National Academy of Sciences of Belarus

Joint Institute for Power and Nuclear Research – Sosny

Ideas for Modernization of Monte-Carlo Generators

(New QCD and QED Phenomena for CLIC)

V. Kuvshinov, M. Galynskii, V. Gilewsky,
V. Shaparau

V.kuvshinov@sosny.bas-net.by

CLIC Workshop 2013
January 28-February 02, 2013

CERN
SWITZERLAND

QCD. Experimental search for squeezed and entangled states inside jets (modernization of PYTHIA)

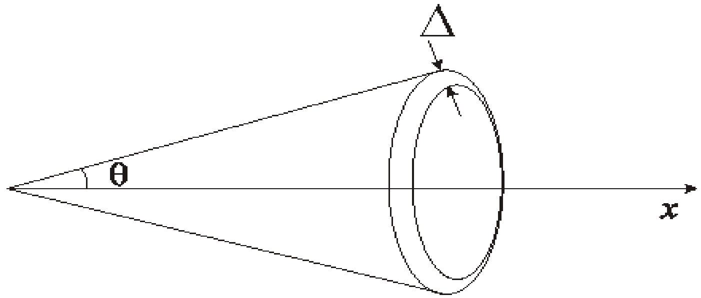
V.Kuvshinov, V. Shaparau

--Both perturbative and non-perturbative stages of the jet evolution are important with sub-Poissonian MD at NPB stage (Kokoulina, Kuvshinov)

--Gluon multiplicity distribution at the end of the perturbative cascade in the range of the small transverse momenta (thin ring of jet) is Poissonian (Lupia, Ochs, Wosiek). MD for the whole jet at the end of the perturbative cascade can be represented as a combination of Poissonian distributions (coherent states)

--Gluon coherent states under the influence of the nonlinearities of QCD Hamiltonian transform into the squeezed and entangled states with sub-Poissonian MD (Kuvshinov, Shaparau)

--In the thin jet ring we obtain gluon two-mode squeezed and entangled states



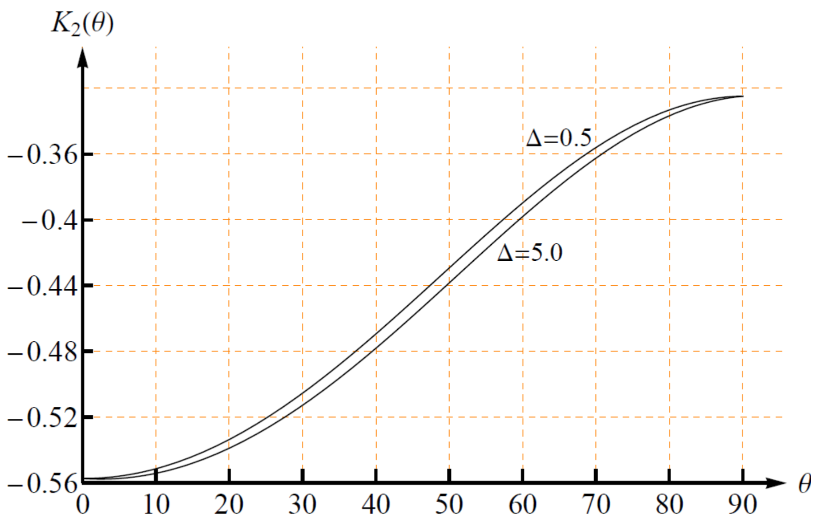
--The emergence of such states becomes is possible due to the four-gluon self-interaction, the three-gluon self-interaction does not lead to squeezing effect

--Two-mode gluon squeezed and entangled states with two different colours can lead to quark-antiquark-entangled states, role of which could be important for of the confinement phenomenon.

