AD POLOSA — SAPIENZA UNIVERSITY OF ROME

“MOLTO INTERESSANTE…”

MY COLLABORATION WITH R. GATTO

FIRST ENCOUNTER '97 (PERSONAL RECOLLECTIONS)

"…you are a frustrated mathematician,
go to get some **real** physics from Gatto"

(G. Nardulli, my PhD supervisor in Bari)

"La physique, la déception de ma vie…"

(Gatto… Did I understand well??)

THE HIERARCHY OF SAINTS

Francesco Botticini – The Assumption of the Virgin

Gatto

Roberto Casalbuoni

Ferruccio Feruglio, Giuseppe Nardulli

Nicola Di Bartolomeo

Aldo Deandrea, Daniele Balboni

Nicola was my hero, and Ferruccio was his hero. Casalbuoni was to me an abstract entity and Gatto was `the voice over the phone'.

THE `CQM' (CONSTITUENT QUARK-MESON) PROJECT

The initiative apparently was taken by Beppe (Nardulli) and Nicola.

But Gatto directed decisively the discussion with a variety of almost imperceptible gestures of face (encoding meanings better known only to closer collaborators) and very short, sharp, comments.

PHYSICAL REVIEW D, VOLUME 58, 034004

Constituent quark-meson model for heavy-meson processes

A. Deandrea
Centre de Physique Théorique, CNRS Luminy, Case 907, F-13288 Marseille Cedex 9, France

N. Di Bartolomeo
Sissa, via Beirut 2-4, I-34014 Trieste, Italy

R. Gatto
Département de Physique Théorique, Université de Genève, 24 quai E.-Ansermet, CH-1211 Genève 4, Switzerland

G. Nardulli and A. D. Polosa
Dipartimento di Fisica, Università di Bari and INFN Bari, via Amendola 173, I-70126 Bari, Italy
(Received 13 February 1998; published 29 June 1998)

We describe the effective heavy meson Lagrangian for S- and P-wave heavy-light mesons in terms of a model based on meson-quark interactions, where mesonic transition amplitudes are represented by diagrams with heavy mesons attached to loops containing heavy and light constituent quarks. The model is relativistic and incorporates the heavy quark symmetries. The universal form factors of the heavy meson transition amplitudes are calculated together with their slopes and compared to existing data and limits. As further applications of the model, strong and radiative decays of D^* and B^* are considered. The agreement with data is surprisingly good and shows that the model offers a viable alternative to effective meson Lagrangians which require a larger number of input parameters.
[S0556-2821(98)02415-1]

PACS number(s): 13.25.Hw, 12.39.Hg, 13.25.Ft

CQM LAGRANGIAN

$$\mathscr{L} = \mathscr{L}_{ll} + \mathscr{L}_{hl}$$

$$\mathscr{L}_{ll} = \bar{\chi}(\gamma \cdot (i\partial + \mathscr{V}) - m)\chi + \bar{\chi}\gamma \cdot \mathscr{A}\gamma_5\chi + \frac{f_\pi}{8}\mathrm{Tr}[\partial^\mu\Sigma\partial_\mu\Sigma^\dagger]$$

where $\chi = \xi q, \qquad \xi = e^{i\frac{\pi}{f_\pi}} = 1 + \cdots, \qquad \Sigma = \xi^2, \qquad g_A = 1 \ (\mathrm{NJL})$

$$\mathscr{V}_\mu = \frac{1}{2}(\xi^\dagger\partial_\mu\xi + \xi\partial_\mu\xi^\dagger)$$

$$\mathscr{A}_\mu = -\frac{i}{2}(\xi^\dagger\partial_\mu\xi - \xi\partial_\mu\xi^\dagger)$$

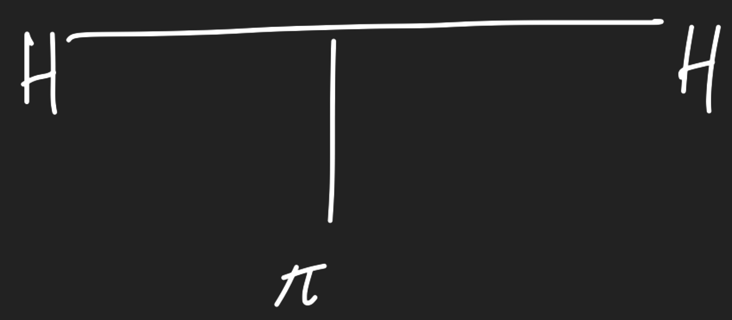
$$\mathscr{L}_{hl} = \bar{Q}_v\,(iv \cdot \partial)\,Q_v - [\chi\,\overline{H}\,Q_v + h.c.] + G\,\mathrm{Tr}[\overline{H}H] + \cdots$$

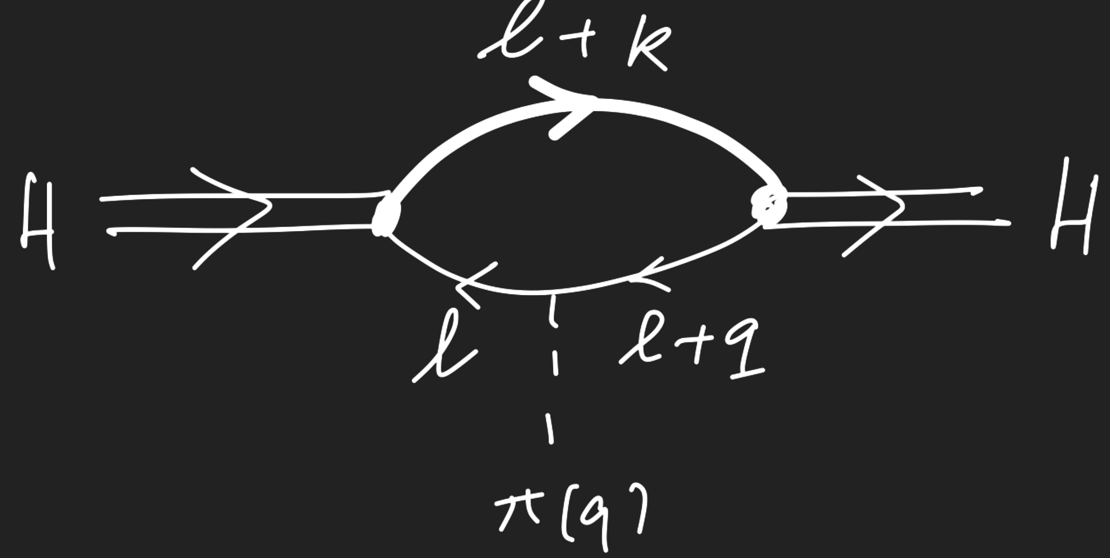
where $H = \dfrac{1 + \gamma \cdot v}{2}[P^*_\mu\gamma^\mu - P\gamma_5]$

