Baryons as solitons a historical perspective

Michal Praszalowicz
M. Smoluchowski Institute of Physics
Jagellonian University, Kraków, Poland

Chiral symmetry

massless Left and Right fermions are „independent”

no massless fermions exist → chiral symmetry is broken

explicit breaking by Higgs mechanism: *m* ~ a few MeV
spontaneous breaking: *M* ~ 300 MeV

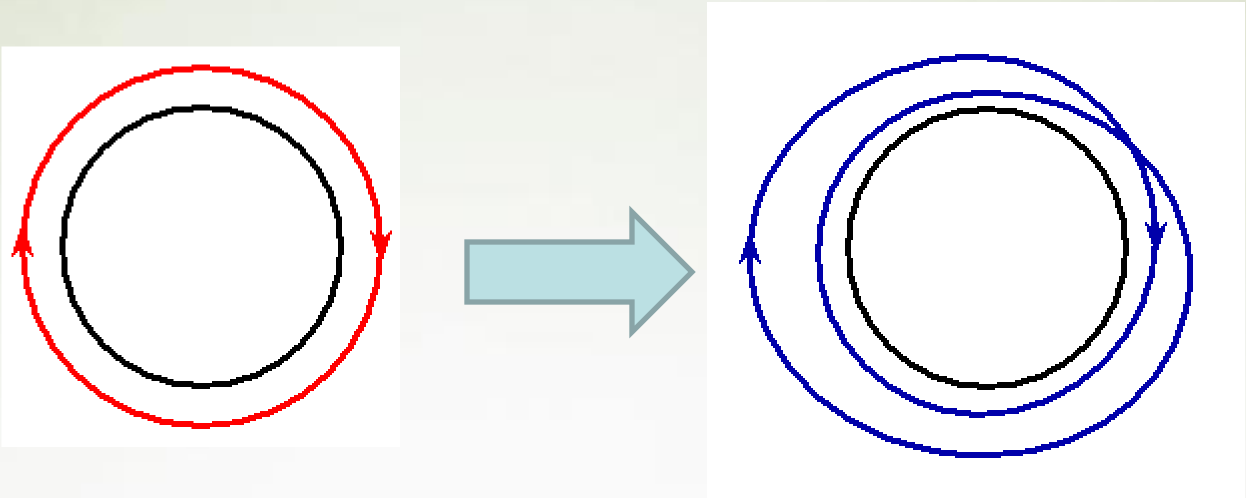
$$U \quad = \quad e^{i\vec{\tau}\cdot\vec{\pi}(x)/F_\pi}$$

(nearly) masless Goldstone bosons ist: pions (kaons, eta)

this is a mapping of our space onto a group space

Something out of nothing *)

winding number



Winding number can be defined for higher dimensional spheres. Of particular interest are mappings of 3-sphere (our 3 dim. space) onto an SU(2) group which is also a 3 dimensional sphere

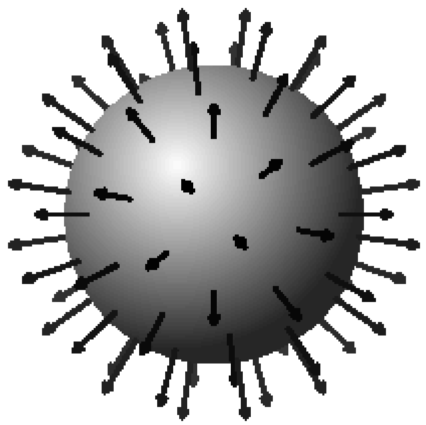
Winding number can be identified with a baryon number

*) Andrzej Białas, opening speach at the Workshop on Skyrmions and Anomalies, 1987

Skyrme Model

$$U_0 = e^{i\vec{n}\cdot\vec{\tau}\,P(r)}$$

winding number is equal to $P(0)/\pi$



hedgehog

What all this has to do with physics?

Nonlinear sigma model describes selfinteraction of pions using U matrix

$$U = e^{i\vec{\tau}\cdot\vec{\pi}(x)/F_\pi}$$

Skyrme–Witten lagrangian

Weinberg's lagrangian

$$\mathcal{L} = \frac{F_\pi^2}{4}\,\mathrm{Tr}\left(\partial_\mu U^\dagger \partial^\mu U\right) + \frac{1}{32e^2}\,\mathrm{Tr}\left(\left[\partial_\mu U\,U^\dagger, \partial_\nu U\,U^\dagger\right]^2\right) + \Gamma_{\mathrm{WZ}} + \ldots.$$

Stable soliton solutions exist, with function $P(r)$ that minimizes the energy

Chrial Quark Model

quark and meson fields coupled together, however there is no kinetic term for pions

$$\mathcal{L} = \bar{q}\,(x)\,(i\partial\!\!\!/ - M\,U^{\gamma_5}(x))\,q(x)$$

$$U = e^{i\vec{\tau}\cdot\vec{\pi}(x)/F_\pi}$$

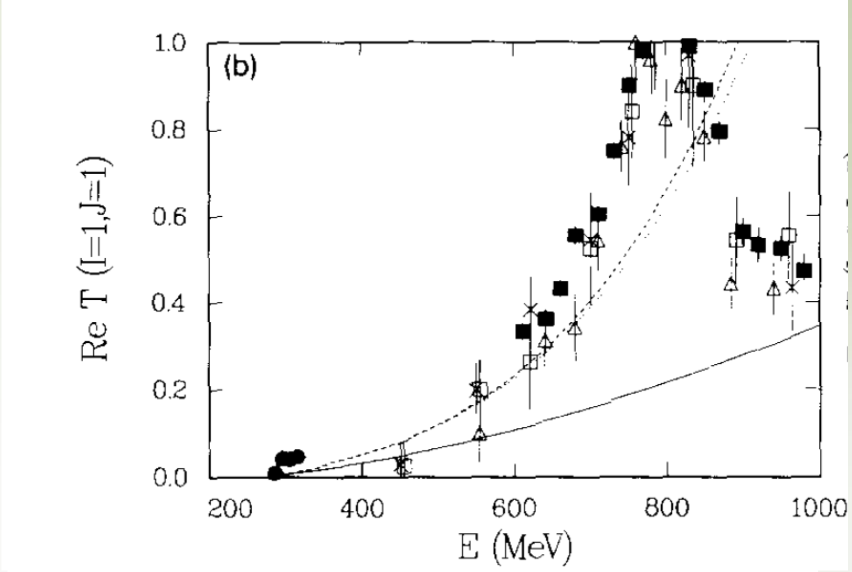
$$\mathcal{L} = \frac{F_\pi^2}{4}\,\mathrm{Tr}\left(\partial_\mu U^\dagger \partial^\mu U\right) + \frac{1}{32e^2}\,\mathrm{Tr}\left(\left[\partial_\mu U\,U^\dagger, \partial_\nu U\,U^\dagger\right]^2\right) + \Gamma_{\mathrm{WZ}} + \ldots.$$

Chiral Quark Model - mesons

pi-pi scattering

Quark Models And Chiral Lagrangians.
M. Praszalowicz, G. Valencia
Nucl.Phys.B341:27-49,1990.