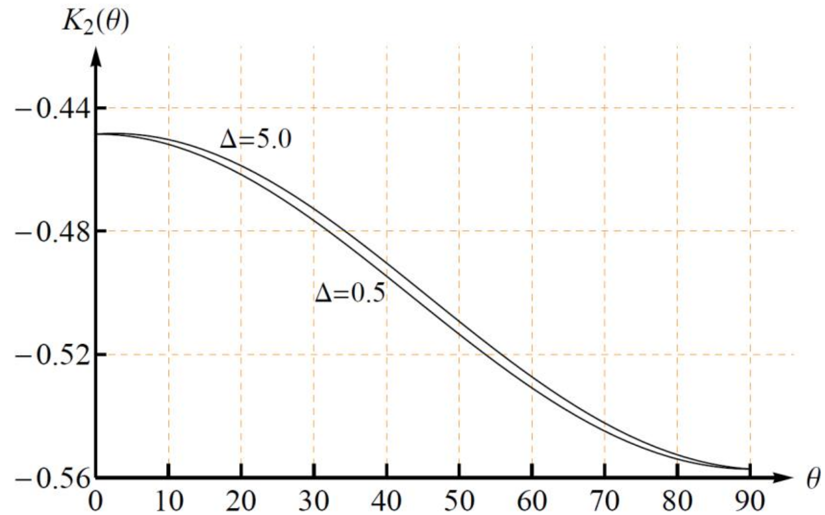
--Within local parton-hadron duality we estimate nonperturbative contribution of the gluon squeezed states to the pion correlation functions in the jet narrow ring (Kuvshinov, Shaparau)

$$K_{(2)}(\theta, \Delta) = \frac{C_{(2)}(\theta, \theta - \Delta)}{\rho_1(\theta)\rho_1(\theta - \Delta)}$$

$$K_{(2)}(\theta,\Delta) = -\sum_{l=1}^{3}\sum_{b=1}^{8}\omega_l^b M_1(\theta,\Delta) \Big/ \left\{ \sum_{l=1}^{3}\sum_{b=1}^{8}\omega_l^b \mid \alpha_l^b \mid^4 - 2\sum_{l=1}^{3}\sum_{b=1}^{8}\omega_l^b \mid \alpha_l^b \mid^2 M_1(\theta,\Delta) + \sum_{l=1}^{3}\sum_{b=1}^{8}\omega_l^b M_2(\theta,\Delta) \right\}$$



Effect of the pion antibunching with corresponding sub-poissonian distribution



Effect of the pion bunching with corresponding super-poissonian distribution

Proposal: Modernization of Monte-Carlo generators (in particular, PYTHIA) taking into account new non-perturbative (squeezed and entangled) states of gluons and quarks

Search of experimental signals (in particular, specific behaviour of correlation functions and moments) characteristic for the new hadron states (pions) in jet events

References

1. S. Lupia, W. Ochs, J. Wosiek, *Nucl. Phys.* **B540**, 405 (1999).
2. D. F. Walls, G. J. Milburn, ***Quantum Optics***, Springer-Verlag, NY., USA, 1995.
3. E. S. Kokoulina, V. I. Kuvshinov, *Acta Phys. Pol.* **B13**, 553 (1982).
4. V. I. Kuvshinov, V. A. Shaparau, *Acta Phys. Pol.* **B30**, 59 (1999).
5. V.I. Kuvshinov, V.A. Shaparau, *Phys. Atom. Nucl.* **65,** 309 (2002) .
6. V. I. Kuvshinov, V. A. Shaparau, *Acta Phys. Pol.* **B35**, 443 (2004).
7. V.I. Kuvshinov, V.A. Shaparau, Proceedings of the 18th seminar "Nonlinear Phenomena in Complex Systems" (Minsk, May 17-20, 2011), Minsk, Vol.18, 2011, pp. 210 – 215.