$$\langle 0\,|\,P\,|\,Q\bar{q}(0^-)\rangle = \sqrt{M_H} \qquad \langle 0\,|\,P^*_\mu\,|\,Q\bar{q}(1^-)\rangle = \sqrt{M_H}\,\epsilon_\mu$$

$$Q_v(x) = e^{im\,v\cdot x}Q(x) = h_v(x) + H_v(x)_{O(1/m_Q)}$$

CQM LOOPS



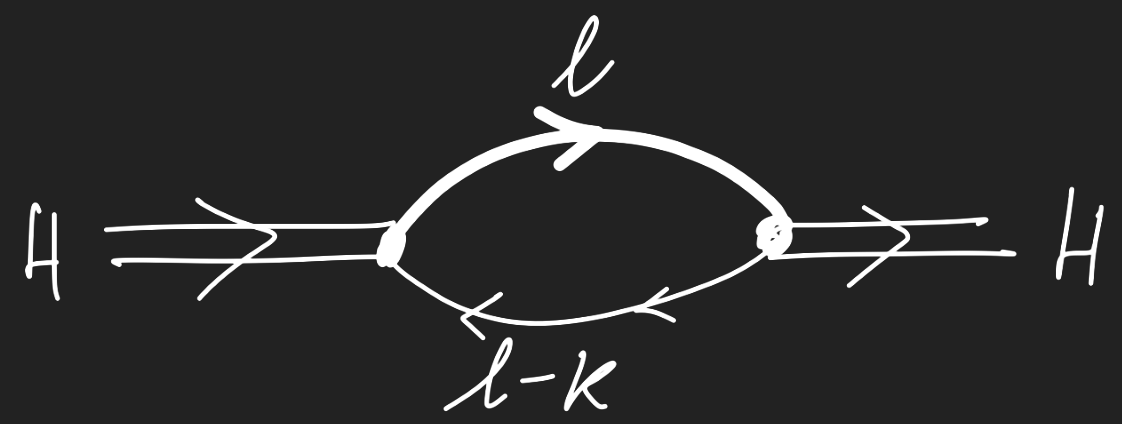


In the soft-pion limit (s.p.l.) one could compute for example the D*-D-pion strong coupling. (*k* is the `residual` momentum of HQET)

$$g_{D^*D\pi}\,\frac{\epsilon\cdot q}{f_\pi} \propto Z_H\, M_H \int d^4\ell\, \frac{\mathrm{Tr}[\,(\ell\cdot\gamma+m)\,(\frac{q^\mu}{f_\pi}\,\gamma_\mu\gamma_5)\,(\ell\cdot\gamma+m)\,\gamma_5\,\frac{(1+\gamma\cdot v)}{2}\,\gamma\cdot\epsilon]}{(\ell^2-m^2)^2\,(v\cdot\ell+\Delta)}$$

We found later an ingenious way to go beyond the s.p.l.

CQM LOOPS



$$\mathrm{Tr}[\overline{H}\,\Pi(v\cdot k)\,H] = -\,iN_c\int d^4\ell\;\frac{\mathrm{Tr}[\,H\,((\ell-k)\cdot\gamma+m)\,\overline{H}]}{(\ell^2-m^2)^2\,(v\cdot\ell+\Delta)}$$

$$\Pi(v\cdot k)\simeq\Pi(\Delta)+\Pi'(\Delta)(v\cdot k-\Delta)$$

In this way one could obtain (by subtracting from $\mathscr{L}_{\mathrm{hl}}$ this counterterm)

[Casalbuoni, Deandrea, Di Bartolomeo, Feruglio, Gatto, Nardulli, Phys Rept 281 (1997) 145]

$$\mathscr{L}_{\mathrm{eff}} = \mathrm{Tr}[H_{\mathrm{ren}}(iv\cdot\partial-\Delta)H_{\mathrm{ren}}]$$

$$H_{\mathrm{ren}} = \frac{H}{\sqrt{Z_H}}\quad\text{provided}\quad G=\Pi(\Delta)\quad\text{where}\quad\frac{1}{Z_H}=\Pi'$$

‘EL CABALLERO DE LA SIGMA’ (E. DE RAFAEL)

Gatto helped me to find a post-doc in Europe. I got two offers: Barcelona and Helsinki. Being from Bari, I opted for Helsinki! There I met Nils Tornqvist, who was obsessed by the problem of the sigma meson.

VOLUME 86, NUMBER 2 PHYSICAL REVIEW LETTERS 8 JANUARY 2001

$B \to \rho\pi$ Decays, Resonant and Nonresonant Contributions

A. Deandrea[1] and A. D. Polosa[2]

[1]*Theory Division, CERN, CH-1211 Genève 23, Switzerland*
[2]*Physics Department, University of Helsinki, POB 9, FIN-00014, Helsinki, Finland*

(Received 10 August 2000)

We point out that a new contribution to B decays to three pions is relevant in explaining recent data from the CLEO and BABAR Collaborations, in particular, the results on quasi-two-body decays via a ρ meson. We also discuss the relevance of these contributions to the measurement of CP violations.

DOI: 10.1103/PhysRevLett.86.216 PACS numbers: 13.25.Hw, 11.30.Er, 12.39.Hg

The ‘new’ contribution was

$$B \to \sigma\pi$$

Something I knew how to estimate with the CQM model – Gatto, Nardulli, Polosa, Tornqvist, PLB494(2000) 168

LOS CABALLEROS DE LA SIGMA

But the suspect that the sigma, and other light scalars, where not a ‘standard mesons’ was rather strong.

–What do you think Prof Gatto?

–``Molto interessante…” …and he was right!!

Nothwithstanding the catastrophic `very interesting’ verdict, we decided to speculate on the molecular hypothesis.

ELSEVIER

15 March 2001

PHYSICS LETTERS B

Physics Letters B 502 (2001) 79–86

www.elsevier.nl/locate/npe

The $s\bar{s}$ and $K\overline{K}$ nature of $f_0(980)$ in D_s decays

A. Deandrea[a], R. Gatto[b], G. Nardulli[c], A.D. Polosa[d], N.A. Törnqvist[d]

[a] *Institut de Physique Nucléaire, Université Lyon I, 43, bd du 11 Novembre 1918, F-69622 Villeurbanne Cedex, France*
[b] *Département de Physique Théorique, Université de Genève, 24 quai E.-Ansermet, CH-1211 Genève 4, Switzerland*
[c] *Dipartimento di Fisica, Università di Bari and INFN Bari, via Amendola 173, I-70126 Bari, Italy*
[d] *Physics Department, P.O.B. 9, FIN-00014, University of Helsinki, Helsinki, Finland*

