Search and study of narrow exotic baryons at JINR Nuclotron

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- ★ **Significance of the problem: why is the "boom"?**
- ★ **Experimental observations since 2003 (selected)**
- ★ **The newest data and some puzzles**
- ★ **How JINR can contribute: the NIS project at Nuclotron**
- ★ **Conclusions**

★ **The problem is not quite new but is more than 40 years old... No conclusive results were obtained before the year 2003.**

★ **After the 1-st steps:** from M.Polyakov, COMPASS Workshop, March 2004

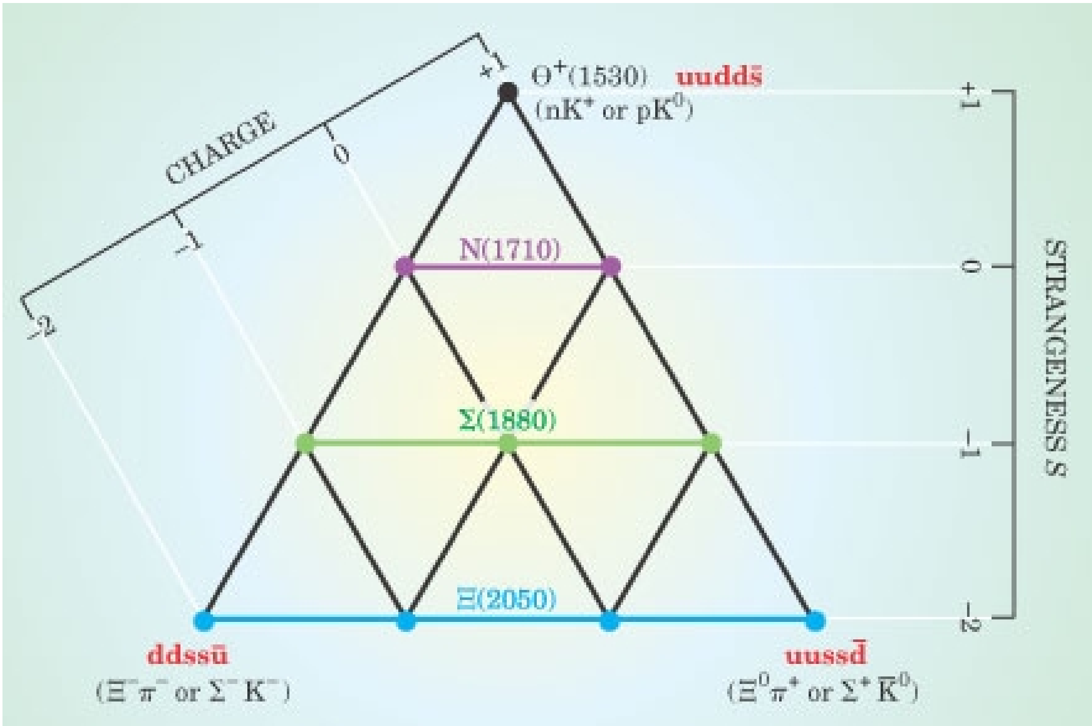
1. Bag models [R.L. Jaffe '76, J. De Swart '80]
$J^P = 1/2^-$ lightest pentaquark
Masses higher than 1700 MeV, width ~ hundreds MeV

Mass of the pentaquark is roughly 5 M +(strangeness) ~ 1800 MeV
An additional q –anti-q pair is added as constituent

2. Soliton models [Diakonov, Petrov '84, Chemtob'85, Praszalowicz '87, Walliser '92]
Exotic anti-decuplet of baryons with lightest S=+1
$J^P = 1/2^+$ pentaquark with mass in the range 1500-1800 MeV.

Mass of the pentaquark is rougly 3 M +(1/baryon size)+(strangeness) ~ 1500MeV
An additional q –anti-q pair is added in the form of excitation of nearly massless chiral field

1997 year: masses, quantum numbers, widths were predicted.

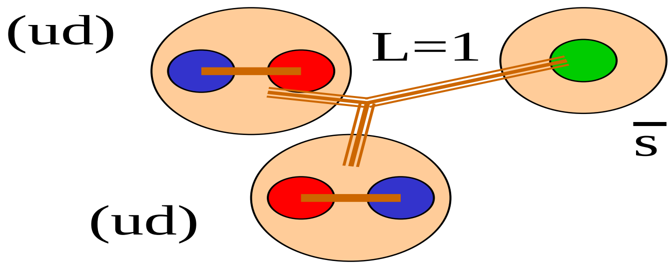


At the corners of the antidecuplet of baryons predicted by Dmitri Diakonov, Victor Petrov, and Maxim Polyakov are three exotic states that require five valence quarks (shown in red) and their decay modes. The recently discovered positive-strangeness baryon near 1540 MeV is tentatively identified with the predicted Θ^+ (1530). The numbers in parentheses are the predicted masses (in MeV) of the charge multiplets for each value of the strangeness.

Conventional approach: a number of models were suggested: "3+2"model by Karliner and Lipkin, "2+2+1"model by Jaffe and Wilszek, etc. From M.Polyakov, COMPASS Workshop, March 2004

Diquark model [Jaffe, Wilczek]

No dynamic explanation of
Strong clustering of quarks



Dynamical calculations suggest large mass
[Narodetsky et al.; Shuryak, Zahed]

$J^P=3/2^+$ pentaquark should be close in mass [Dudek, Close]

Anti-decuplet is accompanied by an octet of pentaquarks.
P11(1440) is a candidate

No prediction for width

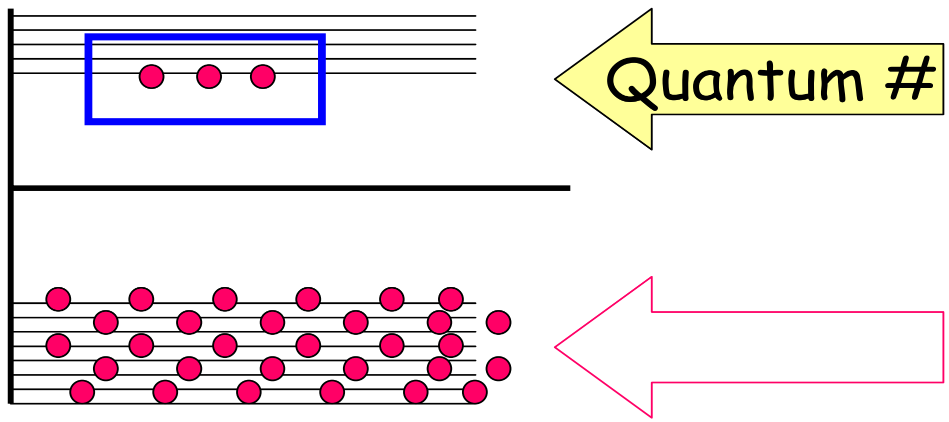
Mass difference $\Xi - \Theta \sim$ 200 MeV -> Light Ξ pentaquark

Chiral soliton:

From M.Polyakov, COMPASS Workshop, March 2004

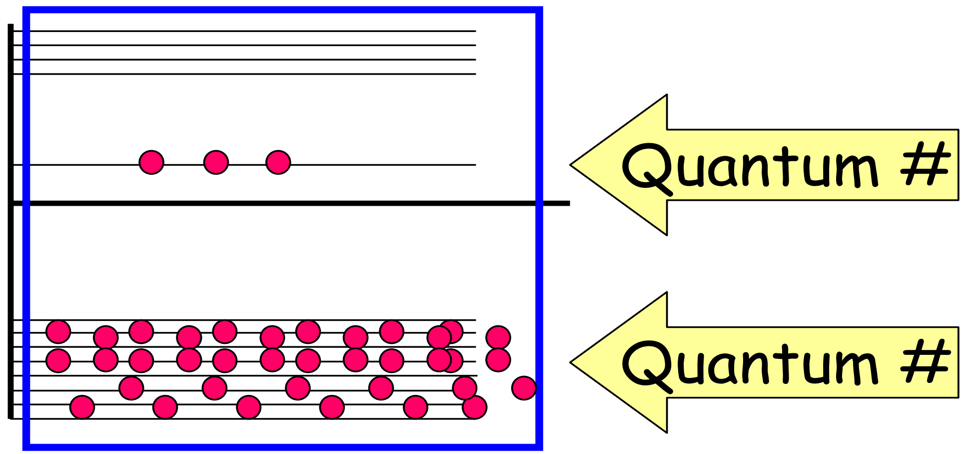
Quantum numbers

Coupling of spins, isospins etc. of 3 quarks



mean field → non-linear system → soliton → rotation of soliton

Coherent :1p-1h,2p-2h,....



