Exotic pion like states as "infra-red" Regge Trajectories and a new view about nuclear physics

M. Pitkänen
Email: matpitka6@gmail.com.
http://tgdtheory.com/.

June 19, 2020

Abstract

There is considerable evidence for what might be called "infrared" Regge trajectories having interpretation in terms of string with string tension considerably lower than hadronic string tension. This article was motivated by a finding new evidence for pion like state in the decays of long-lived kaon. The discussion of these findings leads to a more detailed formulation of nuclear string model in terms of IR Regge trajectories of nucleons allowing to understand the successes of harmonic oscillator model but with totally different interpretation. Also the nuclear binding energy can be understood at rather quantitative level in the model. Nuclear physics would reduce to that for the magnetic body of nucleon.

1 Introduction

TGD based view about non-perturbative aspects of hadron physics (http://tinyurl.com/y8semjtv) relies on the notion of color magnetic flux tubes. These flux tubes are string like objects and it would not be surprising if the outcome would be satellite states of hadrons with string tension below the pion mass scale. One would have kind of infrared Regge trajectories satisfying in a reasonable approximation a mass formula analogous to string mass formula. What is amazing that this phenomenon could allow new interpretation for the claims for a signal interpreted as Higgs at several masses (115 GeV by ATLAS, at 125 GeV by ATLAS and CMS, and at 145 GeV by CDF). They would not be actually statistical fluctuations but observations of states at IR Regge trajectory of pion of M_{89} hadron physics!

Years after writing this new evidence for pionlike state(s) as final state in the decay of long-lived kaon emerged. The detailed consideration of the situation lead to fascinating possibility. I realized that the IR Regge trajectories allow a much more detailed view about nuclear string model allowing to reinterpret the rather successful harmonic oscillator model in terms of the IR Regge trajectories assignable to 3 - possibly electromagnetic - flux tube bonds between 3 quarks forming nucleon. 3 integers label the energy eigenvalues just like in the case of 3-D harmonic oscillator. In harmonic oscillator model nucleons are effectively free: now they are free apart from constraint from belonging to the nuclear string. Also the nuclear binding energy and its behavior can be understood at rather quantitative level in terms of nuclear string model. Nuclear physics would reduce to that for the magnetic body of nucleon, which would mean enormous simplification.

2 IR Regge trajectories

Consider first the mass formula for the hadrons at IR Regge trajectories.

1. There are two options depending on whether the mass squared or mass for hadron and for the flux tubes are assumed to be additive. p-Adic physics would suggest that if the p-adic primes characterizing the flux tubes associated with hadron and hadron proper are different then mass is additive. If the p-adic prime is same, the mass squared is additive.

2. The simplest guess is that the IR stringy spectrum is universal in the sense that m_0 does not depend on hadron at all. This is the case if the flux tubes in question correspond to hadronic space-time sheets characterized by p-adic prime M_{107} in the case of ordinary hadron physics. This would give for the IR contribution to mass the expression

$$m^2 = \sqrt{m_0^2 + nm_1^2} \quad .$$

3. The net mass of hadron results from the contribution of the "core" hadron and the stringy contribution. If mass squared is additive, one obtains $m(H_n) = \sqrt{m^2(H_0) + m_0^2 + nm_1^2}$, where H_0 denotes hadron ground state and H_n its excitation assignable to magnetic flux tube. For heavy hadrons this would give the approximate spectrum

$$m(H_n) \simeq m(H_0) + \frac{m_0^2 + nm_1^2}{2m(H_0)} \quad .$$

The mass unit for the excitations decreases with the mass of the hadron.

4. If mass is additive as one indeed expects since the p-adic primes characterizing heavy quarks are smaller than hadronic p-adic prime, one obtains

$$m(H_n) = m^(H_0) + \sqrt{m_0^2 + nm_1^2} \quad .$$

For $m_0^2 \gg m_1^2$ one has

$$m(H_n) = m^(H_0) + m_0 + n\frac{m_1^2}{2m_0} \quad .$$

If the flux tubes correspond to p-adic prime. This would give linear spectrum which is same for all hadrons.

