20 years of Theta+

Michał Praszałowicz

31.3.2023 Białasówka

Evidence for a Narrow $S = +1$ Baryon Resonance in Photoproduction from the Neutron

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(Received 14 January 2003; published 3 July 2003)

The $\gamma n \rightarrow K^+K^-n$ reaction on ^{12}C has been studied by measuring both K^+ and K^- at forward angles. A sharp baryon resonance peak was observed at 1.54 ± 0.01 GeV$/c^2$ with a width smaller than 25 MeV$/c^2$ and a Gaussian significance of 4.6σ. The strangeness quantum number (S) of the baryon resonance is +1. It can be interpreted as a molecular meson-baryon resonance or alternatively as an exotic five-quark state ($uudd\bar{s}$) that decays into a K^+ and a neutron. The resonance is consistent with the lowest member of an antidecuplet of baryons predicted by the chiral soliton model.

PANIC Oct. 2002 in Osaka

LEPS@SPring-8 in Japan (Laser-Electron Photon facility at Spring-8)

1174 citations in iNSpire.hep

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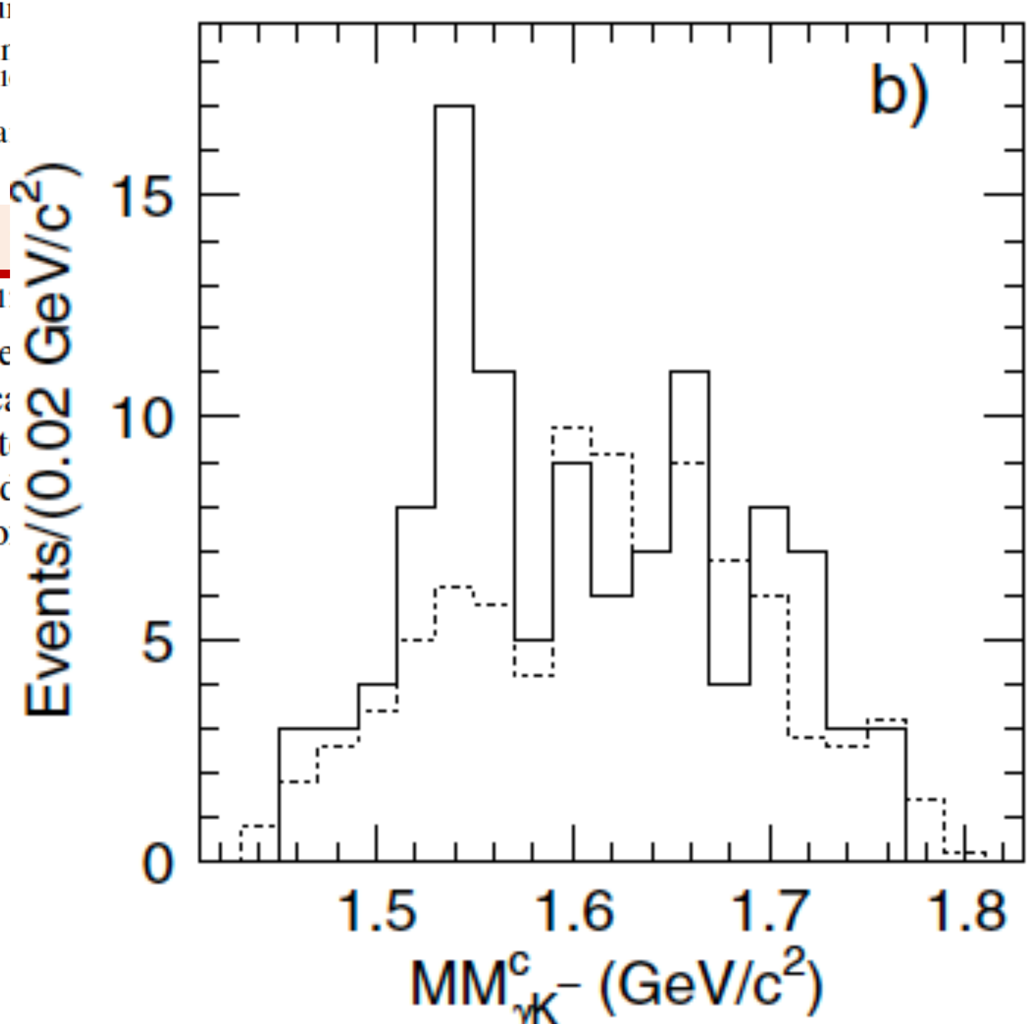

Physics of Atomic Nuclei, Vol. 66, No. 9, 2003, pp. 1715–1718. From Yadernaya Fizika, Vol. 66, No. 9, 2003, pp. 1763–1766.

ELEMENTARY PARTICLES AND FIELDS
Experiment

Observation of a Baryon Resonance with Positive Strangeness in K^+ Collisions with Xe Nuclei[*]**

V. V. Barmin[1)], V. S. Borisov[1)], G. V. Davidenko[1)], A. G. Dolgolenko[1)]*, C. Guaraldo[2)], I. F. Larin[1)], V. A. Matveev[1)], C. Petrascu[2)], V. A. Shebanov[1)], N. N. Shishov[1)], L. I. Sokolov[1)], and G. K. Tumanov[1)]**

The DIANA Collaboration

[1)] *Institute of Theoretical and Experimental Physics, Bol'shaya Cheremushkinskaya ul. 25, Moscow, 117259 Russia*

[2)] *Laboratori Nazionali di Frascati dell' INFN, Italy*

Received May 14, 2003

Abstract—The status of our investigation of low-energy K^+Xe collisions in the xenon bubble chamber DIANA is reported. In the charge-exchange reaction $K^+\mathrm{Xe} \to K^0 p\mathrm{Xe}'$, the spectrum of $K^0 p$ effective mass shows a resonant enhancement with $M = 1539 \pm 2$ MeV/c^2 and $\Gamma \leq 9$ MeV/c^2. The statistical significance of the enhancement is near 4.4σ. The mass and width of the observed resonance are consistent with expectations for the lightest member of the antidecuplet of exotic pentaquark baryons, as predicted in the framework of the chiral soliton model. © *2003 MAIK "Nauka/Interperiodica"*.

**Based on a talk at Session of Nuclear Division of Russian Academy of Sciences, Dec. 3, 2002.

submitted to arXiv on April 30

705 citation in iNSpire.hep

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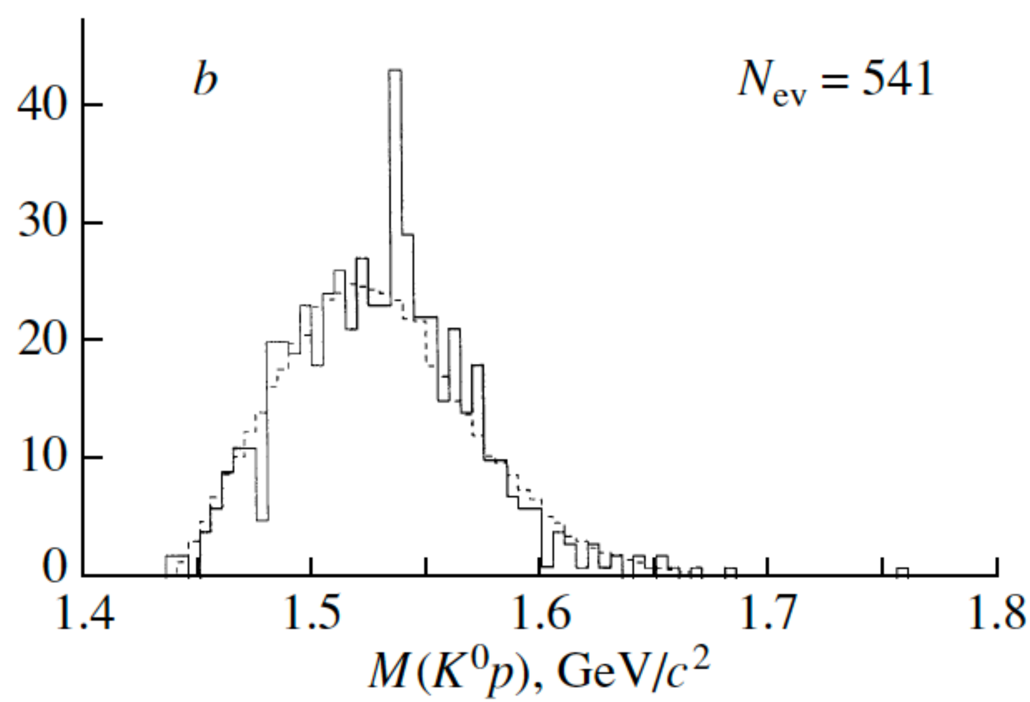
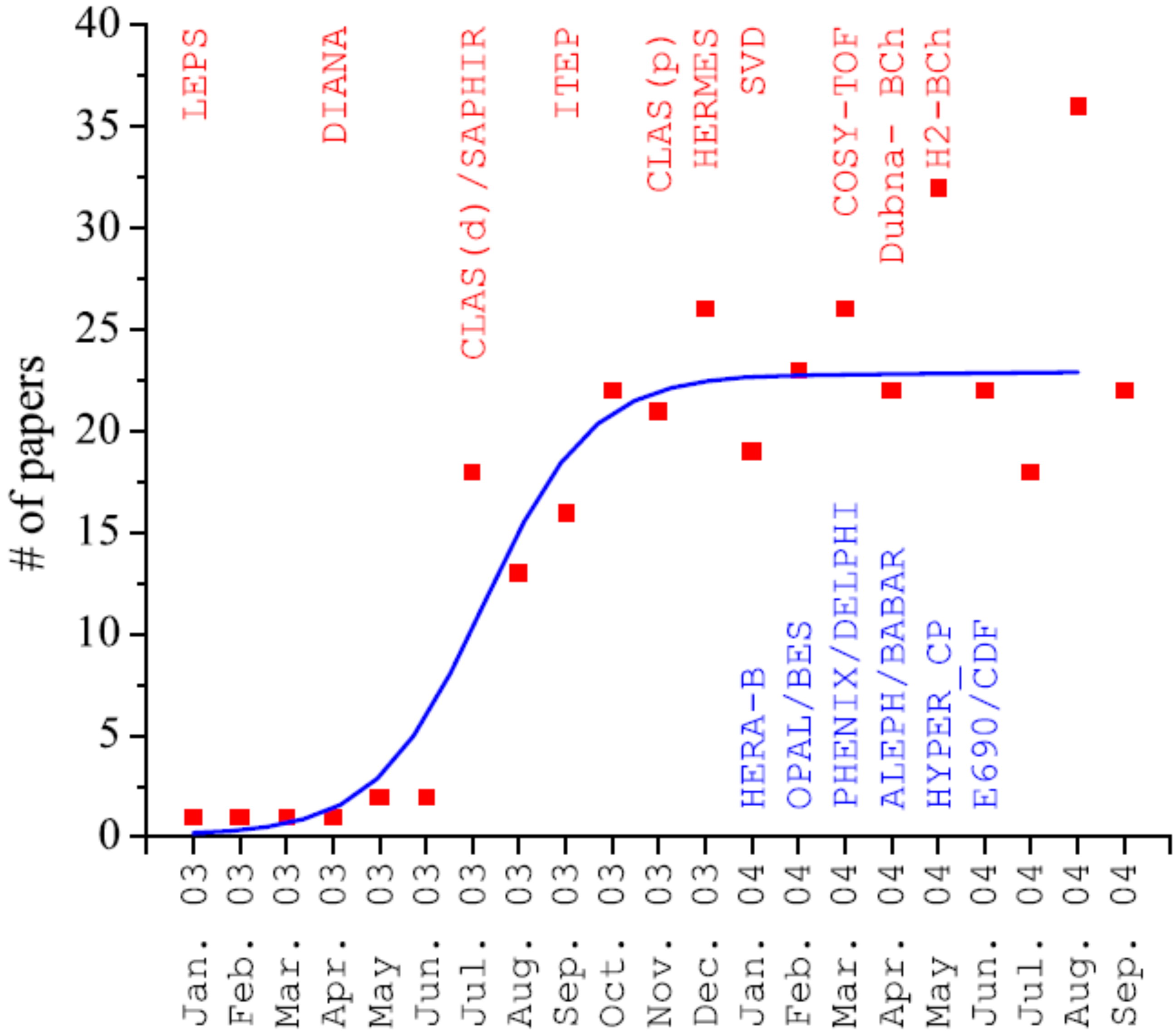


ubble chamber
f K^0p effective
The statistical
e are consistent
, as predicted in



# of papers
LEPS
DIANA
CLAS(d)/SAPHIR
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HERMES
SVD
COSY-TOF
Dubna- BCh
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HERA-B
OPAL/BES
PHENIX/DELPHI
ALEPH/BABAR
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NEW YORK TIMES INTERNATIONAL TUESDAY, JULY 1, 2003

A Subatomic Discovery Emerges From Experiments in Jap

By KENNETH CHANG

Slamming high-energy particles of light into carbon atoms, physicists have unexpectedly produced a new type of subatomic particle.

Protons and neutrons, the building blocks of atoms, are made of smaller particles known as quarks, which come in six varieties. A proton, for example, consists of three quarks — two so-called up quarks and one down quark. Physicists know of slews of particles containing two or three quarks.

Now they believe they know of a particle containing five quarks that perhaps could have been common in the very early universe. (No one

the experiments, Dr. Takashi Nakano, of the Research Center for Nuclear Physics at Osaka University, and told Dr. Nakano that he should look through the data for signs of five-quark particles.

"Dimitri Diakonov was very confident of that," Dr. Nakano said. Dr. Nakano and his collaborators looked, and they found a peak in their graphs corresponding to the mass of the five-quark particle that Dr. Diakonov had predicted. "He was right," Dr. Nakano said. "Actually, I was very surprised."

Dr. Kenneth H. Hicks, a professor of physics at Ohio University and another member of the Spring-

would consist of two up quarks, two down quarks and one known as an anti-strange quark.

The findings will be reported Friday in the journal Physical Review Lette

USA TODAY · TUESDAY, JULY 1, 2003 · 7D

Physics team goes where no quark has gone before

Five alive!