The Low-energy expansion of the generalized SU(3) NJL model. E. Ruiz Arriola
Phys.Lett.B253:430-435,1991

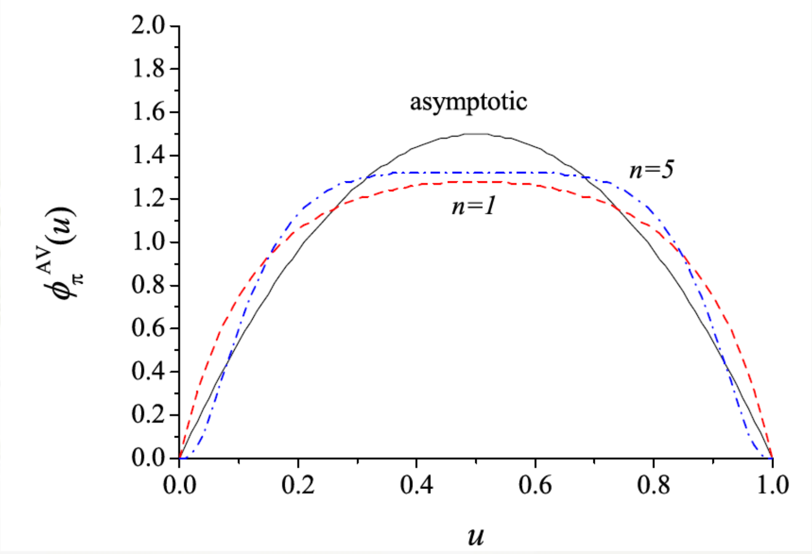


pion distribution amplitudes

Pion wave function from the instanton vacuum model. V.Yu. Petrov, P.V. Pobylitsa
hep-ph/9712203

Pion light cone wave function in the nonlocal NJL model. Phys.Rev.D64:074003,2001
M. Praszalowicz, A. Rostworowski

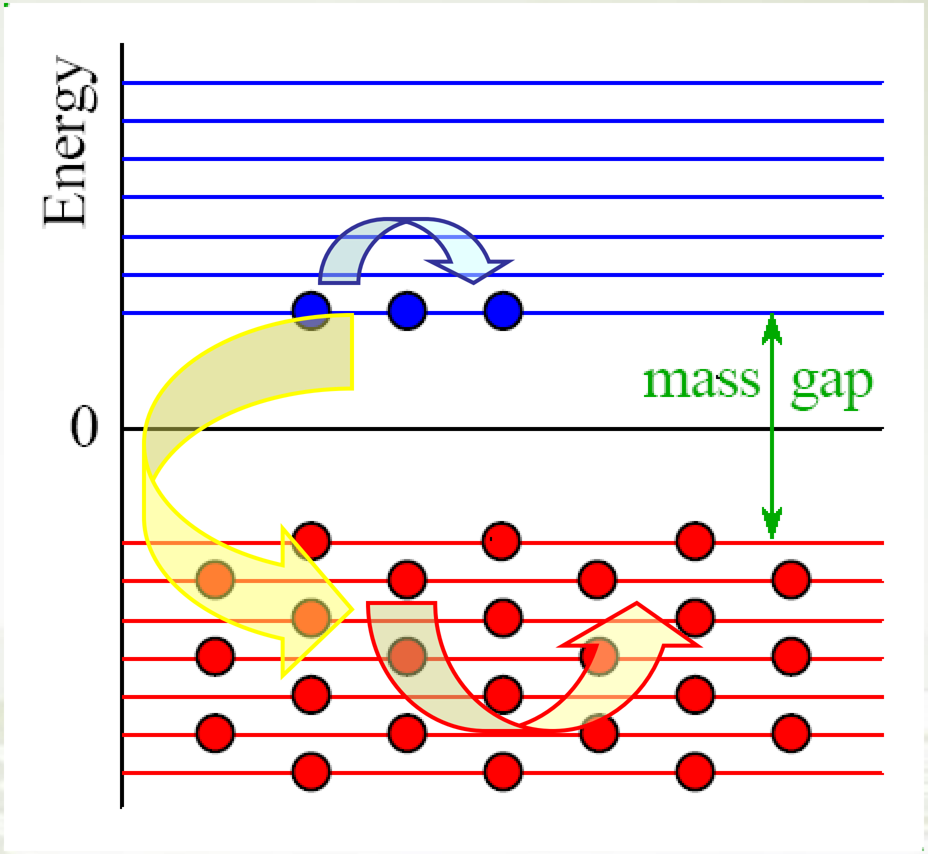
Stefanis, Bakulev, Mukhailov, Broniowski, Arriola, Dorokhov ...