2.1 Evidence for IR Regge trajectories

There is evidence for this kind of states. The experimental claim (see `http://tinyurl.com/ybq323yy`) of Tatischeff and Tomasi-Gustafsson is that pion is accompanied by pion like states organized on Regge trajectory and having mass 60, 80, 100, 140, 181, 198, 215, 227.5, and 235 MeV. means that besides pion also other pion like states should be there. Similar satellites have been observed for nucleons with ground state mass 934 MeV: the masses of the satellites are 1004, 1044, 1094 MeV. Also the signal cross sections for Higgs to gamma pairs at LHC [C3, C4] suggest the existence of several pion and spion like states, and this was the reason why I decided to again the search for data about this kind of states (I remembered vaguely that Tommaso Dorigo had talked about them but I failed to find the posting). What is their interpretation? One can imagine two explanations which could be also equivalent.

The states could be "infrared" Regge trajectories assignable to magnetic flux tubes of order Compton length of u and d quark (very long and with small string tension) could be the explanation. Hadron mass spectrum would have microstructure. This is something very natural in many-sheeted space-time with the predicted p-adic fractal hierarchy of physics. This conforms with the proposal that all baryons have the satellite states and that they correspond to stringy excitations of magnetic flux tubes assignable to quarks. Similar fine structure for nuclei is predicted for nuclei in nuclear string model [K3]. In fact, the first excited state for ^4He has energy equal to 20 MeV not far from the average energy difference 17.5 MeV for the excited states of pion with energies 198, 215, and 227.5 MeV so that this state might correspond to an excitation of a color magnetic flux tube connecting two nucleons.

This idea should be made more precise. Color magnetic flux tubes would correspond to ordinary Regge trajectories. The magnetic flux tubes in electro-magnetic sense would correspond to IR Regge trajectories.

A further piece of evidence for scaled variants of pion comes from two articles by Eef van Beveren and George Rupp. The first article [C1] is titled *First indications of the existence of* *a 38 MeV light scalar boson* (see http://tinyurl.com/yatlb97o). Second article [C2] has title *Material evidence of a 38 MeV boson (see http://tinyurl.com/yczo7juy).*

The basic observations are following. The rate for the annihilation $e^+ + e^- \rightarrow u\overline{u}$ *assignable to the reaction* $e^+ + e^- \rightarrow \pi^+\pi^-$ *has a small periodic oscillation with a period of* 78 ± 2 *MeV and amplitude of about 5 per cent. The rate for the annihilation* $e^+ + e^- \rightarrow b\bar{b}$*, assignable to the reaction* $e^+ + e^- \rightarrow \Upsilon\pi^+\pi^-$ *has similar oscillatory behavior with a period of* 73 ± 3 *MeV and amplitude about 12.5 per cent. The rate for the annihilation* $p\overline{p} \rightarrow c\overline{c}$ *assignable to the reaction* $e^+ + e^- \rightarrow J/\Psi\pi^+\pi^-$ *has similar oscillatory behavior with period of* 79 ± 5 *MeV and amplitude.75 per cent.*

In these examples universal Regge slope is consistent with the experimental findings and supports additive mass formula and the assignment of IR Regge trajectories to hadronic flux tubes with fixed p-adic length scale. There is also consistency with the experiments of Tatitscheff and Tomasi-Gustafsson.

What does one obtain if one scales up the IR Regge trajectories to the M_{89} *hadron physics [K1]?*

1. *In the case of* M_{89} *pion the mass differences 20 MeV and 40 MeV appearing in the IR Regge trajectories of pion would scale up to 10 GeV and 20 GeV respectively. This would suggest the spectrum of pion like states with masses 115, 125, 145, 165 GeV. What makes this interesting that ATLAS reported during last year evidence for a signal at 115 GeV taken as evidence for Higgs and CDF reported before this signal taken as evidence for Higgs around 145 GeV! 125 GeV is the mass of the most recent Higgs candidate. Could it be that all these reported signals have been genuine signals - not for Higgs- but for* M_{89} *pion and corresponding spion consisting of squark pair and its IR satellites?*

2. *I the case of* M_{89} *hadron physics the naive scaling of the parameters* m_0 *and* m_1 *by factor 512 would scale 38 MeV to 19.5 GeV.*