QED. Modernization of generator o'mega
by the advantages of diagonal spin bases in
which spin 4-vectors of fermions are expressed via their 4-momenta

M.Galynskii

- --Generator O'Mega is used for calculation of amplitudes for different diagramms in quantum electrodinemics

- --New techniques for calculation of matrix elements in QED -"Diagonal Spin Basis" (DSB)

Diagonal spin basis and calculation of processes involving polarized particles

- --New techniques for calculation of matrix elements in QED -"Diagonal Spin Basis" (DSB)
- --Calculation of differential cross sections of processes when polarization of particles is to be taken into account
- --Spin 4-vectors of in-and out-fermions are expressed just in terms of their 4-momenta
- In DSB Little Lorentz group common for the initial and final states is being realized
- Spin operators of in-and out-particles coincidence, allowing to separate the spin-flip and non spin-flip interactions
- -In contrast to methods of CALKUL-group etc, it is valid both for massive and for massless fermions Formalism was applied to the following processes:
- 1) Möller's and Bhabha's bremsstrahlung $(e^{\pm}e^{-} \to e^{\pm}e^{-}\gamma)$
- in the ultrarelativistic (massless) limit when initial particles and photon are helicity polarized;
- 2) back Compton scattering of photons of intensive circularly polarized laser wave focused on a beam $(e + n\gamma_0 \to e + \gamma)$
- of longitudinally polarized ultrarelativistic electrons ; 3) $e^{+}e^{-}$ -pair production
- by a hard photon in simultaneous collision with several laser beam photons ($\gamma + n\gamma_0 \to e^{+} + e^{-}$);
- 4) Bethe-Heitler process in the case of a linearly polarized photon emission by an electron with
- account for proton recoil and form factors; 5) the reaction $ep \to ep\gamma$ with proton polarizability being $e^{-}e^{-} \to 3\gamma$

O'Mega: An Optimizing Matrix Element Generator (arXiv:hep-ph/0102195v1).

O'Mega generates now is the most efficient code currently available for tree-level scattering amplitudes in the Standard Model and its extensions. We offer upgrades generator O'Mega by taking advantage of the diagonal spin basis in which spin 4-vectors of fermions are expressed through their four-momenta.

In DSB, the spin 4-vectors s_1 and s_2 of fermions with 4-momenta q_1 (before the interaction) and q_2 (after it) have the form

$$s_1 = -\frac{(v_1 v_2)v_1 - v_2}{\sqrt{(v_1 v_2)^2 - 1}}\,, \quad s_2 = \frac{(v_1 v_2)v_2 - v_1}{\sqrt{(v_1 v_2)^2 - 1}}\,,$$

where $v_1 = q_1 / m$ and $v_2 = q_2 / m$. Obviously, the spin 4-vectors in DSB satisfy ordinary conditions and are invariant under the transformations of the little group of Lorentz group (little Wigner group) $L_{q_1 q_2}$ common to particles with 4-momenta q_1 and q_2. The matrix elements for QED processes reduces to evaluating the trace of the product of Dirac operators

$$M^{\pm\delta,\delta} = \overline{u}^{\pm\delta}(q_2) Q u^{\delta}(q_1) = Tr(P_{21}^{\pm\delta,\delta} Q)\,,\; P_{21}^{\pm\delta,\delta} = u^{\delta}(q_1)\,\overline{u}^{\pm\delta}(q_2)$$

The explicit form of the operators $P_{21}^{\pm\delta,\delta}$ in DSB is given by

$$P_{21}^{\delta,\delta} = (\hat{q}_1 + m)\hat{b}_\delta \hat{b}_0\, \hat{b}_\delta^* / 4\,, P_{21}^{-\delta,\delta} = \delta(\hat{q}_1 + m)\, \hat{b}_\delta\, \hat{b}_3 / 2\,,$$

$$(b_1)_\mu = \varepsilon_{\mu\nu\kappa\sigma} b_0^\nu b_3^\kappa b_2^\sigma\,, (b_2)_\mu = \varepsilon_{\mu\nu\kappa\sigma} q_1^\nu q_2^\kappa r^\sigma / \rho, b_3 = q_- / \sqrt{-q_-^2}\,, b_0 = q_+ / \sqrt{q_+^2}\,,$$

The fundamental fact that the Lorentz little group common to particles with momenta q_1 and q_2 is realized in the DSB leads to a number of remarkable consequences. First, in this basis particles with 4-momenta q_1 (before the interaction) and q_2 after the interaction) have the same spin operators, which allows the covariant separation of the interactions with and without change of the spin states of the particles involving in the reaction, making it possible to trace the dynamics of the spin interaction.