Scientists find fleeting form of basic matter

John Mangels
Plain Dealer Science Writer

PARTICLE
FROM A1

Scientists find unknown form of basic matter

HIGH-ENERGY PHYSICS

Evidence for 'Pentaquark' Particle Sets Theorists Re-Joyce-ing

CERN COURIER

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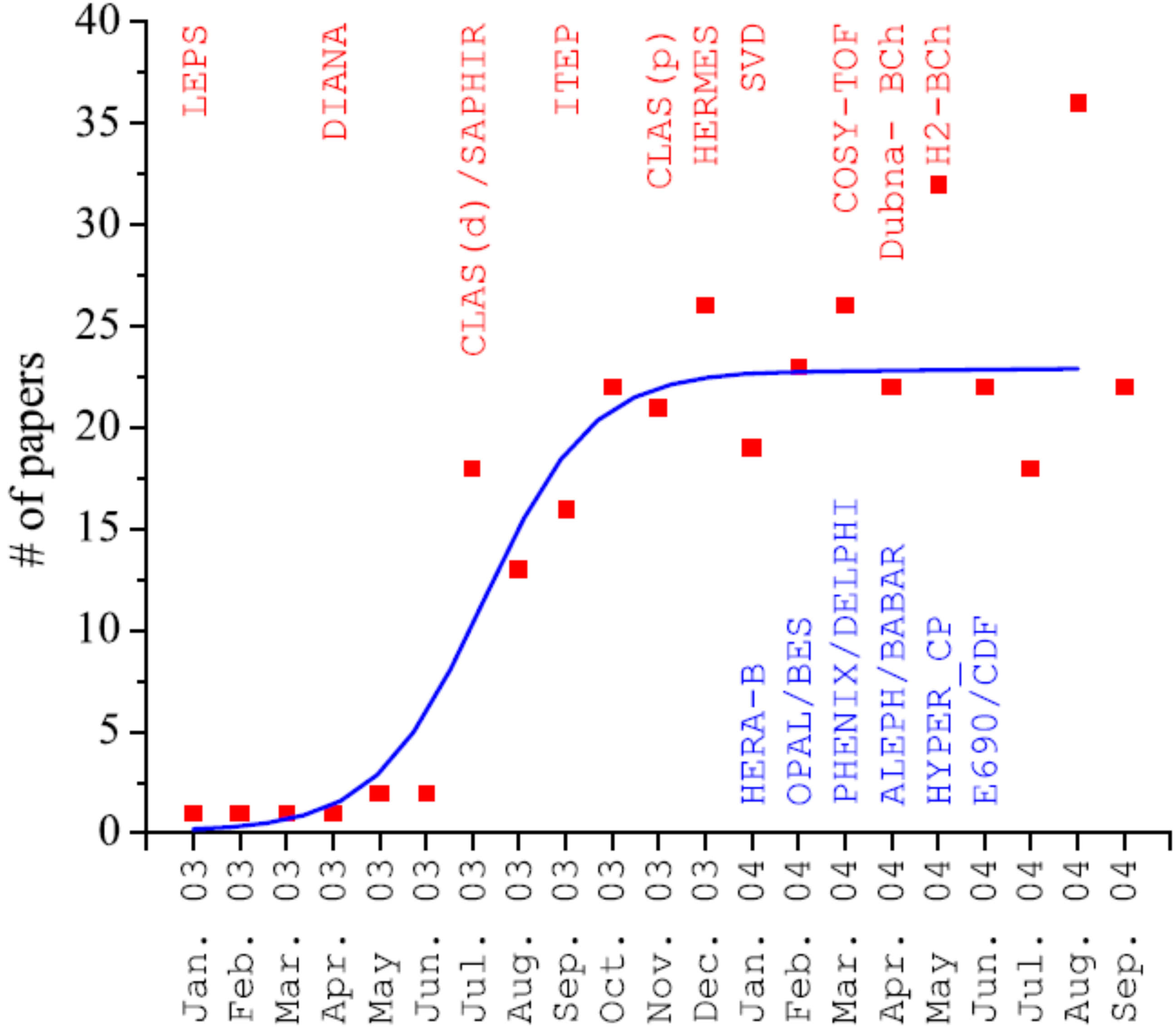
News

New five-quark states found at CERN



# of papers
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LEPS
DIANA
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E690/CDF
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Aug. 04
Sep. 04

Exotics and the Birth of Quarks

A SCHEMATIC MODEL OF BARYONS AND MESONS *

M. GELL-MANN
California Institute of Technology, Pasadena, California

Received 4 January 1964

If we assume that the strong interactions of baryons and mesons are correctly described in terms of the broken "eightfold way" [1-3], we are tempted to look for some fundamental explanation of the situation. A highly promised approach is the purely dynamical "boo trap" model for all the strongly interacting particles within which one may try to derive isotopic spin and strangeness conservation and broken eightfold symmetry from self-consistency alone [4]. Of course, with only strong interactions, the orientation of the asymmetry in the unitary space cannot be specified; one hopes that in some way the selection of specific components of the F-spin by electromagnetism and the weak interactions determines the choice of isotopic spin and hypercharge directions.

Even if we consider the scattering amplitudes of strongly interacting particles on the mass shell only and treat the matrix elements of the weak, electromagnetic, and gravitational interactions by means of dispersion theory, there are still meaningful and important questions regarding the algebraic properties of these interactions that have so far been dis-

ber $n_t - n_{\bar{t}}$ would be zero for all known baryons and mesons. The most interesting example of such a model is one in which the triplet has spin $\frac{1}{2}$ and $z = -1$, so that the four particles d^-, s^-, u^0 and b^0 exhibit a parallel with the leptons.

A simpler and more elegant scheme can be constructed if we allow non-integral values for the charges. We can dispense entirely with the basic baryon b if we assign to the triplet t the following properties: spin $\frac{1}{2}$, $z = -\frac{1}{3}$, and baryon number $\frac{1}{3}$. We then refer to the members $u^{\frac{2}{3}}$, $d^{-\frac{1}{3}}$, and $s^{-\frac{1}{3}}$ of the triplet as "quarks" [6] q and the members of the anti-triplet as anti-quarks $\bar{q}$. Baryons can now be constructed from quarks by using the combinations (qqq), $(qqqq\bar{q})$, etc., while mesons are made out of $(q\bar{q})$, $(qq\bar{q}\bar{q})$, etc. It is assuming that the lowest baryon configuration (qqq) gives just the representations **1**, **8**, and **10** that have been observed, while the lowest meson configuration $(q\bar{q})$ similarly gives just **1** and **8**.

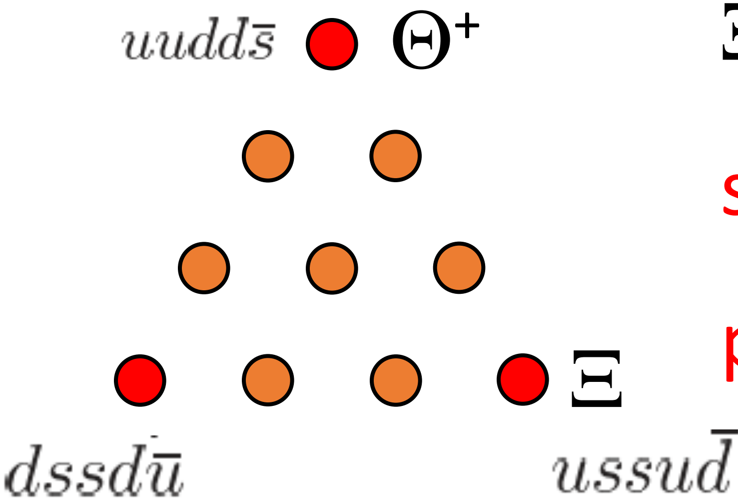
A formal mathematical model based on field theory can be built up for the quarks exactly as for p, n, Λ in the old Sakata model, for example [3]

Quark Model

(uudd$\bar{s}$):   4 * 310 + 550 ~ 1790 MeV

pentaquark: strangeness +1

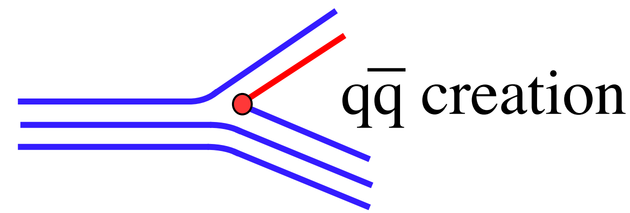
Γ ~ 200 - 400 MeV

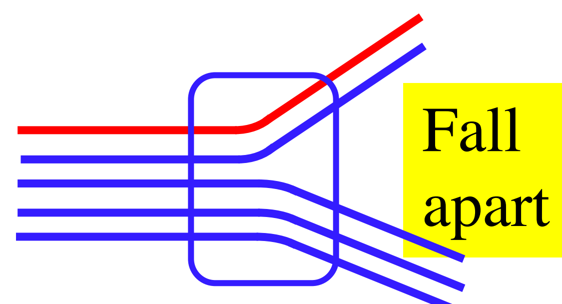


$\Xi(2s) - \Theta(s) =$ 150 MeV

spin 1/2

parity –





Particle Data Group 1986

NOTE ON THE S = +1 BARYON SYSTEM

The evidence for strangeness +1 baryon resonances was reviewed in our 1976 edition,[1] and more recently by Kelly[2] and by Oades.[3] Two new partial-wave analyses[4] have appeared since our 1984 edition. Both claim that the P_{13} and perhaps other waves resonate. However, the results permit no definite conclusion — the same story heard for 15 years. The standards of proof must simply be much more severe here than in a channel in which many resonances are already known to exist. The general prejudice against baryons not made of three quarks and the lack of any experimental activity in this area make it likely that it will be another 15 years before the issue is decided.

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Two year underesimate

Chiral Models

Masses are naturally smaller than in the Quark Model:
rather than adding a constituent starange quark we
add a Goldstone boson:

No 310 + 550 = 860 MeV but M_K = 490 MeV

To understand small width requires some more information.

Parity is positive!

Skyrme Model

T.H.R Skyrme, Proc. Royal Soc. **A260** (1961) 127; Nucl. Phys. **31** (1962) 556.

E. Witten, Nucl. Phys. **B160** (1979) 57; **B223** (1983) 422; **B223** (1983) 433.

G.S. Adkins, C.R. Nappi and E. Witten, Nucl. Phys. **B228** (1983) 552; G.S. Adkins and C.R. Nappi, Nucl.Phys. **B233** (1984) 109.

Take Goldstone boson Lagrangian (very specific!):

$$\mathcal{L} = \frac{F_\pi^2}{16}\,\mathrm{Tr}\left(\partial_\mu U^\dagger \partial^\mu U\right) + \frac{1}{32e^2}\,\mathrm{Tr}\left(\left[\partial_\mu U\, U^\dagger, \partial_\nu U\, U^\dagger\right]^2\right)$$

where the unitary matrix U is given in terms of pions, kaons and eta (denoted as φ_a) :

$$U = \exp\left(i2\varphi_a\lambda_a/F_\pi\right),\ F_\pi = 186\ \mathrm{MeV}$$

Expanding exponent gives the GBs interaction Lagrangian (predecessor of chiral perturbation theory) organized as a power series in the number of fields and their momenta. This works for low energy GB scattering.

Baryons in the Skyrme Model

T.H.R Skyrme, Proc. Royal Soc. **A260** (1961) 127; Nucl. Phys. **31** (1962) 556.

E. Witten, Nucl. Phys. **B160** (1979) 57; **B223** (1983) 422; **B223** (1983) 433.

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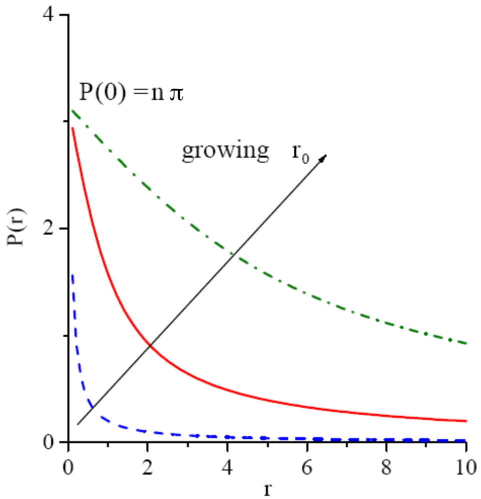
This lagrangian adimts classical solution in a form of the hedgehog Ansatz

$$U_0 = \begin{bmatrix} e^{i\vec{n}\cdot\vec{\tau}\,P(r)} & 0 \\ 0 & 1 \end{bmatrix}$$



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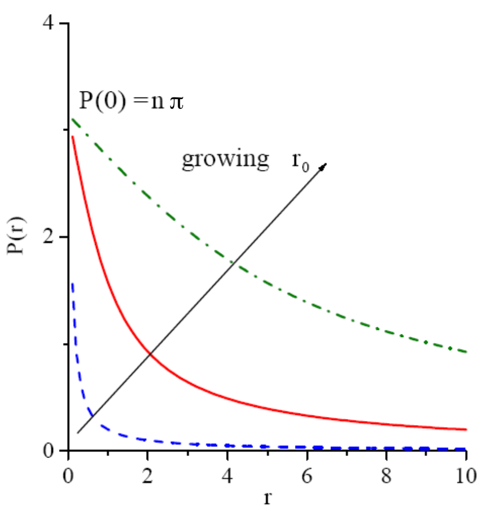


Skyrme Lagrangian has a global symmetry

$$U \to A U A^\dagger$$

corresponding to zero modes (same energy)

Collective quantization

$$U = AU_0A^\dagger \qquad A \to A(t)$$

However:

$$\boxed{[U_0, \lambda_8] = 0} \qquad U_0 = \begin{bmatrix} e^{i\vec{n}\cdot\vec{\tau}\,P(r)} & 0 \\ 0 & 1 \end{bmatrix} \qquad \lambda^8 = \frac{1}{\sqrt{3}}\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -2 \end{bmatrix}$$

As a conseqence there is an equivalence: $A(t) \sim A(t)e^{-i\varphi\lambda_8}$

$$A(t)e^{-i\varphi\lambda_8}\,U_0\,e^{i\varphi\lambda_8}A^\dagger(t) = A(t)U_0A^\dagger(t)$$

and the right index of matrix $A(t)$ lives in the SU(2) subgroup of SU(3) that correspopnds to spin. On the contrary the left index goes over the entire SU(3), and corresponds to flavor.

