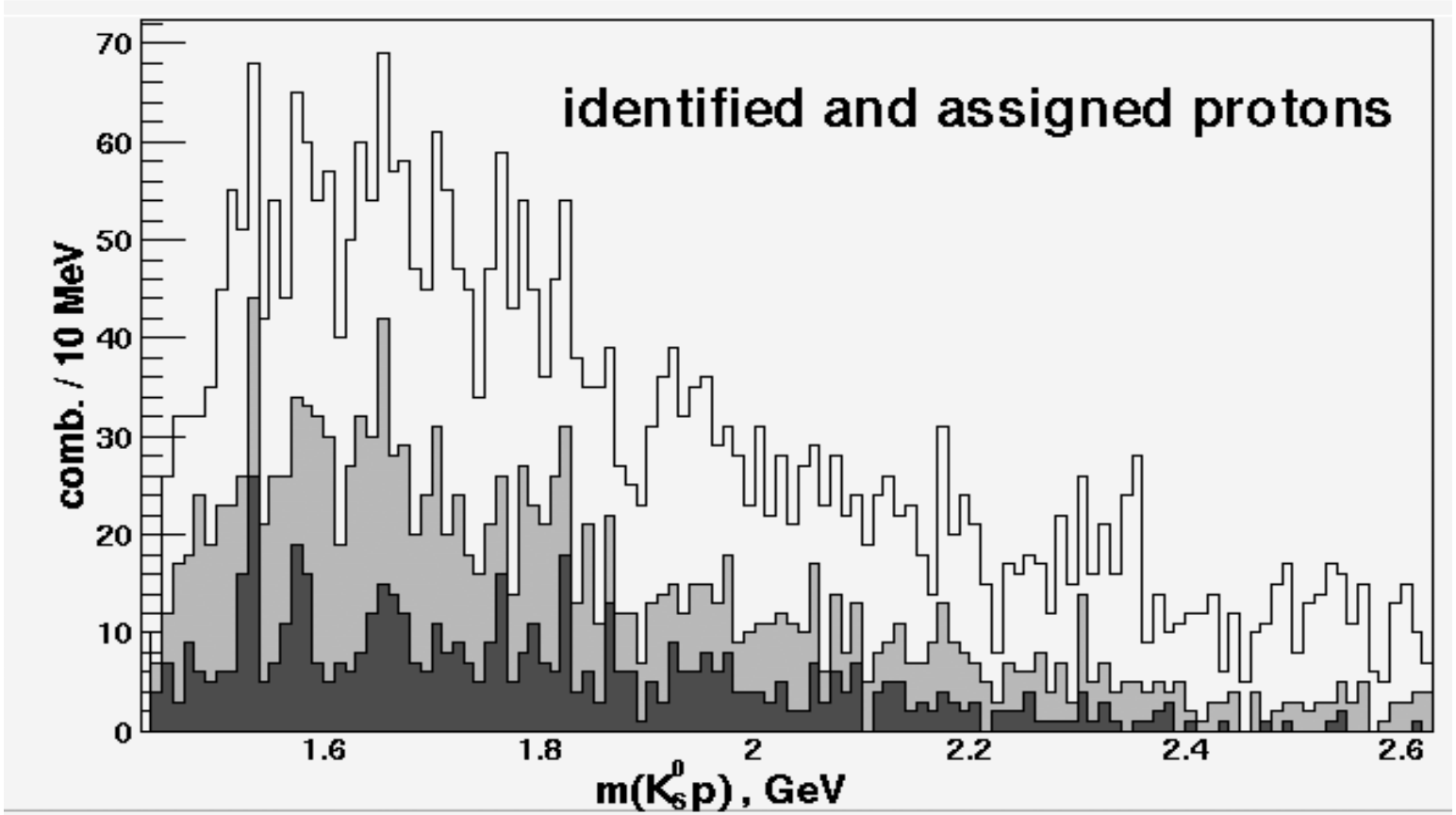
Distributions of K^0p and $K^0\pi^+$ invariant masses (top and bottom). Shaded areas correspond to the K^{*+} (890) mass region of

$840 < m(K^0\pi^+) < 940$ MeV/c^2

Further this region is excluded.