"Consistency check": From P.Schweitzer, hep-ph/0312376

$$\frac{m_s}{m}\sigma_{\pi N} = \underbrace{3(4M_\Sigma - 3M_\Lambda - M_N)}_{octet} + \underbrace{4(M_\Omega - M_\Delta)}_{decuplet} - \underbrace{4(M_{\Xi_{3/2}} - M_{\Theta^+})}_{antidecuplet} \quad (20)$$

- From this formula: $\sigma_{\pi N} = (74 \pm 12)$ **MeV**
- From the πN data: $\sigma_{\pi N} \approx 60 \div 80$ **MeV**

$\Rightarrow$ high strangeness content of the nucleon :

$$y = 2 \cdot \frac{< N|s\bar{s}|N >}{< N|u\bar{u} + d\bar{d}|N >} \approx 0.6$$

$\Rightarrow$ In particlular, significant consequences follow for the nucleon spin problem and OZI rule.

A parallel with the Lamb shift is obvious

(The interaction of electron with photon vacuum in atoms brings the $P_{1/2}$ levels under $S_{1/2}$.)

It seems that there is a good piece of physical truth in the chiral soliton approach: fluctuations of the vacuum of fields binding quarks inside hadrons must be taken into account; interaction of constituent quarks with these fluctuations changes the spectrum of baryons etc.; effects depend upon the fluctuations density/strength...

Something interacts with the Nothing,
the Nothing changes Something...

OBSERVATIONS

(selected examples)

★ "$(uud d\bar{s})$": Θ^+ (K^+n and K^0p systems)
(up to now - limited statistics: from 20 to ~100 events in the peak). The observable width: instrumental.
More than 10 experiments.

★ "$(dsds\bar{u})$": $\Xi_{3/2}$ ($\Xi^-\pi^-$ and $\Xi^-\pi^+$ systems)
The mass: 1862±2 MeV/c^2; $\Gamma < 18$ MeV/c^2 (instrumental).
Single experiment.

★ "$(uudd\bar{c})$": $D^{*-}p$ and $D^{*+}\bar{p}$ systems
The mass: 3099±3±5 MeV/c^2; $\Gamma \approx 12$ ±3MeV/c^2 (instrumental.) Single experiment.

★ Θ^+ is expected to be included with $***$ rating in the latest PDG Tables.