Second, in the DSB the mathematical structure of the amplitudes is maximally simplified, owing to the coincidence of the particle spin operators, the separation of Wigner rotations from the amplitudes, and the decrease in the number of various scalar products of 4-vectors which characterize the reaction. Third, in the DSB the spin states of massless particless coincide up to a sign with the helicity states.

Amplitudes of the Proton Current in DSB

$$(J_p^{\pm\delta,\delta})_\mu = \bar{u}^{\pm\delta}(q_2)\Gamma_\mu(q^2)u^\delta(q_1),\ \Gamma_\mu(q^2) = F_1\gamma_\mu + \frac{F_2}{4M}(\hat{q}\gamma_\mu - \gamma_\mu\hat{q}).$$

$$(J_p^{\delta,\delta})_\mu = 2mG_E(b_0)_\mu, (J_p^{-\delta,\delta})_\mu = -2m\delta\sqrt{\tau}G_M(b_\delta)_\mu,$$

$$G_E = F_1 + \frac{q^2}{4m^2}F_2,\ G_M = F_1 + F_2\ ,$$

$$J_p^{\delta,\delta} \sim G_E, J_p^{-\delta,\delta} \sim \sqrt{\tau}\ G_M, J_q^{\delta,\delta} \sim 1, J_q^{-\delta,\delta} \sim \sqrt{\tau_q}\ .$$

$$\frac{G_E}{G_M} = \frac{\alpha_0 + \alpha_2\tau}{\beta_1 + \beta_3\tau},\ \tau \ll 1\ \ \frac{G_E}{G_M} \sim 1 - \frac{(\beta_3 - \alpha_2)}{4m^2}Q^2. \quad \tau = Q^2/4m^2$$

The linear dependence is caused at $\tau \ll 1$ by the contributions to $J_p^{\delta,\delta}$ from spin-flip transi-tions for two quarks or by the contribution to $J_p^{-\delta,\delta}$ from spin-flip transitions for all three quarks constituting the proton [1].

The backward Compton scattering (BCS)

- --To obtain a high probability of e-gamma conversion the density of laser photons in the conversion region should be so high that simultaneous interaction of one electron with several laser photons is possible (nonlinear BCS).
- --Energy spectra, helicities of final photons and electrons in nonlinear backward Compton scattering of circularly polarized laser photons is given. Distributions of gamma gamma luminosities with total helicities 0 and 2 are investigated
- --Very high intensity of laser wave leads to broadening of the energy (luminosity) spectra and shift to lower energies (invariant masses)
- -- General formulae for energy spectrum and polarization of backscattered photons are given for arbitrary and relatively small nonlinear parameter ξ^2 .
- --All this is necessary for optimization of the conversion region at photon colliders and study of physics processes, where a sharp edge of the luminosity spectrum and monochromaticity of collisions are important

In the case of head-on collision ultrarelativistic electrons with photons of circularly polarized laser wave, the energy dependence of the differential cross section of process BCS as a function of $y = \omega / \varepsilon$ (where ε is the electron energy) has the form (The polarization states of all particles involved in reaction are helicity ones), $J_n, J_{n\pm1}$ are the Bessel functions various order.