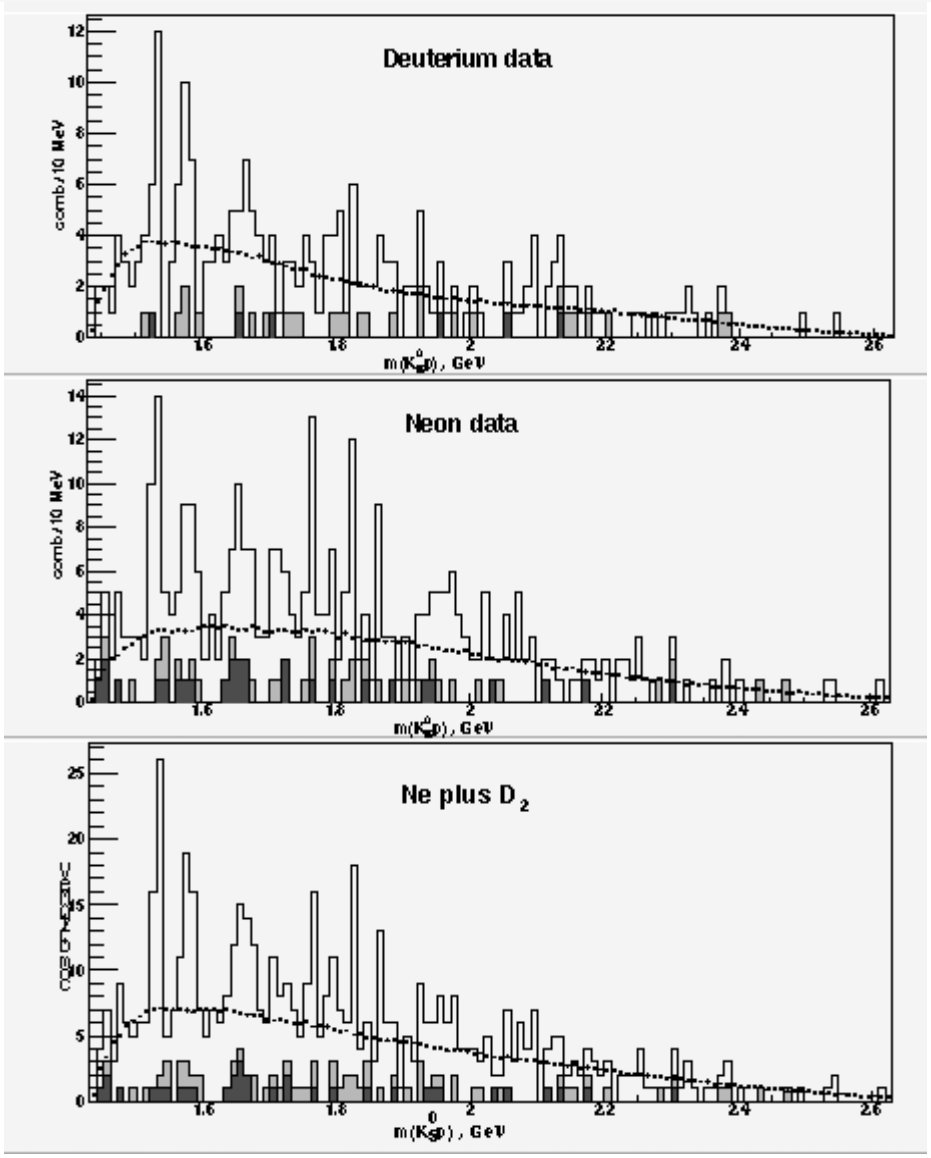
Combinatory background is very high.

