Explanation for the soft photon excess in hadron production

M. Pitkänen
Email: matpitka@luukku.com.
`http://tgd.wippiespace.com/public_html/`.

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1 Introduction

There is quite a recent article entitled Study of the Dependence of Direct Soft Photon Production on the Jet Characteristics in Hadronic Z^0 Decays discussing one particular manifestation of an anomaly of hadron physics known for two decades: the soft photon production rate in hadronic reactions is by an averge factor of about four higher than expected. In the article soft photons assignable to the decays of Z^0 to quark-antiquark pairs. This anomaly has not reached the attention of particle physics which seems to be the fate of anomalies quite generally nowadays: large extra dimensions and blackholes at LHC are much more sexy topics of study than the anomalies about which both existing and speculative theories must remain silent.

TGD leads to an explanation of anomaly in terms of the basic differences between TGD and QCD.

1. The first difference is due to induced gauge field concept: both classical color gauge fields and the U(1) part of electromagnetic field are proportional to induced Kähler form. Second difference is topological field quantization meaning that electric and magnetic fluxes are associated with flux tubes. Taken together this means that for neutral hadrons color flux tubes and electric flux tubes can be and will be assumed to be one and same thing. In the case of charged hadrons the em flux tubes must connect different hadrons: this is essential for understanding why neutral hadrons seem to contribute much more effectively to the brehmstrahlung than charged hadrons- which is just the opposite for the prediction of hadronic inner bremsstrahlung model in which only charged hadrons contribute. Now all both sea and valence quarks of neutral hadrons contribute but in the case of charged hadrons only valence quarks do so.

2. Sea quarks of neutral hadrons seem to give the largest contribution to bremsstrahlung. p-Adic length scale hypothesis predicting that quarks can appear in several mass scales represents the third difference and the experimental findings suggest that sea quarks are by a factor of 1/2 lighter than valence quarks implying that brehmstrahlung for given sea quark is by a factor 4 more intense than for corresponding valence quark.

2 Soft photon anomaly

The general observations are summarized by the abstract of the paper.

An analysis of the direct soft photon production rate as a function of the par ent jet characteristics is presented, based on hadronic events collected by the DELPHI experiment at LEP1. The dependences of the photon rates on the jet kinematic characteristics (momentum, mass, etc.) and on the jet charged, neutral and total hadron multiplicities are reported. Up to a scale factor of about four, which characterizes the overall value of the soft photon excess, a similarity of the observed soft photon behaviour to that of the inner hadronic bremsstrahlung predictions is found for the momentum, mass, and jet charged multiplicity dependences. However for the dependence of the soft photon rate on the jet neutral and total hadron multiplicities a prominent difference is found for the observed soft photon signal as compared to the expected bremsstrahlung from final state hadrons. The observed linear increase of the soft photon production rate with the jet total hadron multiplicity and its strong dependence on the jet neutral multiplicity suggest that the rate is proportional to the number of quark *pairs produced in the fragmentation process, with the neutral pairs being more effectively radiating than the charged ones.*

I try to abstract the essentials of the article.

1. One considers soft photon production in kinematic range .2 GeV$< E <$ 1 GeV, $p_T <$ .08 GeV, where p_T is photon transverse momentum with respect to the parent jet direction. The soft photon excess is associated with hadron production only and does not appear in leptonic sector. As one subtracts the photon yield due to the decays of hadrons (mainly neutral pions), one finds that what remains is on the average 4 times larger than the photon yield by inner hadronic brehmstrahlung, which means bremsstrahlung by charged final state hadrons. This suggests that the description in terms of charged hadron bremstrahlung is not correct and one must go to quark level.

2. Up to the scale factor with average value four, the dependence of soft photon production on jet momentum, mass, and jet charged multiplicity is consistent with the inner hadronic bremsstrahlung predictions.

3. The dependence of the soft photon rate on jet neural and total hadron multiplicities differs from the expected bremsstrahlung from final state hadons. The linear increase of the rate with the jet total hadron multiplicity and strong dependence on the jet neutral multiplicity does not conform with internal hadron bremsstrahlung prediction which suggests that the anomalous soft photon production is proportional to the number of neutral quark pairs giving rise to neutral mesons. For some reason neutral pairs would thus radiate more effectively than the charged ones. Therefore the hypothesis that sea quarks alone are responsible for anomalous brehmstrahlung cannot hold true as such.

The article discusses the data and also the models that has been proposed. Incoherent production of photons by quarks predict satisfactorily the linear dependence of total intensity of bremmstrahling on total number of jet particle if the number of quarks in jet is assumed to be proportional to the number jet particles (see Fig. 7 of [1]). The model cannot however explain the deviations from the model based on charged hadron inner bremmstrahling: the problems are produced by the sensitive dependence on the number of neutral hadrons (see Fig. 6 of [1]).