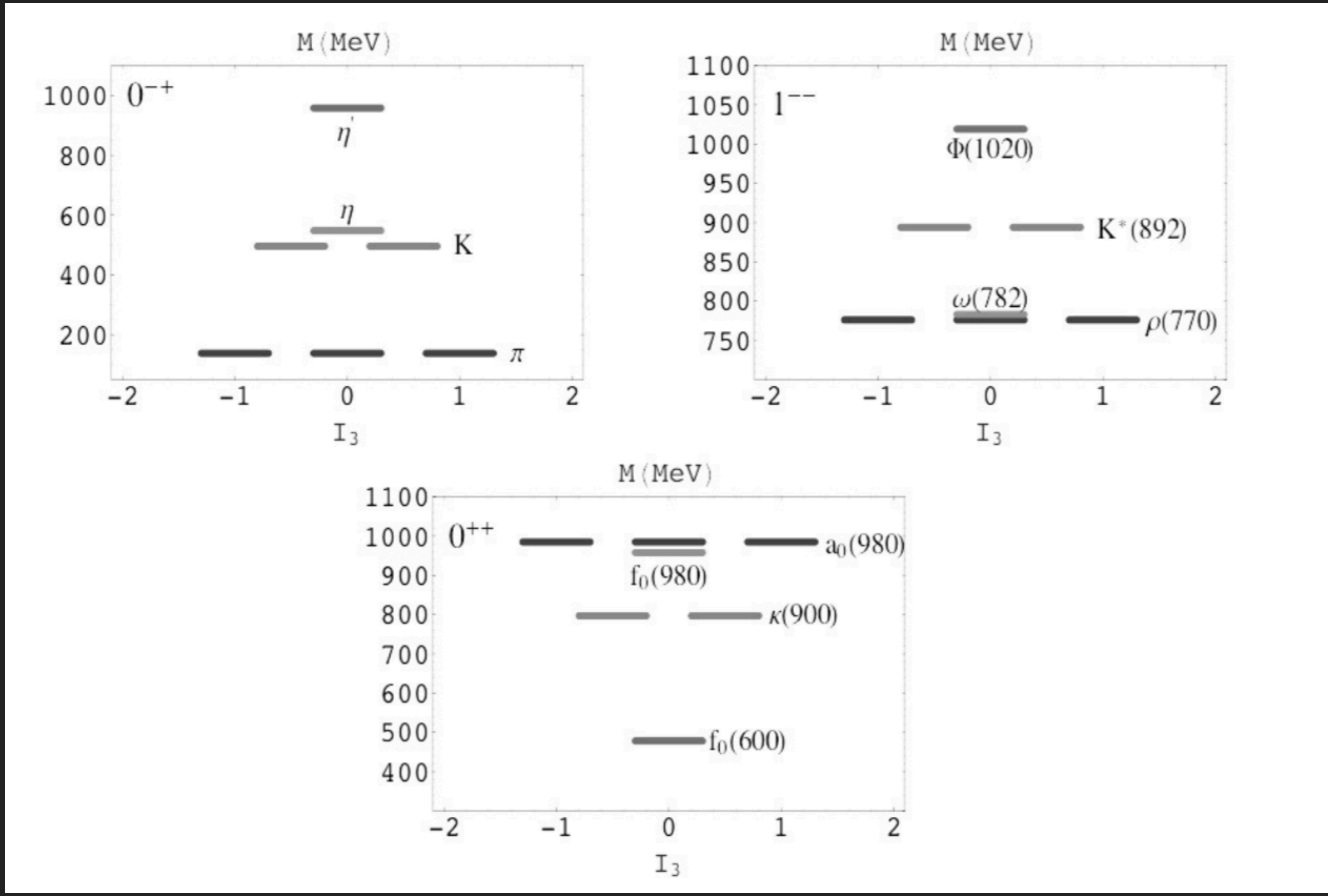
Received 10 December 2000; accepted 26 January 2001
Editor: L. Alvarez-Gaumé

TETRAQUARKS FROM THE PENTAQUARK

In 2003 there was the K^+n pentaquark explosion.

Jaffe & Wilczek wrote a brilliant paper on ``Diquarks and Exotic Spectroscopy''

to explain the pentaquark as a [ud][ud]s*. *We thought to tetraquarks instead.*



From A Ali, L Maiani, ADP, *Multiquark Resonances,* Cambridge U. Press (2019)

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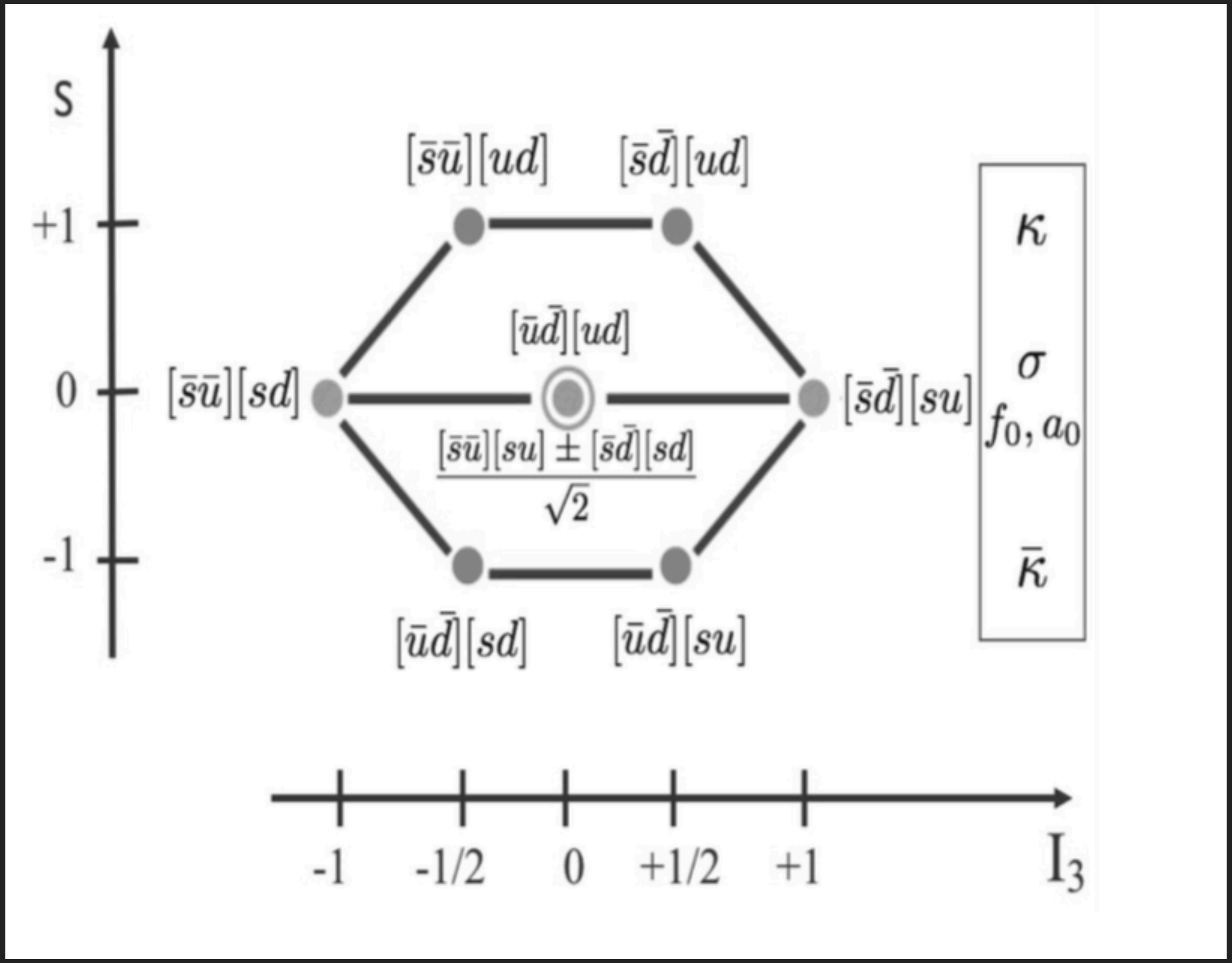