$K^0_s p$ resonance's in neutrino interactions



Combined sample of identified and assigned protons(no K*). The light- and dark-shaded histogamms are for selections p_L < 5.0 and 2.5 GeV/c on logitudinal momentum of the $K^0_s p$

$K^0_s p$ resonance's in neutrino interactions

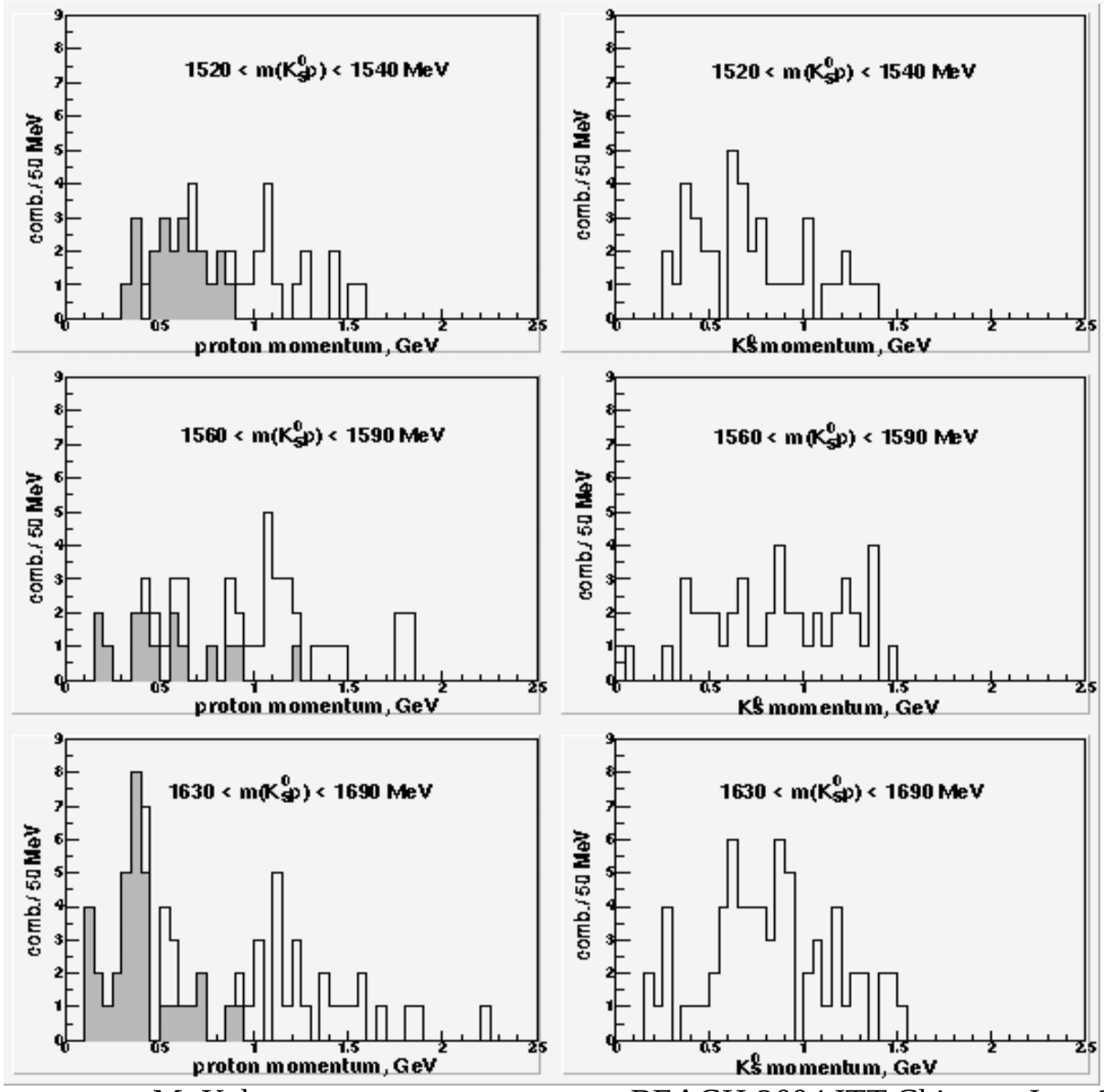


Close look at the $K^0_s p$ system with p_L < 2.5 GeV/c:

Dotted histogram depicts the "random star" background normalized at masses above 2 GeV/c^2.