The models assuming that jet acts as a coherent structure fail also and it is proposed that somehow neutral quark pairs must act as electric dipoles generating dipole radiation at low energies. The dipole moments assignable to neutral quark pairs $U\overline{U}$ and $D\overline{D}$. $U\overline{D}$, $D\overline{U}$ with given respect to center of mass are proportional to the difference of the quark charges $4/3, 2/3, 1/3, -1/3$ so that one might argue that the dipole radiation from neutral pairs is by a factor 16 *resp.* 4 stronger than from charged pair and authors argue that this might be part of the explanation. This would suggest that the excess radiation comes from dipole radiation from quarks inside neutral hadrons. The dipole radiation intensity is expected to be weaker than monopole radiation by a factor $1/\lambda^2$ roughly so that this line of thought does not look promising.

3 TGD based explanation of the anomaly

Could one find an explanation for the anomaly in TGD framework? The following model finds its inspiration from TGD inspired models for two other anomalies.

1. The first model explains the reported deviation of the charge radius of muonic hydrogen from the predicted radius [**?**]. Key role is played by the electric flux tubes associated with quarks and having size scale of order quark Compton radius and therefore extending up to the Bohr radius of muonic hydrogen in the case of u quark.

2. Second model explains the observed anomalous behavior of the quark-gluon plasma [**?**]. What is observed is almost perfect fluid behavior instead of gas like behavior reflecting itself as small viscosity to entropy ratio. The findings suggest coherence in rather long length scales and also existence of string like objects. Color magnetic (or color electric or both) flux tubes containing quarks and antiquarks are proposed as a space-time correlate for the quark gluon plasma.

Essential element of the model is also the prediction that the extremals of Kähler action have hydrodynamic interpretation and that preferred extremals describe perfect fluids [?].

Electric flux tubes as basic objects provide a promising candidate for the counterparts of dipoles now. In the case of neutral hadrons color flux tubes and em flux tubes can be one and the same thing. In the case of charged hadrons this cannot be the case and em flux tubes connect oppositely charged hadrons. This could explain the difference between neutral and charged hadrons. If the production amplitude is coherent sum over amplitudes for quarks and antiquarks inside hadron and if also sea quarks contribute, only neutral hadrons would contribute to the brehmstrahlung at long wave length limit and the excess would correspond to the contribution of sea quarks insided neutral hadrons.

A more precise argument goes as follows.

1. The first guess would be that the production amplitude of photons is sum over incoherent contributions of valence and sea quarks. This cannot be the case since both charged and neutral hadrons would contribute equally.

2. Quantum classical correspondence requires some space-time correlate for the classical electric fields. In TGD electric flux is carred by flux tubes and this suggests that flux tubes serve as this correlate. These flux tubes must begin from quark and end to an anti-quark of opposite charge. One must distinguish between the flux tubes assignable to electric field and gluon field. The flux tubes connecting charged hadrons cannot correspond to color flux tubes. For electromagnetically neutral hadrons color flux tubes and em flux tubes can be one and the same thing: this conforms with the fact that classical color fields are proportional to the induced Kähler form as is also the U(1) part of the classical em field. This will be assumed so that only the flux tubes associated with neutral quark pairs (hadrons) can contribute to the coherent dipole radiation. In particular, the sea quarks at these flux tubes can contribute. The flux tubes connecting different hadrons of the final state would not carry color gauge flux making possible materialization of sea quarks from vacuum. If the sea quarks at flux electric flux tubes are responsible for the anomaly, the excess is present only for the neutral hadrons.

3. Low energy phenomenon is in question. This means that the description of quark pairs as coherently scattering pairs of charges (dipole approximation is not necessary) should make sense only when the photon wavelength is longer than the size scale of the dipole: the relevant length scale could be expressed in terms of the distance d between the quark and antiquark of the pair. The criterion can be written as $\lambda \geq xd/2$, where x is a numerical constant of order unity whose value, which should be fixed by the precise criterion of coherence length which should be few wave lengths. For higher energies description as incoherently radiating quarks should be a good approximation. The quark and antiquark with opposite charges can belong to the same to-be-hadron or different charged to-be-hadrons. In the first case there distance remainsmore or leass the same during fragmentation process. In the latter case it increases. In the first case the treatment of the flux tube as a coherently radiating unit makes sense for wavelengths $\lambda \geq xd/2$.

4. The assumption that the bremsstrahling amplitude is a coherent sum over the amplitudes for the quarks and antiquarks inside to-be-hadron gives a heuristic estimate for the radiation power. Consider first the situation in which the ends of the flux tube contain quark and antiquark. Denoting by A value of the photon emission amplitude for free quark, this would give amplitude squared $|A|^2|(1-exp(exp(ik\cdot d))|^2$, whose maximum value is by a factor 4 larger than that for a single particle. The maxima would correspond to $\lambda = 2dcos(\theta)/(2n+1)$, where θ is the angle between the wave vector of photon and d. $n = 0$ would correspond to $\lambda = 2dcos(\theta)$. For given value of λ one would obtain a diffraction pattern with maxima at $cos(\theta) = (n+1/2)\lambda/d$. This cannot however give large enough radiation power: the angle average of the factor $|1-exp(i\phi)|^2$ is 2 instead of 4 and corresponds to the incoherent sum of production rates.