$$A_{\mathrm{flavor},\mathrm{spin}}$$

Collective Hamiltonian

Rotational nergy (mass) of a rotating baryon in SU(3) representation $\mathcal{R} = (p,\, q)$ is analgous to the quantum mechanical symmetric top:

$$\mathcal{E}^{\rm rot}_{(p,\,q)} = M_{\rm sol} + \frac{J(J+1)}{2I_1} + \frac{C_2(p,q) - J(J+1) - 3/4\,Y'^2}{2I_2}$$

Soliton mass $M_{\rm sol}$ and moments of ineria $I_{1,2}$ are calculable functions of the profile function $P(r)$

J^2 - soliton angular momentum = baryon spin

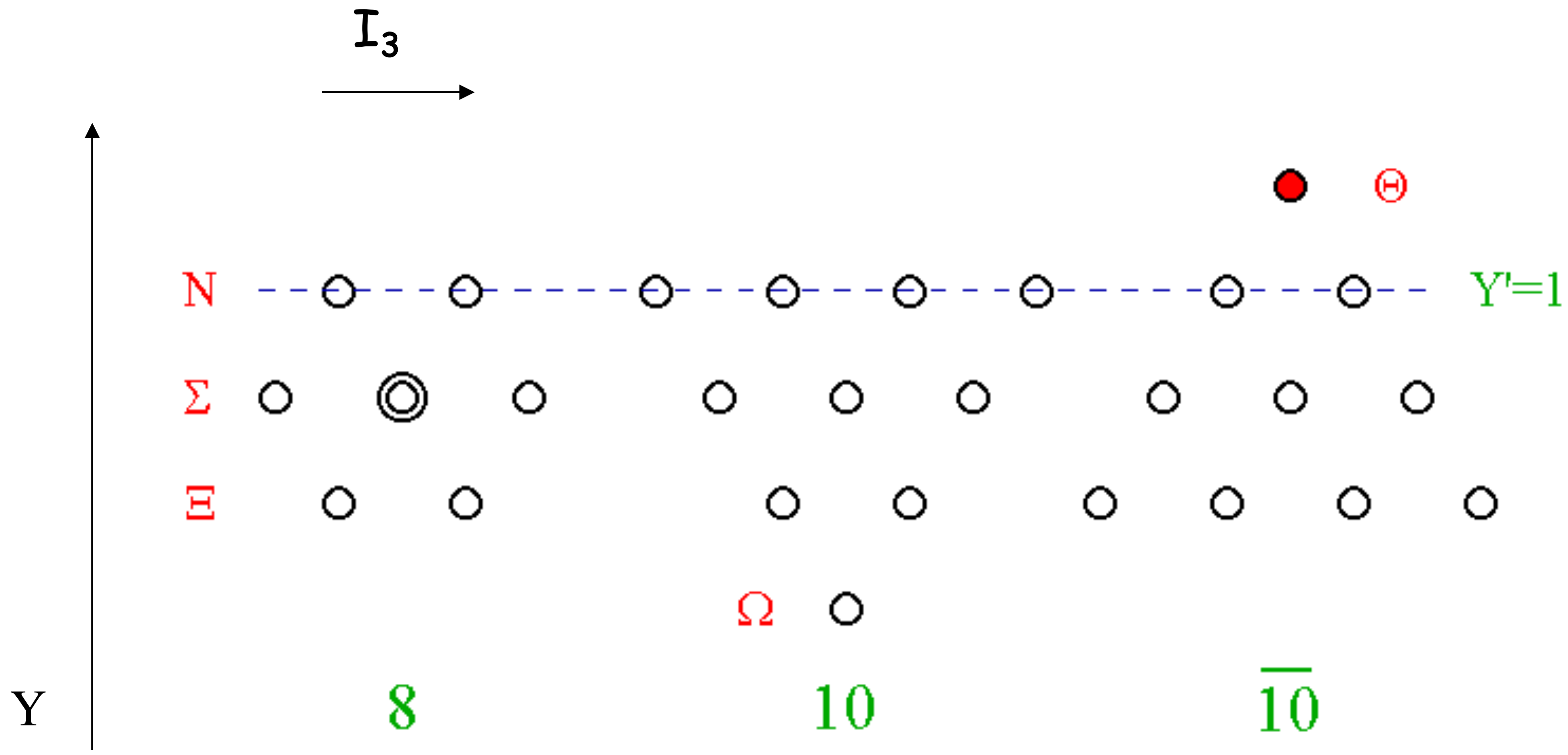
$C_2(p,q)$ - SU(3) Casimir operator

$Y' = N_c/3$ - constraint selecting allowed SU(3) representations

Isospin of states on Y' line is equal to J

Allowed SU(3) multiplets and w.f's

$$|R,B,S\rangle = \sqrt{R}\, D^{(\mathcal{R})*}_{\underbrace{Y I I_3}_{B}\;\underbrace{Y' J J_3}_{S}}(A) \qquad\qquad J_3 = -S_3$$



Pheomenology

$$\mathcal{E}^{\text{rot}}_{(p,\,q)} = M_{\text{sol}} + \frac{J(J+1)}{2I_1} + \frac{C_2(p,q) - J(J+1) - 3/4\, Y'^2}{2I_2}$$

symmetry breaking GB's are not massless

$$H_{\text{br}} = \alpha\, D^{(8)}_{88}$$

- absolute masse are not well reproduced, N_c^0 terms are missing
- splittings are well reproduced
- I_1 can be extracted from $\Delta - N$ splitting
- no handle on I_2 from regular non-exotic baryons
- model idependent relations

$$2(\mathrm{N} + \Xi) = 3\Lambda + \Sigma$$

$$\Sigma^* - \Delta = \Xi^* - \Sigma^* = \Omega^- - \Xi^*$$

$$\boxed{8(\Xi^* - \Sigma^*) = 11\Lambda - 8\mathrm{N} - 3\Sigma}$$

E. Guadagnini Nucl.Phys.**B236** (1984) 35

Pheomenology

$$\frac{1}{I_1} = \frac{2}{3}\left(M_{10} - M_8\right) = 153 \text{ MeV}$$

$$\frac{1}{I_2} = \frac{2}{3}\left(M_{\overline{10}} - M_8\right) = ?$$

What is Theta+ mass?

What is the value of I_2 ? Model calculation from 1984:

Monopolar Harmonics in $SU_f(3)$ as Eigenstates of the Skyrme-Witten Model for Baryons*

L. C. Biedenharn

and

Yossef Dothan**

Physics Department, Duke University
Durham, NC 27706 USA

To Professor Yuval Ne'eman on the occasion of his Sixtieth Birthday

Thus the first state violating the three quark rule is a $(\overline{10},\frac{1}{2})$, which--using numerical values[4] in the Hamiltonian--yields an excitation energy $\approx$ 600 Mev above the $(8,\frac{1}{2})$. Since the theory is a low energy effective theory we believe that this gives an aposteriori excitation energy limit on the validity. Otherwise stated this means that when baryons are probed with momentum transfers of the order of 600 MeV one starts to feel their compositness.

Footnotes and References

1) E. Witten, Nucl. Phys. B223(1982) 422.

2) T.H.R. Skyrme, Proc. Roy. Soc. A260 (1961) 127.

3) E. Guadagnini, Nucl. Phys., B236, (1984), 35.
L.C. Biedenharn, Y. Dothan and A. Stern, Phys. Lett. 146D (1983) 289.

4) L.C. Biedenharn, J.D. Louck, Encl. for Math. and Appl., Vol. 9: "The Racah-Wigner Algebra in Quantum Theory", Additon-Wesley (Reading, MA) 1981.

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BARYONS AS QUARKS IN A SKYRMION BUBBLE

L.C. BIEDENHARN [1], Y. DOTHAN [2] and A. STERN
Center for Particle Theory, Physics Department, University of Texas at Austin, Austin, TX 78712, USA

Received 4 June 1984
Revised manuscript received 24 July 1984

$$E_{\mathrm{qu}}^{\mathrm{SU}(3)} = E_0 + (2F_\pi^2 R^3)^{-1}\left[(p^2 + 3p + q^2 - pq - \tfrac{9}{4}B^2)/3C_{\mathrm{SU}(3)} + J(J+1)(C_{\mathrm{rot}}^{-1} - C_{\mathrm{SU}(3)}^{-1})\right], \tag{24}$$

$$E_0 = M_{\mathrm{sol}}$$

$$C_{\mathrm{SU}(3)} = 2I_2$$

$$C_{\mathrm{rot}} = 2I_1$$

with the wave section having the form of an $(\mathrm{SU}(3))_{\mathrm{f}} \times (\mathrm{SU}(2))_{\mathrm{spin}}$ monopolar harmonic [21]:

$$\phi(A) = D^{[pqo]^*}{}_{I,I_3,Y;J,J_3,B}(\phi_1, \ldots, \phi_7, \phi_8 = \pm\phi_4). \tag{25}$$

The quantum numbers are: $(\mathrm{SU}(3))_{\mathrm{f}}$ irrep labels $[pqo]$; isospin I, I_3; hypercharge Y; spin J, J_3; baryon number $B = B_{\mathrm{U}}$.

The additional moment of inertia is

$$C_{\mathrm{SU}(3)} = \tfrac{1}{2}\pi \int_0^\infty \mathrm{e}^{3s}[1 - \cos\theta(s)]\, \mathrm{d}s \simeq 12.93\,. \tag{26}$$

$$\Delta_{\overline{10}-8} = 330 \quad \mathrm{MeV}$$

$+\,3q$

$$\begin{aligned} E^{\mathrm{SU}(3)}_{\mathrm{qu}} = E_0 & \\ & + (2F_\pi^2 R^3)^{-1}\left[(p^2+3p+q^2+pq-\tfrac{9}{4}B^2)/3C_{\mathrm{SU}(3)}\right. \\ & \left. + J(J+1)(C_{\mathrm{rot}}^{-1} - C_{\mathrm{SU}(3)}^{-1})\right] , \end{aligned} \tag{24}$$

with the wave section having the form of an $(\mathrm{SU}(3))_{\mathrm{f}} \times (\mathrm{SU}(2))_{\mathrm{spin}}$ monopolar harmonic [21]:

$$\phi(A) = D^{[pqo]^*}{}_{I,I_3,Y;J,J_3,B}(\phi_1, \ldots, \phi_7, \phi_8 = \pm\phi_4) . \tag{25}$$

The quantum numbers are: $(\mathrm{SU}(3))_{\mathrm{f}}$ irrep labels $[pqo]$; isospin I, I_3; hypercharge Y; spin J, J_3; baryon number $B = B_{\mathrm{U}}$.

The additional moment of inertia is

$$C_{\mathrm{SU}(3)} = \tfrac{1}{2}\pi \int_0^\infty \mathrm{e}^{3s}[1 - \cos\theta(s)]\, \mathrm{d}s \simeq 12.93 . \tag{26}$$

$$\Delta_{\overline{10}-8} = 590 \quad \mathrm{MeV}$$

What is Theta+ mass?

MP 1987 in *Workshop on Skyrmions and Anomalies and* Physics Letters B 575 (2003) 234–241

$$H_{\rm br} = \alpha\, D^{(8)}_{88}$$

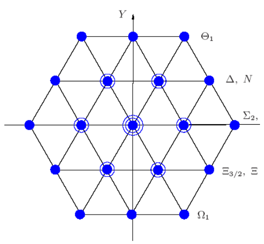
Compute first order and also second order corrections

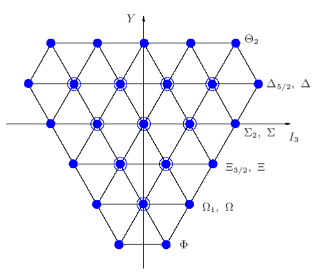
$$M^{(1)}_{B(R)} = -\alpha \delta^{R}_{B(R)} \qquad M^{(2)}_{B(R)} = -2 I_2 \alpha^2 \sum_{R' \neq R} \frac{(\delta^{R'}_{B(R)})^2}{\Delta_{R'R}}$$

where:

$$\delta^{R'}_{B(R)} = \langle R', B, S | D^{(8)}_{88} | R, B, S \rangle \qquad \Delta_{R'R} = C_2(R') - C_2(R)$$

Symmetry breaking operator does not change the quantum numbers, except of the representation $R' = 8,\, \overline{10},\, 27,\, \overline{35}$





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New sum rules can be derived that are satisfied at the promile level!

$$\frac{132}{65} N + \frac{11}{5} \Xi = \frac{33}{26} \Sigma + \frac{77}{26} \Lambda$$

$$\frac{2627}{594} \Delta + \frac{213}{22} \Xi^* = \frac{1136}{99} \Sigma^* + \frac{71}{27} \Omega$$

Above only two examples are given.

What is Theta+ mass?