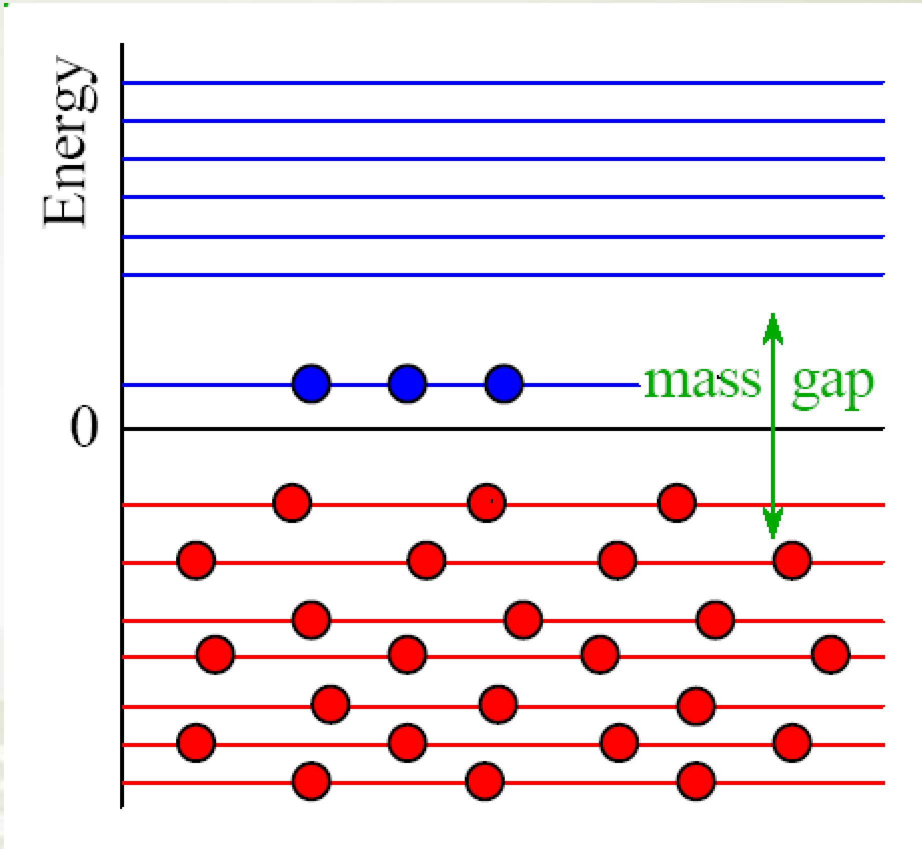
Chiral Quark Model - baryons

consider spectrum of the Dirac operator
in the presenece of the topologaclly nontrivial meson field

Spectrum of the Dirac operator



Spectrum of the Dirac operator



for winding number = 1 one valence level appears,
however it is in a singlet flavor and spin state
→ no other quantum numbers apart from baryon number

Soliton with Valence Quarks in the Chiral Invariant Sigma Model.
S. Kahana, G. Ripka, V. Soni Nucl.Phys.A415:351-364,1984.

A Chiral Theory of Nucleons.
Dmitri Diakonov, V.Yu. Petrov, P.V. Pobylitsa Nucl.Phys.B306:809,1988

Sea Quark Effects In Nontopological Chiral Soliton Models And The Nambu-Jona-Lasinio Approach Phys.Lett.B214:312-316,1988
T. Meissner, E. Ruiz Arriola, F. Grummer, H. Mavromatis, K. Goeke

The Soliton of the Effective Chiral Action.
H. Reinhardt, R. Wunsch Phys.Lett.B215:577,1988

Nucleon Mass And Nucleon Sigma Term.
Dmitri Diakonov, V.Yu. Petrov, M. Praszalowicz Nucl.Phys.B323:53,1989.

Solitons In The Nambu-Jona-Lasinio Model.
T. Meissner, F. Grummer, K. Goeke Phys.Lett.B227:296-300,1989.

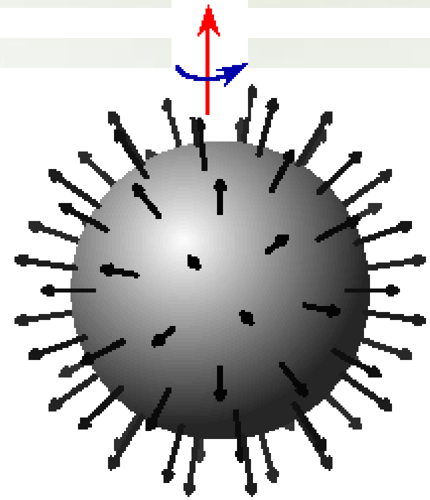
A Chiral quark model of the nucleon.
M. Wakamatsu, H. Yoshiki Nucl.Phys.A524:561-600,1991.

Other quantum numbers

$U(x)$ and $AU(x)A^\dagger$ have the same energy

promote $A \rightarrow A(t)$ and quantize rotations as a symmetric top

$$\mathcal{H} = M_{sol} + \frac{1}{2I_1} J(J+1)$$

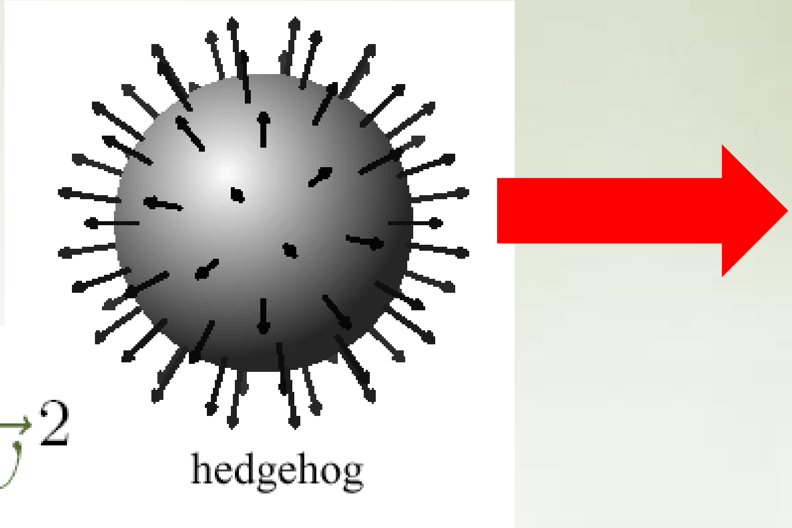


A Chiral Theory of Nucleons.
Dmitri Diakonov, V.Yu. Petrov, P.V. Pobylitsa
Nucl.Phys.B306:809,1988

Quantization of the Nambu-Jona-Lasinio soliton and the nucleon Delta splitting.
K. Goeke, A.Z. Gorski, F. Gruemmer, T. Meissner, H. Reinhardt, R. Wunsch
Phys.Lett.B256:321-324,1991.

Other quantum numbers

$$\mathcal{L} = -M_{sol} + \frac{1}{2} M_{sol} \vec{v}^{\,2}$$



Pushing the Nambu-Jona-Lasinio soliton and the zero point energy.
P.V. Pobylitsa, E. Ruiz Arriola, T. Meissner, F. Grummer, K. Goeke, W. Broniowski
J.Phys.G18:1455-1466,1992.