2.2 New particle having no interpretation in standard model discovered?

A new piece of evidence for IR Regge trajectories years after writing the above text - thanks for Wilhelmus de Wilde for a link. The popular article in Schitechdaily (http://tinyurl.com/wb98u6u) tells about completely unexpected finding by a team led by professors Tacemichi Okui and Kohsaku Tobioka. The decay of longlived kaon K_L *suggests the existence of new longlived particle with quantum numbers of axion - or equivalently pion. The finding is published in Physical Review Letters [C6] (http://tinyurl.com/v2rwh3e). Standard model cannot explain this kind of particle.*

A rough estimate for mass is not far from pion mass. There exists earlier evidence that pion has mass spectrum. Could an excitation of pion be involved?

This is actually not new. The experimental claim [C8] (see http://tinyurl.com/ybq323yy) of Tatischeff and Tomasi-Gustafsson is that pion is accompanied by pion like states organized on Regge trajectory and having mass 60, 80, 100, 140, 181, 198, 215, 227.5, and 235 MeV means that besides pion also other pion like states should be there. Similar satellites have been observed for nucleons with ground state mass 934 MeV: the masses of the satellites are 1004, 1044, 1094 MeV. Also the signal cross sections for Higgs to gamma pairs at LHC suggest the existence of several pion and spion like states, and this was the reason why I decided to again the search for data about this kind of states. Their possible interpretation in TGD framework is discussed in [K1] (http://tinyurl.com/rk7b3dd).

One explanation could be that the states correspond to "infrared Regge trajectories" of pion related to the structure of its magnetic body. Genuine Regge trajectories would have slope of about GeV and now the slope less than 10 per cent of this, which conforms with the ratio of fine structure constant to coupling strength. IR trajectories would be associated with the electromagnetic body and ordinary Regge trajectories with the color magnetic body. One can also consider p-adically scaled down variant of color interactions.

It is interesting to look the situation quantitatively.

1. *It is clear that the masses in question do not fit to a single Regge trajectory. One can however restrict the consideration to Regge trajectory* $M^2 = M_0^2 + nT(\pi)$*, where* $T(\pi)$ *denotes*

string tension. Since the masses obey approximately linear formula one can assume linear approximation $\Delta M^2 = 2M\Delta M$ *at pion mass* $M_1 = m(\pi) = .140$ *GeV and consider the mass squared difference for pion and its predecessor with* $M_0 = .100$ *GeV so that one has* $\Delta M = .040$ *GeV.*

One obtains $\Delta M^2 = M_1^2 - M_0^2 = T(\pi)$. *This would give for the string tension* $T(\pi) = 0.96 \times 10^{-2} T_H \simeq .96 \times 10^{-2}$ GeV^2, *where* $T_H \simeq 1$ GeV^2 *is hadronic string tension assignable to color interactions.*

2. *What about the value of* M_0^2*? In string models it tends to be negative but one can assume that the values of mass squared for physical states are negative. Also in TGD the value is negative in p-adic mass calculations. One must require that several values for pion mass below* $m(\pi)$ *are possible. The formula* $m(\pi)^2 = M_0^2 + nT(\pi)$ *gives formula* $M_0^2 = (m(\pi)^2 - nT(\pi)$. *For* $n(\pi) = 2$, *which looks rather reasonable guess, one has* $M_0^2 = .04$ GeV^2, *which corresponds to* $M_0 = 20$ *MeV.*

There is actually a lot of confusion about the value of hadronic string tension.

1. *In early models hadronic string tension was taken to be 1 GeV. Much smaller values for the string tension smaller by a factor or order* $x \times 10^{-2}$ GeV^2, *x in the range 2-11.1 for mesons and in the range 2.2-4.55 for baryons are however suggested by the study of hadronic spectrum (`http://tinyurl.com/s5jwawx`). Intriguingly, the lower bounds is twice the above estimate* $T(\pi) \simeq .01$ GeV^2 *obtained above. Does this mean that the p-adic prime involved is about 2 times smaller or is this factor due to a numerical factor 1/2 related to the difference between N-S and Ramond type representations of Super-Virasoro algebra.*

2. *The reason for the confusion about string tension could be simple: besides the string tension 1 GeV assignable to color flux tubes there are string tensions assignable to possible scaled down color flux tubes and possible elecromagnetic and even weak flux tubes. Several p-adic length scales could be associated coming in powers of 2 by p-adic length scales hypothesis are involved.*

2.3 Indications for an axion-like state in mass range 1.7 eV from XENON

There was a popular article about bump claimed by XENON group (`https://tinyurl.com/yaqoo2y9`) and suggesting the existence of an axion-like state with mass in the range 1-7 keV. Also Jester (`https://tinyurl.com/y94hcmdj`) discusses the evidence for the claimed bump.