MP 1987 in *Workshop on Skyrmions and Anomalies and* Physics Letters B 575 (2003) 234–241

$$H_{\mathrm{br}} = \alpha\, D^{(8)}_{88}$$

Compute first order and also second order corrections

$$M^{(1)}_{B(R)} = -\alpha \delta^{R}_{B(R)} \qquad M^{(2)}_{B(R)} = -2 I_2 \alpha^2 \sum_{R' \neq R} \frac{(\delta^{R'}_{B(R)})^2}{\Delta_{R'R}}$$

Prediction of the Theta+ mass:

	M_8	$M_{\overline{10}}$	α	ε	$1/I_1$	$1/I_2$
Fit I	1213	1503	720	1442	193	360
	$M_{\Theta^+} =$	1534		$\varepsilon = I_2\alpha^2$		

Quark-soliton model

Based on the spontanous chiral symmetry breaking and instanton model of the QCD vacuum:

$$q \to \exp(i\gamma_5 \alpha^A \lambda^A)\, q, \quad \bar{q} \to \bar{q}\, \exp(i\gamma_5 \alpha^A \lambda^A), \quad A = 1..8$$

Lagrangian

$$\bar{q}\ \left[i\partial\!\!\!/ - M\exp(i\,\gamma_5\, \pi^A \lambda^A / F_\pi)\right]\ q$$

is invariant, because one can absorb chiral rotation
into the redefined pseudoscalar meson fields π^A

Chiral symmetry is spontaneously broken

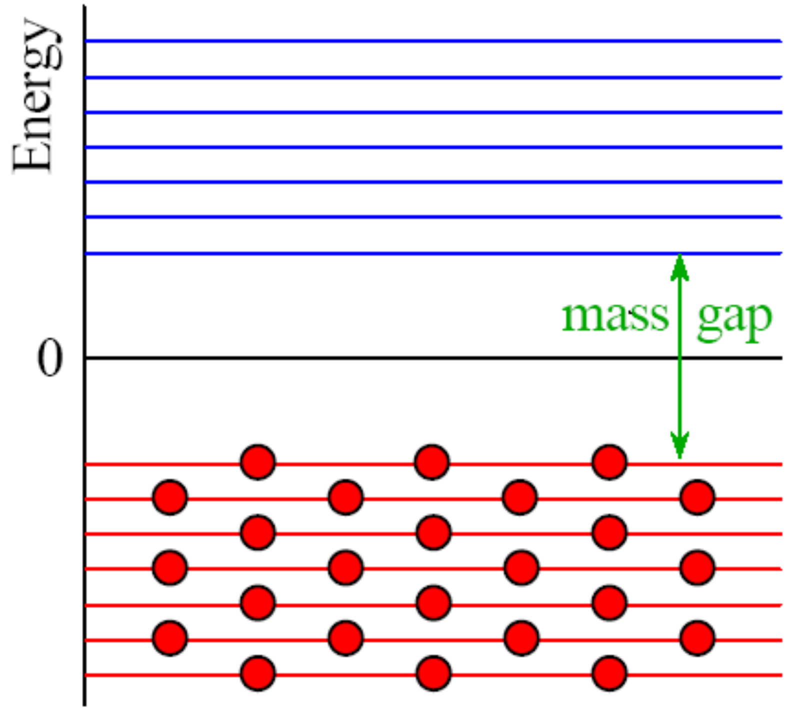
Goldstone bosons are massless

Dirac equation in external chiral field

$$\left[i\partial\!\!\!/ - M \exp\left(i\boldsymbol{n} \cdot \boldsymbol{\lambda}\, \gamma_5\, P(r) \right) \right] q = 0$$

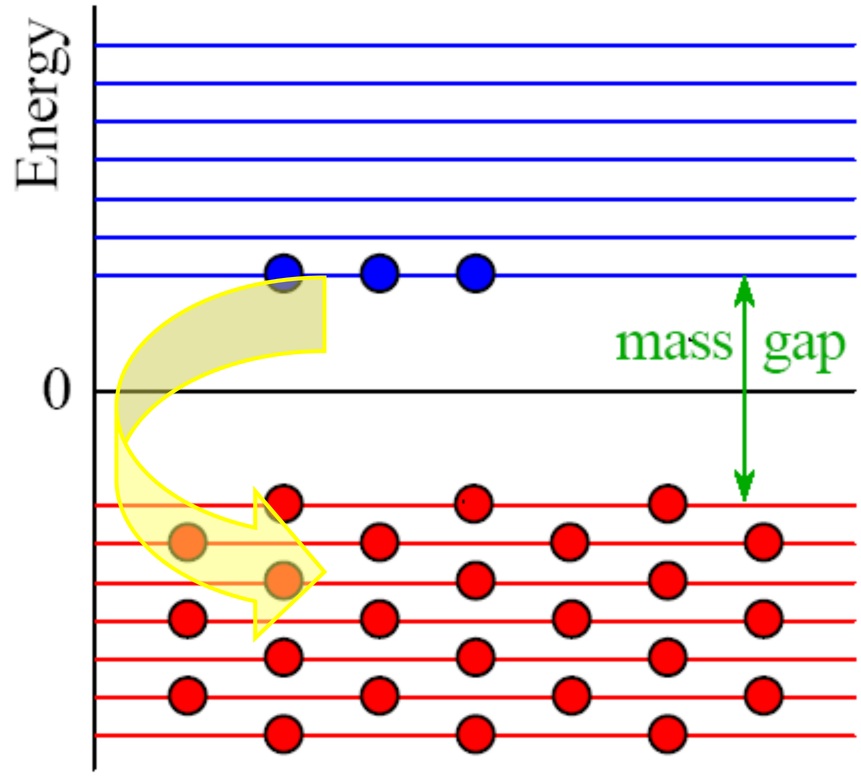
Minimize energy with respect to $P(r)$.

Vacuum.



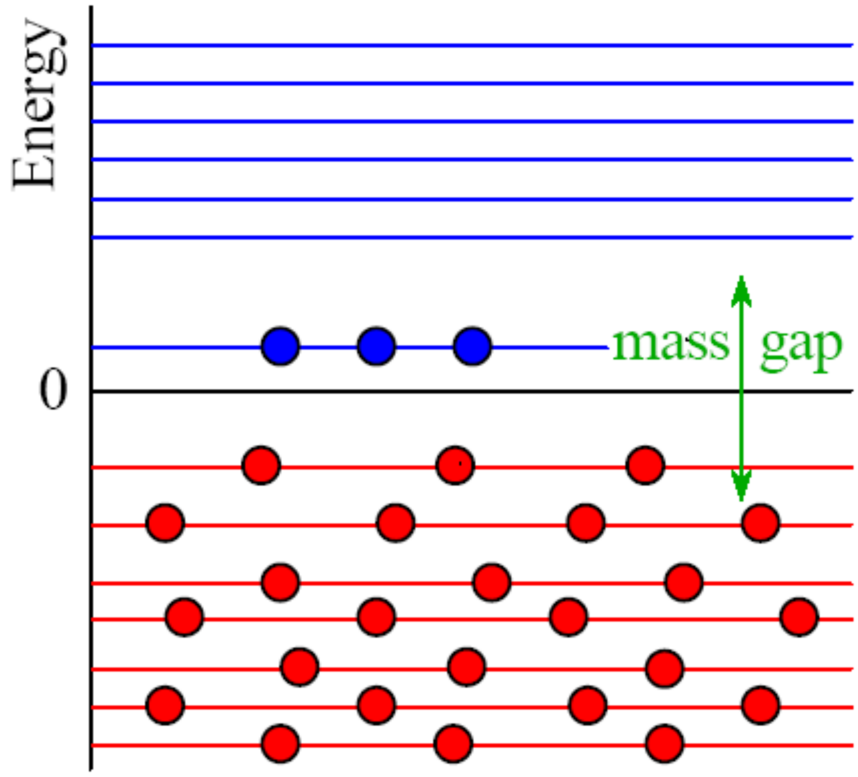
Spectrum of the Dirac operator

Baryon:



Spectrum of the Dirac operator

Baryon:

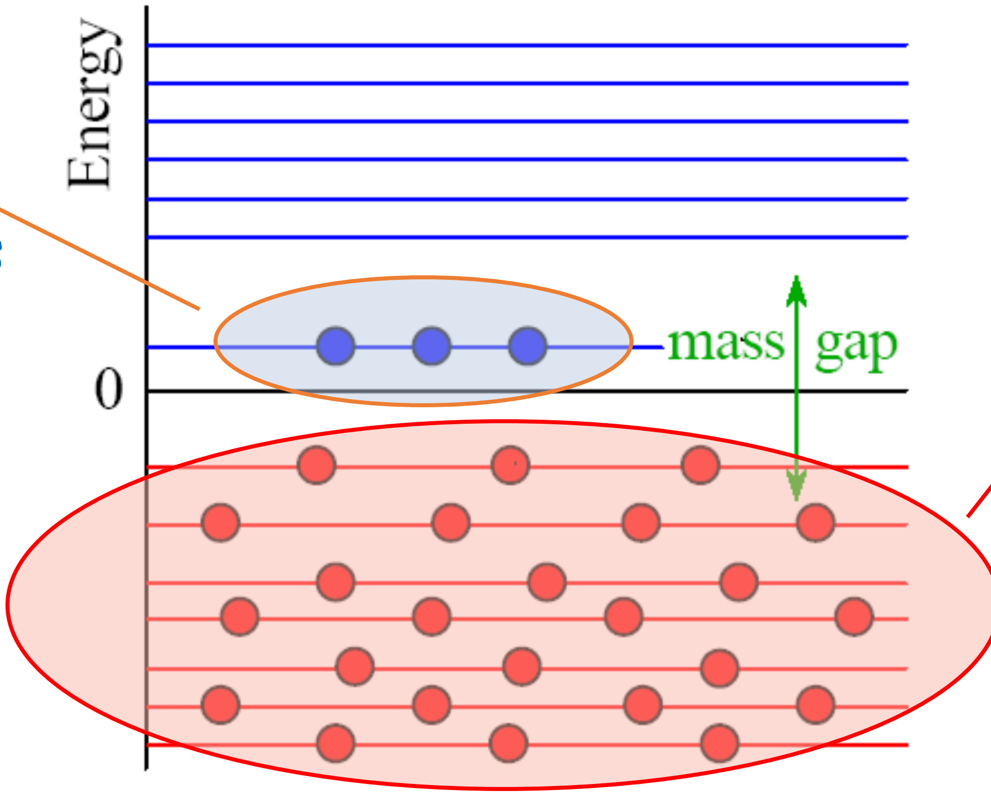


Spectrum of the Dirac operator

valence level:

energy decreases

Baryon:



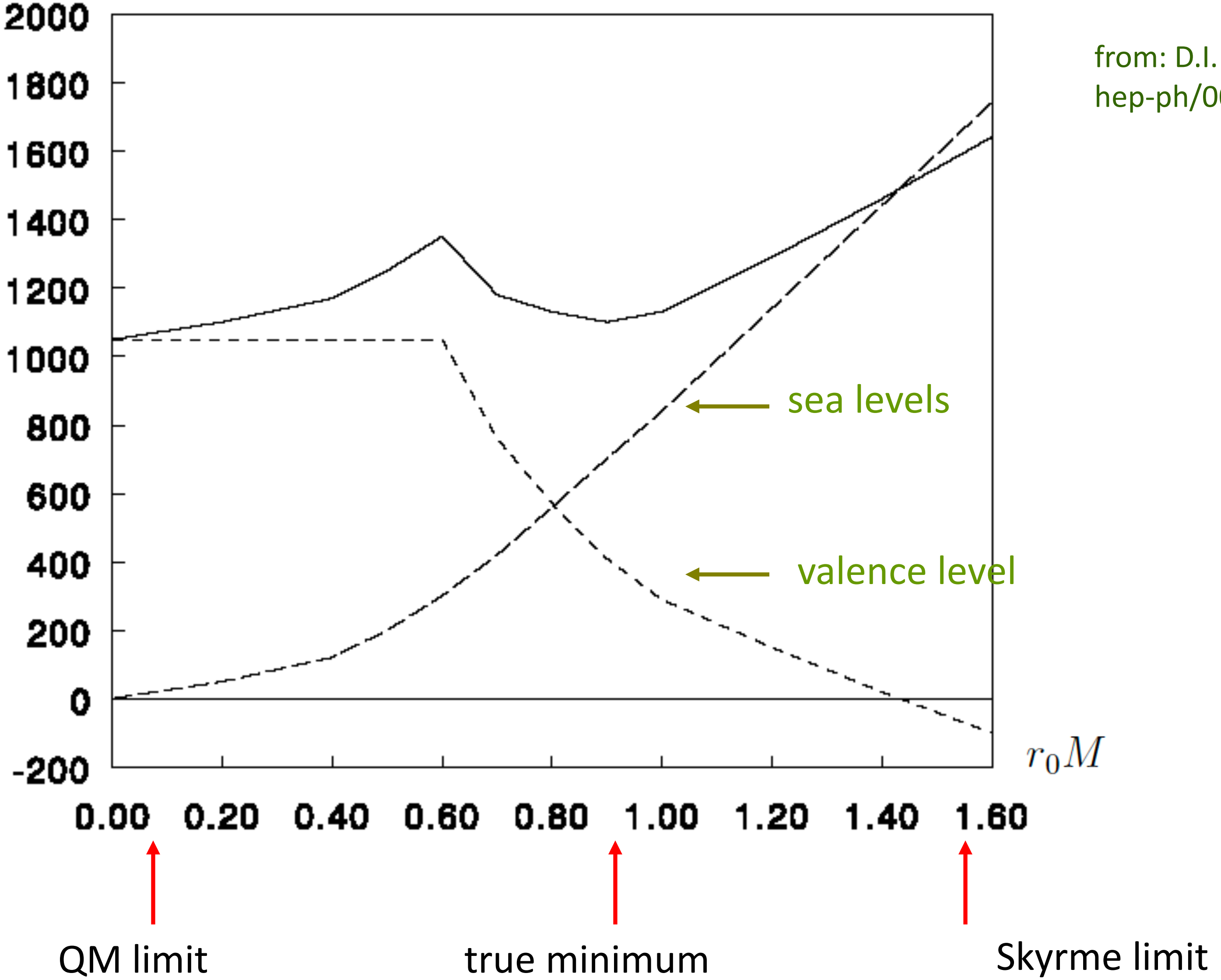
sea levels:

energy increases

system stabilzes

variational approach: $P(r)=P(r/r_0)$
r_0 - soliton size

from: D.I. Diakonov, hep-ph/0009006



Mass formula in the χQSM

$$\mathcal{E}^{\rm rot}_{(p,\,q)} = M_{\rm sol} + \frac{J(J+1)}{2I_1} + \frac{C_2(p,q) - J(J+1) - 3/4\,Y'^2}{2I_2}$$

$$H_{\rm br} = \alpha\, D^{(8)}_{88} + \beta\,\hat{Y} + \frac{\gamma}{\sqrt{3}} \sum_{i=1}^{3} D^{(8)}_{8i}\,\hat{J}_i$$

Hamiltonian is the same as in the Skyrme model (includes $1/N_c$ corrections in SU(3) breaking part.

All parameters are now regularized sums over the Dirac energy levels.

Same problem with fixing I_2.