SU(3) case

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

← commutes with λ_8

$$\mathcal{L} = -M_{sol} + \frac{I_1}{2}\sum_{i=1}^{3}{\Omega_i}^2$$

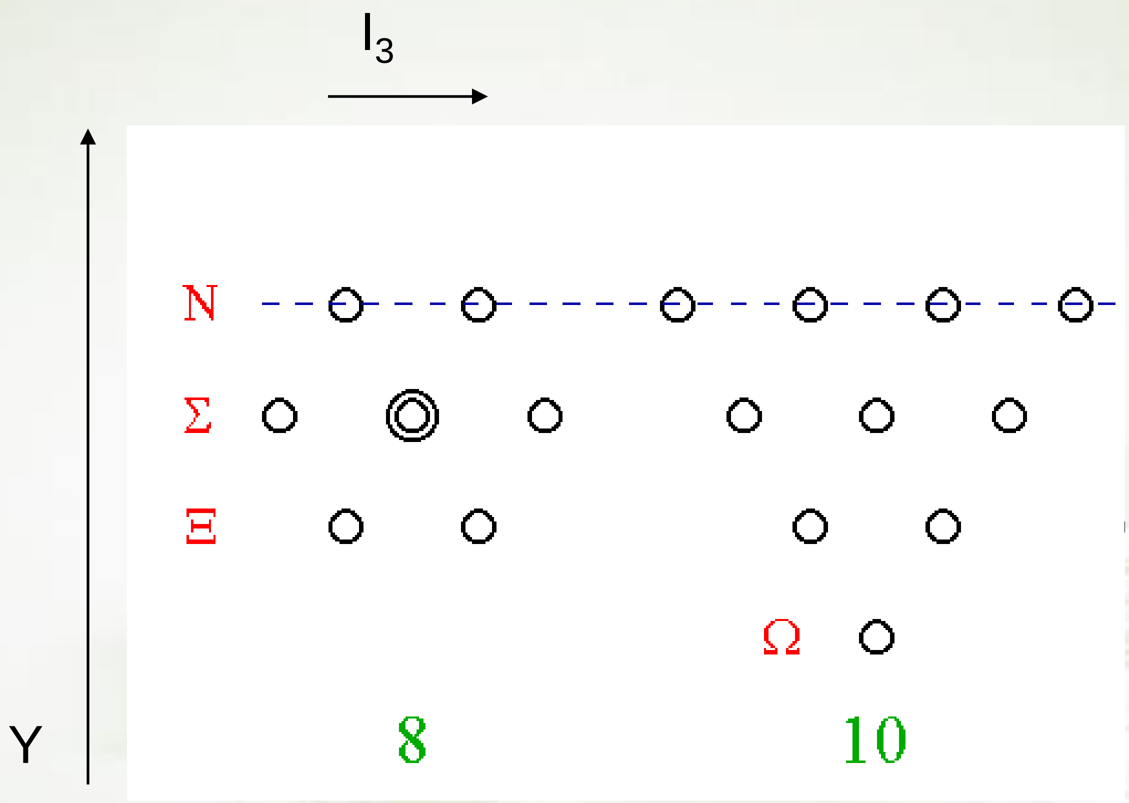
Baryons as Solitons and Mass Formulae.
E. Guadagnini Nucl.Phys.B236:35,1984.

SU(3) Extension of the Skyrme Model.
Pawel O. Mazur, Maciej A. Nowak, Michal Praszalowicz Phys.Lett.B147:137,1984.

Large N Baryons: Collective Coordinates Of The Topological Soliton In SU(3) Chiral Model.
Sanjay Jain, Spenta R. Wadia Nucl.Phys.B258:713,1985

SU(3) case

Only representations containing hypercharge $Y = 1 = N_c / 3$ are allowed



The Strange chiral soliton of the Nambu-Jona-Lasinio model.
H. Weigel, Reinhard Alkofer, H. Reinhardt Phys.Lett.B284:296-302,1992.

Strange baryons as chiral solitons of the Nambu-Jona-Lasinio model.
H. Weigel, Reinhard Alkofer, H. Reinhardt Nucl.Phys.B387:638-674,1992.

The SU(3) Nambu-Jona-Lasinio soliton in the collective quantization formulation.
A. Blotz, Dmitri Diakonov, K. Goeke, N.W. Park, V. Petrov, P.V. Pobylitsa
Nucl.Phys.A555:765-792,1993.