$$\frac{d\sigma_c}{dy}(\lambda, \lambda_e, \lambda', \lambda'_e) = \frac{\pi\alpha^2}{2xm^2\xi^2}\sum_{n=1}^{\infty}\{\,(1+\lambda_e\lambda'_e)F_{1n} + \lambda(\lambda_e+\lambda'_e)F_{2n} + \lambda'(\lambda F_{3n} + \lambda_e F_{4n}) + \lambda_e\lambda'_e F_{5n}\,\}\,,$$

$$F_{1n} = -4\,J_n^2 + \xi^2\,\left(1 - y + \frac{1}{1-y}\right)\,(J_{n-1}^2 + J_{n+1}^2 - 2J_n^2)\,,$$

$$F_{2n} = \xi^2\left(-1 + y + \frac{1}{1-y}\right)\,\left(1 - 2\frac{y}{y_n}\frac{(1-y_n)}{(1-y)}\right)\,(J_{n-1}^2 - J_{n+1}^2)\,,$$

$$F_{3n} = \xi^2\,\left(1 - y + \frac{1}{1-y}\right)\,\left(1 - 2\,\frac{y}{y_n}\frac{(1-y_n)}{(1-y)}\right)\,(J_{n-1}^2 - J_{n+1}^2)\,,$$

$$F_{4n} = -4y\,J_n^2 + \xi^2\left(-1 + y + \frac{1}{1-y}\right)\,(J_{n-1}^2 + J_{n+1}^2 - 2J_n^2\,)\,,$$

$$F_{5n} = 4J_n^2\left(1 + y - \frac{1}{1-y}\right)\,,$$

$$z_n = \frac{2n\xi}{\sqrt{1+\xi^2}}\,\sqrt{\alpha_n}\,,\ \alpha_n = r_n(1-r_n) = \frac{y}{y_n}\left(1 - \frac{y}{y_n}\right)\frac{(1-y_n)}{(1-y)^2}\,,$$

$$y_n = \frac{u_n}{1+u_n}\,,\ r_n = \frac{y}{u_n(1-y)}\,,\ u_n = \frac{nx}{1+\xi^2}\,,\ x = \frac{2k_0 p}{m^2} = \frac{4\omega_0\varepsilon}{m^2}\,,$$

The photon energy spectra f(x,y) are defined through the differential cross section $d\sigma_c(\lambda, \lambda_e)/dy$

In the case when hard γ-quanta colliding just after Compton conversion, the distribution of the spectral luminosity $\gamma\gamma$ collisions $L_{\gamma\gamma}$ over the invariant mass of colliding photons is expressed through the energy spectra of the photons

$$\frac{1}{L_{\gamma\gamma}} \frac{dL_{\gamma\gamma}}{dz} = 2z \int_{-\eta_m}^{+\eta_m} f(x, ze^{+\eta})\ f(x, ze^{-\eta})\ d\eta\ , \quad \eta \equiv \ln\sqrt{y_1/y_2}$$