Mass formula in the χQSM

$$\mathcal{E}^{\mathrm{rot}}_{(p,q)} = M_{\mathrm{sol}} + \frac{J(J+1)}{2I_1} + \frac{C_2(p,q) - J(J+1) - 3/4\,Y'^2}{2I_2}$$

M = 1530

$$H_{\mathrm{br}} = \alpha\, D^{(8)}_{88} + \beta\, \hat{Y} + \frac{\gamma}{\sqrt{3}} \sum_{i=1}^{3} D^{(8)}_{8i}\, \hat{J}_i$$

ZEITSCHRIFT FÜR PHYSIK A

Exotic anti-decuplet of baryons: prediction from chiral solitons

Dmitri Diakonov[1,2], Victor Petrov[1], Maxim Polyakov[1,3]

[1] Petersburg Nuclear Physics Institute, Gatchina, St.Petersburg 188 350, Russia
[2] NORDITA, Blegdamsvej 17, 2100 Copenhagen, Denmark
[3] Inst. für Theor. Physik II, Ruhr-Universität Bochum, D-44780 Bochum, Germany (e-mail: maximp@hadron.tp2.ruhr-uni-bochum.de)

986 citations

Mitya Diakonov +2012

Vitya Petrov +2021

Maxim Polyakov +2021

Zeischrift für Physik +1997

Decay width

Abstract. We predict an exotic Z^+ baryon (having spin $1/2$, isospin 0 and strangeness +1) with a relatively low mass of about 1530 MeV and total width of less than 15 MeV. It seems that this region of masses has avoided thorough searches in the past.

Decay width – cont.

Eur. Phys. J. C 35, 221–222 (2004)
Digital Object Identifier (DOI) 10.1140/epjc/s2004-01815-4

THE EUROPEAN PHYSICAL JOURNAL C

The width of the Θ^+ exotic baryon in the chiral soliton model

R.L. Jaffe

Center for Theoretical Physics, Laboratory for Nuclear Science and Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA

Received: 29 January 2004 /
Published online: 5 May 2004 – © Springer-Verlag / Società Italiana di Fisica 2004

Abstract. In 1997 Diakonov, Petrov, and Polyakov, calculated the width of the exotic baryon that they called Θ^+. The prediction, $\Gamma(\Theta^+) \lesssim 15\,\mathrm{MeV}$, has received considerable attention, especially in light of the narrowness of the experimentally reported Θ^+ resonance. However, there is an arithmetic error in their work: when corrected, the width estimate quoted in that paper should have been $\lesssim 30\,\mathrm{MeV}$.

Acknowledgements. I thank H. Weigel for correspondence

Decay width – cont.

arXiv:hep-ph/0404212

Comment on the Θ^+ width and mass

Dmitri Diakonov[a,b,c], Victor Petrov[c], and Maxim Polyakov[c,d]
[a] *Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA*
[b] *NORDITA, Blegdamsvej 17, DK-2100 Copenhagen, Denmark*
[c] *St. Petersburg Nuclear Physics Institute, Gatchina, 188 300, St. Petersburg, Russia*
[d] *Université de Liege, B-4000 Liege 1, Belgium*
(Dated: May 18, 2004)

We discuss the relatively low mass and narrow width prediction for the exotic baryon Θ^+, and comment on recent statements by R.L. Jaffe on the subject. We reaffirm that a narrow width of 3.6 – 11.2 MeV follows from the equations of our 1997 paper.

DPP admit a misprint in Δ decay

$$\Gamma(\Delta \to N\pi) = \frac{3G_{10}^2}{2\pi(M_\Delta + M_N)^2}|\mathbf{p}|^3 \boxed{\frac{M_N}{M_\Delta}} \cdot \frac{1}{5} \quad \Rightarrow \quad \Gamma(\Delta \to N\pi) = \frac{3G_{10}^2}{2\pi(m_\Delta + m_N)^2}|\mathbf{p}|^3 \boxed{\frac{m_\Delta}{m_N}} \cdot \frac{1}{5}$$

$$\Gamma(Z^+ \to NK) = \frac{3G_{\overline{10}}^2}{2\pi(M_N + M_Z)^2}|\mathbf{p}|^3 \frac{M_N}{M_Z}$$

but in the numerics they used the correct formula

Decay width – cont.

Comment on hep-ph/0404212 by D. Diakonov, V. Petrov, and M. Polyakov

arXiv:hep-ph/045268

R. L. Jaffe

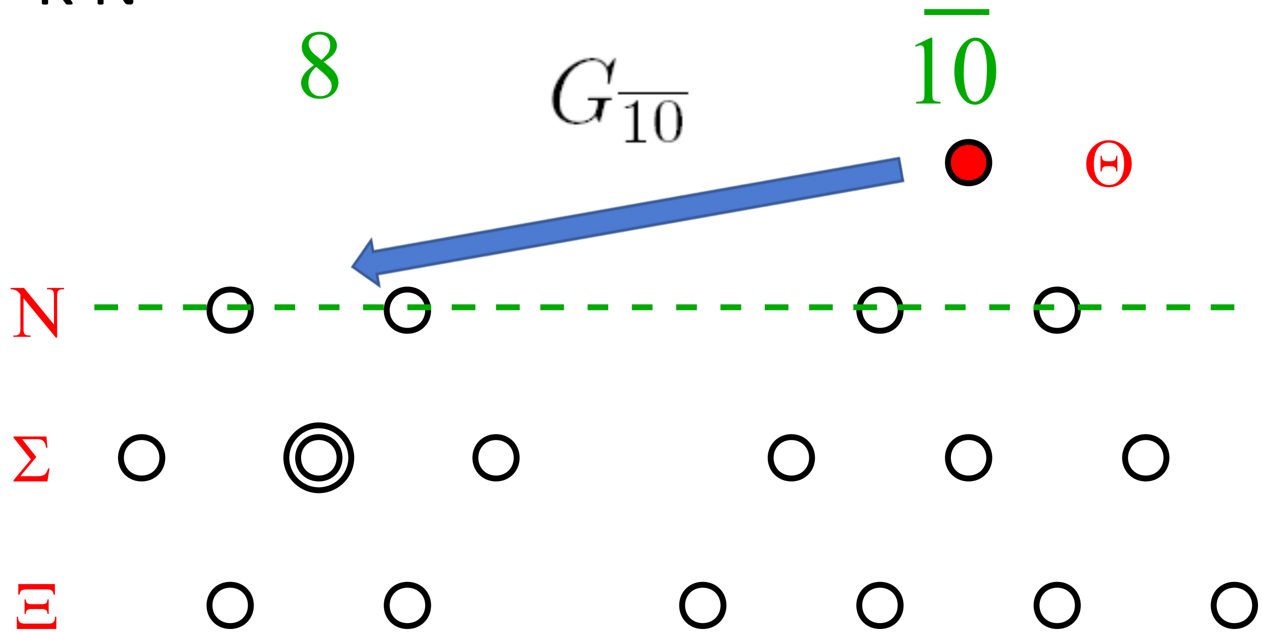
Center for Theoretical Physics,
Laboratory for Nuclear Science and Department of Physics,
Massachusetts Institute of Technology,
Cambridge, Massachusetts 02139
MIT-CTP-3498

In hep-ph/0404212 Diakonov, Petrov, and Polyakov respond to my recent comments on their 1997 paper, "Exotic anti-decuplet of baryons: prediction from chiral solitons". Their responses do not address the basic issues or alter the conclusions in my paper.

My persistence in this matter has been fuelled principally by an e-mail exchange between M. Polyakov and H. Weigel which took place in 1998. In it Weigel asks about the same apparent inconsistency in Ref. [2] that I discuss in Ref. [1]†. In his reply to Weigel Polyakov clearly and directly admits that he made an arithmetic error in the calculation in question. Since Polyakov apparently was responsible for the calculation and explicitly admits the only point at issue, it seems unnecessary to continue this discussion further.

Decay of Theta$^+$

$\Theta^+ \to K\ N$

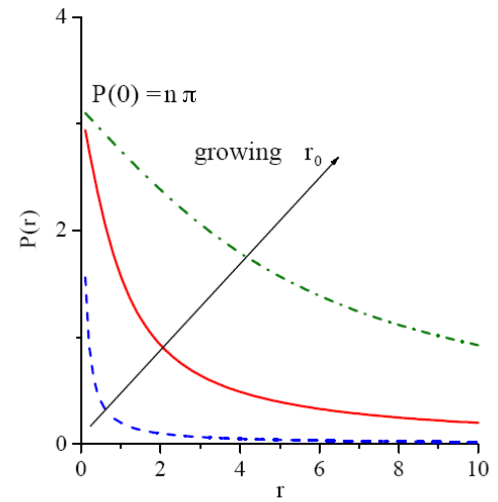


$$g_{\Theta NK} = G_{\overline{10}}$$

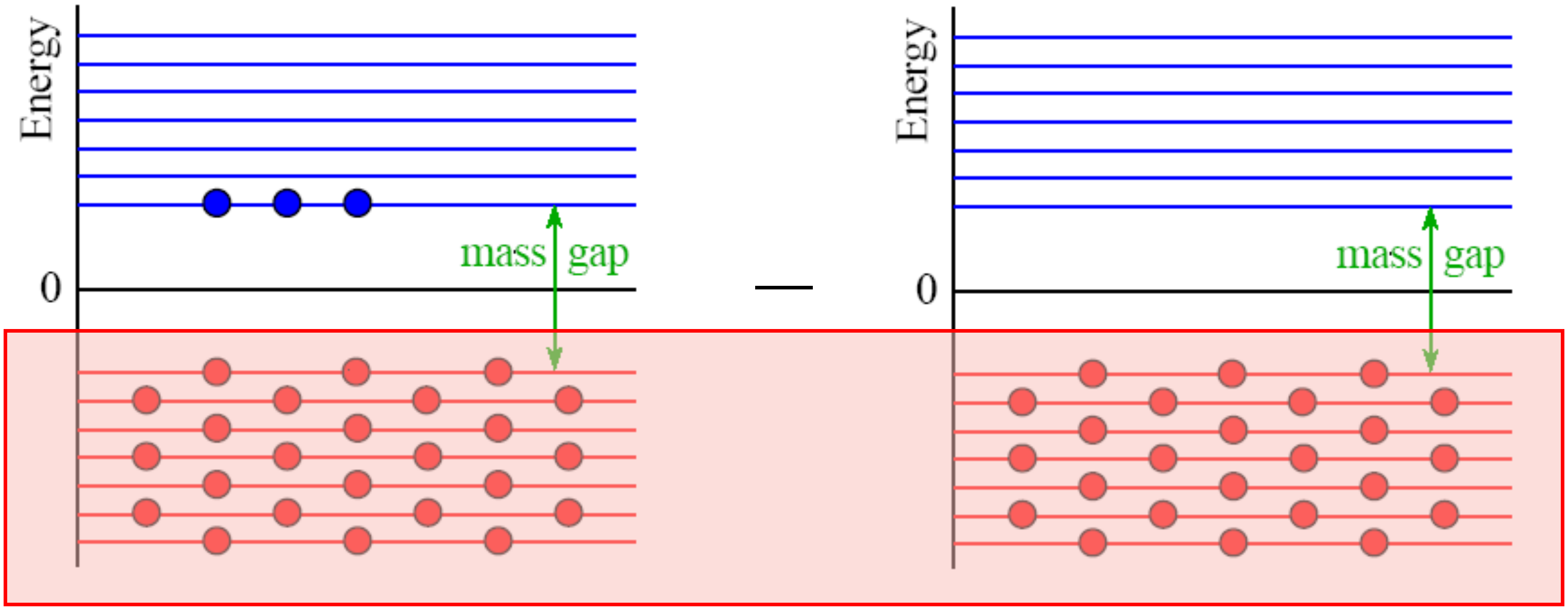
NRQM Limit

Diakonov, Petrov, Polyakov, Z.Phys **A359** (97) 305

MP, A.Blotz K.Goeke, Phys.Lett.**B354**:415-422,1995



energy is calculated
with respect to the vacuum:



in the NRQM limit only valence level contributes

NRQM Limit

$$g_A^{(3)} = \frac{5}{3}, \quad \Delta\Sigma = 1, \quad \frac{\mu_p}{\mu_n} = -\frac{3}{2}$$

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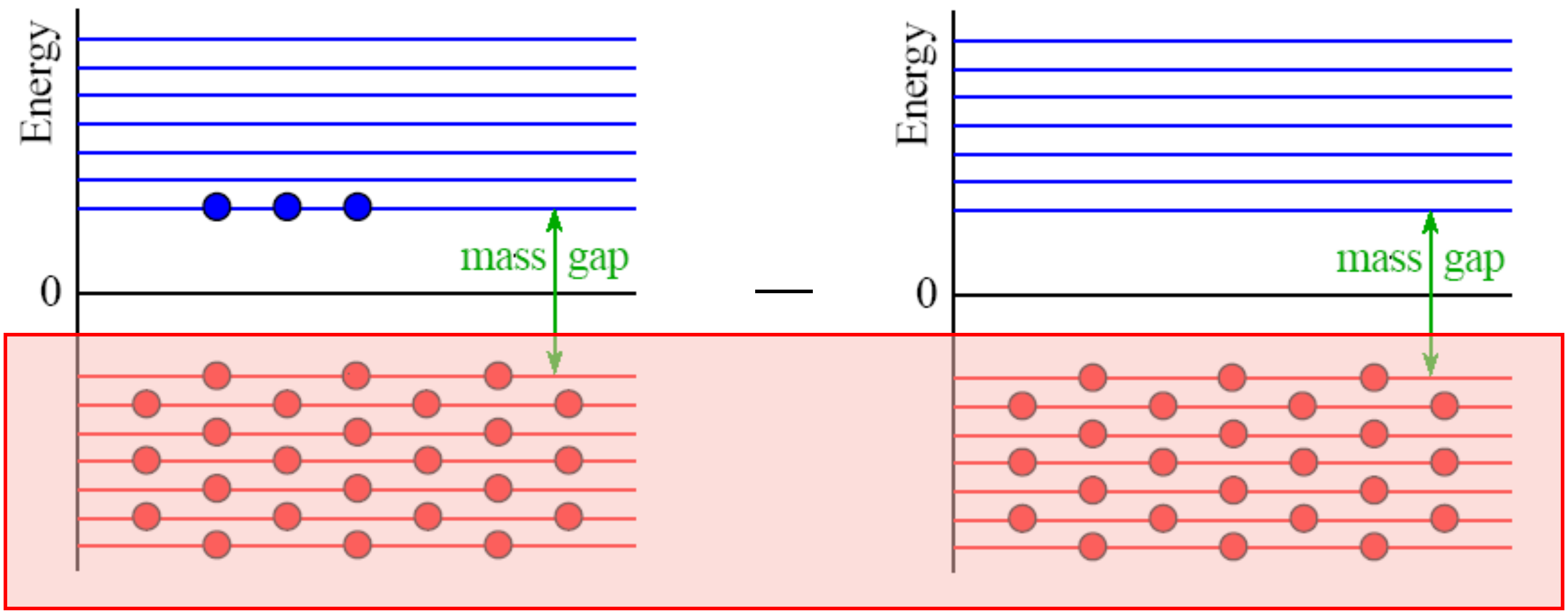