Originally XENON searched evidence for WIMPs - weak interacting very massive particles. They would have made themselves visible via scattering from ZENON nuclei. Nothing was found. Second candidate for dark matter particles are very light axions, which could be produced copiously in Sun. They would not have any detectable effect on heavy XENON atom but they could scatter from electrons and ionize XENON atom. The figure in the posting of Jester summarizes the energy spectrum of the observed ionization events. There is approximately constant background below 30 keV down to 1 keV below which it drops abruptly suggesting a threshold. There are also indications for a peak around 1-2 keV. There is 3.5 sigma excess of events in the range 1-7 keV.

The mass of the dark particle candidate is in the range 1-7 keV. TGD allows to imagine several options but for all of them one would have analog of pion as dark matter candidate.

1. *TGD Universe is fractal and this predicts p-adically scaled variants of hadron physics and electroweak physics. Mass squared scales would come as powers of 2. Mersenne primes and Gaussian Mersennes define especially promising candidates.*

    1. M_{89} *hadron physics [K1] would be scaled up variant of ordinary hadron physics* (M_{107}) *and would make itself visible at LHC. The masses of* M_{89} *hadrons would be scaled up by factor 512 from those of ordinary hadrons. There is evidence for bumps with predicted masses and the original proposal as Higgs did not work and they were forgotten. The mesons of this physics would be dark with* $h_{eff}/h_0 = n \simeq 512$ *so that the Compton lengths would be those of ordinary mesons and they would appear at quantum criticality for what was expected to be de-confiment phase transition.*

2. *There are indications for the particles of these physics having mass scaled by a power of 2 from that for say ordinary meson. Could the particle be a scaled down pion of some kind. There are actually several candidates for scaled variants of pion. There is evidence for so called X boson with mass around 16-17 MeV proposed to be spin 1 bosonof a fifth force [L1, C5] (see `http://arxiv.org/abs/1604.07411`). In TGD framework the identification as pion-like state is more natural and provides new insights on the relation between weak and strong interactions [L1]. There is also quite recent evidence for pionlike exotic particle with mass not far from that of pion showing itself in the decays of long-lived kaon [C6]: there is actually evidence for scaled variants of pion also from earlier experiments [C1, C8]. These pieces of evidence are discussed from TGD point of view in [L5] (`https://tinyurl.com/y9clyf5y`).*

3. *In biologically important length scales there are as many as 4 Gaussian Mersenne $M_{G,n} = (1+i)^n - 1$ with $n = 151, 157, 163, 167$ defining p-adic length scales in the range 10 nm (cell membrane thickness) and 2.5 μm (cell nucleus size) and might involve scaled variants of hadron and electroweak physics..*

   p-Adic length scale hypothesis also allows the possibility of p-adically scaled variants of leptons and quarks with mass scaled down or up by a power of 2 and there are some indications for this kind of states. For instance, the claimed axionlike state could be a scaled down pion as bound state of scaled down quarks.

4. *Heavy ion collisions near Coulomb wall gave already around seventies indicatons for a pion-like state of mass 1 MeV decaying to electron positron pair. TGD inspred interpretation [K5] was in terms of electropion identified as bound state of color octet electrons. TGD view about color indeed allows colored excitation of leptons since color is not spin-like but angular momentum like quantum number assignable to CP_2 color partial waves. Later evidence for muon and tau analogs of this state has emerged. The decay widths of weak bosons do not allow color octet ptons in MeV scale and this forced the interpretation that they are dark in some sense and appear ony at quantum criticality - now at collision energies around Coulomb wall.*

   Leptopion could also be color bound state of quark and antiquark. As noticed, there is evidence for several bound states of this kind.