Light shaded events with additional K^0_S and dark-shaded ones are with additional Λ^0. Associated Λ^0 events suggest positive strangeness of observed $K^0_s p$ states.

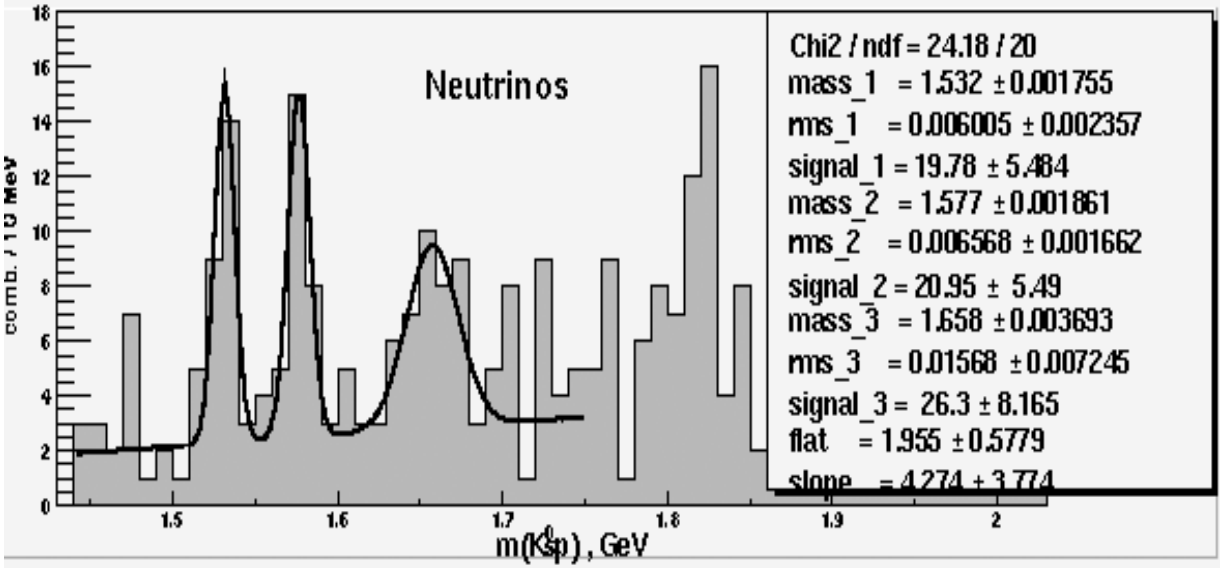
$K^0_s p$ resonance's in neutrino interactions