From A Ali, L Maiani, ADP, *Multiquark Resonances,* Cambridge U. Press (2019)

SCALAR TETRAQUARKS

VOLUME 93, NUMBER 21 PHYSICAL REVIEW LETTERS week ending 19 NOVEMBER 2004

New Look at Scalar Mesons

L. Maiani*

Università di Roma "La Sapienza" and I.N.F.N., Roma, Italy

F. Piccinini†

I.N.F.N. Sezione di Pavia and Dipartimento di Fisica Nucleare e Teorica, via A. Bassi, 6, I-27100, Pavia, Italy

A. D. Polosa‡

Centro Studi e Ricerche "E. Fermi," via Panisperna 89/A-00184 Roma, Italy

V. Riquer§

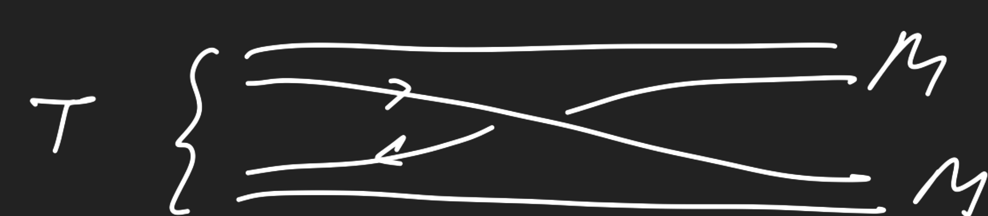
CERN Theory Department, CH-1211, Switzerland

(Received 1 July 2004; published 16 November 2004)

Light scalar mesons are found to fit rather well a diquark-antidiquark description. The resulting nonet obeys mass formulas which respect, to a good extent, the Okubo-Zweig-Iizuka (OZI) rule. OZI allowed strong decays are reasonably reproduced by a single amplitude describing the switch of a $q\bar{q}$ pair, which transforms the state into two colorless pseudoscalar mesons. Predicted heavy states with one or more quarks replaced by charm or beauty are briefly described; they should give rise to narrow states with exotic quantum numbers.

(1) (2) X, Y, Z

DOI: 10.1103/PhysRevLett.93.212002 PACS numbers: 12.39.–x, 12.38.–t



LOS CABALLEROS DE LA SIGMA II

A theory of scalar mesons

G. 't Hooft [a], G. Isidori [b,c], L. Maiani [d,e], A.D. Polosa [e,*], V. Riquer [e]

[a] *Institute for Theoretical Physics, Utrecht University, and Spinoza Institute, Postbus 8000, 3508 TA Utrecht, The Netherlands*
[b] *Scuola Normale Superiore, Piazza dei Cavalieri 7, 56126 Pisa, Italy*
[c] *INFN, Laboratori Nazionali di Frascati, Via E.Fermi 40, 00044 Frascati, Italy*
[d] *Dipartimento di Fisica, Università di Roma "La Sapienza", P.le A. Moro 2, 00185 Roma, Italy*
[e] *INFN, Sezione di Roma "La Sapienza", P.le A. Moro 2, 00185 Roma, Italy*

Received 18 January 2008; received in revised form 15 February 2008; accepted 18 March 2008

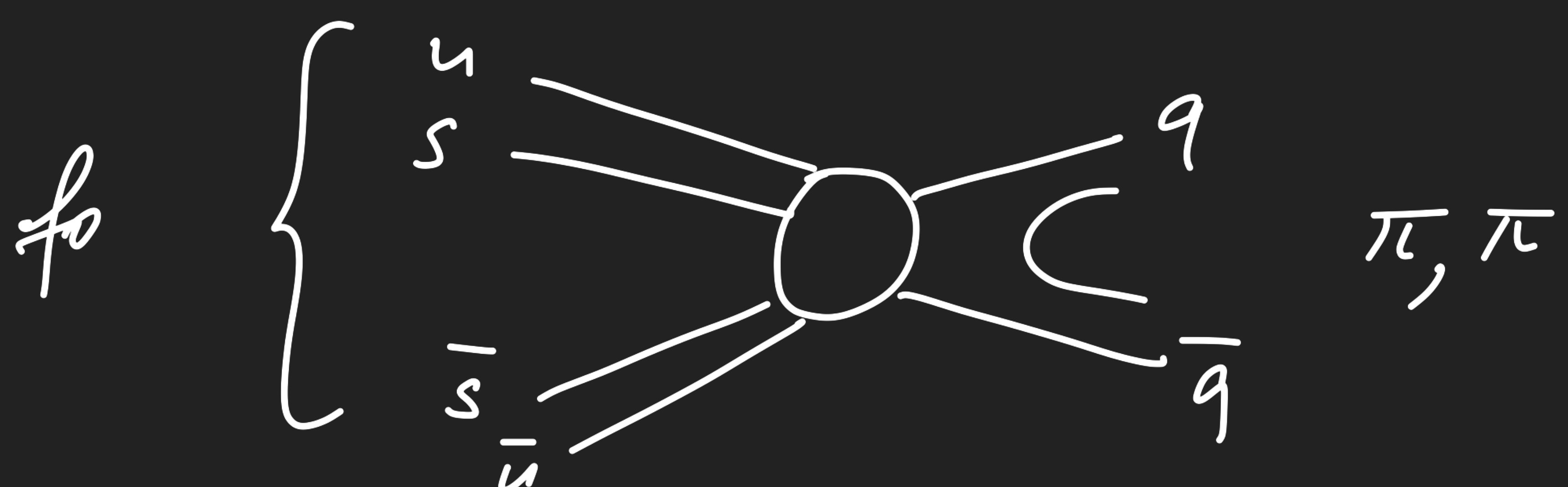
Available online 21 March 2008

Editor: G.F. Giudice

Abstract

We discuss the effect of the instanton induced, six-fermion effective Lagrangian on the decays of the lightest scalar mesons in the diquark–antidiquark picture. This addition allows for a remarkably good description of light scalar meson decays. The same effective Lagrangian produces a mixing of the lightest scalars with the positive parity $q\bar{q}$ states. Comparing with previous work where the $q\bar{q}$ mesons are identified with the nonet at 1200–1700 MeV, we find that the mixing required to fit the mass spectrum is in good agreement with the instanton coupling obtained from light scalar decays. A coherent picture of scalar mesons as a mixture of tetraquark states (dominating in the lightest mesons) and heavy $q\bar{q}$ states (dominating in the heavier mesons) emerges.