5. *The TGD based model for "cold fusion" [K2] [L2, L4] led to a new view about nuclear physics [K4] in which dark nuclei appear also as intermediate states of ordinary nuclear reactions. Dark nuclei as nuclear string with distance of about electron Compton length would be crucial for "cold fusion".*

   What is remarkable is they would have scaled down dark nuclear binding energies in few keV range. This because the binding energy scale of ordinary nuclear physics about 7 MeV would be scaled down by the ratio $2^{-10} \simeq 10^{-3}$ of the p-adic length scales of proton and electron labelled by $k = 107$ and $k = 127$ to a value about 7 keV, which represents the upper end of the range 1-7 keV. There is also evidence that X ray emission with energies of this order of magnitude from Sun affects nuclear decay rates at Earth.

   The pion-like particles could be indeed dark in TGD sense (ordinary particle but with $h_{eff} = n \times h_0 > h$). Could the axion candidate be scaled down variant of electro-pion with mass 1 MeV with $k = 127$: if the mass of electro-pion scales down like the nuclear binding energy, the scaling $k = 107 \rightarrow 127$ would take the mass of electro-pion to 1 keV. Also scaled down pion formed by quarks could be in question.

2.4 New view about nuclear physics provided by IR Regge trajectories

This picture led to an unexpected development in the nuclear string model that I constructed more than 2 decades ago [K3] (`http://tinyurl.com/rc4umgv`). The key assumption - very natural in TGD, where monopole flux tubes prevail in all scales - is that nucleons form nuclear strings. Nuclear radius satisfies $R \propto A^{1/3}$, A mass number, so that nuclei have constant density in good approximation (`http://tinyurl.com/rtc9jdh`) so that the flux tube would will the entire volume. I have proposed that also blackholes and other final states of stars are flux tube spaghettis of this kind [L3].

The basic objection against the model is that the harmonic oscillator model for nuclear works surprisingly well. The justification for this model is that one can reasonably well describe nucleus as motion of nucleons in an effective nuclear potential, which in linearization becomes harmonic. Nucleons themselves have no mutual interactions in this approximation.

Could nuclear string model allow to understand harmonic oscillator model of nuclei as an approximation?

1. *It is best to start from the problems of the harmonic oscillator model. The first problem is that the description of nuclear binding energies is poorly understood. For instance, nuclear binding energies have scale measured in MeVs. The scale is much smaller than energy scale of hadronic strong interactions for which pion mass is a natural scale. Rather remarkably, the ratio of the scales is roughly the ratio of fine structure constant to color coupling strength. Could one imagine that electromagnetic interactions somehow determine the energy scale of nuclear binding energies and excitations?*

2. *As noticed, also nucleons are reported to have IR Regge trajectories. The first guess is that the trajectories have same string tension as in the case of pion. TGD suggests a model of nuclei as three nucleons connected by color flux tubes characterized by hadronic string tension $T_H \simeq 1$ GeV^2. Besides color flux tubes hadrons are expected to have also electromagnetic and perhaps also weak flux tubes with a smaller value of string tension. Em flux tubes should give a contribution to the energy, which is of the order of Coulomb energy of nucleon about $\alpha/L^c(p) \simeq 7.5$ MeV. Intriguingly, this is of same order of magnitude as nuclear binding energy: could IR Regge trajectories correspond to em interaction so that the spectrum of nuclear binding energies and excitation energies would be determined by electromagnetic interactions?*

3. *If the value of p-adic prime $p \simeq 2^k$ corresponds to $k = 113$ assumed to characterize nuclei in nuclear string model, hadronic string tension would be scaled down by factor $2^{107-113} = 1/64$ to $T_H/64$, which corresponds to a mass of 125 MeV, which is somewhat larger than the value about 96 MeV obtained from the above estimate. For $\Delta M^2 \simeq 2M\Delta M = nT(\pi)$ this gives $\Delta M \simeq 7.8$ MeV for $\Delta n = 1$, which corresponds to the maximal nuclear binding energy per nucleon do be denoted by e_B. This string tension is naturally assignable to em flux tubes assignable nuclei as 3 -quark states. Color flux tubes would be responsible for the hadronic string tension T_H.*