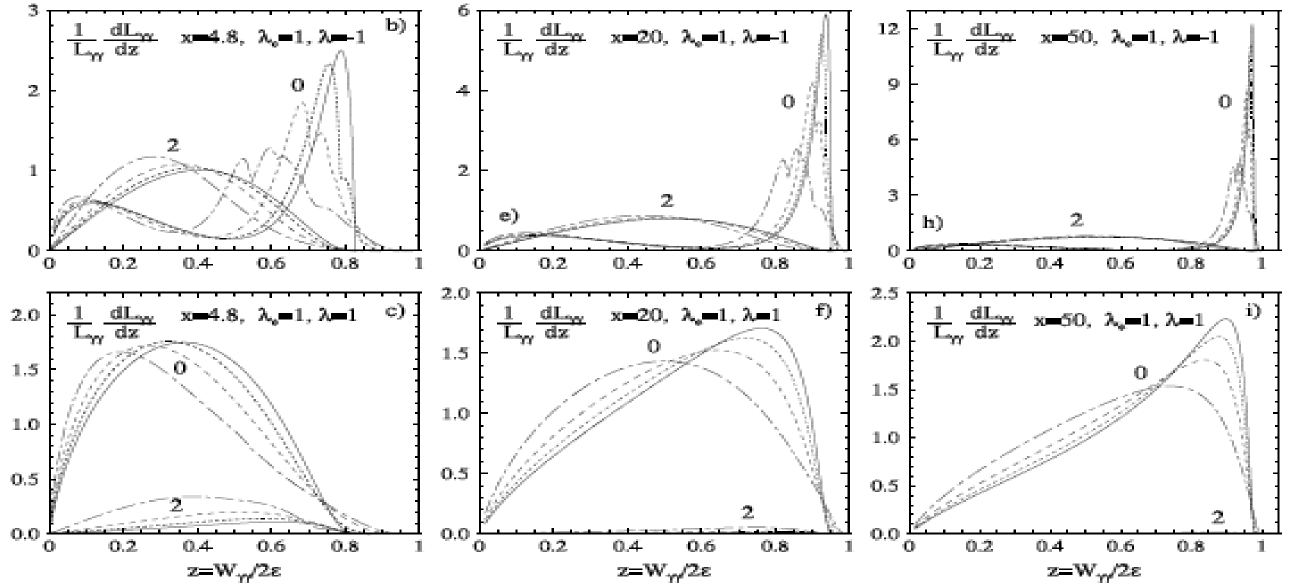


Fig. 5. The distribution of spectral luminosities dL_0/dz and dL_2/dz of the $\gamma\gamma$ system over the invariant mass of photons $z = W_{\gamma\gamma}/2\varepsilon$. Corresponding curves are labelled by numbers 0 and 2 (for spin 0 and 2). The left, central, and right panels correspond to $x = 4.8$, 20, and 50, respectively. Fig.(a,d,g), (b,e,h), and (c,f,i) were built for $\lambda\lambda_e = 0$, $\lambda\lambda_e = -1$, and $\lambda\lambda_e = 1$, respectively. The solid, dotted, dashed, and dash-dotted curves correspond to the intensity parameter $\xi^2 = 0.0, 0.3, 1.0$, and 3.0, respectively.