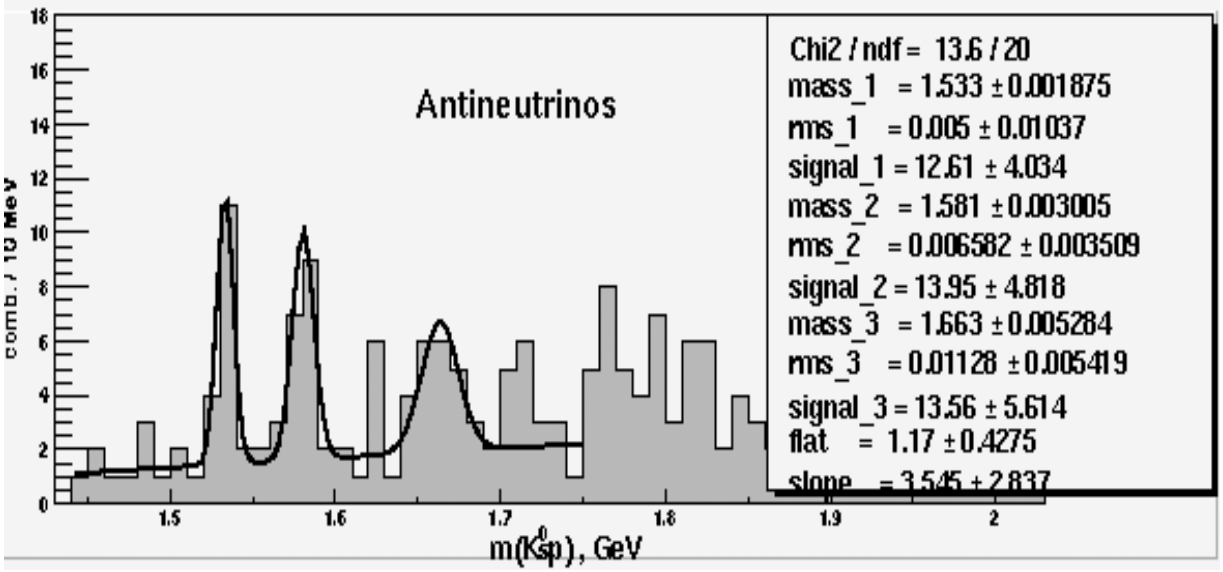


Proton and Kaon momentum spectra for three peak regions:

- ✓ all spectra are looking similar:
- ✓ no significant K^0_s/p assymetries;