PACS: 12.38.Aw; 12.39.Mk; 14.40.-n



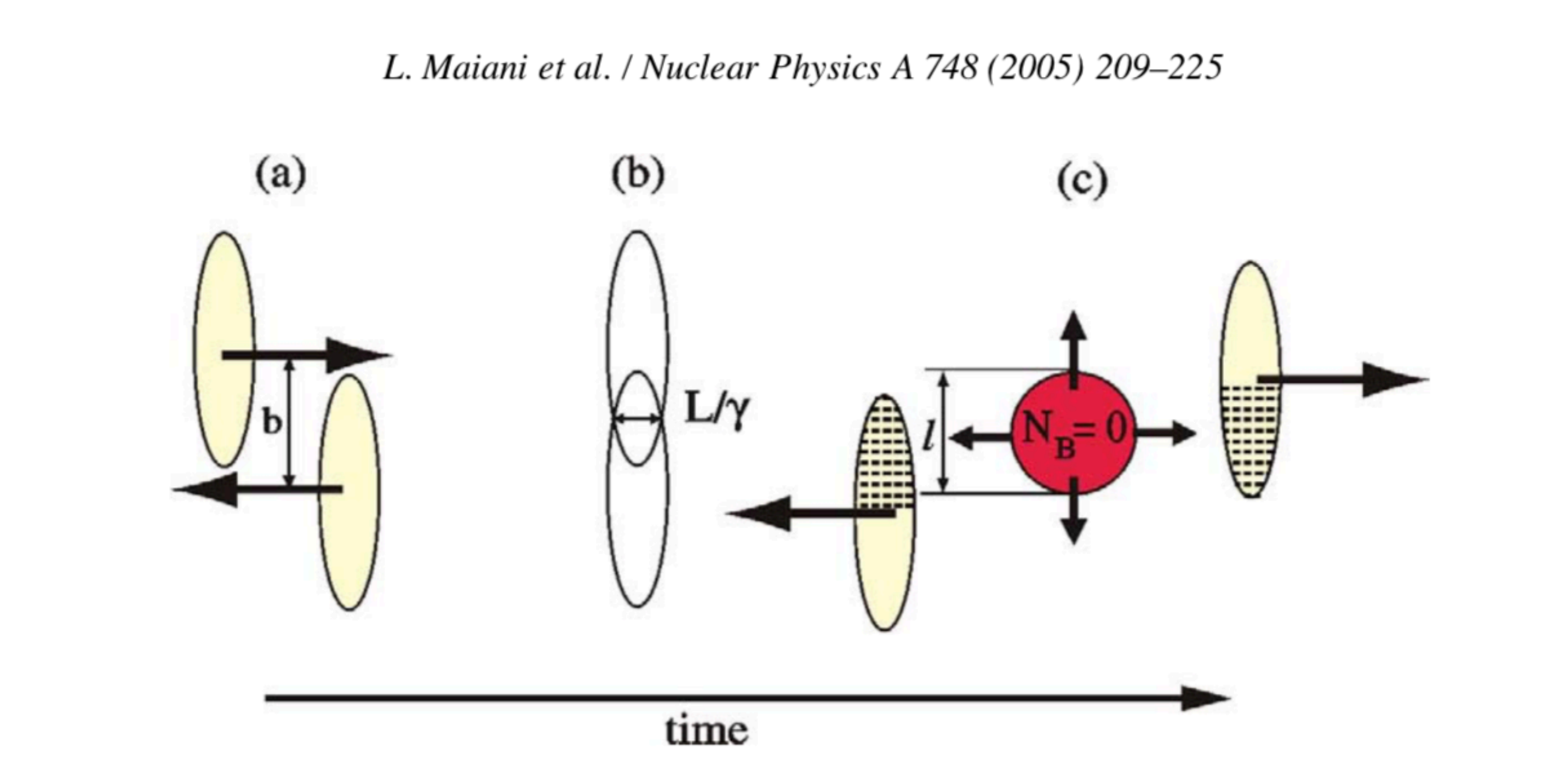
ZWEIG-VIOLATING $\sigma \to \pi\pi$ AMPLITUDE

J/Ψ SUPPRESSION AT NA50

CQM turned out to be useful to another project we worked to, back in 2004: can the J/ψ suppression signal claimed by the NA50 collaboration be explained simply with

$$\pi + J/\psi \to D + D^*$$

where the J/ψ is assumed to be produced in a thermalized pion gas (Björken). The temperature and energy density of the pion gas are determined from low centrality collisions (and extrapolated to higher centrality).