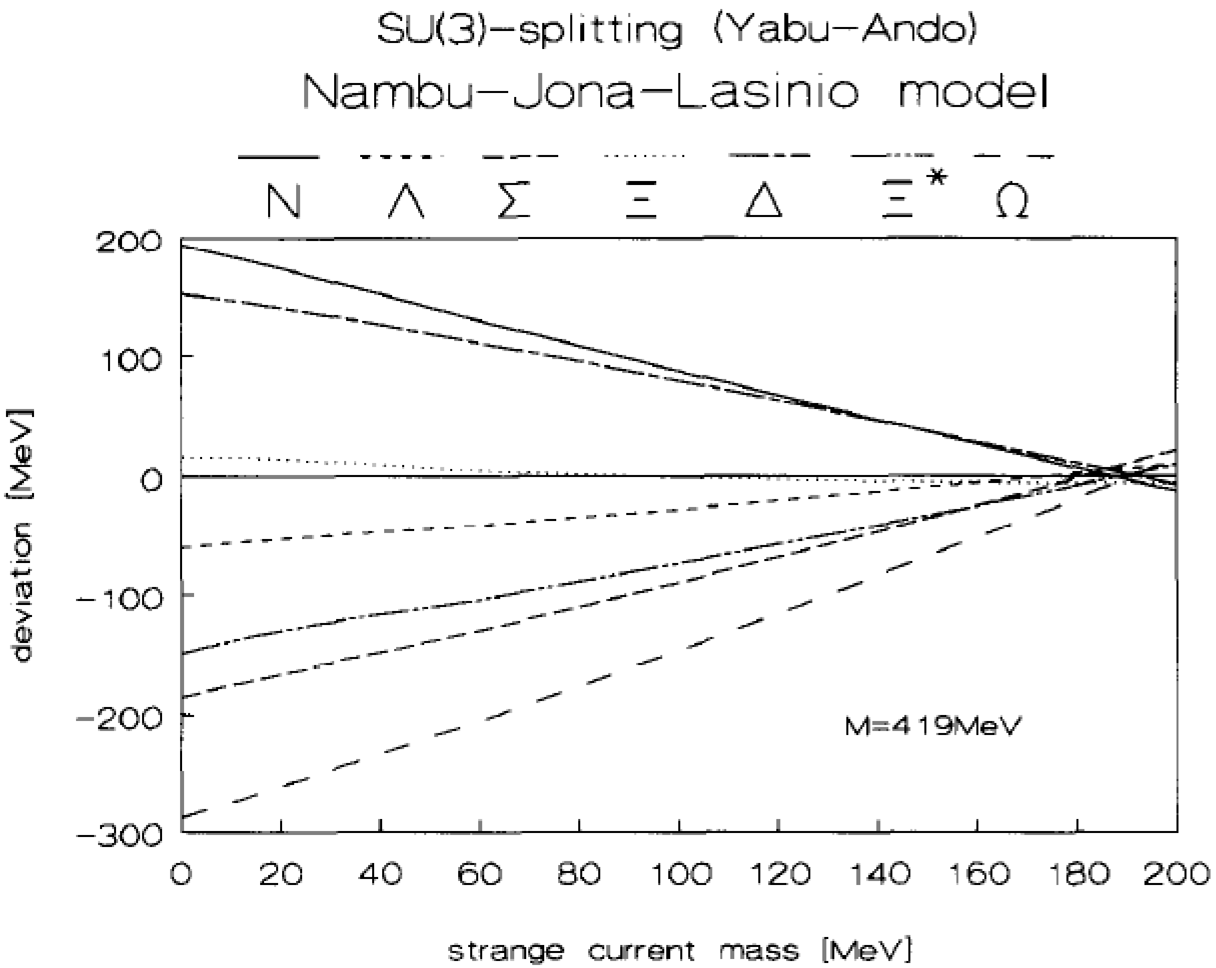


Fig. 5. The deviation of the theoretical mass from the experimental one is shown for the Yabu-Ando treatment and a constituent quark mass of $M = 419$ MeV.

Problem with g_A

The Axial form-factor in the Nambu-Jona-Lasinio model.
T. Meissner, K. Goeke Z.Phys.A339:513-522,1991.

The value of g_A is $g_A = 0.8$ and hence too low in comparison with experiment. This is like in the Skyrme model and migth change if one takes higher order cranking corrections into account. This point is presently under consideration.

Problem with g_A

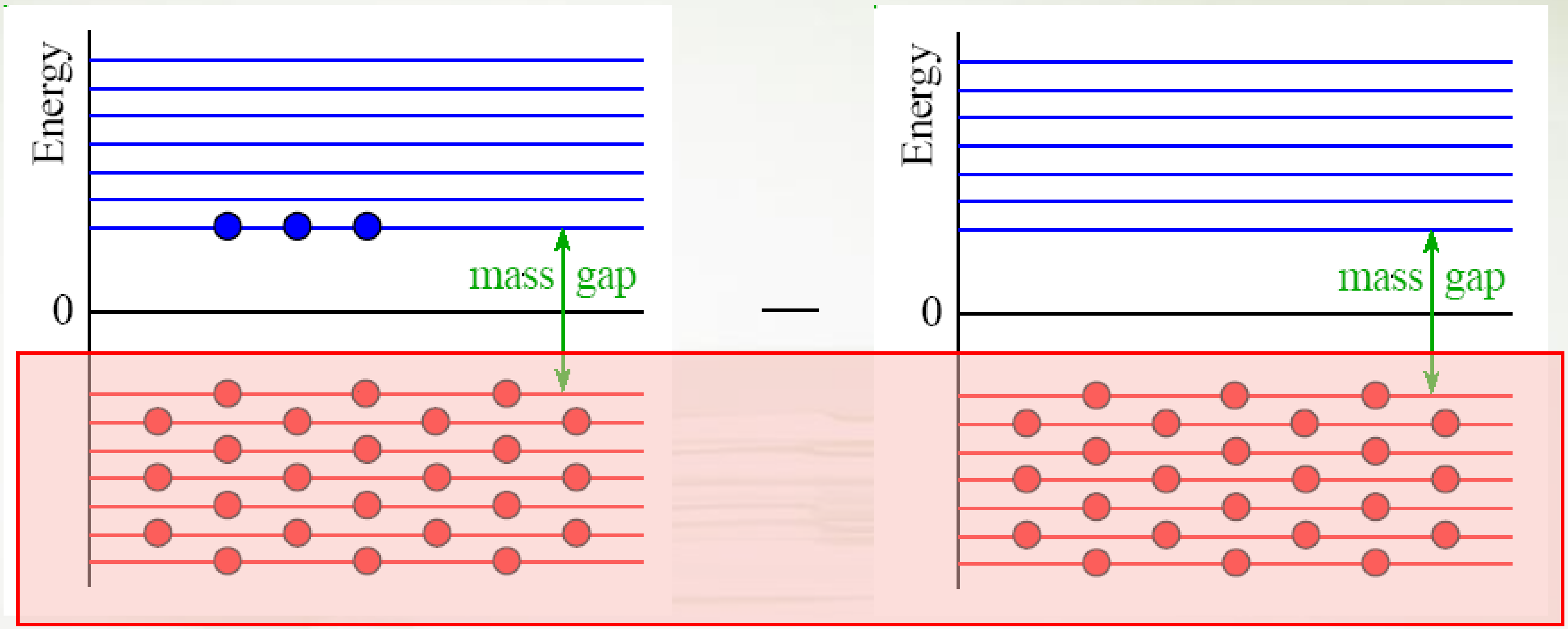
The g(A) problem in hedgehog soliton models revisited.
M. Wakamatsu, T. Watabe Phys.Lett.B312:184-190,1993.

1/N(c) rotational corrections to g(A) and isovector magnetic moment of the nucleon.
C.V. Christov, A. Blotz, K. Goeke, P. Pobylitsa , V. Petrov, M. Wakamatsu , T. Watabe
Phys.Lett.B325:467-472,1994.

$$
\begin{aligned}
\mathcal{O}_\alpha^\Gamma &= N_c D_{\alpha\beta} \sum_m \langle m|\lambda_\beta \Gamma|m\rangle \\
&- \frac{N_c}{4} \{D_{\alpha\rho}, \Omega_\beta\} \sum_{m,n} \frac{\langle m|\lambda_\rho \Gamma|n\rangle\langle n|\lambda_\beta|m\rangle + \langle m|\lambda_\beta|n\rangle\langle n|\lambda_\rho \Gamma|m\rangle}{\varepsilon_n - \varepsilon_m} \\
&- \frac{N_c}{4} [D_{\alpha\rho}, \Omega_\beta] \sum_{m,n} \frac{\langle m|\lambda_\rho \Gamma|n\rangle\langle n|\lambda_\beta|m\rangle - \langle m|\lambda_\beta|n\rangle\langle n|\lambda_\rho \Gamma|m\rangle}{\varepsilon_n - \varepsilon_m}
\end{aligned}
$$