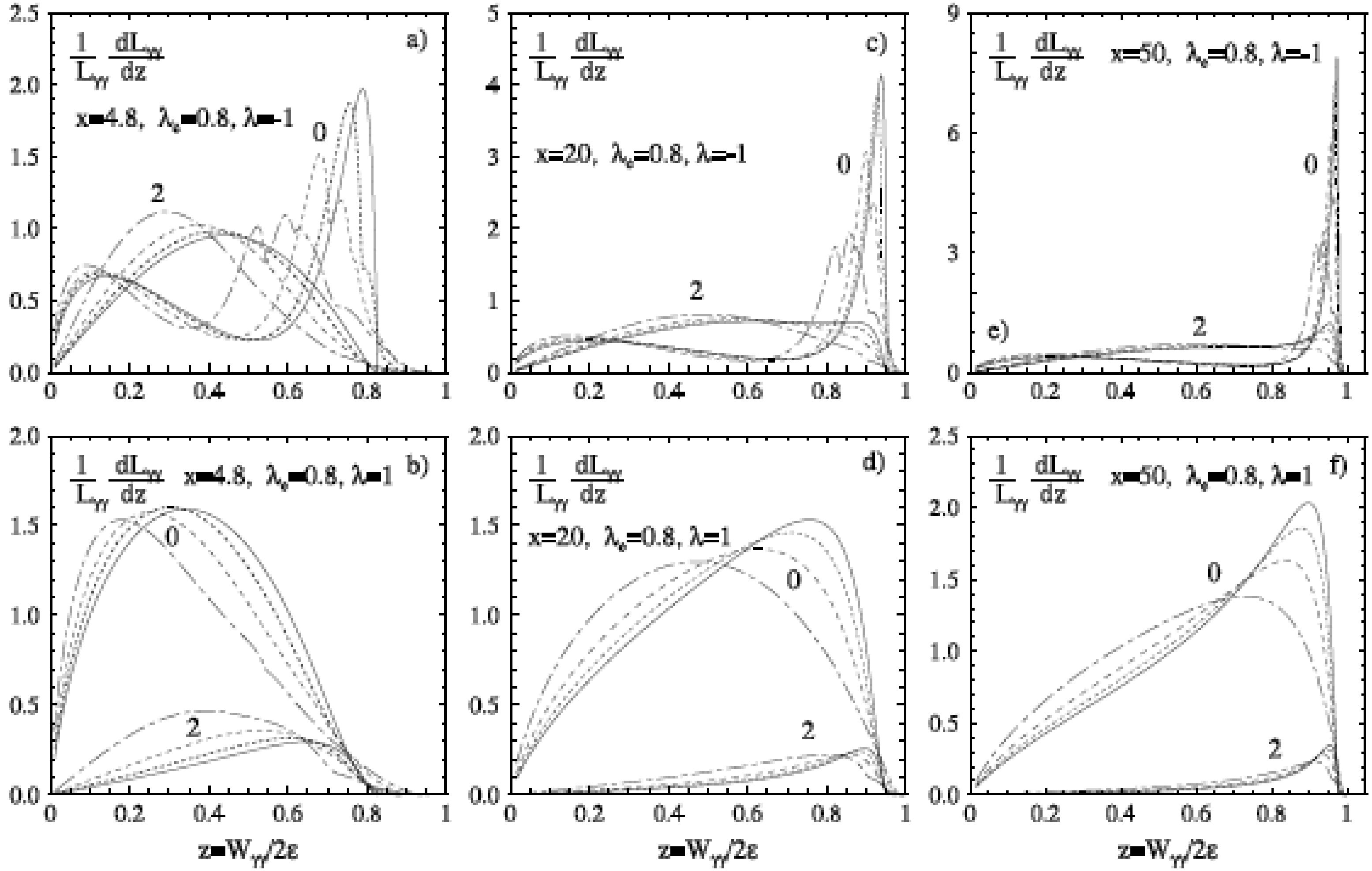


Fig. 6. The distribution of spectral luminosities dL_0/dz and dL_2/dz of the $\gamma\gamma$ system over $z = W_{\gamma\gamma}/2\varepsilon$. Corresponding curves are labelled by numbers 0 and 2. The left, central, and right panels correspond to $x = 4.8$, 20 and 50, respectively. Fig.(a,c,e) and (b,d,f) stand for $\lambda\lambda_e = -0.8$ and $\lambda\lambda_e = +0.8$, respectively. The solid, dotted, dashed, and dash-dotted curves correspond to the intensity parameter $\xi^2 = 0.0, 0.3, 1.0$, and 3.0, respectively.

The process of BCS will be the main method to produce high energy photons in future PLC. As we have just seen nonlinear effects in BCS lead to increase of the energy of scattered photons. However, when the intensity of laser wave grows the monochromaticity of $\gamma\gamma$ collisions becomes to be worse because of the increase of the spectral luminosity in the region of low and intermediate invariant masses. The reason for this increase consists in the fact that only photons of the first harmonic can be emitted along the direction of the initial electron beam. Such a behavior is not permitted for photons of higher order harmonics because of the helicity conservation for the particle system $e + n\gamma_0$ before interaction and $e + \gamma$ after interaction [22]. This leads to widening the angular distribution of the higher order harmonics and in its turn decreases the monochromaticity of $\gamma\gamma$ collisions.

As has already been shown the helicity of final photon at large $x = 20, 50$ in the case when $\lambda\lambda_e = 1$ is most insensitive to nonlinear effects. In the range of $\xi^2 \leq 1$ it is practically equal to one in all region $0 < z < z_m$. As a consequence, the contribution of the spin 2 state to the total luminosity zeroizes and the total luminosity is equal to dL_0/dz. This fact offers new possibilities for search of Higgs bozon.