ITEP (DIANA coll., K^+Xe) and neutrino data from the old BEBC films

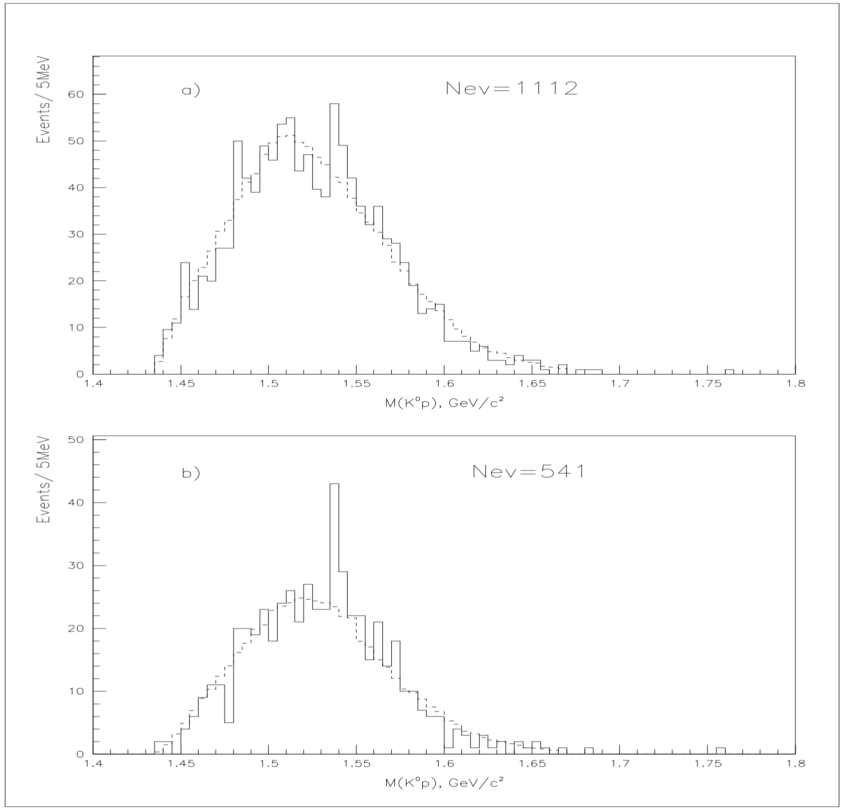
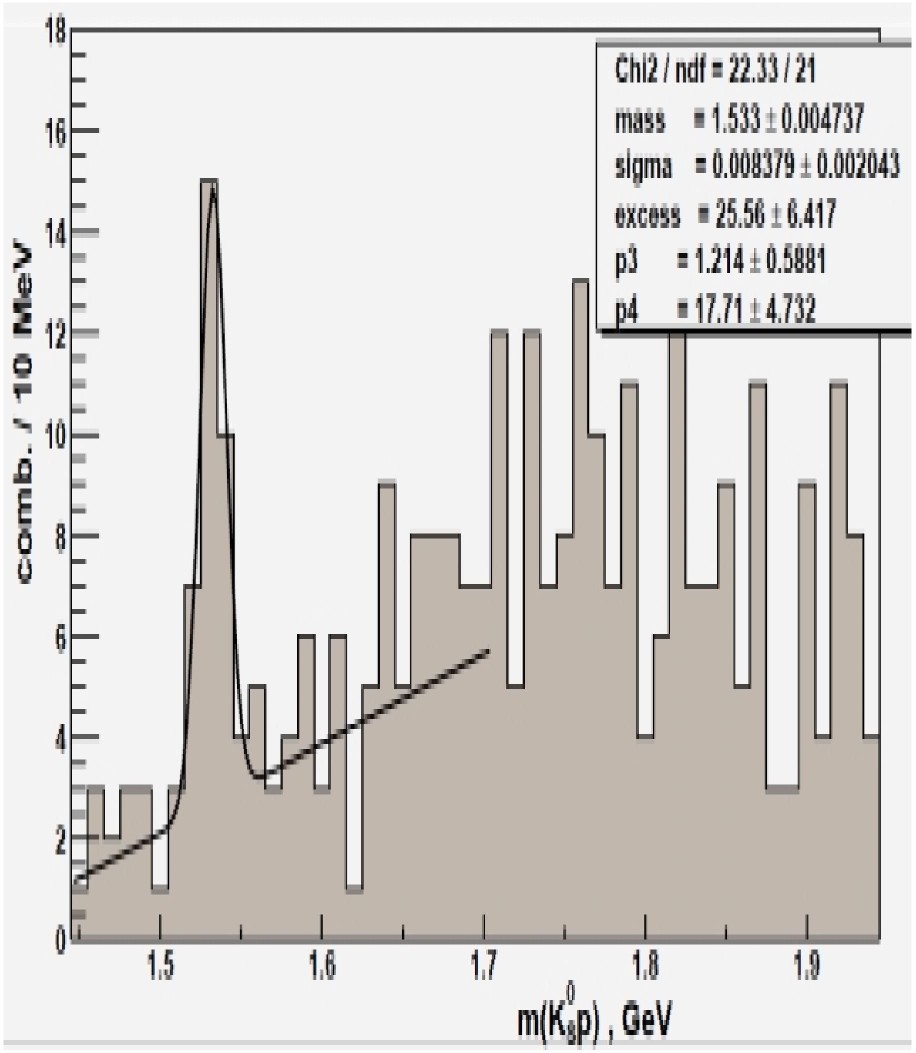
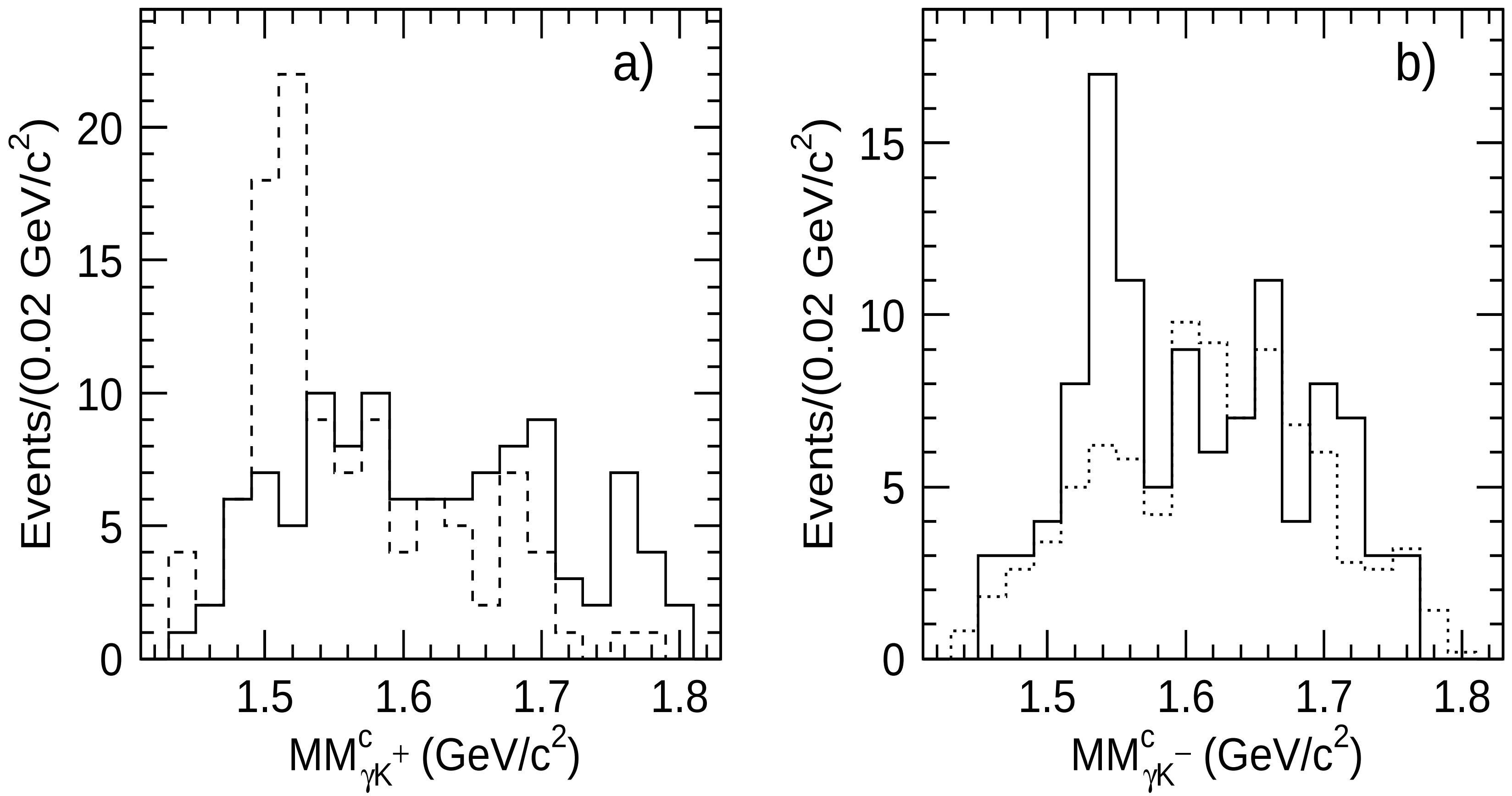
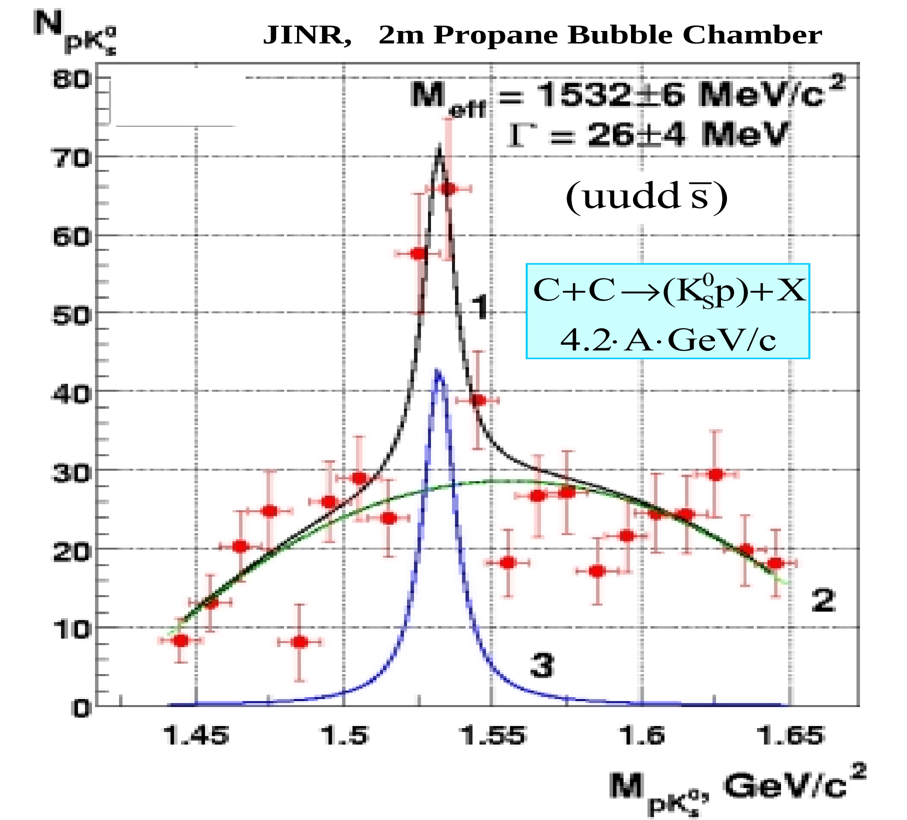


Figure 4: Effective mass of the K^0p system formed in the reaction $K^+\mathrm{Xe} \to K^0p\mathrm{Xe}'$: (a) for all measured events, (b) for events that pass additional selections aimed at suppressing proton and K^0 reinteractions in nuclear matter (see text). The fit to the expected functional form is depicted by the dashed line.

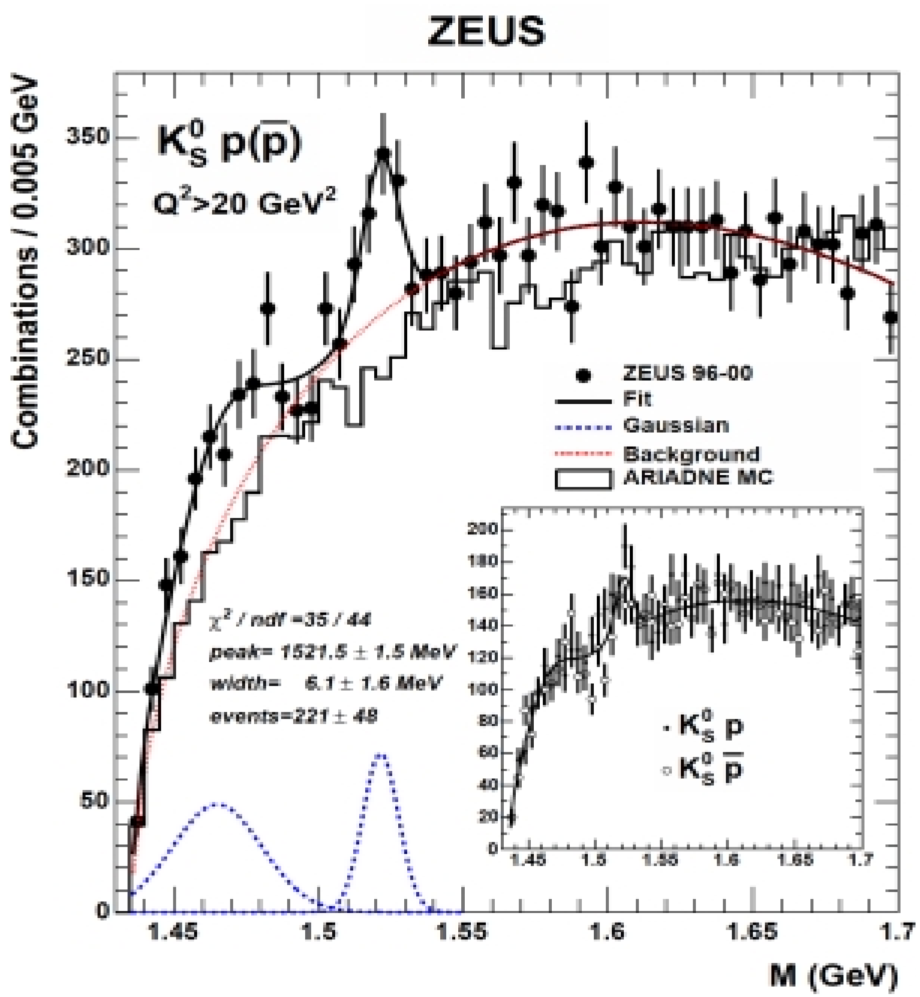


LEPS data (SPring-8)