5. More complex model would assume that the flux tubes contain quarks and antiquarks also in their interior so that one would have coherent sum of a larger number of amplitudes which would give diffraction conditions for λ analogous to those above. In this case the maximum of the diffractive factor would be N^2, where $N = 2n$ is total number of quarks and antiquarks for mesons. For neutral baryons flux tube would contain odd number of quarks. The angle average would be in this case be equal to N. If all quarks and antiquarks inside the flux tube appear as

valence quarks of the final state hadron, one obtains just the result predicted by the independent quark model. Therefore the only possible interpretation for additional contribution is in terms of sea quarks.

Consider now a more detailed quantitative estimate. Assume that the emission inside flux tubes is incoherent. Assume that the sea quarks with charges ±2/3 and ±1/3 appear with same probablities and this is true also for valence quarks for energetic enough jets. Therefore the average quark charge squared is $\langle Q_q^2\rangle = 5/18$.

1. The model based on incoherent bremmstrahlung on quarks mentioned in [1] assumes that the number of partons in jet is proportional to the hadrons in the jet:

$$R \propto (N_{sea,neu} + N_{val,neu} + N_{sea,ch} + N_{val,ch}) \propto N_{tot} \ . \tag{3.1}$$

   According to [1] the model explains the excess as a a linear function of jet total hadron multiplicity N_{tot} (see Fig. 7 of [1]). This behavior is obtained if the production rate satisifies

$$R \propto (N_{sea,neu} + N_{val,neu} + N_{sea,ch} + N_{val,ch})\langle Q_q^2\rangle \ .$$

   One however considers inclusive distribution meaning integration over the various combinations (N_{neu}, N_{ch}) and also other jet variables weighted by differential cross section so that similar result is obtained under much weaker conditions.

2. Indeed, if sea quarks and valence quarks have same p-adic mass scale, one has

$$R \propto (N_{sea,neu} + N_{val,neu} + N_{val,ch})\langle Q_q^2\rangle \tag{3.2}$$

   p-Adic length cale hypothesis however allows the sea quarks to be considerably lighter than valence quarks so that their contribution to the brehmstrahlung can be larger. This would mean the proportionality

$$\begin{aligned} R &\propto (xN_{sea,neu} + N_{val,neu} + N_{val,ch})\langle Q_q^2\rangle \ , \\ x &= (\frac{m_{val}}{m_{sea}})^2 \ . \end{aligned} \tag{3.3}$$

   p-Adic length scale hypothesis predicts that x is power of two: $x = 2^k$, $k \in \{0, 1, 2, ..\}$.

   The above constraint gives rise to the consistency condition

$$\langle R\rangle \propto \langle xN_{sea,neu} + N_{val,neu} + N_{val,ch}\rangle \propto N_{tot} \ . \tag{3.4}$$

3. The data [1] support the the appearence of $N_{sea,neu}$ in the rate.
   (a) The dependence on xN_{sea} could explain the exceptionally large deviation (by factor of 8, see Fig. 5 of [1]) from hadronic inner bremsstrahlung for smallest charged multiplicity meaning large number sea quarks assignable to neutral hadrons. For large values of charged multiplicity the contribution of $xN_{sea,neu} + N_{val,neu}$ becomes small and the one should obtain approximate factor 4.
   (b) The linear fit of the distribution in the form $R = a_1N_{ch} + a_2N_{neu}$ gives $a_2/a_1 \simeq 6$ so that the dependence on neutral multiplicity is six time stronger than on charged multiplicity (see table 6 of [1]). This suggests that $xN_{sea,neu}$ dominates in the formula. The first possibility is that the parameter $r = N_{sea,neu}/N_{val,neu}$ is considerably larger than unity. Second possibility is that one has $x > 1$.

(c) The ratio of signal to bremsstrahlung prediction increases rapidly as a function of neutral jet multiplicity n_{neu} and increases from 2.5 to about 16 in the range $[0, 6]$ for the neutral multiplicity (see Fig. 6 of [1]). This conforms with the dependence on $N_{sea,neu}$. Also the dependence of the signal to bremsstralung ratio on the core charged multiplicity is non-trivial being largest for vanishing core charge and decreasing with core n_{ch}. Also this confirms with the proposal.

To sum up, the model depends crucially on the notion of induced gauge field and proportionality of the classical color fields and U(1) part of em field to the induced Kähler form and therefore the anomaly gives support for the basic prediction of TGD distinguishing it from QCD. It is possible that two times lighter p-adic mass scale for sea quarks than for valence quarks is needed in order to explain the findings.

References

[1] Delphi Collaboration (2010), *Study of the Dependence of Direct Soft Photon Production on the Jet Characteristics in Hadronic Z^0 Decays.* CERNPHEP/2009-014. arXiv:1004.1587v1 [hep-ex]. `http://arxiv.org/PS_cache/arxiv/pdf/1004/1004.1587v1.pdf`.