Dynamics of quarks and gauge fields in the lowest-energy states in QCD and QED

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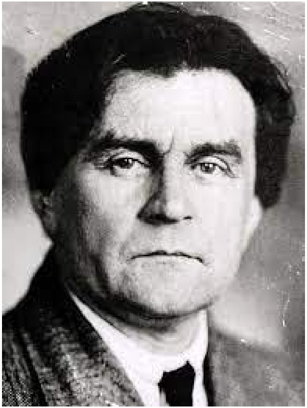


Supermatist square is

DM forerunner? 

Introduction

DM MODELS

1. Weakly interacting massive particles (WIMPs)
2. Axions and axion-like aarticles
3. Dark photons
4. Sterile neutrinos
5. So on...

OUR MODEL

QED CONFINEMENT

Introduction

NO CONFINEMENT IN STANDARD (3+1) QED!!!

K.G. Wilson, *Confinement of quarks* Phys. Rev. D10 2445 (1974)

A. M. Polyakov, *Quark confinement and topology of gauge theories* Nucl. Phys. B120, 429 (1977).

S. D. Drell, H. R. Quinn, B. Svetitsky, and M. Weinstein, *Quantum electrodynamics on a lattice: A Hamiltonian variational approach to the physics of the weak-coupling region*, Phys. Rev. D19, 619 (1979)

Introduction

HOWEVER,
THERE IS CONFINEMENT IN THE WEAK COUPLING (!!!)

1. (1+1) QED

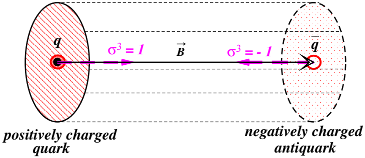
J. Schwinger, *Gauge invariance and mass II*, Phys. Rev. 128, 2425 (1962)

2.(2+1) QED

A. M. Polyakov, *Quark confinement and topology of gauge theories* Nucl. Phys. B120, 429 (1977)

Introduction

WE COMBINE (2+1) and (1+1) SITUATIONS, STRETCHING A STRING BETWEEN A $(q - \bar{q})$ PAIR



Introduction

WHY IS IT BETWEEN $(q - \bar{q})$ PAIRS???

BECAUSE

1. Anomalous soft photons

C. Y. Wong, *Anomalous soft photons in hadron production*, Phys. Rev. C81, 064903 (2010).

2. X17 and E38 particles

i) A. J. Krasznahorkay *et al.*, *Observation of anomalous internal pair creation in 8Be: a possible indication of a light, neutral boson*, Phys. Rev. Lett. 116, 042501 (2016).

ii) K. Abraamyan, et.al, *Check of the structure in photon pairs spectra at the invariant mass of about 38 MeV*, EPJ Web of Conferences 204, 08004 (2019).

Initial Lagrangian

HOW TO DO IT ?

We start from from the very general (3+1) $U(1) \bigotimes SU(3)$ action integral

$$\mathcal{A}_{\rm 4D} = \int d^4x \; Tr\left\{ \bar{\Psi}(x)\gamma^{\mu}\Pi_{\mu}\Psi(x) - \bar{\Psi}(x)m\Psi(x) - \mathcal{L}_A \right\}, \tag{1}$$

where

$$\gamma^{\mu}\Pi_{\mu} = \gamma^{\mu}(i\partial_{\mu} + g_{\rm 4D}A_{\mu}) = \gamma^{\mu}(p_{\mu} + g_{\rm 4D}A_{\mu}), \tag{2a}$$

$$\mathcal{L}_A = \frac{1}{2\pi^2 R_T^4 g_{\rm 4D}^2}[1 - \cos(\pi R_T^2 g_{\rm 4D} F_{\mu\nu}(x))], \tag{2b}$$

$$F_{\mu\nu} = \partial_{\mu}A_{\nu} - \partial_{\nu}A_{\mu} - ig_{\rm 4D}[A_{\mu}, A_{\nu}], \tag{2c}$$

$$F_{\mu\nu} = F^a_{\mu\nu}t_a, \quad A_{\mu} = A^a_{\mu}t_a. \tag{2d}$$

(1+1) Lagrangian and motiom equations

Separating the longitudinal (1+1) and transverse (1+1) motion of both the fermion and gauge fields we go to the (1+1) action integral (A.Koshelkin and C.Y.Wong, arxiv:2111.14933, submitted to PRD)

$$\mathcal{A}_{\rm 2D} = Tr\int dX \left\{\bar\psi(X)\gamma^{\mu}_{2D}(p_\mu + g_{2D}A_\mu(X))\psi(X) - m_T\ \bar\psi(X)\psi(X)\right\}$$
$$- \int dt\ (\kappa_1+\kappa_2)|x^3(\bar q) - x^3(q)| + Tr\int dX\left\{-\frac{1}{2}F_{03}(X)F^{03}(X)\right\}, \tag{3}$$

where everything, including the coupled constant $g_{\rm 2D}$, which is dimensional, is in (1+1).