R.Togoo, Ts.Baatar, B.Khurlebaatar, G.Shakhuu, E.N. Kladnitskaya, A.A.Kuznetsov
In: Proceedings of the Mongolian Academy of Sciences, v.170, No.4 (2003) 3.



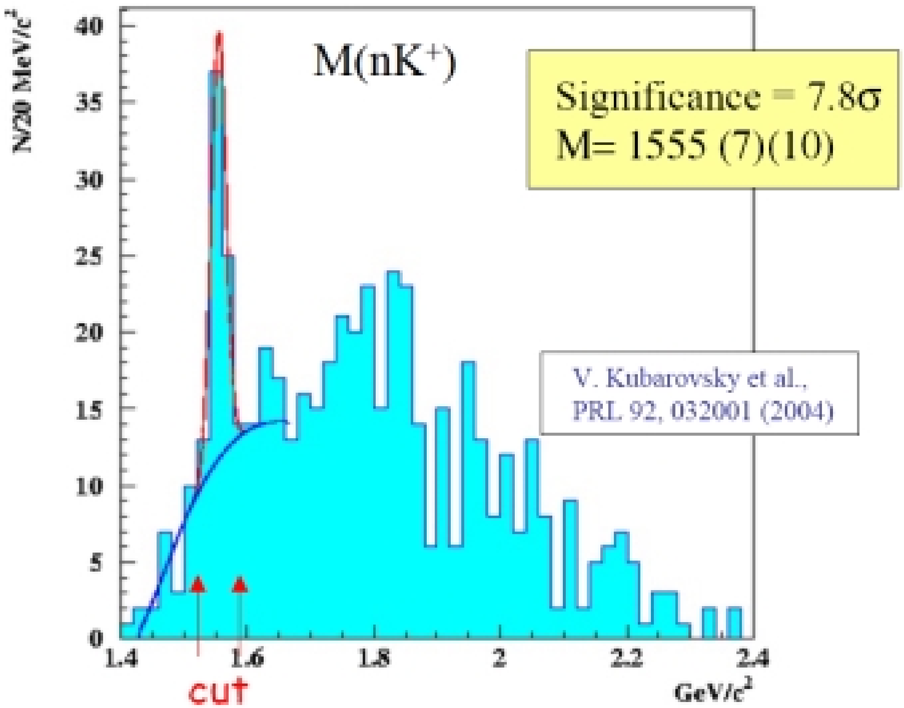
Deep inelastic ep (the central rapidity region)

JINR: LHE propan BC

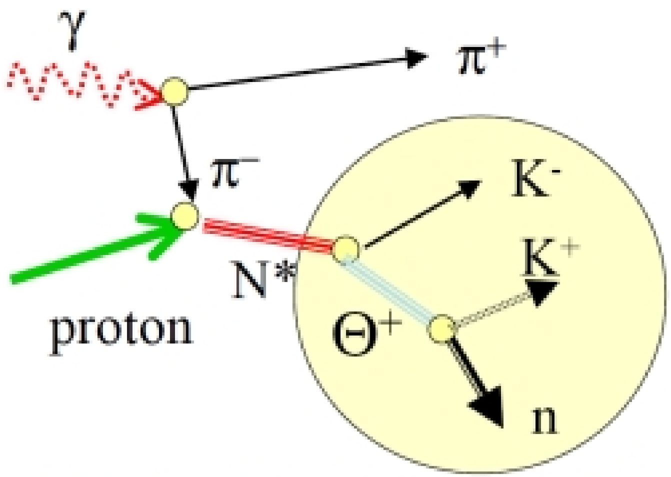
CLAS - $\Theta^+(1540)$ on protons

$E\gamma = 3 - 5.4$ GeV

$\gamma p \rightarrow \pi^+ K^+ K^- n$

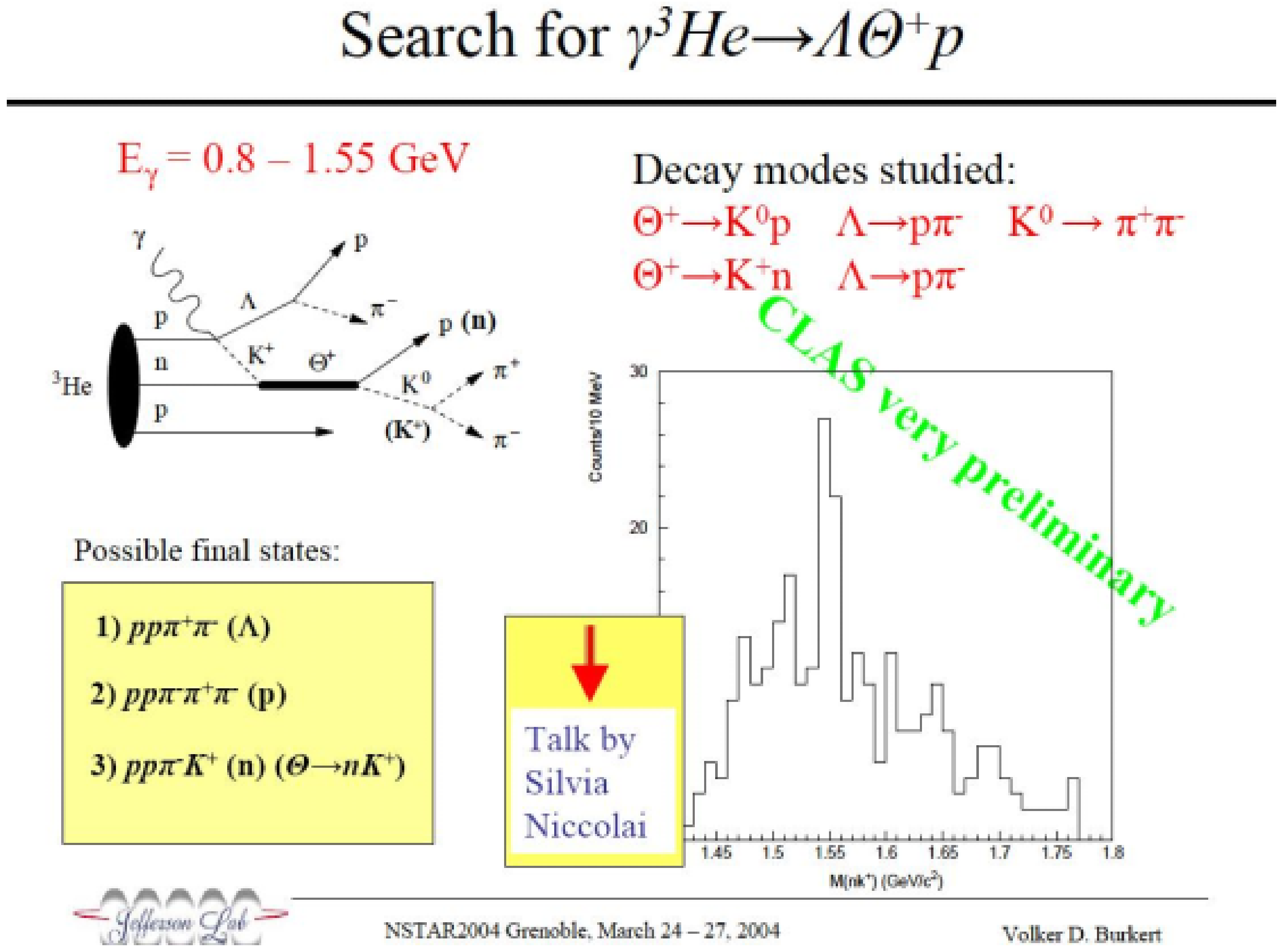


- Θ^+ production through N^* resonance decays?