J/Ψ SUPPRESSION AT NA50

The nuclear absorption is due to

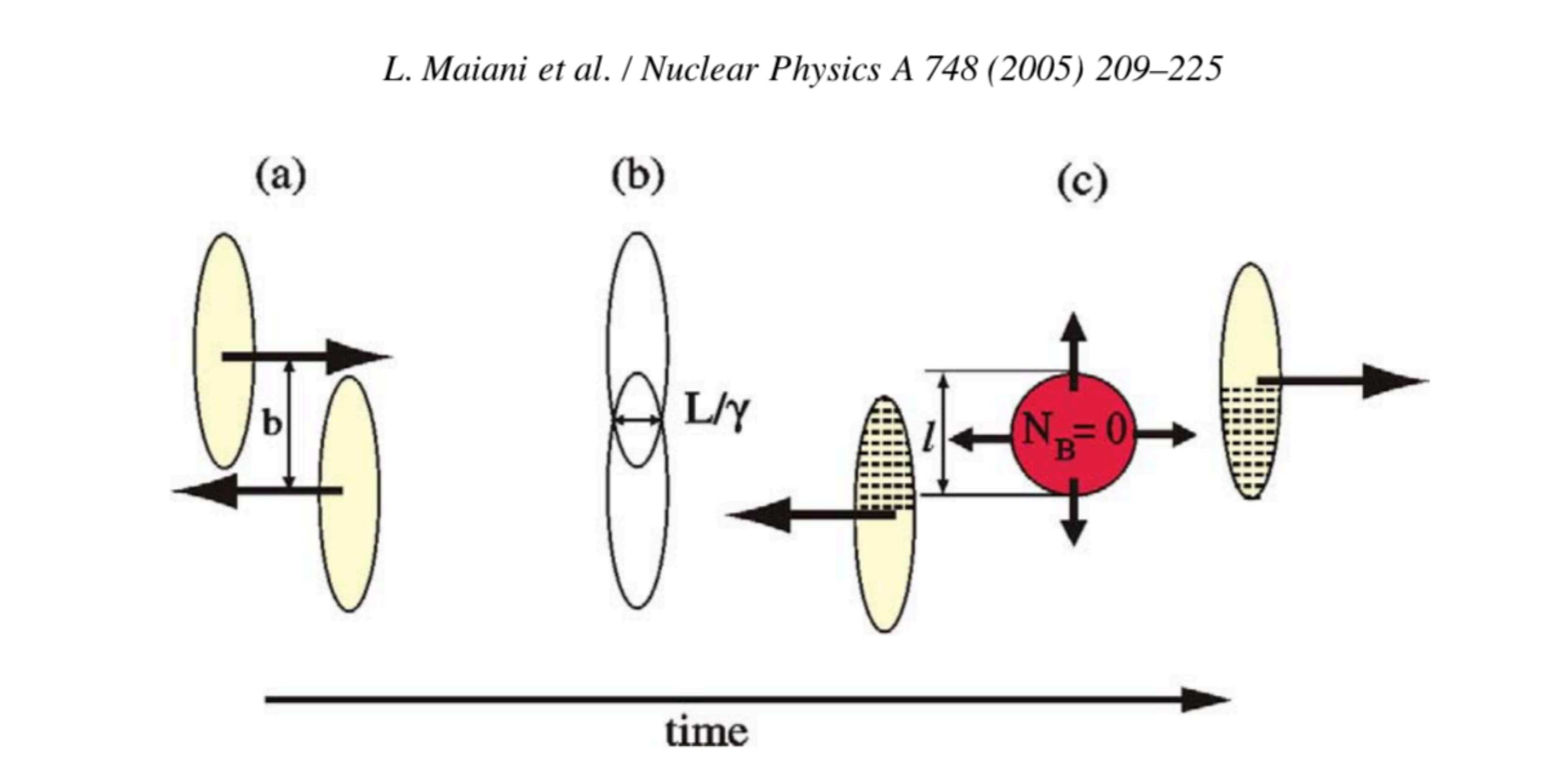
$$\mathscr{A} \propto \exp(-\rho_{\text{nucl}}\,\gamma \times L/\gamma \times \sigma_{\text{nucl}})$$

where the σ_{nucl} was determined by NA50 from

$$p + A \to J/\psi + \text{anything}$$

The attenuation due to `comoving` particles is

$$\mathscr{A} \propto \exp(-\sum_i \langle \rho_i \sigma_i \rangle_T \times \frac{3}{8} \ell\,)$$



J/Ψ SUPPRESSION AT NA50

The total absorption is

$$\mathscr{A}(\ell) = N \exp(-\rho_{\text{nucl}} \times L(\ell) \times \sigma_{\text{nucl}}) \times \exp\left(- \sum_i \langle \rho_i \sigma_i \rangle_{T(\ell)} \times \frac{3}{8} \ell \right)$$

The impact parameter *b* is measured collision by collision from debris.

L is obtained from *b* using the Glauber model and finally $\ell = 2R - b$.

In addition to pions, the contribution of ϱ,ω was found to be relevant.

Here:

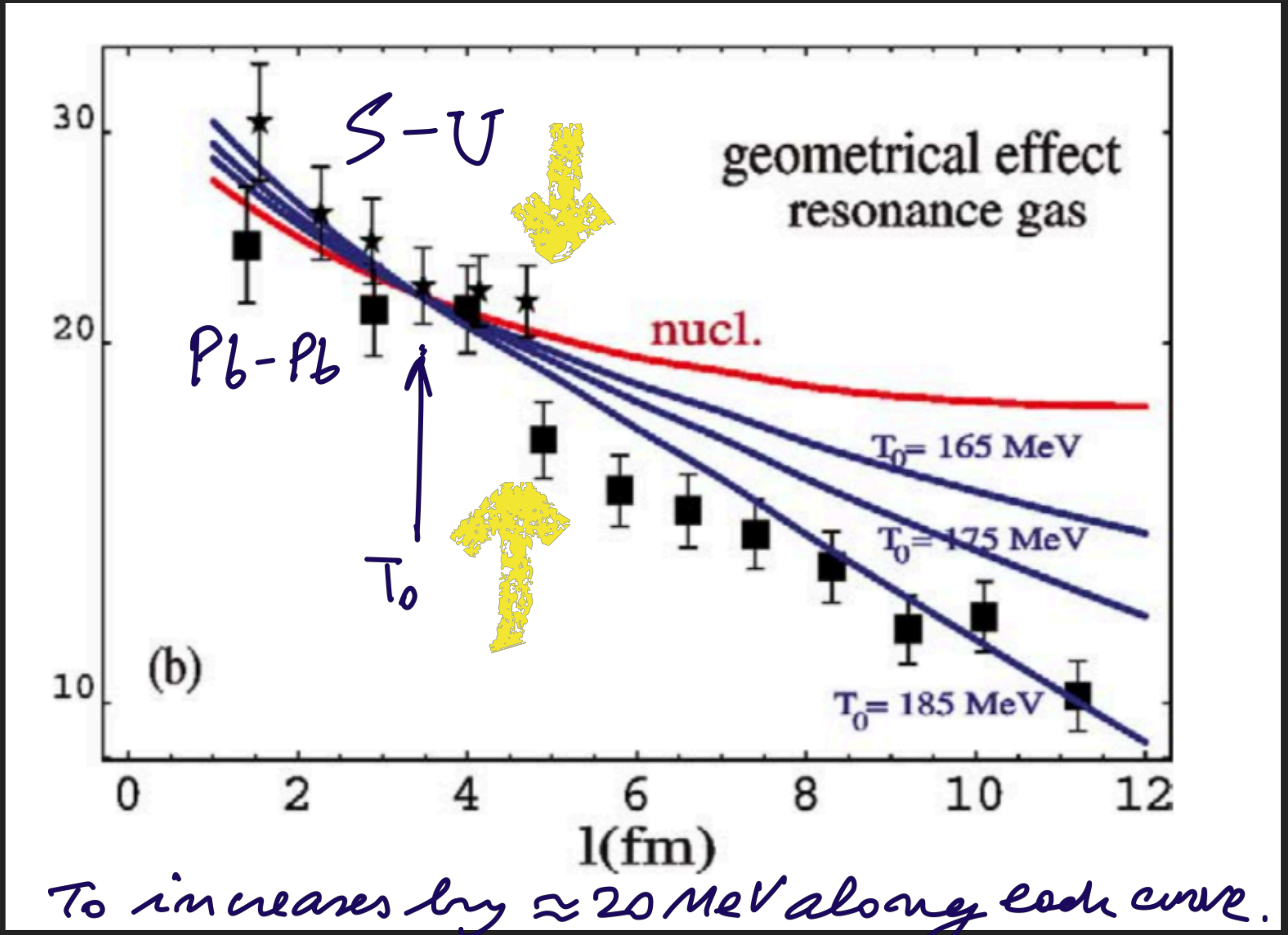
$$T(\ell) = T_0 \times \left(\frac{g(1 - \ell/R)}{g(1 - \ell_0/R)} \right)^{1/4}$$

The function *g* was found studying geometrically the variation of the (surface) energy density with *b*.