- ✓ all particles come from target fragmentation.

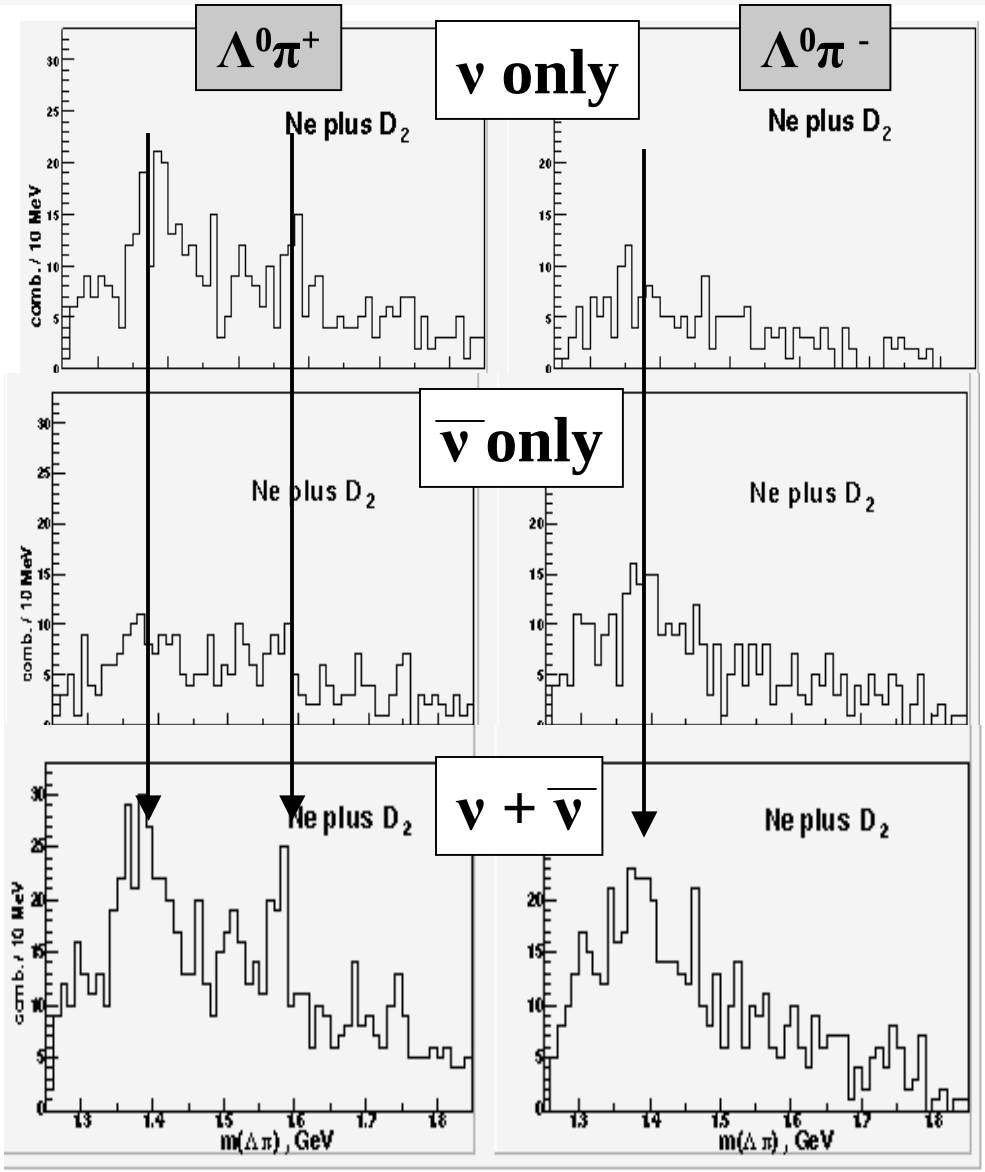
$K^0_s p$ resonance's in neutrino interactions