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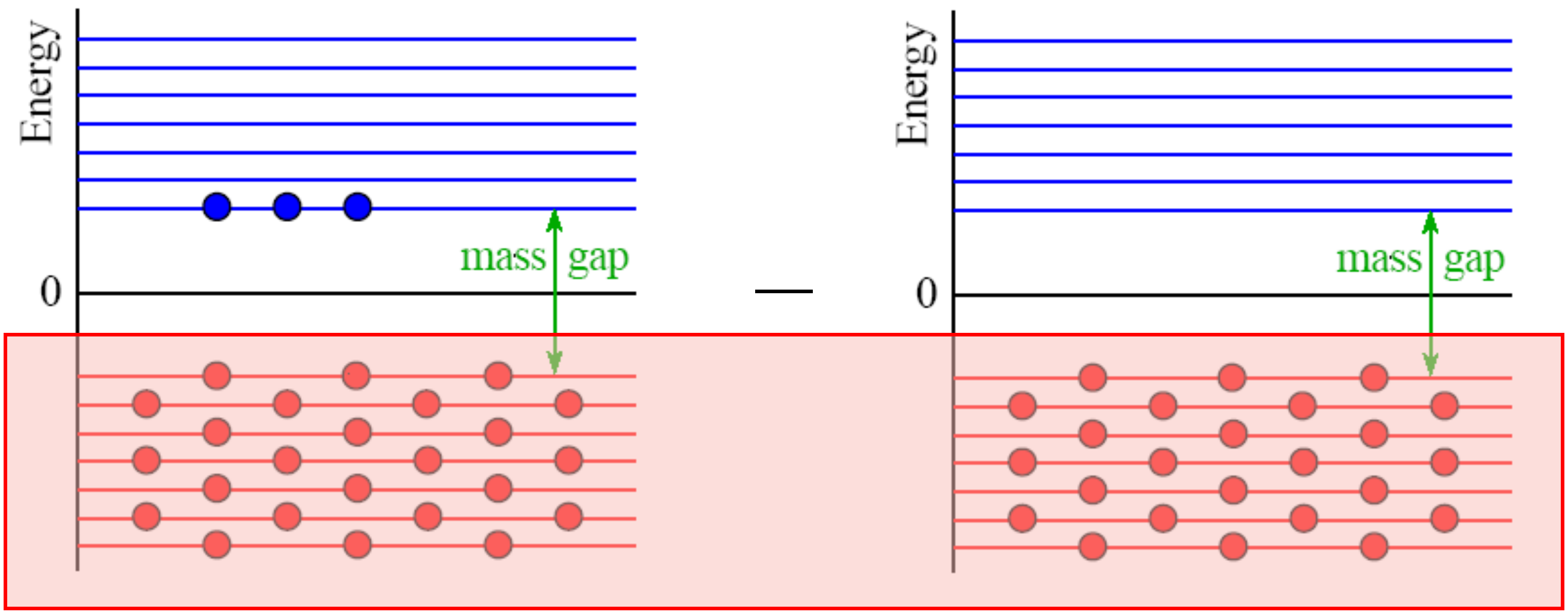
Diakonov, Petrov, Polyakov, Z.Phys **A359** (97) 305

MP, A.Blotz K.Goeke, Phys.Lett.**B354**:415-422,1995

energy is calculated
with respect to the vacuum:

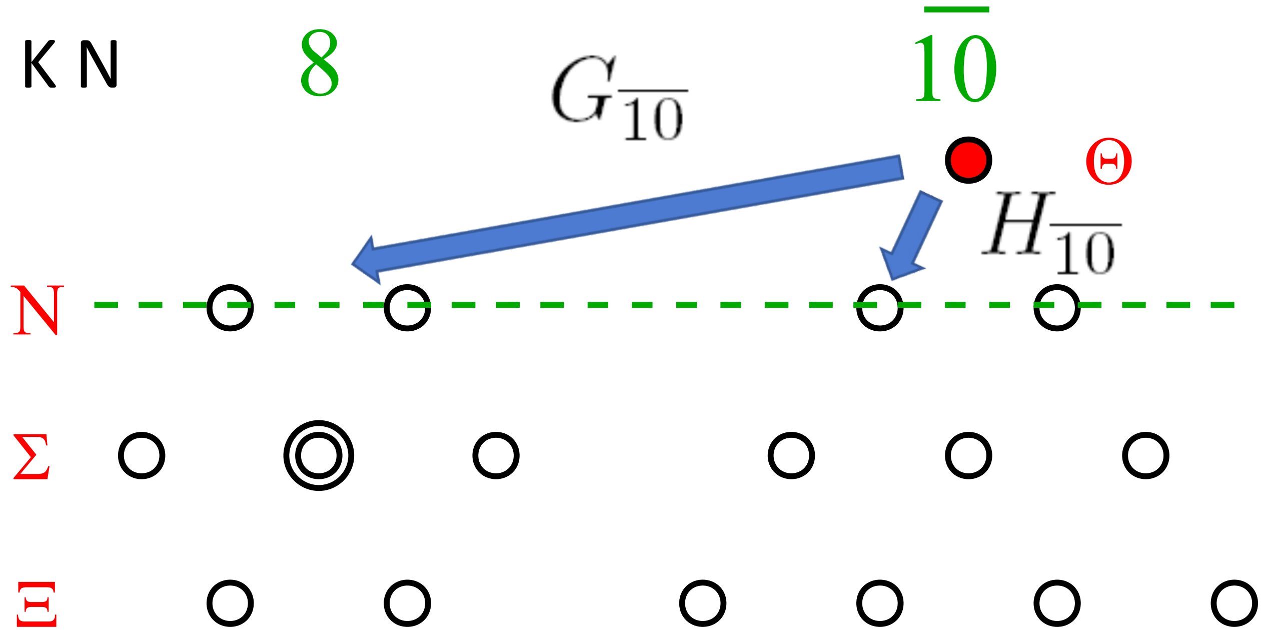
$$\boxed{G_{\overline{10}} = 0}$$



in the NRQM limit only valence level contributes

Decay of Theta$^+$

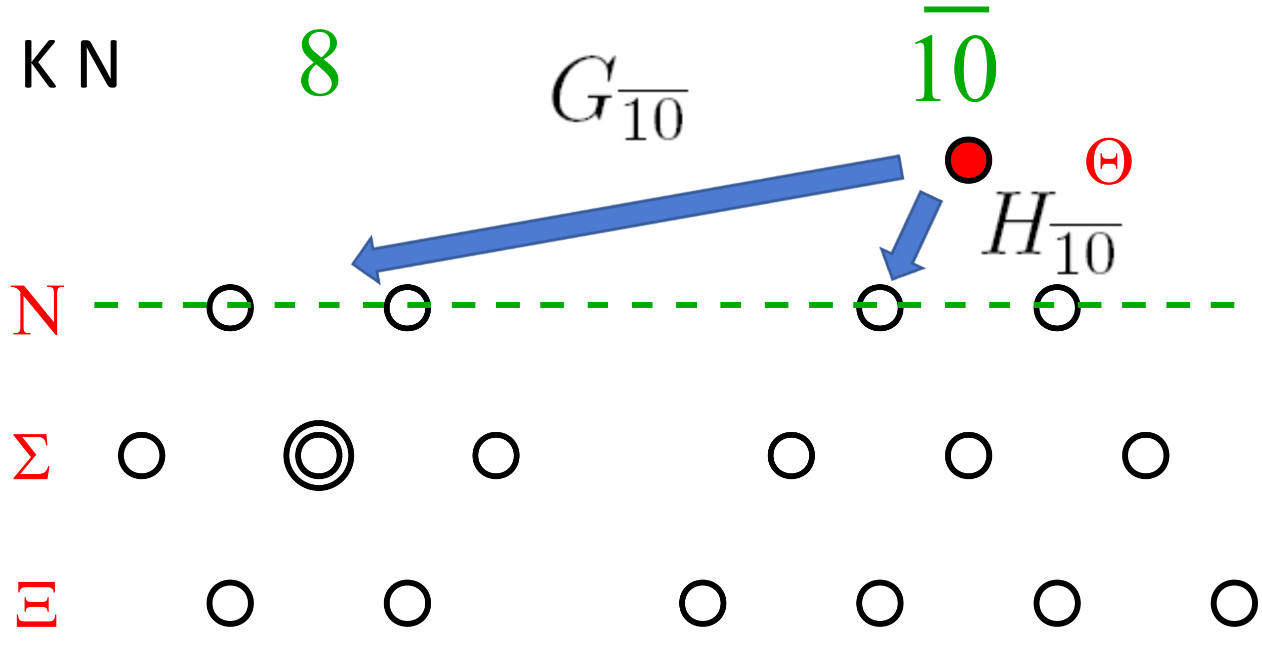
$\Theta^+ \to K\ N$



$$g_{\Theta NK} = G_{\overline{10}} + \sin\alpha\, H_{\overline{10}}$$

Decay of Theta$^+$

$\Theta^+ \to K\,N$



$$g_{\Theta NK} = G_{\overline{10}} + \sin\alpha\, H_{\overline{10}}$$

K. Goeke, M.V. Polyakov
M.Praszalowicz
Acta Phys.Polon.B 42 (2011) 61

Antidecuplet: small small large negative!

Is small width "unnatural"?

$$\Theta^+ \to KN \qquad p_K = 262 \text{ MeV} \quad \Gamma < 0.64 \text{ (BELLE)}$$

Is small width “unnatural”?

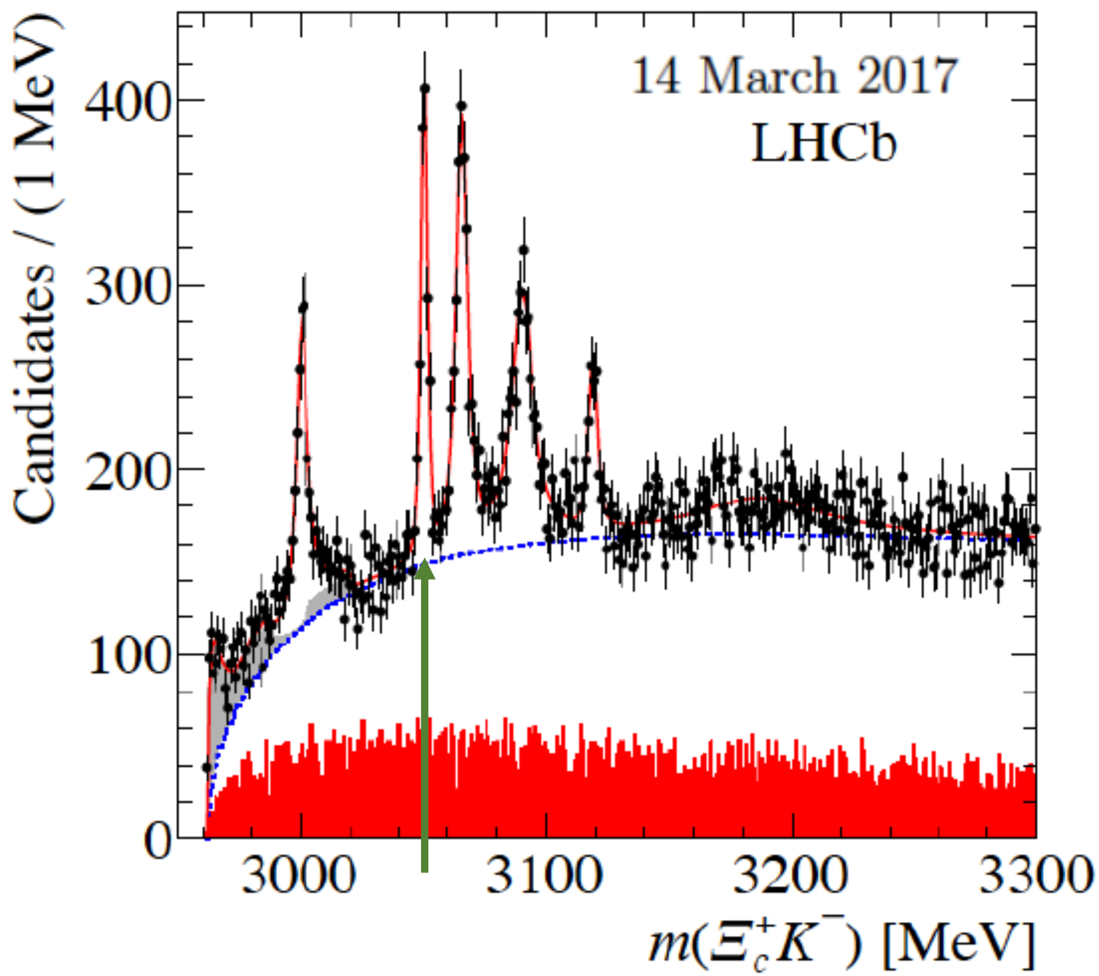
$\Theta^+ \to KN \qquad p_K = 262 \text{ MeV} \quad \Gamma < 0.64 \text{ (BELLE)}$