(1+1) Lagrangian and motion equations

2D Dirac and Maxwell equation for longitudinal motion

$$\begin{aligned} &\{\gamma^{\mu}_{\rm 2D}(p_\mu + g_{\rm 2D}A^{\rm 2D}_{\mu}(X)) - m_T\}\psi_{\rm 2D}(X) = 0, \quad \mu = 0,3. \\ &\partial_\nu(\partial^\nu A^\mu - \partial^\mu A^\nu) = -g_{\rm 2D}j^\mu, \quad \mu,\nu = 0,3. \end{aligned} \tag{4}$$

2D coupling constant

$$g^2_{\rm 2D} = g^2_{\rm 4D}\int d\boldsymbol{r}_\perp\Big[G_1(\boldsymbol{r}_\perp)^* G_1(\boldsymbol{r}_\perp) + G_2(\boldsymbol{r}_\perp)^* G_2(\boldsymbol{r}_\perp)\Big]^2, \tag{5}$$

Transverse motion

$$G_{1,2}(\boldsymbol{r}_\perp) = C_{1,2}e^{i\Lambda_{1,2}\phi}e^{-x^2/2}x^{|\Lambda_{1,2}|}L_n^{(|\Lambda_{1,2}|)}(x^2), \tag{6}$$

Fermion current

$$j^\mu = \frac{g_{\rm 2D}}{\pi}(A^\mu - \partial^\mu\frac{1}{\partial_\lambda\partial^\lambda}\partial_\nu A^\nu), \quad \mu,\lambda,\nu = 0,3, \tag{7}$$

Proca-like equation and masses

In the covariant Lorentz gauge we have from Eqs.(7), (9)

$$\partial_\nu \partial^\nu A^\mu - = -m^2 A^\mu, \tag{8}$$

which coincides with the Proca equation for a particle whose mass square is $m^2 = g_{_{\rm 2D}}^2/\pi$.

Proca-like equation and masses

$U(1) \bigotimes SU(3)$ symmetry

$\Downarrow$

QED and QCD modes

$\Downarrow$

two kind of boson masses: m_{QED} and m_{QCD}

C.Y.Wong, PRC **81** *(2010) 064923,*

C.Y.Wong, JHEP **08** *(2020) 165,*

A.Koshelkin and C.Y.Wong, arxiv:2111.14933

$\Downarrow$

$$m^2_{\lambda l} = \left[\sum_{f=1}^{N_f} D^\lambda_{lf} Q^\lambda_f\right]^2 \frac{4\alpha_{\{\rm QCD,QED\}}}{\pi R_T^2} + m_\pi^2 \frac{\alpha_{\{\rm QCD,QED\}}}{\alpha_{\rm QCD}} \frac{\sum_f^{N_f} m_f (D^\lambda_{lf})^2}{m_{ud}}, \quad (9)$$

where D^λ_{lf} is the mixing flavor f matrix, λ numerates the type of a mass, QED ($\lambda = 0$) and QCD ($\lambda = 1$), R_T is a tube radius.

Proca-like equation and masses

Table: The experimental and theoretical masses of neutral, I_3=0, QCD and QED mesons, obtained with the semi-empirical mass formula (9) for QCD and QED mesons.

		$[I(J^\pi)]$	Experimental mass (MeV)	Mass formula Eq. (9) (MeV)
QCD meson	π^0	$[1(0^-)]$	134.9768 ± 0.0005	$134.9^\ddagger$
	η	$[0(0^-)]$	547.862 ± 0.017	498.4 ± 39.8
	η'	$[0(0^-)]$	957.78 ± 0.06	948.2 ± 99.6
QED meson	X17	$[0(0^-)]$	$16.94\pm0.24^\#$	17.9 ± 1.5
	E38	$[1(0^-)]$	$37.38\pm0.71^\oplus$	36.4 ± 3.8

‡ Calibration mass

$^\#$A. Krasznahorkay *et al.*, arxiv:2104.10075

$^\oplus$ K. Abraamyan *et al.*, EPJ Web Conf 204,08004(2019)

Conclusion

1. Starting from the exact (3+1) $U(1) \bigotimes SU(3)$ Lagrangian we have compactified it up to (3+1) $U(1) \bigotimes SU(3)$, so that the both longitudinal and transverse motions are found to be confined. In the result of such a compactification the gauge fields gain masses in both QED and QCD modes.
2. We have calculate these masses. Comparing the obtained mass with experimental results we achieve a good agreement with experimental data.
3. We propose the developed approach to discovering the dark matter origin.

Acknowledgments

THANK YOU FOR ATTENTION!!!