Yields of the three peaks (relative to all events) are close in neutrino and antineutrino beams. So far we do not consider masses above 1.7 GeV/c^2

$K^0_s p$ resonances vs $\Lambda^0\pi$



Further probing negative strangeness states: $\Sigma^{*+}(1385)$ and $\Sigma^{*+}(1583)$ are seen in ν and $\Sigma^{*-}(1385)$ in $\bar{\nu}$.

Note: branching of the $\Sigma^{*+}(1583)$ to $K^0_s p$ is about 40 times lower that to $\Lambda^0\pi^+$

$K^0_S p$ resonance's in neutrino interactions

We make following observations for $K^0_S p$ resonance's:

•no strangeness directly determined for K^0_S

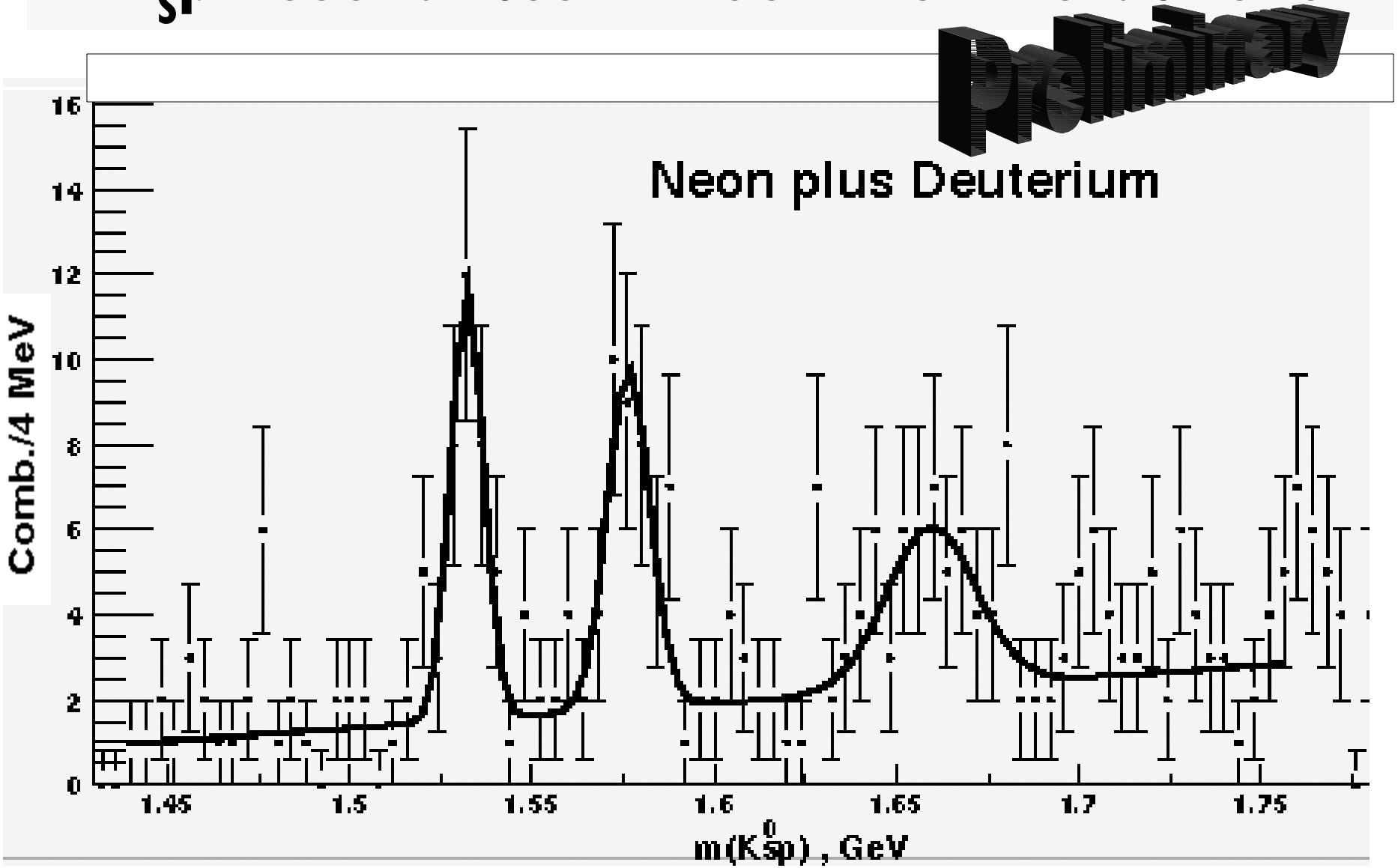
• excess of associated Λ^0 in these events;

•Known Σ^* states in this region follow the charge of the current: in ν beam produced Σ^{*+} , in $\bar{\nu}$ – Σ^{*-};
$\Sigma^{*+}(1583)$ can not produce second peak in $K^0_s p$

•At the same time relative number of the peak $K^0_S p$ events is about to be proportional to number of all CC events in the ν and $\bar{\nu}$ samples.

The Σ^{*+} hypothesis for these three observed states is not supported

$K^0_S p$ resonances in neutrino interactions



$K^0_s p$ resonances in neutrino interactions

Preliminary

Mass, MeV/c^2	Width, Mev /c^2	Events	Significance
153.1 ± 1.0 (Deuterium)	<9 (90% CL)	32	7.5 σ
1573.7 ± 1.4 (Deuterium)	<12 (90% CL)	31	5.5 σ
1659 ± 5 (Neon +Deuterium)	20-30	31	5.0 σ

Conclusions: still preliminary!