J/Ψ SUPPRESSION AT NA50

Comparison to data

$$\mathscr{A}(\ell) = N \exp(-\rho_{\text{nucl}} \times L(\ell) \times \sigma_{\text{nucl}}) \times \exp\left(- \sum_i \langle \rho_i \sigma_i \rangle_{T(\ell)} \times \frac{3}{8} \ell \right)$$

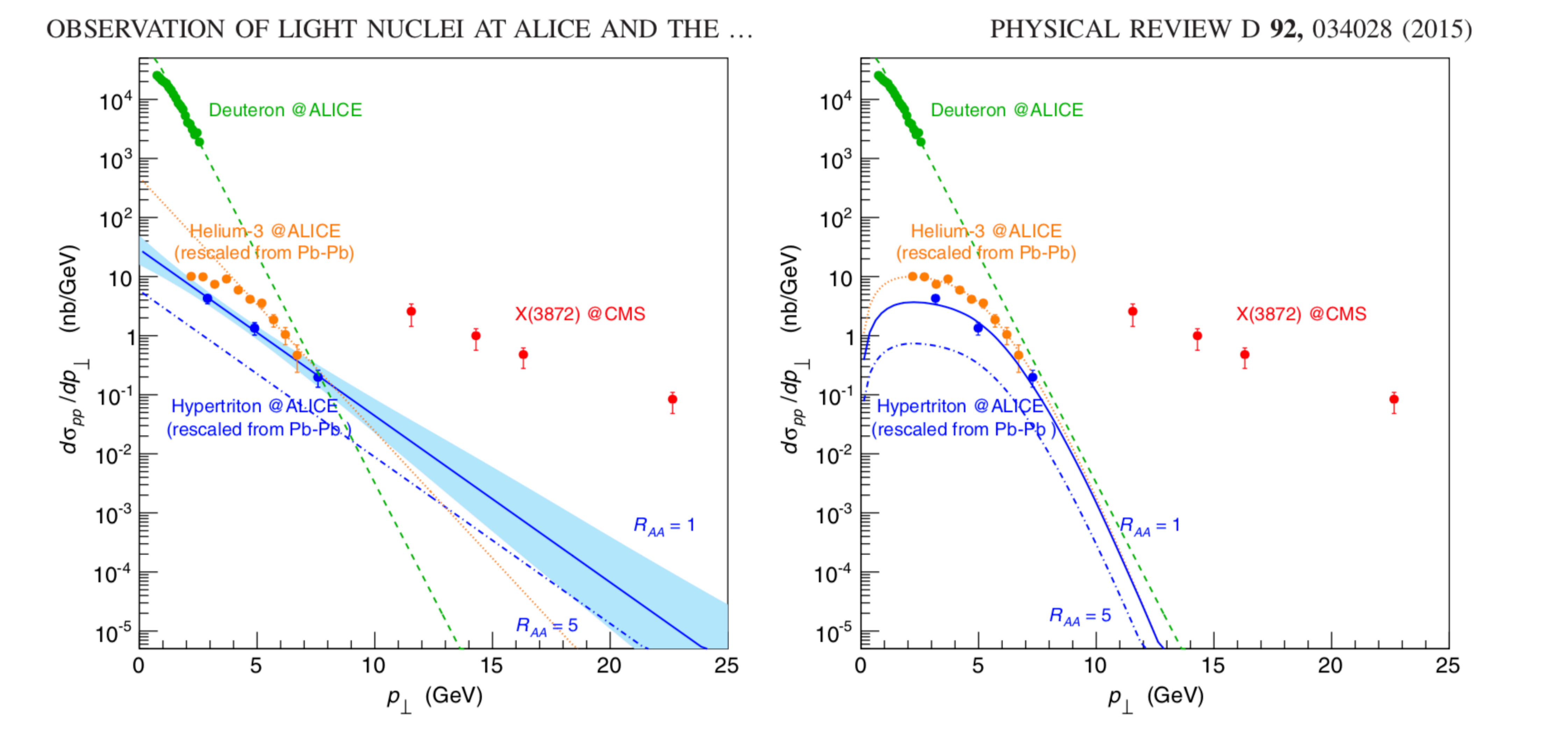


THE X, Y, Z EXOTIC RESONANCE EXPLOSION

Differently from the `old' light pentaquark, the X(3872) has been observed by all collider experiments (Belle, CDF, BaBar, D0, Bes, CMS, ATLAS).

It looked immediately as a very strange (1^{++}) charmonium.

Right at the DD* meson threshold but with high xsect at pp(p*).



Esposito et al.

DIQUARKS: REPULSION AT SMALL DISTANCES?

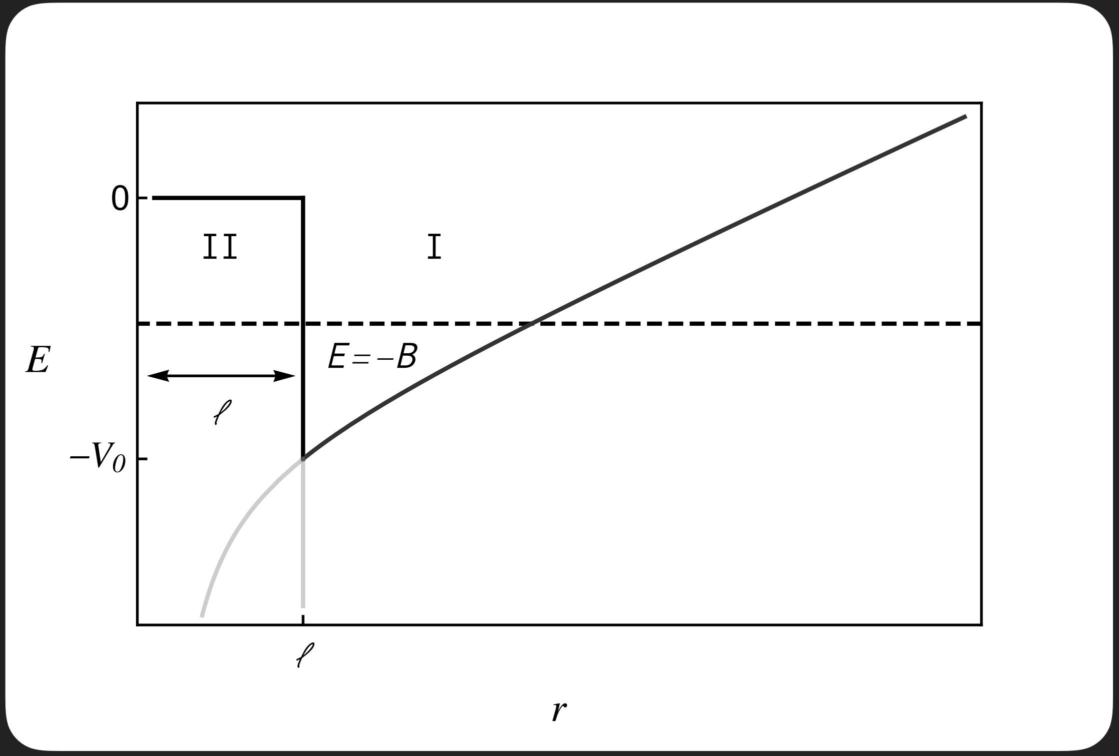
Two quarks can be found in the color representations