Quark Model limit

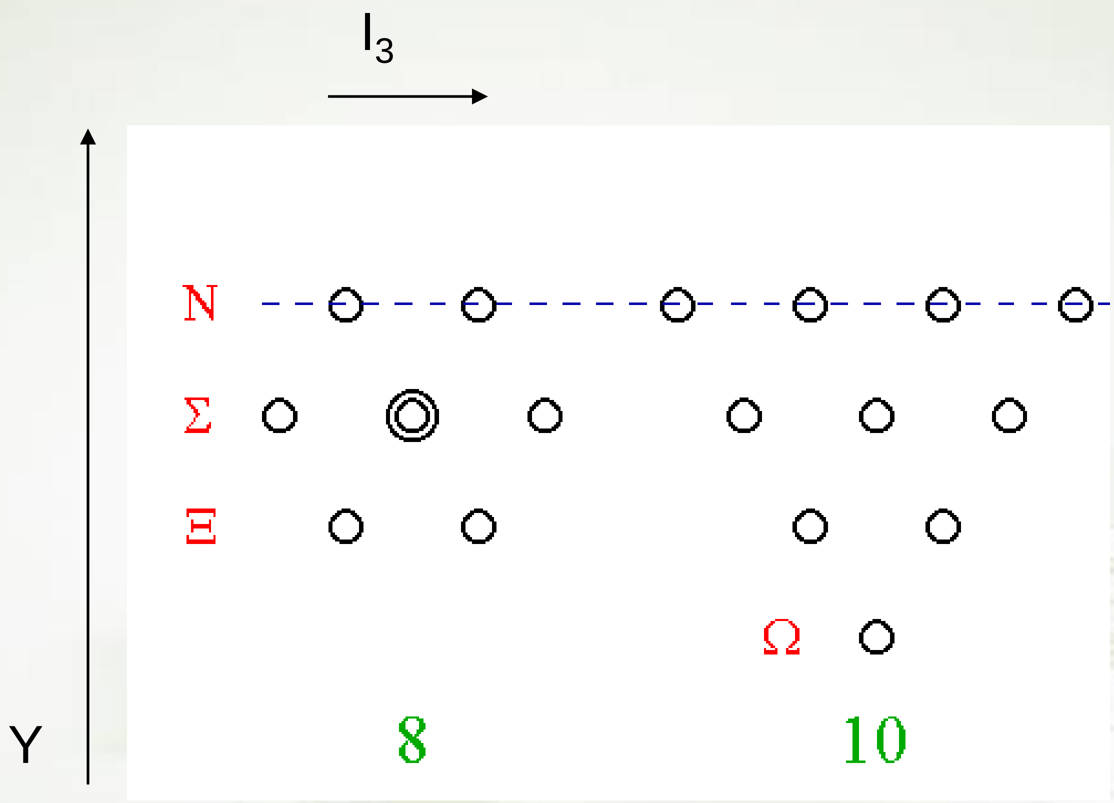
$$g_A = \frac{N_c + 2}{3}, \quad g_A^{(0)} = 1, \quad \frac{\mu_p}{\mu_n} = -\frac{3}{2}$$



in the NRQM limit only valence level contributes

SU(3) case

Only representations containing hypercharge $Y = 1 = N_c / 3$ are allowed



Theta +

Biedenharn, Dothan (1984):

$\Delta_{\overline{10}-8} \sim$ 600 MeV from Skyrme model

MP (1987):

M_{Θ}= 1535 MeV from Skyrme model
in model independent approach,
second order

Diakonov, Petrov, Polyakov (1997):

χQM - model independent approach,
$1/N_c$ corrections $\rightarrow$ M_{Θ}= 1530 MeV
small width < 15 MeV !

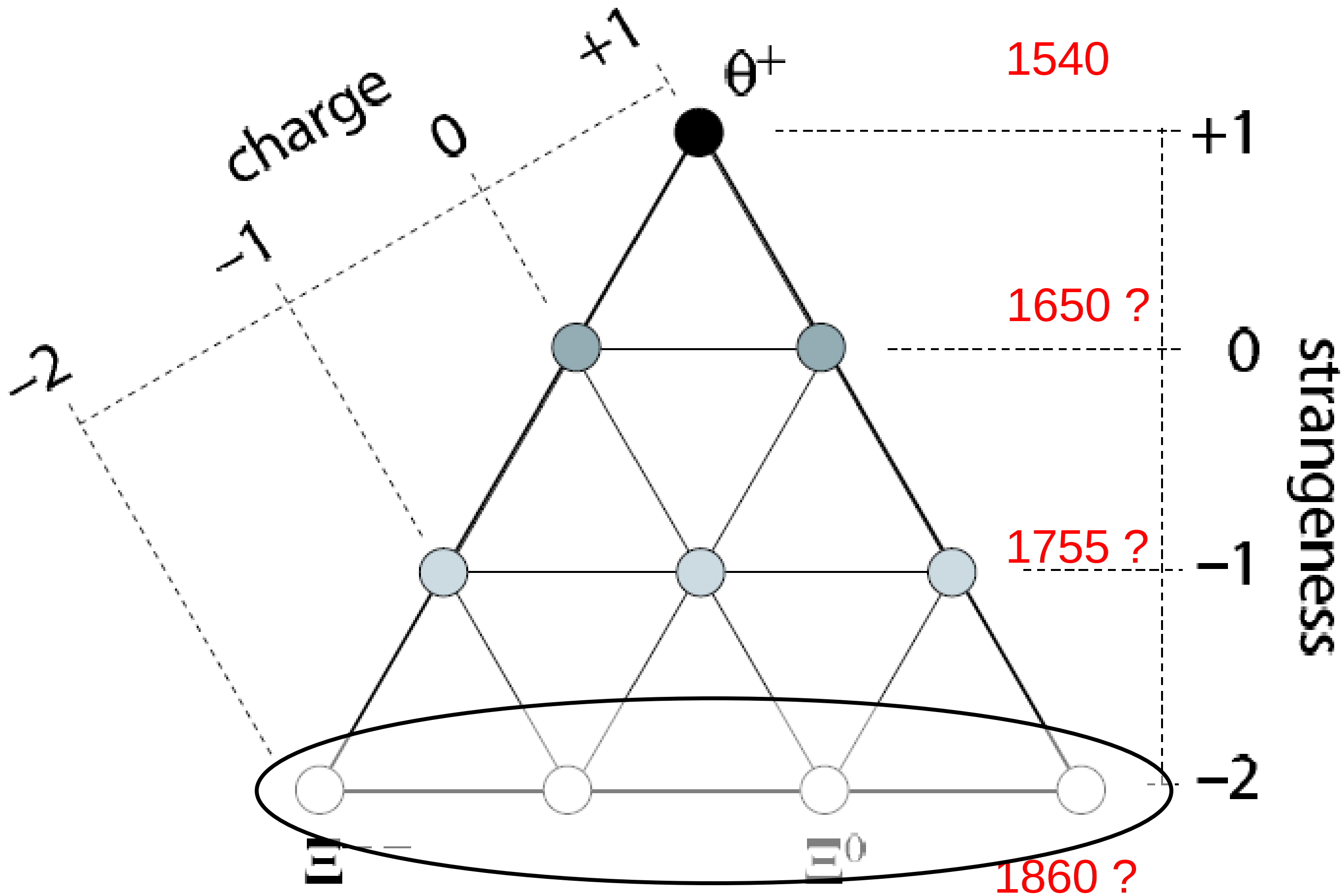
today we know that if Θ exists Γ_{Θ} < 1 MeV