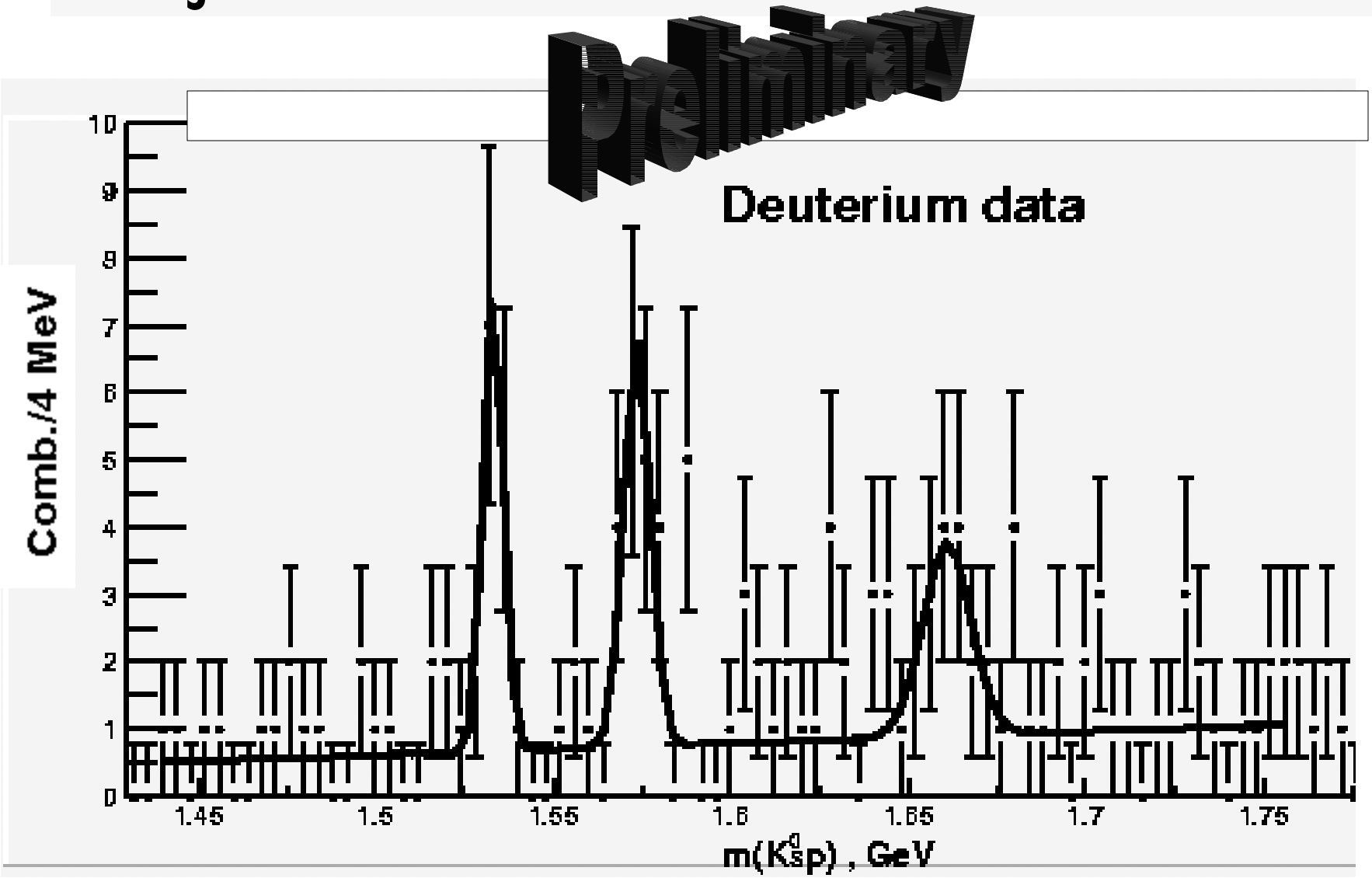
✓In expanded sample of (anti)neutrino events three baryon resonance's with masses of 1533.2 ± 1.0, 1573.7 ± 1.4 and 1659 ± 5 MeV/c^2 are observed in $K^0_s p$ system with p_L<2.5 GeV/c in (anti)neutrino interactions with Neon and Deuterium

✓Widths of 1531 and 1577 Mev peaks <9 MeV/c^2 and < 12 MeV/c^2 (90% C.L.). 1659 Mev peak may have intrinsic width of 20-30 MeV/c^2

✓Estimated signal significance 7.5, 5.5 and 5.0 σ

✓The Σ^{*+} hypothesis for observed states is disfavored.

✓These states are tentatively interpreted as the pentaquark Θ^+ (1530) and first observed spin/isospin partners thereof.

Authors are specially thankful to I. Strakovski and Ya. Azimov for fruitful discussions

$K^0_s p$ resonances in neutrino interactions