   Remark: *Flux tubes carry all classical gauge fields, which are induced from the spinor connection of CP_2 but it seems that one can assign to given flux tube quanta of particular interaction.*

4. *In the case of baryons one would have 3 color flux tubes and and 3 em flux tubes. For large mass excitations one would have in linear approximation for M^2 harmonic oscillator spectrum! Could linearization of mass squared formula replace linearization of effective potential function leading to harmonic oscillator model? The dimension $D = 3$ for the nuclear harmonic oscillators would correspond to the fact that nucleons consist of 3 quarks. The free nucleon approximation would have simple justification: in good approximation one can treat the nucleons of nuclear strings as independent particles!*

5. *Could the nuclear e_B correspond to a reduction of the value of n for the IR Regge trajectory of free nucleon? The mass squared formula for IR trajectory would be $M^2 = M_0^2(N)+nT(\pi)$. This mechanism requires that the one has $M_0 \leq m(N)$ so that one has $n > 0$ for nucleons. For $\Delta n = -1$ one has $\Delta M = T(\pi)/2m(N) \simeq 7.8$ MeV.*

Could one understand the qualitative features of the nuclear binding energy spectrum on basis of this picture?

1. *e_B is below 3 MeV for nuclei lighter than ^4He and has tendency to increase up to Fe. For the most abundant stable isotope of Fe with (Z,A)=(26,56) it is 8.78 MeV. For heavier nuclei neutron number N increases and e_B starts to decrease.*

2. *For D one must have $\Delta n = 0$ and p-n pairing would be somehow responsible for the binding. For T the total binding energy is 8.478 MeV and could involve $\Delta n = -1$ for one nucleon.*

^3He has total binding energy 7.715 MeV and also now one nucleon could have $\Delta n = -1$. ^4He has $e_B = 7.07$ eV. This suggests that p-n pairing causes reduction $\Delta n = -1$ for all nucleons in ^4He units proposed to be building bricks of nuclei.

For nuclei with odd Z and nuclei there are would be also deuteron sub-unit present and also $|A - Z|$ unpaired neutrons. This would reduce the binding energy. The prediction is that for nuclei with N=Z with even Z the binding energy exceeds that for ^4He. For heavier nuclei this can happen also for odd Z and also for N different from Z.

3. *The pairing of to D subunits should be rise to binding energy 2.223 MeV per deuteron unit. Why the value is so small? Could deuteron unit correspond to a smaller string tension: perhaps corresponding to $k = 9$ instead of $k = 6$ as the ratio of $^4He/D$ binding energies per nucleon would suggest. The ratio of the maximal binding energy 8.7892 MeV per nucleon to deuteron binding energy is rather precisely 8, which supports the interpretation.*

4. *What causes the increase of e_B up to Fe? Attractive potential energy does not look like an elegant interpretation in TGD framework. Some repulsive interaction should reduce the binding energy per nucleon for lighter nuclei than Fe from the value 8.8 MeV. The increase from ^4He to Fe is about 1 MeV. Why does this repulsive contribution decrease up to Fe? Does it start to increase after that or is the presence of surplus neutrons the reason for the reduction? Or are both mechanisms involved?*

   The IR Regge trajectories considered are not the only ones as already the findings of Tatischeff and Tomasi-Gustafsson suggest and there might be trajectories with smaller string tension. The value of $k = 9$ with string tension $T(\pi)/8$ assignable to D, which corresponds to a e_B of about 1 MeV and this is roughly the total variation of the e_B from ^4He to Fe. Could both $k = 6$ and $k = 9$ flux tubes be present for given nucleon. Could the reduction of n for $k = 9$ flux tubes take place also for ^4He units as nuclei become heavier. What happens in nuclei heavier than Fe? Could the increase of neutron surplus reduce e_B?

   Nuclear string has tension and reduces total binding energy e_B a contribution proportional to the length L of the string. Constant density for nuclei gives $R = r_0 A^{1/3}$, $r_0 = 1.2$ fm for the nuclear radius and $L \propto A \propto R^3$ for L. From this the contribution of string energy per nucleon is proportion to $L/A = constant$. The 20 per cent variation of r_0 is due the variation of e_B and cannot explain the variation of e_B.