Antidecuplet decay width

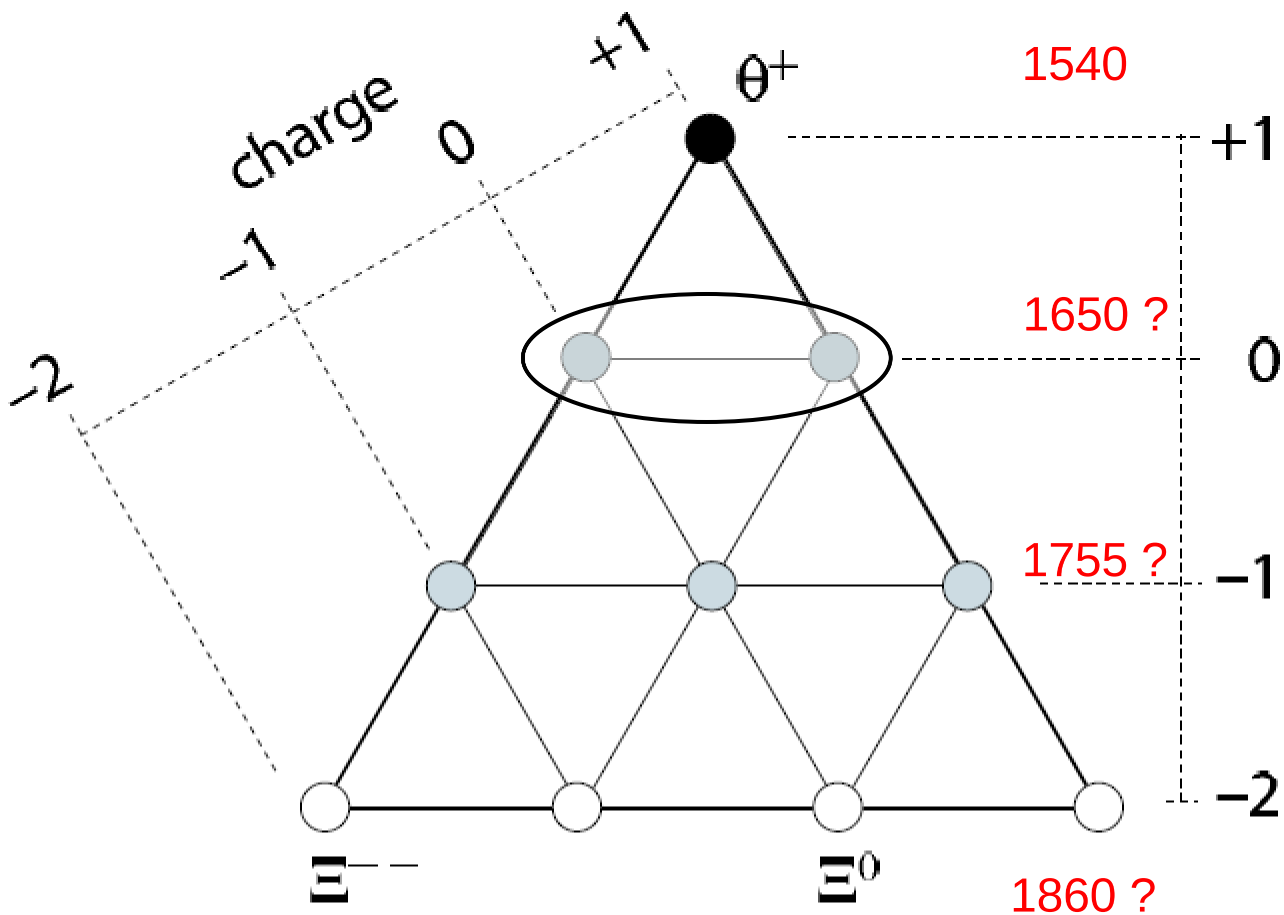
$$\Gamma^{(\overline{10})}_{B_1\to B_2\varphi} = \frac{G^2_{\overline{10}}}{8\pi M_1 M_2} \times C^{(\overline{10})}(B_1, B_2, \varphi) \times p^3_\varphi$$

In NRQM limit:

$$G_{\overline{10}} = G_0 - G_1 - \frac{1}{2}G_2 = 0$$



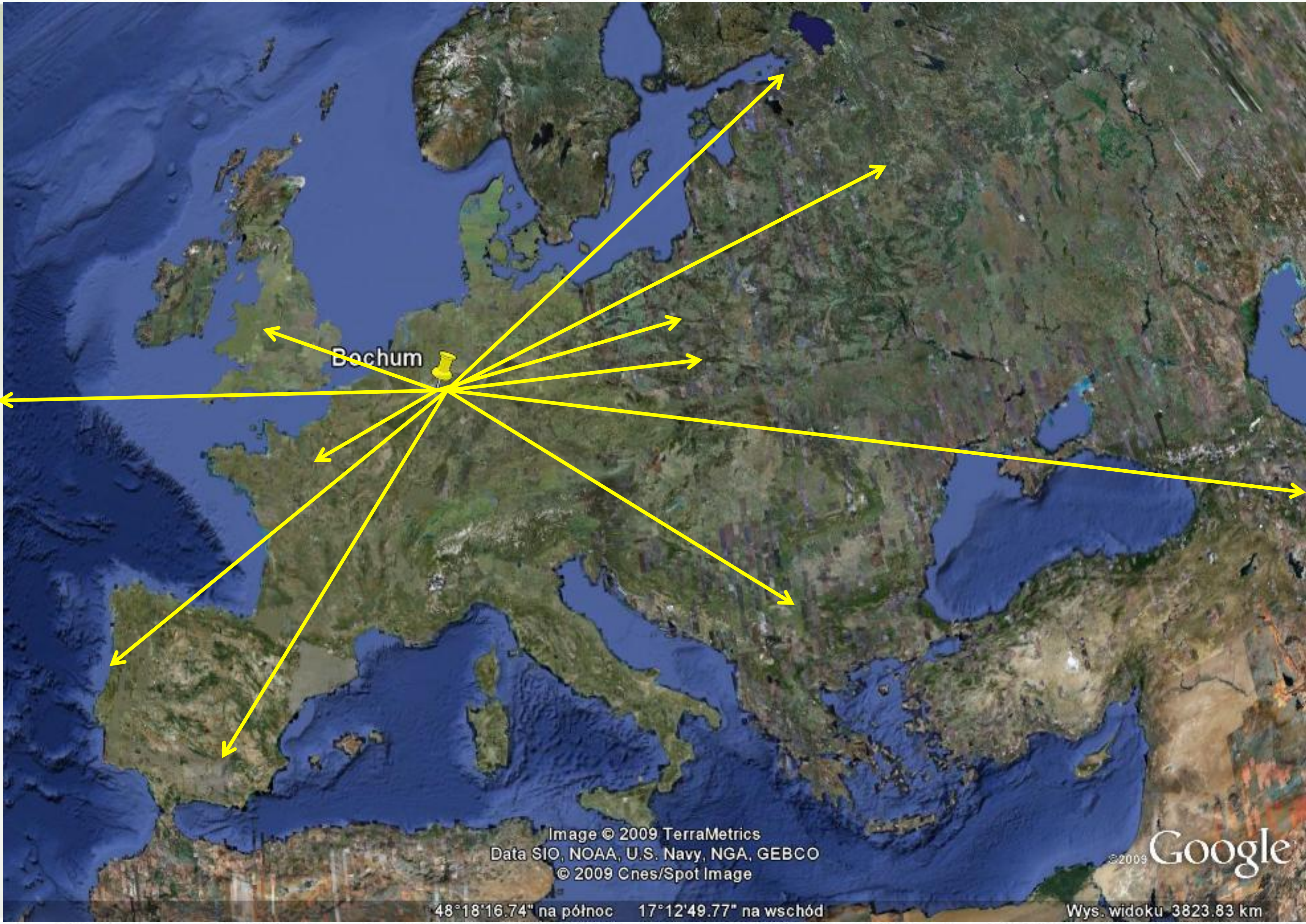
NA 49
NA 61 ?


charge
+1
0
−1
−2
Θ^+
1540
+1
1650 ?
0
strangeness
1755 ?
−1
−2
Ξ^{--}
Ξ^0
1860 ?

Chiral soliton in Bochum

- **vector mesons:** Arriola, Schuren, Doring
- **in medium properties:** Arriola, Christov, Nikolov, Broniowski, Schaldach,
- **form factors:** Grummer, Gorski, T. Meissner, Nikolov, Bergmann, Christov, Watabe, Silva, Urbano
- **strangeness:** Blotz, Pobylitsa, Diakonov, Kim, Sieber, Schneider
- **spin:** Blotz, Polyakov, Metz, Schweitzer, Weiss, Lee, Menzel, S.Messner, Schlegel
- **gradient expansion:** Arriola, Kim, Franz
- **mesons:** Ripka, Nikolov, Broniowski, Rostworowski, Arriola, Petrov, Pobylitsa, Ruskov, Lee
- **structure functions:** Diakonov, Petrov, Weiss, Dressler, Watabe, Bornig, Urbano
- **GPDs:** Polyakov, Pobylitsa, Penttinen, Ossman, Kirch
- **pentaquarks:** Polyakov, Diakonov, Petrov, Pobylitsa, Kim, Yang, Ledwig, Silva

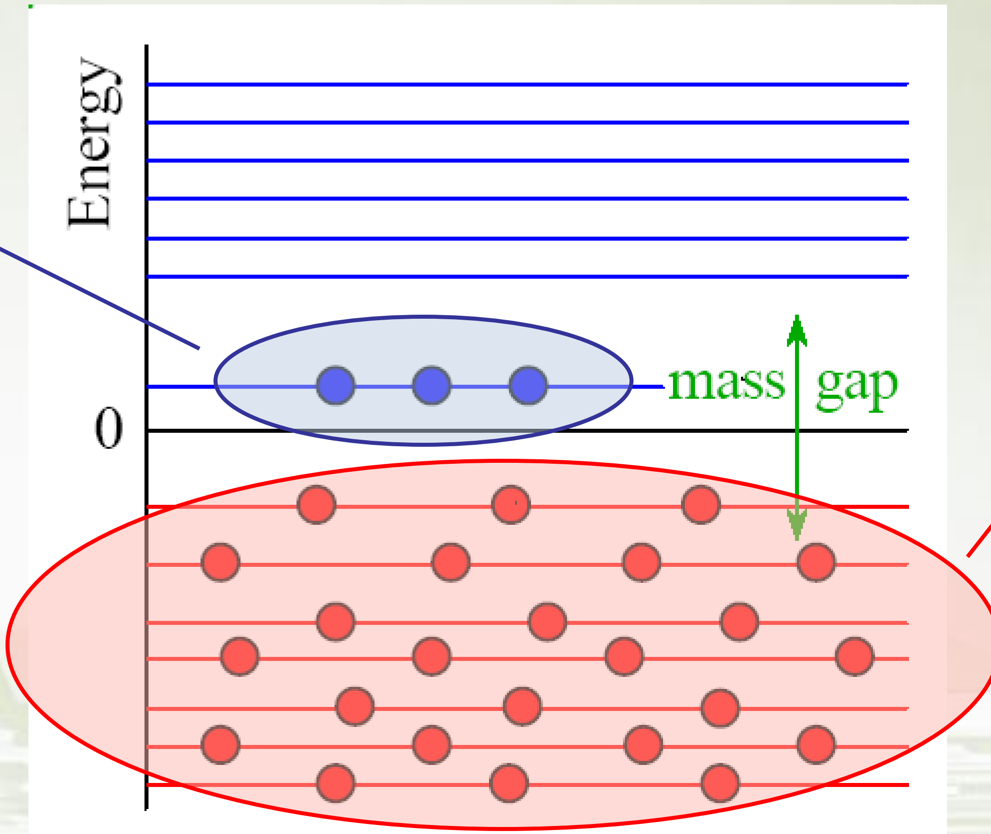
other subjects are also present: Stefanis et. al., Kivel, Manaschov, ...


Bochum
Image © 2009 TerraMetrics
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
© 2009 Cnes/Spot Image
©2009 Google
48°18'16.74" na północ 17°12'49.77" na wschód
Wys. widoku 3823.83 km

Spectrum of the Dirac operator

valence
level:

energy
decreases



sea
levels:

energy
increases

system stabilzes