- Cut on Θ^+ mass, and plot $M(nK^+K^-)$

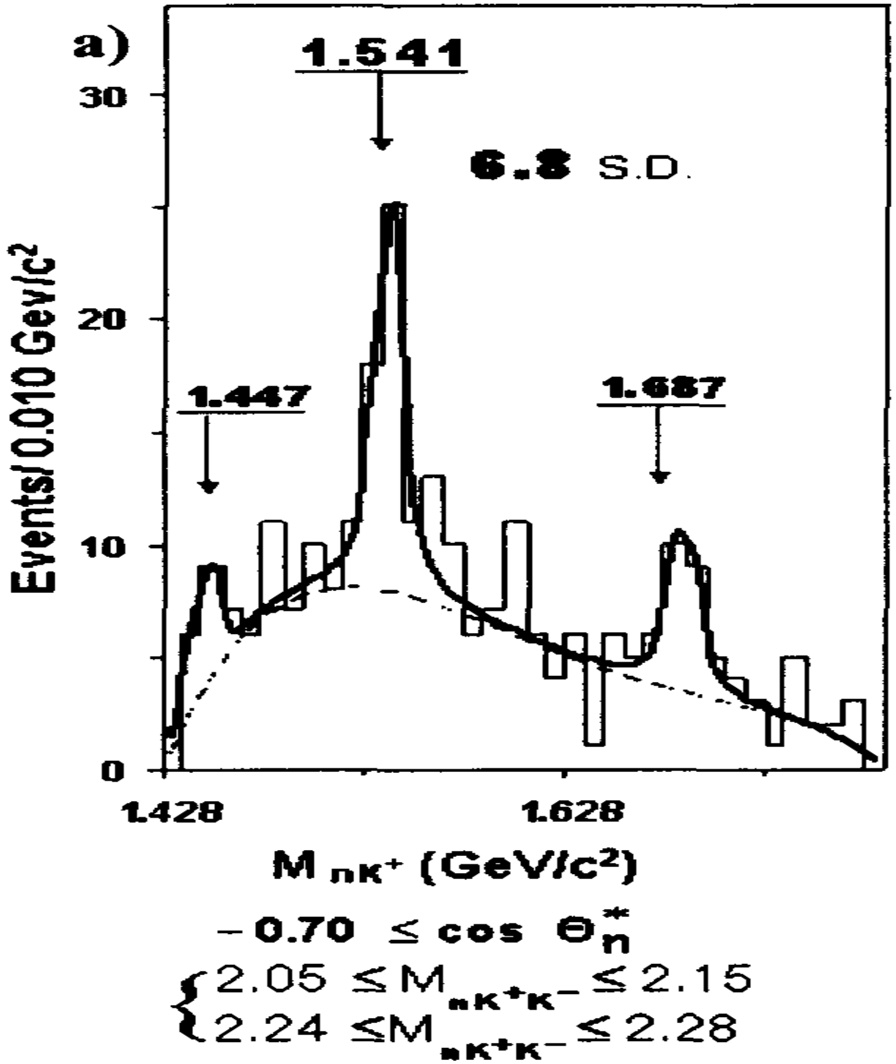
Exploitation of the two-particle correlations in nuclei: typical for the "cumulative"production



JINR: LHE Hydrogen Bubble Chamber, D1-2004-39, Yu.A.Troyan et al; $np \to npK^+K^-$ at 5.2±0.12 GeV/c

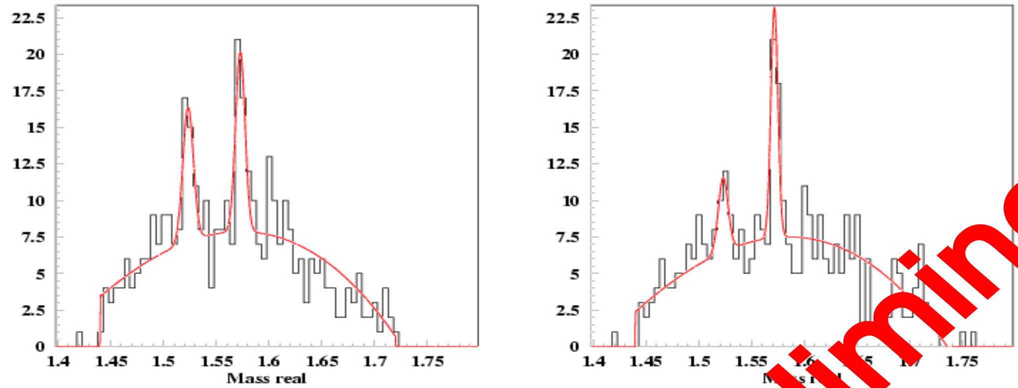
- The Fig. with a special cuts applied to enhance the signal $\Rightarrow$
- Several peaks; 3 peaks with signinicance $> 5\sigma$
- First estimation of the spin: $J_{\Theta^+} > 1/2$ (!?)

Surprising results...
Systematics of the analysis is not quite clear...



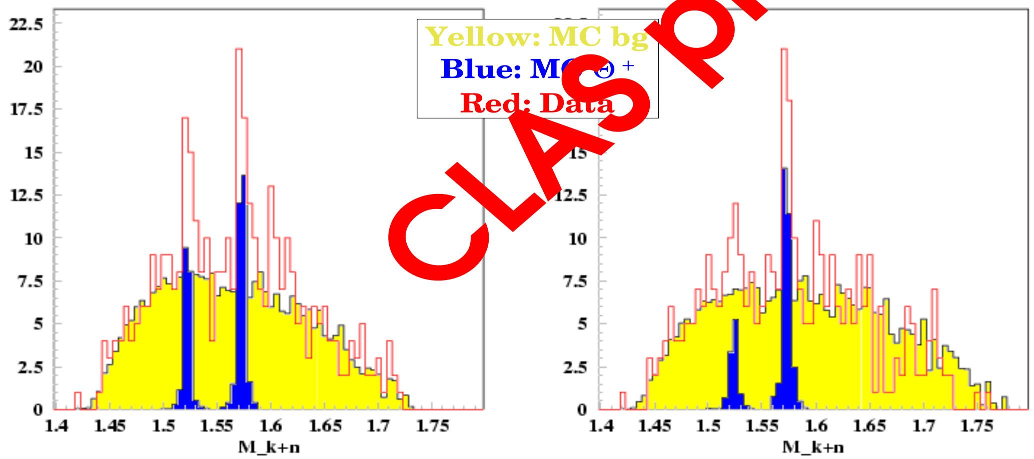
CLAS: a puzzle? $\gamma p \rightarrow \Theta^+ \bar{K}^0$, $\Theta^+ \rightarrow K^+ n$

- **The spectrum has been fitted to a (Gaussian + 5th order polynomial) using an unbinned Likelihood procedure**



- **A side-band subtraction method (2 and 4 nearest bins) was applied giving similar results**