In 2017 LHCb discovers five excited Ω_c^* states

$\Omega_c^*(3050) \to \Xi_c K$

$\Gamma < 0.8 \pm 0.2 \pm 0.1$

$p_K = 275 \text{ MeV}$



Experiment

LEPS @ Spring-8: $\gamma n \to \Theta^+ K^-$

T. Nakano et al., [hep-ex/0301020] Phys.Rev.Lett. **91** (2003) 012002

Detector was constructed for another experiment: $\phi \longrightarrow K^- K^+$

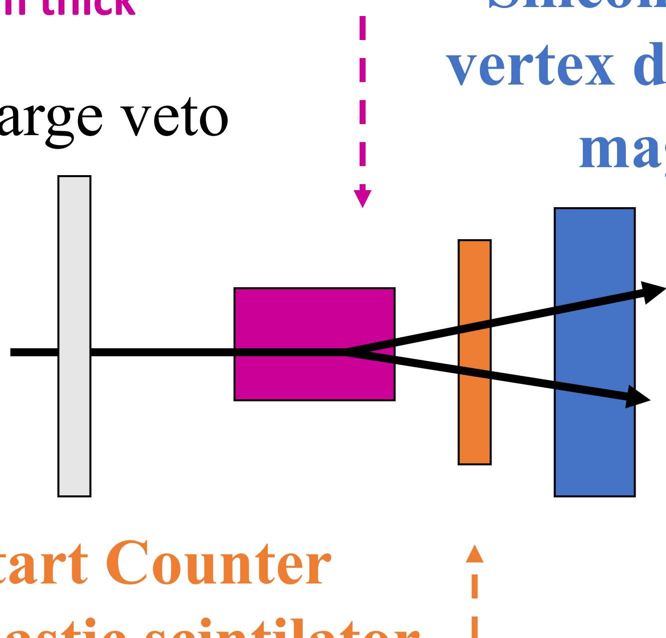
Liquid Hydrogen

5 cm thick

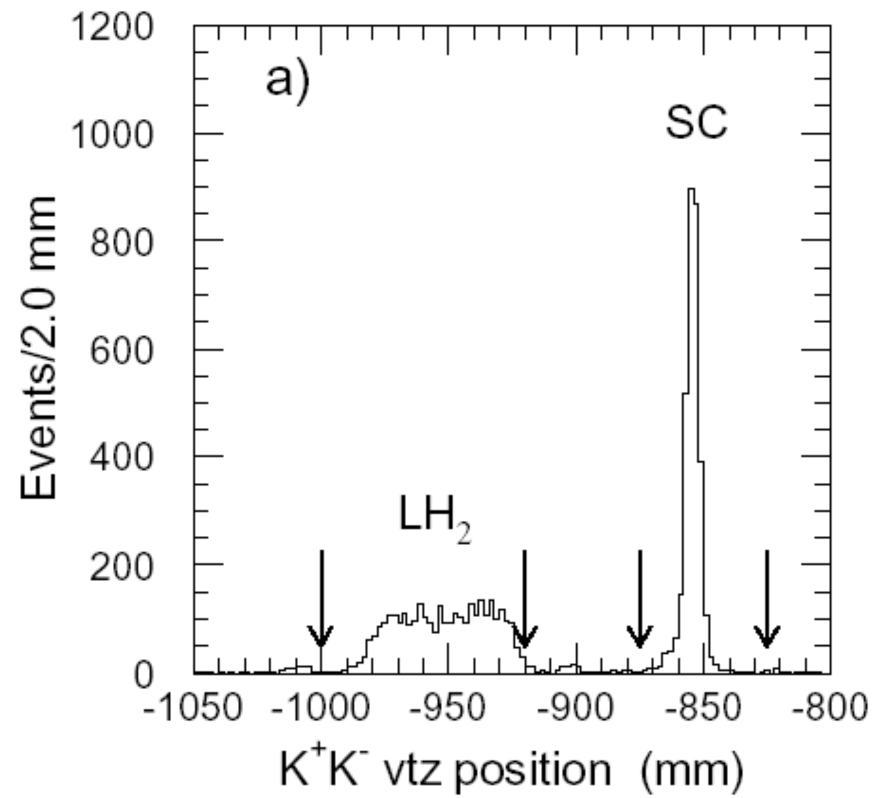
Silicon strip vertex detector

Charge veto

magnetic field 0.7 T

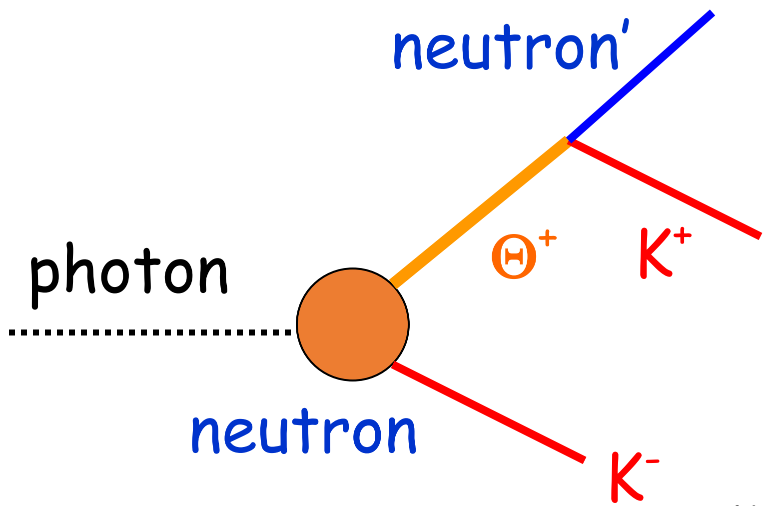


Start Counter
plastic scintilator
0.5 cm thick 9.5 cm from LH_2
contains carbon




注 意
励磁中

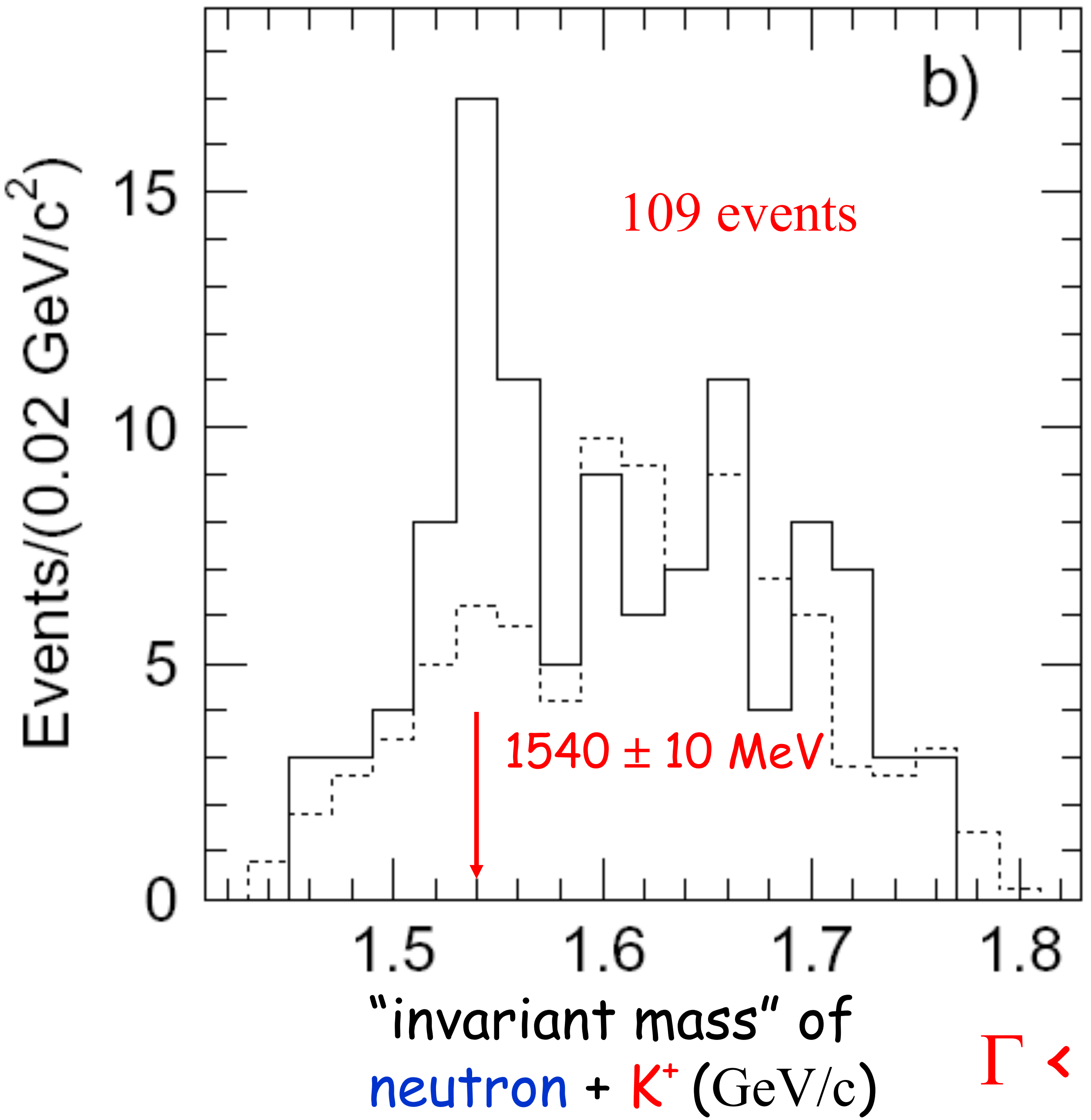
LEPS @ Spring-8: $\gamma n \rightarrow \Theta^{+} K^{-}$



mass distribution,
but neutron'
escapes detection

$$MM_{\gamma K^{-}} = \gamma + n - K^{-} = n' + K^{+}$$

we do not know momentum of neutron because it is inside Carbon, correction for Fermi motion is needed


b)
109 events
1540 ± 10 MeV
Events/(0.02 GeV/c²)
15
10
5
0
1.5
1.6
1.7
1.8
"invariant mass" of
neutron + K⁺ (GeV/c)

Γ < 25 MeV

Experimental evidence: LEPS

$$\gamma n \rightarrow K^- \Theta^+ \rightarrow K^- K^+ n$$

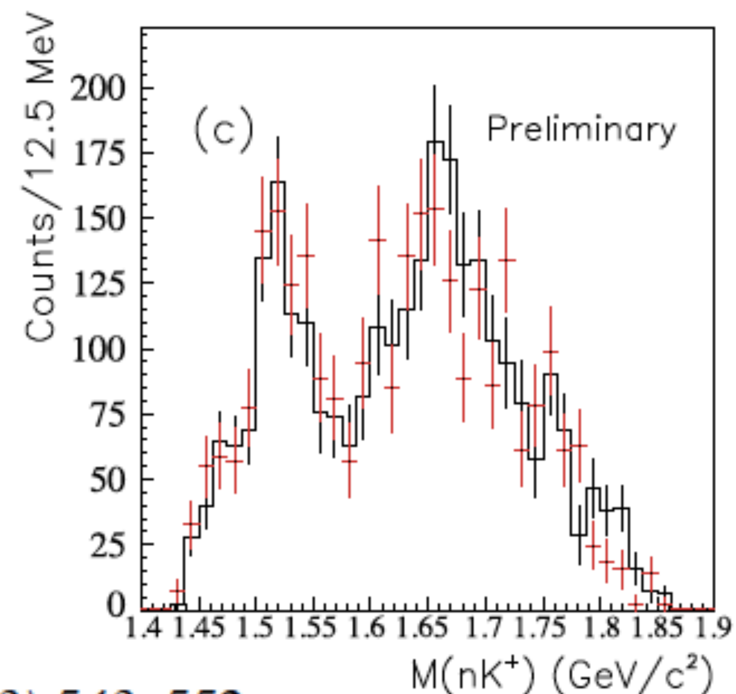
- Photoproduction on C target (neutron): PANIC Oct. 2002
- CLAS: gamma-d similar peak intepreted as fluctuation (unpubl.)
- 2009 LEPS confirms earlier result on C in gamma-d (5 sigma)

  PRC 79 (2009) 025210 M = 1524

- 2013 LEPS2 gamma-d
  no firm statement, analysis
  in progress

main problems:

- neutron not seen
- Fermi motion
- background estimation



M. Niiyama / Nuclear Physics A 914 (2013) 543–552

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  no firm statement, analysis
  in progress

main problems:
- neutron not seen
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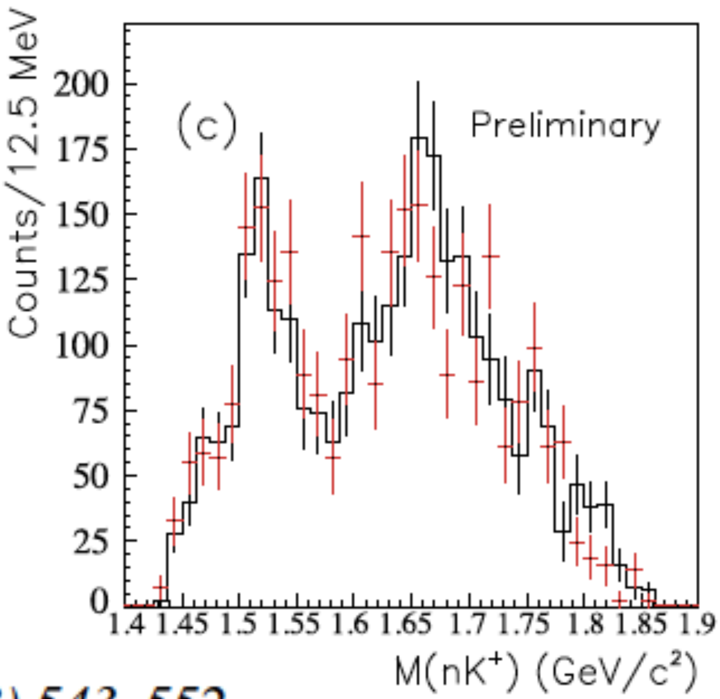
- background estimation

LEPS2 taking data 2022/23 !!!!