$$\bar{\mathbf{3}}_{\mathbf{c}} \quad \text{or} \quad \mathbf{6}_{\mathbf{c}}$$

The antisymmetric representation is attractive, and the symmetric is repulsive (one-gluon-exchange).

A diquark and an antidiquark attract at 'large' distance, but, at small distances, the compositeness of the diquark might play a role: there could be a component in the mutual potential increasing at decreasing distance – to disintegrate the diquarks their binding energy must be overcome.

If this wins against the decrease due to color attraction there could be a short distance barrier stabilizing the tetraquark.



Selem and Wilczek, hep-ph/0602128

Maiani, ADP, Riquer, PLB778 (2018) 247

Esposito, ADP, 1807.06040

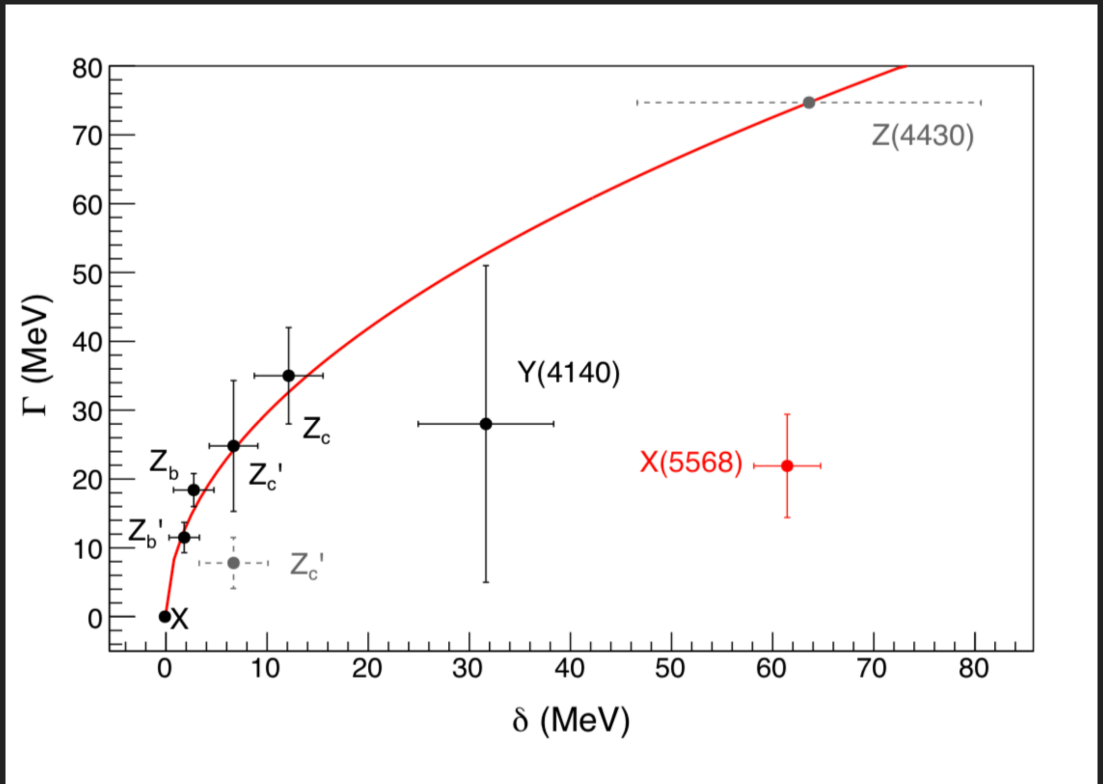
TOTAL WIDTHS OF X AND Z TETRAQUARKS

One can find a formula for the total width of X,Z states

$$\Gamma \simeq \frac{\pi^2}{R}\frac{\sqrt{m}}{m_{dq}}\exp\left(-2\ell\sqrt{2MB}\right)\sqrt{\delta}$$

Where M is the mass of the quark making the tunneling, m the mass of the final state mesons, and m_{dq} the mass of the diquark(s).

δ = the mass gap between the observed tetraquark and the meson-meson threshold.



Esposito, Pilloni, ADP, PLB758 (2016) 292

Esposito, ADP, 1807.06040

BACKUP

$$\mathscr{L}_{hl} \supset \bar{h}_v(iv \cdot D)h_v + \frac{1}{2m_Q}\bar{h}_v(i\tilde{D})^2 h_v + \frac{g}{4m_Q}\bar{h}_v(\sigma_{\mu\nu}G^{\mu\nu})h_v + O(1/m_Q^2)$$

where $[D^\mu, D^\nu] = -igG^{\mu\nu}$ $\quad \tilde{D}^\mu = D^\mu - v^\mu v \cdot D$ $\quad \not{v}h_v = h_v$

$$k \sim \Lambda_{\mathrm{QCD}} < \Lambda_\chi = 4\pi f_\pi \sim 1\ \mathrm{GeV}$$

$$M > m_Q + m \mapsto v \cdot k > m \quad \text{or} \quad \inf(k) = m \sim 300\ \mathrm{MeV}$$

$m_Q\, v$ – is not dynamical due to the superselection rule on v

$$\Delta = M - m_Q + O(1/m_Q)$$

Used 0.3, 0.4, 0.5 GeV

MY LAST MEETING WITH GATTO, IN PERSON

To express my gratitude to Gatto, soon after my PhD thesis discussion, and before leaving for Finland, I made him a small present – an OMAS pen.

Being a 'connaisseur' of fountain pens, I was quite satisfied with my choice.

– Ohh, what is this?

– An OMAS pen Prof., it is a very special Italian brand

– I see … I thought Aurora were the best ones …

– Very interesting

The only time I have been in the position to shoot a `*very interesting*` to him