To sum up, nuclear string model would reduce nuclear physics that for the magnetic body of the nucleon - obviously an enormous simplification.

REFERENCES

Particle and Nuclear Physics

[C1] *Rupp G Beveren van E. First indications of the existence of a 38 MeV light scalar boson.* Available at: `http://arxiv.org/pdf/1102.1863v2.pdf`, *2011.*

[C2] *Rupp G Beveren van E. Material evidence of a 38 MeV boson.* Available at: `http://arxiv.org/pdf/1202.1739.pdf`, *2011.*

[C3] *ATLAS collaboration. Search for the Standard Model Higgs boson in the diphoton decay channel with with 4.9 fb^1 of pp collisions at $\sqrt{s} = 7$ TeV.* Available at: `http://cdsweb.cern.ch/record/1406356/files/ATLAS-CONF-2011-161.pdf`, *2011.*

[C4] *CMS collaboration. Search for a Higgs boson decaying into two photons in the CMS detector.* Available at: `http://cdsweb.cern.ch/record/1406346/files/HIG-11-030-pas.pdf`, *2011.*

[C5] *Feng JL et al. Evidence for a protophobic fifth force from ^8be nuclear transitions.* Available at: `http://arxiv.org/abs/1604.07411`, *2015.*

[C6] *Kitahara T et al. New Physics Implications of Recent Search for $K_L \to \pi_0 \nu \overline{\nu}$ at KOTO.* Phys Rev Lett. Available at:https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.124.071801, *124(071801), 2020.*

[C7] *Krasznahorkay A et al. Observation of anomalous internal pair creation in 8be: A possible indication of a light, neutral boson.* Available at: https://arxiv.org/abs/1504.0152, *2016.*

[C8] *Tomasi-Gustafsson E Taticheff B. Search for low-mass exotic mesonic structures: II. Attempts to understand the experimental results.* Part Nucl Lett, *5(5):709–713, 2008.*

Books related to TGD

[K1] *Pitkänen M. New Particle Physics Predicted by TGD: Part I. In* p-Adic Physics. Available at: *http://tgdtheory.fi/pdfpool/mass4.pdf, 2006.*

[K2] *Pitkänen M. Cold Fusion Again. In* Hyper-finite Factors and Dark Matter Hierarchy: Part II. Available at: *http://tgdtheory.fi/pdfpool/coldfusionagain.pdf, 2019.*

[K3] *Pitkänen M. Nuclear String Hypothesis. In* Hyper-finite Factors and Dark Matter Hierarchy: Part II. Available at: *http://tgdtheory.fi/pdfpool/nuclstring.pdf, 2019.*

[K4] *Pitkänen M. Solar Metallicity Problem from TGD Perspective.* Available at: http://tgdtheory.fi/pdfpool/darkcore.pdf, *2019.*

[K5] *Pitkänen M. The Recent Status of Lepto-hadron Hypothesis. In* Hyper-finite Factors and Dark Matter Hierarchy: Part II. Available at: *http://tgdtheory.fi/pdfpool/leptc.pdf, 2019.*

Articles about TGD

[L1] *Pitkänen M. X boson as evidence for nuclear string model.* Available at: *http://tgdtheory.fi/public_html/articles/Xboson.pdf, 2016.*

[L2] *Pitkänen M. Cold fusion, low energy nuclear reactions, or dark nuclear synthesis?* Available at: http://tgdtheory.fi/public_html/articles/krivit.pdf, *2017.*

[L3] *Pitkänen M. Cosmic string model for the formation of galaxies and stars.* Available at: http://tgdtheory.fi/public_html/articles/galaxystars.pdf, *2019.*

[L4] *Pitkänen M. Could TGD provide new solutions to the energy problem?* Available at: http://tgdtheory.fi/public_html/articles/proposal.pdf, *2020.*

[L5] *Pitkänen M. Exotic pion like states as "infra-red" Regge Trajectories and a new view about nuclear physics.* Available at: http://tgdtheory.fi/public_html/articles/pionlikestate.pdf, *2020.*