- **The spectrum has been compared to MC simulation**



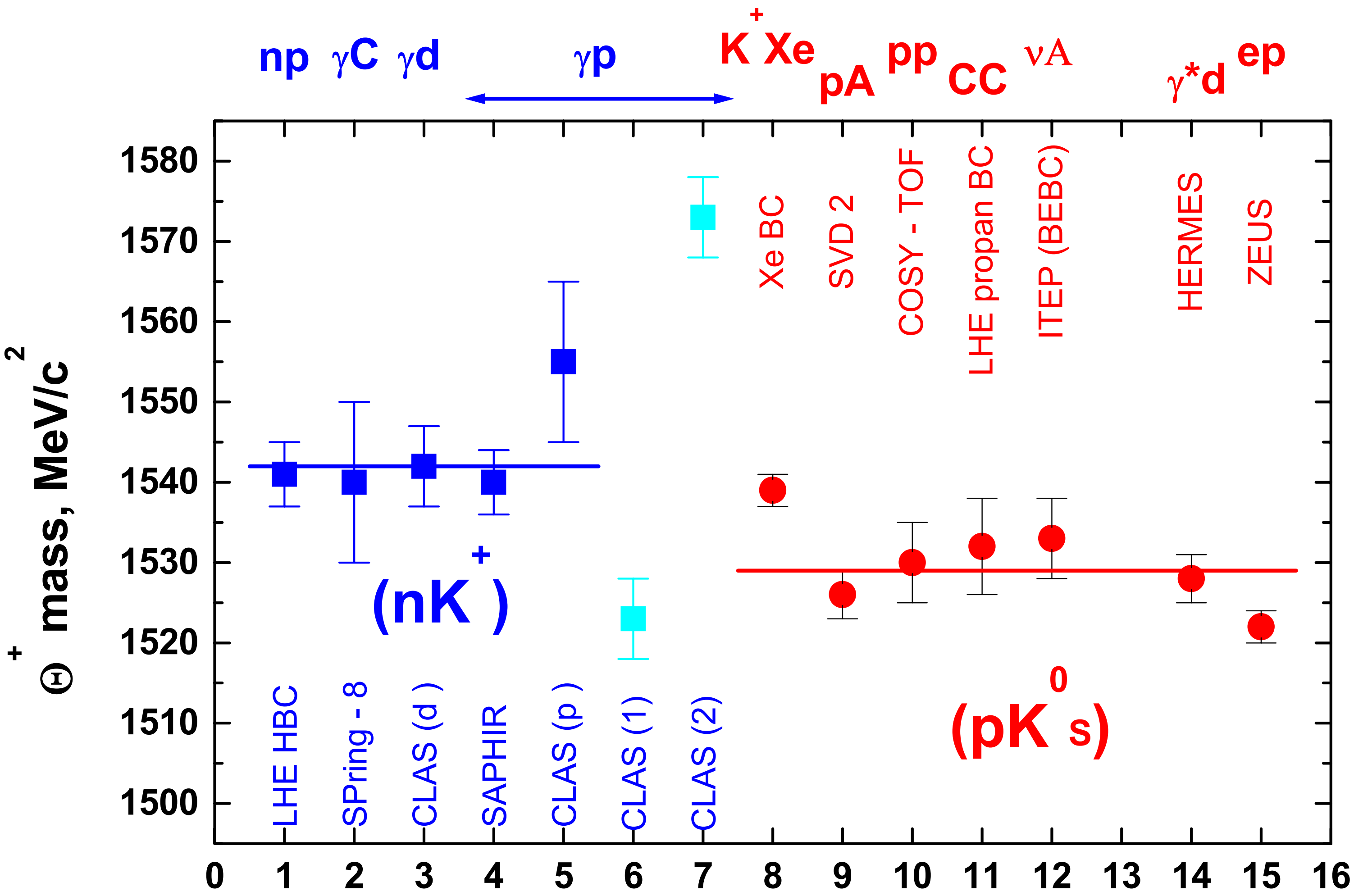
All methods give similar results

$N_{peak} \pm sqrt(N_{bg})$
22 $\pm$ sqrt(30)
stat. sig. = (3.9 $\pm$ 0.2)σ
Mass = 1523 +/- 5 MeV
FWHM ~ 9 MeV

$N_{peak} \pm sqrt(N_{bg})$
27 $\pm$ sqrt(26)
stat. sig. = (6.0 $\pm$ 0.2)σ
Mass = 1573 +/- 5 MeV
FWHM ~ 9 MeV

Published data for the Θ^+ mass.
Note: data with nuclear targets dominate.

The systematic uncertainties are included in the error bars.



- ★ K^0p differs from K^+n? (1529±6 against 1542±6)
- ★ CLAS puzzle:
  $\gamma p \rightarrow \Theta^+ K^- \pi^+ \Rightarrow$ one peak
  $\gamma p \rightarrow \Theta^+ \bar{K}^0 \Rightarrow$ two peaks (?!)
- ★ CLAS does not observe Ξ^{--} in photoproduction.
- ★ HERA-B and SPHINX (IHEP) do not see the Θ^+ under conditions similar (apparently!) to SVD-2.
- ★ PHENIX does not observe Θ^+ production in $d + Au$ interactions; STAR does not observe in $Au + Au$.
- ★ Controversies about (pK^+) system.
- ★ Other negative signals (WA89, BES etc.)
- ★ The width of Θ^+: existing kaon data at momenta below 1 GeV/c demand Γ<1 MeV/c^2. Theory must adapt to this.

May be the exotics are different from the theoretically expected??

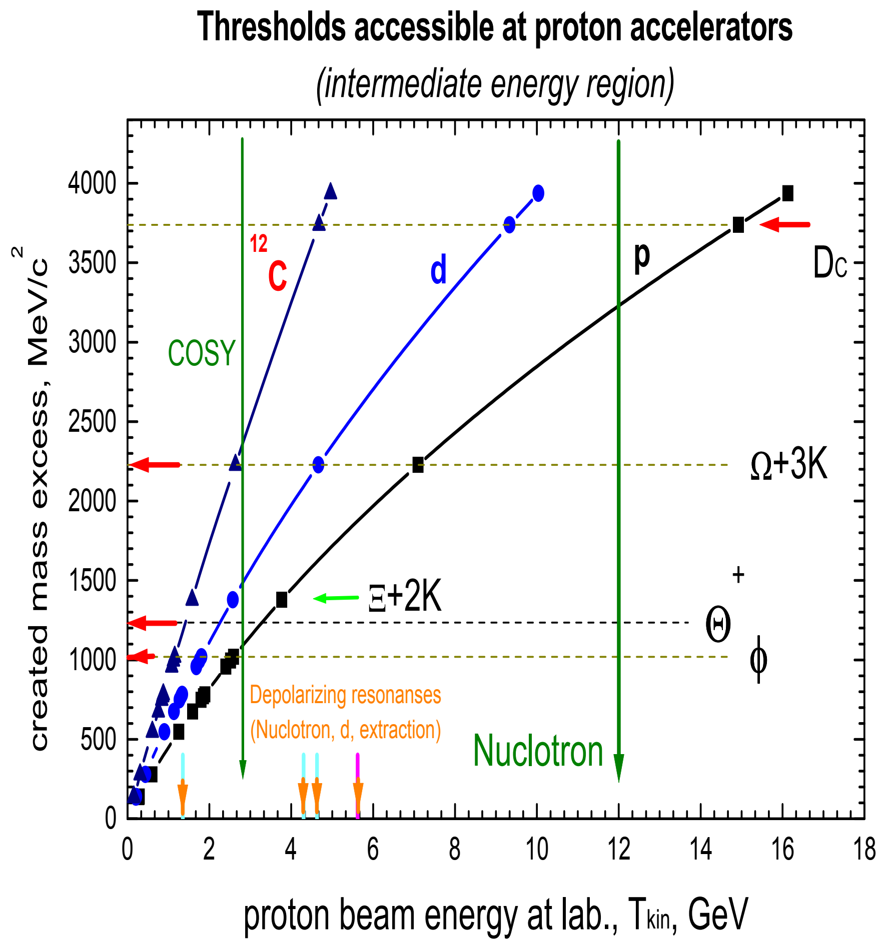
The very existence of the exotics is not firmly established at the moment.