M. Niiyama / Nuclear Physics A 914 (2013) 543–552

Experimental evidence: DIANA

Ideal formation experiment: K^+n (in practice K^+ beam on nuclear target)

Breit-Wigner cross-section

$$\sigma_{BW}(E) = \frac{2\overset{1/2}{J}+1}{(2\underset{0}{S_1}+1)(2\underset{1/2}{S_2}+1)}\frac{\pi}{k^2}\underset{1/2}{B_{in}}\underset{1/2}{B_{out}}\frac{\Gamma^2}{(E-M)^2+\Gamma^2/4}$$

$$\sigma_{BW}(M) = \frac{\pi}{k^2} \sim 16.8\ [\mathrm{mb}]$$

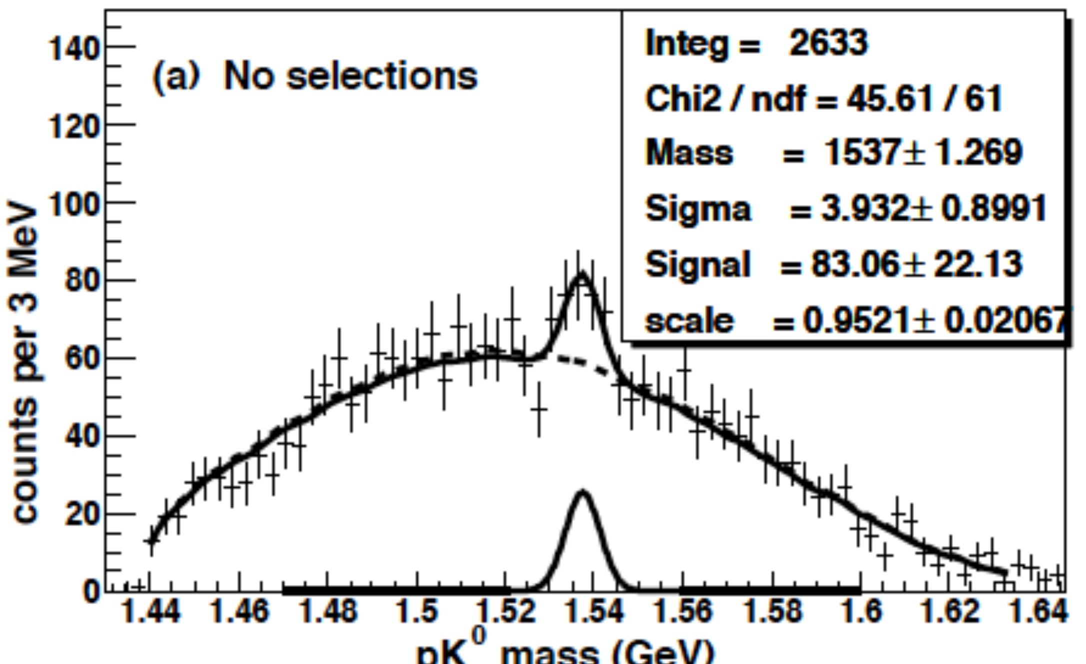
$$\boxed{\sigma_{BW}^{tot} = \frac{\pi}{4k^2}2\pi\Gamma \sim 26.4 \times \frac{\Gamma}{1\ \mathrm{MeV}}\ [\mathrm{mb}\times\mathrm{MeV}]}$$

Experimental evidence: DIANA

DIANA@ITEP Xe bubble chamber K^+ 850 MeV beam

- Phys.Rev. C89 (2014) 4, 045204: M= 1538 ± 2 MeV, Γ = 0.34 ± 01 MeV
- 2003 Yad. Phys. 66 (2003) 1763
- 2007 Yad. Phys. 70
- 2010 Yad. Phys. 73

not seen with the secondary K^+ beam at BELLE experiment $\Gamma <$ 0.6 MeV



Rare kaon decay exp. E949@BNL

From: **Laurence Littenberg** littenbe@bnl.gov
Subject: Pentaquarks in E949?
Date: 22 June 2004 at 20:04
To: Takashi Nakano nakano@rcnp.osaka-u.ac.jp
Cc: Jim Frank frank@bnl.gov, Steve Kettell kettell@bnl.gov, Milind Diwan diwan@bnl.gov, archive litt@sun2.bnl.gov

LL

Hi Takashi,

Today we got a visit from Nick Samios and Michal Praszalowicz pressing us to try to do a formation experiment for the theta+ with the E949 beam and detector. They pointed out that it could be done relatively economically during the upcoming RHIC polarized proton run. The idea is to take out most of the degrader, turn the beam down to ~500 MeV/c, charge exchange the K+ off the neutrons in the carbon of the scintillator stopping target and detect the K_S => pi+,pi- decay. If the recoil proton could also be measured in the target, one could be immune from the Fermi smearing of the target neutron. If this is not possible, one would probably be in the position of trying to measure about a 10% excursion in a linearly rising cross section, spread out over the range of Fermi smearing.

There are some obvious challenges, but the idea doesn't seem hopeless to me. I'm curious whether you think the idea is technically viable and if so, whether you'd be interested in participating in such an experiment (probably next winter).

Regards,
Laur

Rare kaon decay exp. E949@BNL

- Proposal submitted in April 2005

Rare kaon decay exp. E949@BNL

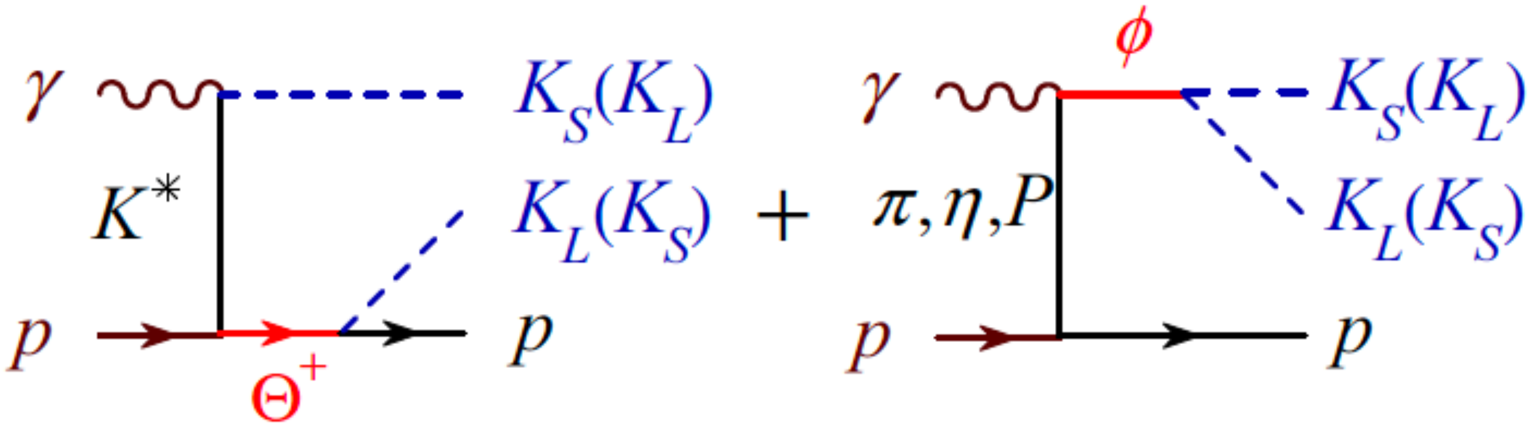
- proposal submitted in April 2005
- soon after E949 discontinued
- detector shipped to J-PARC in Japan
- Theta+ experiment in the pipeline @ J-PARC

Rare kaon decay exp. E949@BNL

- proposal submitted in April 2005
- soon after E949 discontinued
- detector shipped to J-PARC in Japan
- Theta+ experiment in the pipeline @ J-PARC
- 2011 eartquake seriously damages J-PARC
- Theta+ searches abandonned

CLAS@JLab interference experiment

Photoproduction cross-section for Theta+ production is small due to the smnallnes of $g_{\Theta NK}$ coupling and unknown (small) coupling of gamma to K*K.
Negative result from CLAS. However, Phi meson is copiously produced.



To see the exotic Θ^+ baryon from interference

Moskov Amarian[a], Dmitri Diakonov[b,c], and Maxim V. Polyakov[b,c]
[a] *Old Dominion University, Norfolk, Virginia 22901, USA*
[b] *Petersburg Nuclear Physics Institute, Gatchina, 188 300, St. Petersburg, Russia*
[c] *Institut für Theoretische Physik II, Ruhr-Universität Bochum, Bochum D-44780, Germany*
(Dated: December 12, 2006)

CLAS@JLab interference experiment

PHYSICAL REVIEW C 85, 035209 (2012)

Observation of a narrow structure in ^{1}H$(\gamma, K_S^0)X$ via interference with ϕ-meson production

M. J. Amaryan,[1,*] G. Gavalian,[1] C. Nepali,[1] M. V. Polyakov,[2,3] Ya. Azimov,[3] W. J. Briscoe,[4] G. E. Dodge,[1] C. E. Hyde,[1]
F. Klein,[5] V. Kuznetsov,[6,7] I. Strakovsky,[4] and J. Zhang[8]

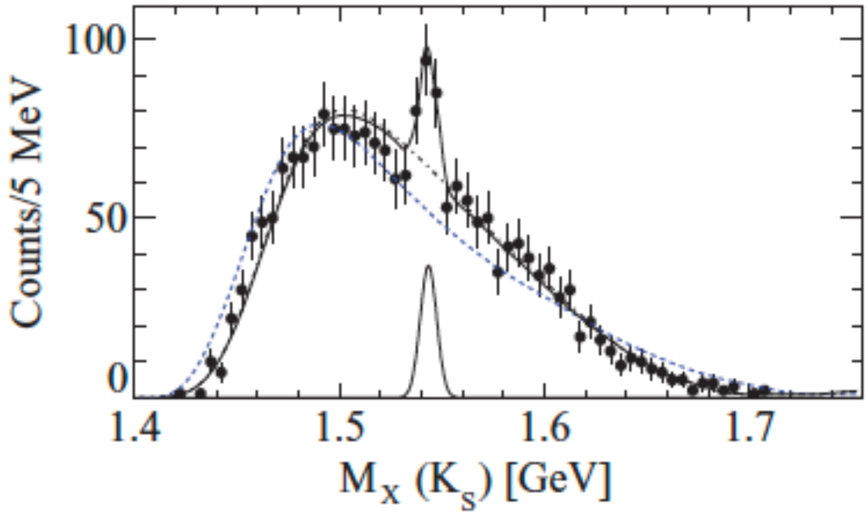


FIG. 11. (Color online) Missing mass of K_S with cuts $-t_\Theta <$ 0.45 GeV^2 and $M(pK_S) <$ 1.56 GeV. The dashed line is the result of a ϕ Monte Carlo simulation, the dashed-dotted line is a modified Monte Carlo distribution, and the solid line is the result of a fit with a modified Monte Carlo distribution plus a Gaussian function.

M = 1543 MeV
Gaussian width = 6 MeV
significance = 5.3 σ

CLAS@JLab interference experiment

Comment on the narrow structure reported by Amaryan *et al.*

M. Anghinolfi,[18] J. Ball,[8] N.A. Baltzell,[1,29] M. Battaglieri,[18] I. Bedlinskiy,[20] M. Bellis,[25,6] A.S. Biselli,[11] C. Bookwalter,[13] S. Boiarinov,[30,20] P. Bosted,[30] V.D. Burkert,[30] D.S. Carman,[30] A. Celentano,[18] S. Chandavar,[24] P.L. Cole,[16,30] V. Crede,[13] R. De Vita,[18] E. De Sanctis,[17] B. Dey,[6] R. Dickson,[6] D. Doughty,[9,30] M. Dugger,[2] R. Dupre,[1] H. Egiyan,[30,35] A. El Alaoui,[1] L. El Fassi,[1] L. Elouadrhiri,[30] P. Eugenio,[13] G. Fedotov,[29] M.Y. Gabrielyan,[12] M. Garcon,[8] G.P. Gilfoyle,[27] K.L. Giovanetti,[21] F.X. Girod,[30] J.T. Goetz,[3] E. Golovatch,[28] M. Guidal,[19] L. Guo,[12,30] K. Hafidi,[1] H. Hakobyan,[32] D. Heddle,[9,30] K. Hicks,[24] M. Holtrop,[23] D.G. Ireland,[33] B.S. Ishkhanov,[28] E.L. Isupov,[28] H.S. Jo,[19] K. Joo,[10,30] P. Khetarpal,[12] A. Kim,[22] W. Kim,[22] V. Kubarovsky,[30] S.V. Kuleshov,[32,20] H.Y. Lu,[6] I.J.D. MacGregor,[33] N. Markov,[10] M.E. McCracken,[34,6] B. McKinnon,[33] M.D. Mestayer,[30] C.A. Meyer,[6] M. Mirazita,[17] V. Mokeev,[30,28] K. Moriya,[6,*] B. Morrison,[2] A. Ni,[22] S. Niccolai,[19] G. Niculescu,[21,24] I. Niculescu,[21,30,15] M. Osipenko,[18] A.I. Ostrovidov,[13] K. Park,[30,22] S. Park,[13] S. Anefalos Pereira,[17] S. Pisano,[17] O. Pogorelko,[20] S. Pozdniakov,[20] J.W. Price,[4] G. Ricco,[14] M. Ripani,[18] B.G. Ritchie,[2] P. Rossi,[17] D. Schott,[12] R.A. Schumacher,[6] E. Seder,[10] Y.G. Sharabian,[30] E.S. Smith,[30] D.I. Sober,[7] S.S. Stepanyan,[22] P. Stoler,[26] W. Tang,[24] M. Ungaro,[30,26,10] B .Vernarsky,[6] M.F. Vineyard,[31,27] D.P. Weygand,[30] M.H. Wood,[5,29] N. Zachariou,[15] and B. Zhao[35]

(The CLAS Collaboration)

CLAS@JLab interference experiment

5 years!

An extensive review of the analysis in Ref. [1] was carried out by two separate committees of the Hadron Spectroscopy Physics Working Group in the CLAS Collaboration. In both cases, the committees came to the same conclusion: the physics claims of Ref. [1] could not be supported. The reasons for this conclusion are manyfold, but a primary concern is the lack of justification for the kinematic cuts used in that analysis.

Future program at CLAS

History and Geography of Light Pentaquark Searches: Challenges and Pitfalls

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(Dated: May 31, 2022)

Finally, let me mention that the most direct way to observe Θ^+ would be by secondary beams of kaons, especially at the approved experiment with K-long facility in Hall D at JLab [26] in a two-body reaction $K_L p \to K^+ n$ with the $M(K^+ n)$ resolution on the order of 1-2 MeV in the range from almost the threshold up to 1.6 GeV measured simultaneously because of the broad momentum range of the secondary K_L beam impinging on the hydrogen target, contrary to the charged kaon beams with the fixed beam energy.

Happy ending?

It is a strong belief of the present speaker that
the reports of Theta+ death are greatly exaggerated.
We still need to wait for a conclusive formation experiment.
In the meantime new LEPS2 results may shed some light
on a missing victim.

Thank you