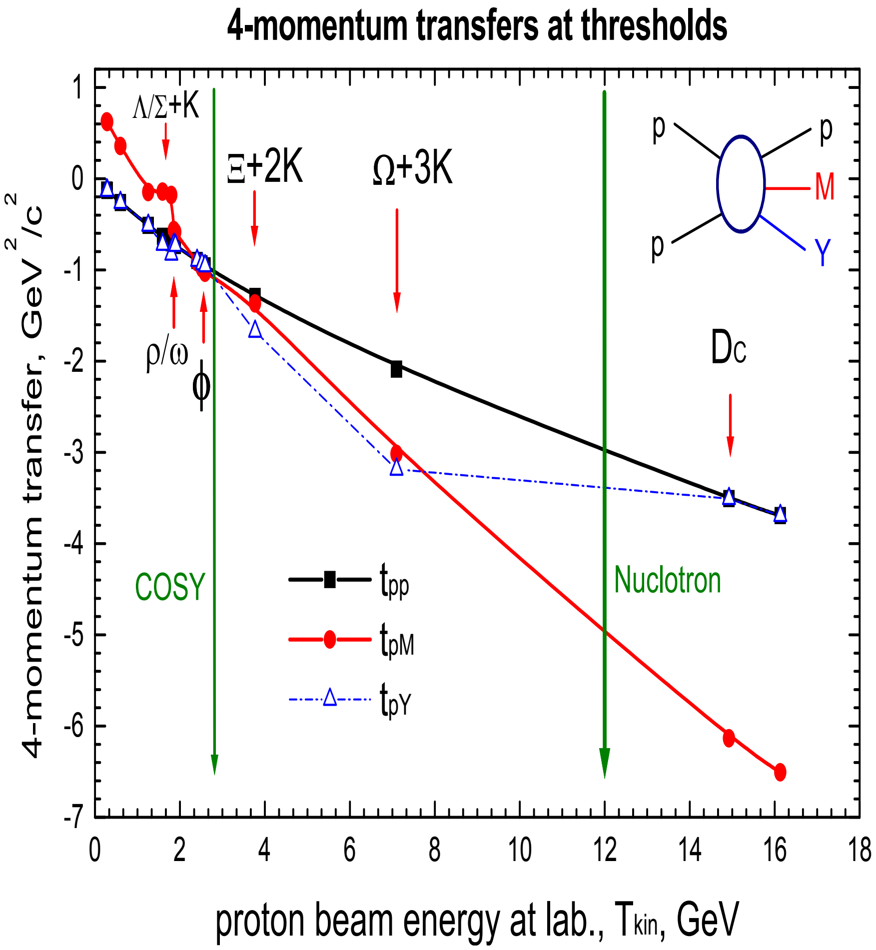
Even if it exists, neither the quark structure is clear (is a matter of a belief) nor the spin/parity/isospin.

The problem is attacked in many Labs over the world. News are coming permanently. But production of the exotics by hadron beams at intermediate energies can be done in the very few places. JINR Nuclotron is the one and the most appropriate for the task.

We propose to perform a dedicated search for Θ-baryons at the Nuclotron using the NIS setup.
Study of the production mechanisms; determination of quantum numbers etc...

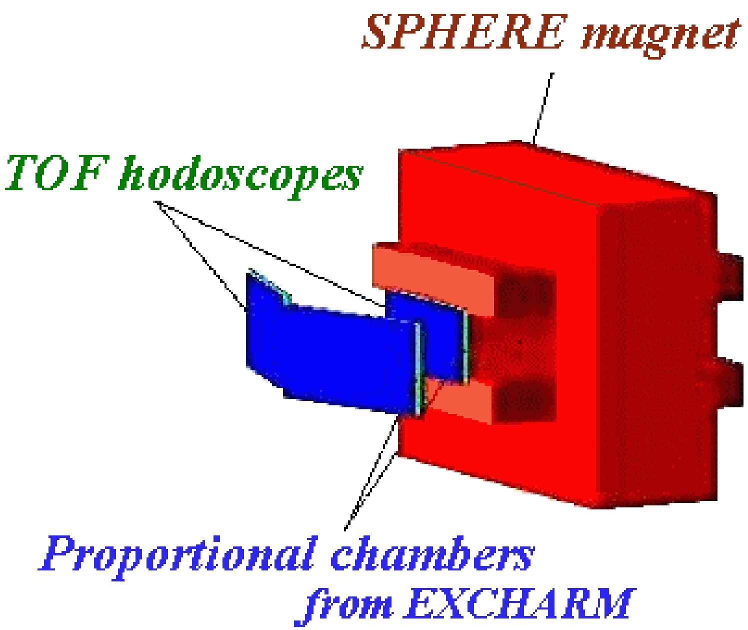
JINR Nuclotron energy is optimal for exclusive experiments.
Polarized $\mathrm{d, p, n}$ beams $\Rightarrow$ spin-spin correlations, polarization transfers $\Rightarrow$ determination of $\mathrm{J^P}$
Energy dependence of the σ_{prod} $\Rightarrow$ estimate of J as well

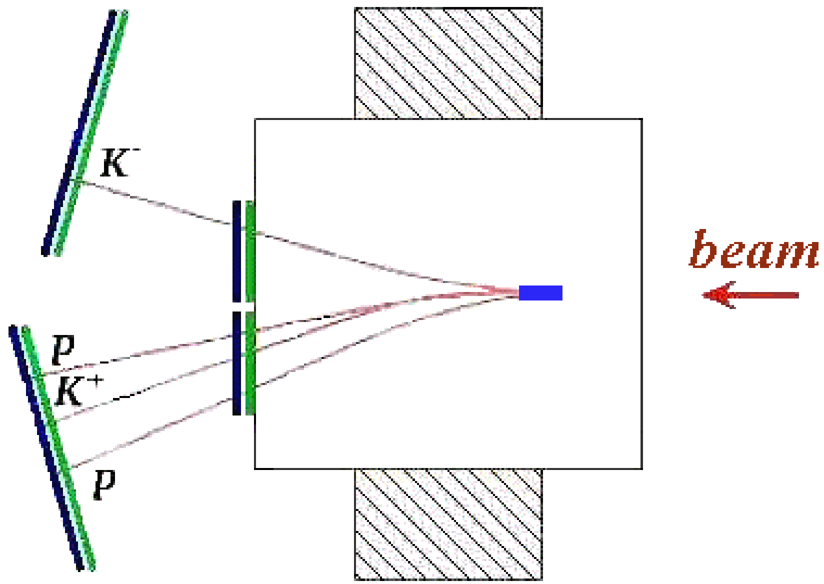




Project NIS: *Search for effects of*

Nucleon Intrinsic Strangeness at JINR Nuclotron





Test of OZI rule in

$p + p \rightarrow p + p + \phi$

$p + p \rightarrow p + p + \omega$

production near threshold

Nucleon intrinsic strangeness should be an additional source of ϕ *-mesons*

First indication - DISTO: $R(\phi/\omega) = 13R(\phi/\omega)_{OZI}$

Participating organizations:

- JINR: LPP, LHE, LNP, LIT, BLTP
- Jagiellonian University, Cracow, Poland
- Ludwig Maximilians University, Munich, Germany
- BINTP, Kiev, Ukraine
- HEPI TSU, Tbilisi, Georgia

Participating countries:
Russia, Armenia, Georgia, Ukraine, Poland, Germany

1-st stage of the setup is planned for the beam tests/calibrations at the end of this year.

The physical program of the NIS experiment includes:

(A) Search for effects of nucleon polarized strangeness in production of ϕ and ω mesons in $\mathbf{pp}$ and $\mathbf{np}$ scattering close to thresholds (at $\varepsilon \sim 30 \div 100$ MeV above the thresholds).

(B) Search for production of the Θ^+ baryons in $\mathbf{pp}$ interactions close to threshold in reactions:

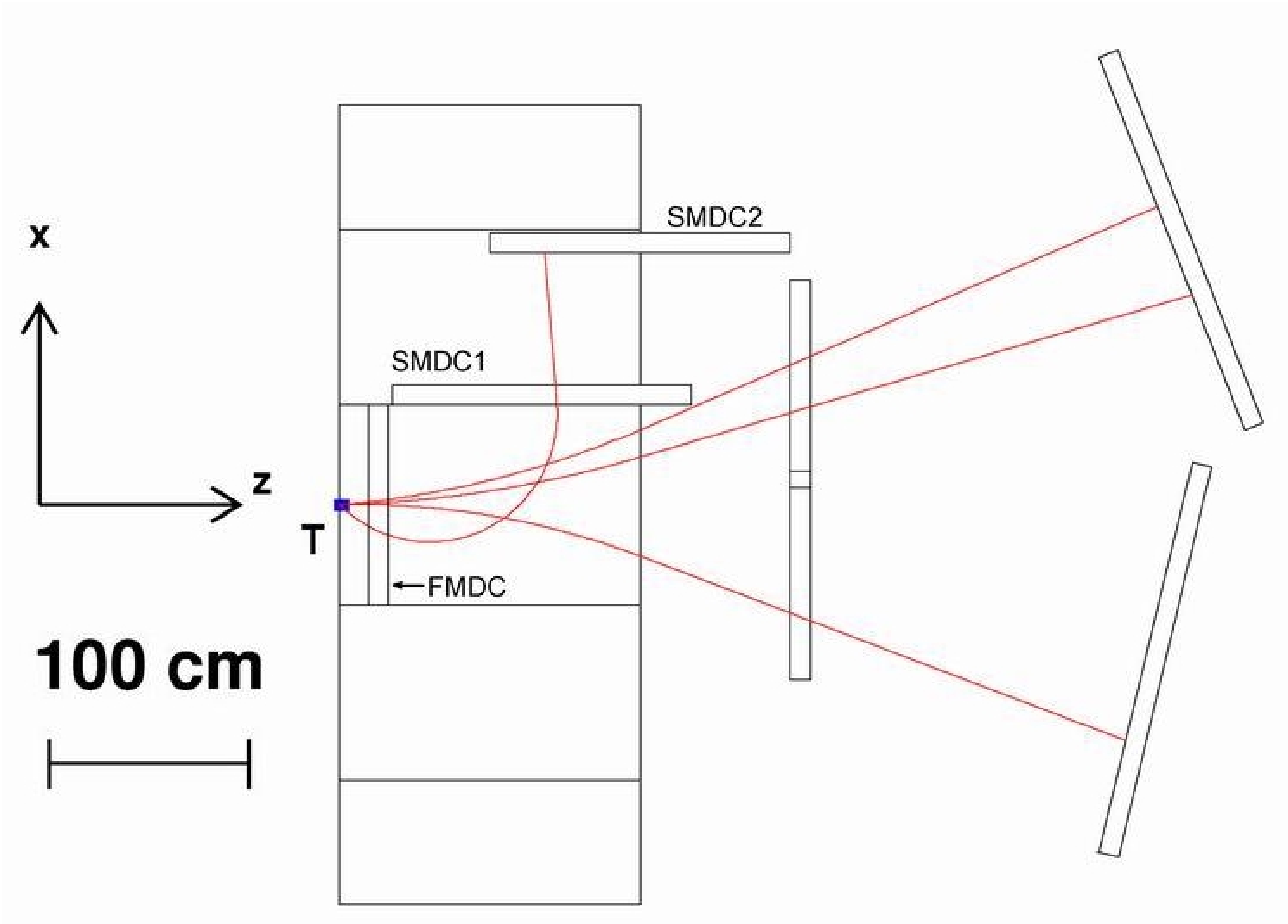
$$\mathrm{pp} \to \Theta^+ + \mathrm{K}^- + \mathrm{p} + \pi^+ \;,\;\; \Theta \to \mathrm{nK}^+$$
$$\mathrm{pp} \to \Theta^+ + \mathrm{K}^- + \mathrm{p} + \pi^+ \;,\;\; \Theta \to \mathrm{pK}^0 \;,\;\; \mathrm{K}^0_\mathrm{S} \to \pi^+\pi^-$$

To do this search, the setup is to be enhanced with new trackers (the minidrift chambers) installed inside the analyzing magnet.

Very attractive option (with additional trackers) is:

$$\mathrm{dp} \to \Theta^+ + \mathrm{p_S} + \Lambda \;,\;\; \Lambda \to \mathrm{p}\pi^-$$

The "forward"MDC is of vital importance for this experiment.


SMDC2
x
SMDC1
z
T
FMDC
100 cm

Main components of NIS setup

Subsystem	Equipment	Comment
Tracking	MPWC, 2 mm step,	
	3 stations	2×1 m^2
	MDC, 4 mm sell,	
	3 stations	$\sim1.5\times0.6$ m^2
TOF PID	RPC walls,	$\sim$40 modules
	3 stations,	2×0.2 m^2
		each module
SciFi start	1 station	$\sim5\times5$ cm^2
LH2 target	10 cm thick	

The production cross section of Θ^+ in pn, pp, pA reactions at $\mathrm{p_{lab}}$ =2.95÷70 GeV/c is in the range of $0.4 \div 120\mu b$.

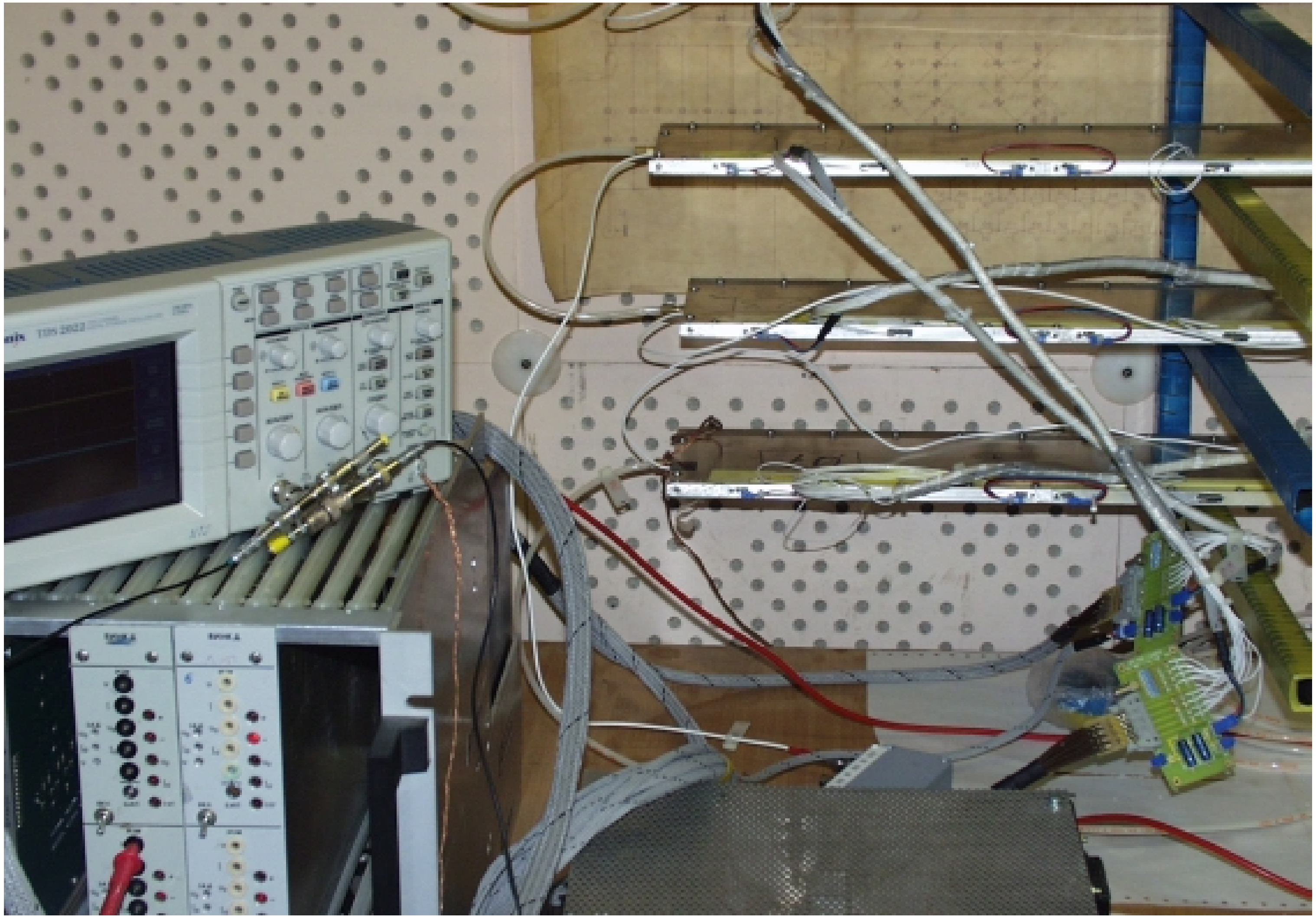
$\Rightarrow$ NIS should detect $>$ 1000 reconstructed events/week with the beam of 10^7/sec, repetition rate of 10 sec and spill duration of 5 sec (the duty factor 0.5).

Preparation for the field map measurements

Proportional chambers at the test-bench.

RPC modules at the test-bench.

RPC modules at the test-bench. The front-end electronics.



The proof of the new exotic baryons will definitely result in a drastic change of the particle theory.

Present situation is controversial...

JINR has contributed using its archives. Maybe there is something else. But JINR can and must contribute much more using Nuclotron which has significant potential for research in this field.

The NIS project at Nuclotron meets the challenge.