References

- 1. M. Galynskii, E. Kuraev, JETP Letters. 07/2012; 96(1):6-12
- 2. M. Galynskii, E. Kuraev, M. Levchuk and V.I. Telnov. Nonlinear effects in Compton scattering at photon colliders. Nucl.Instrum.Meth. A472 (2001) 267-279
- 3. M V Galynskii, S M Sikach Physics of Particles and Nuclei, vol. 29, issue 5, pages 469-495.
  E. Bartos, M. Galynskii et al, Physics of Particles and Nuclei. 01/2004; 35(7-35
- **4. TESLA Technical Design Report, Part VI, Chapter 1: The Photon Collider**
- B. Badelek, C. et al.
- 5. A I Ahmadov, M V Galynskii, Yu M Bystritskiy, E A Kuraev, M G Shatnev
- Physical Review D. 10/2008; · 4.56
- 6. S Bakmaev, E A Kuraev, E Bartoš, M.Galynskii European Physical Journal C. 07/2007; 524088(13):75-82.

QCD - INSTANTONS SEARCH AT THE CLIC
(Modernization of QCDINS)

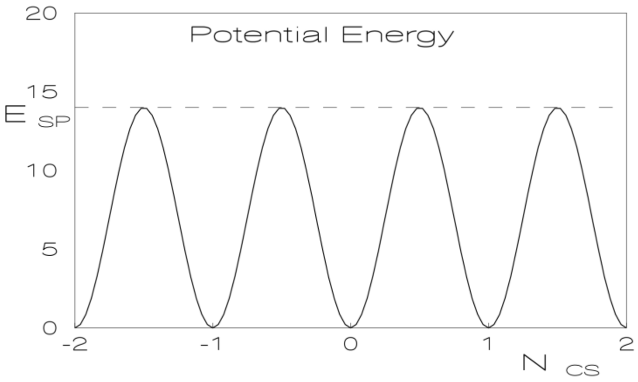
V.Kuvshinov, R.Shulyakovsky, V. Kashkan

(Experimental search of QCD instantons in quark-gluon subproceses of e+e- or γγ colliders.) (Ringwald; Kuvshinov, Shulyakovsky, Kashkan,.Kuzmin)

...when instanton effects are important, the calculational tools do not work; when they work, the instanton effects are unobservable. In this, the instantons resemble that mythical animal, the basilisk, whose sight was supposed to cause the death of the beholder.

F. Yndurain, The Theory of Quark and Gluon Interactions

Non-trivial structure of QCD vacuum:



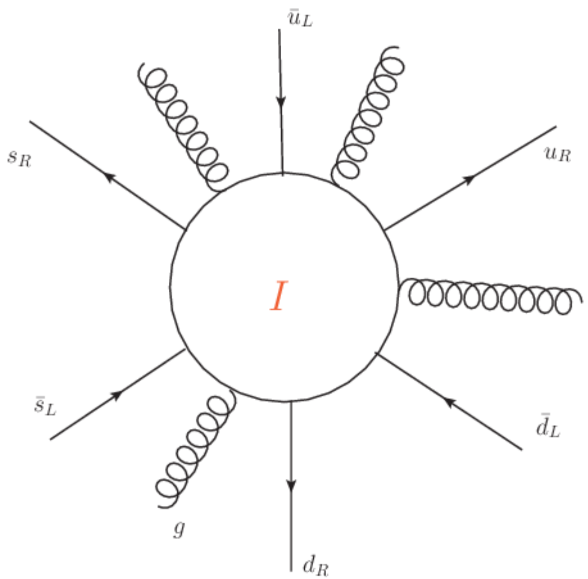
$$N_{cs} = \frac{g^2}{16\pi^2} \int d^3x \varepsilon_{ijk} \left(A_i^a \partial_j A_k^a + \frac{g}{3} \varepsilon^{abc} A_i^a A_j^b A_k^c \right)$$

Quantum tunneling between vacua with different N_{cs}

The larger energy scale the more is the tunneling rate
DIS at 0.9 TeV (DESY) vs. e^+e^- at 3 TeV (CLIC)

Can different vacuums be physically distinguished? Yes, by axial charge!

Chirality violating QCD-instanton subprocess

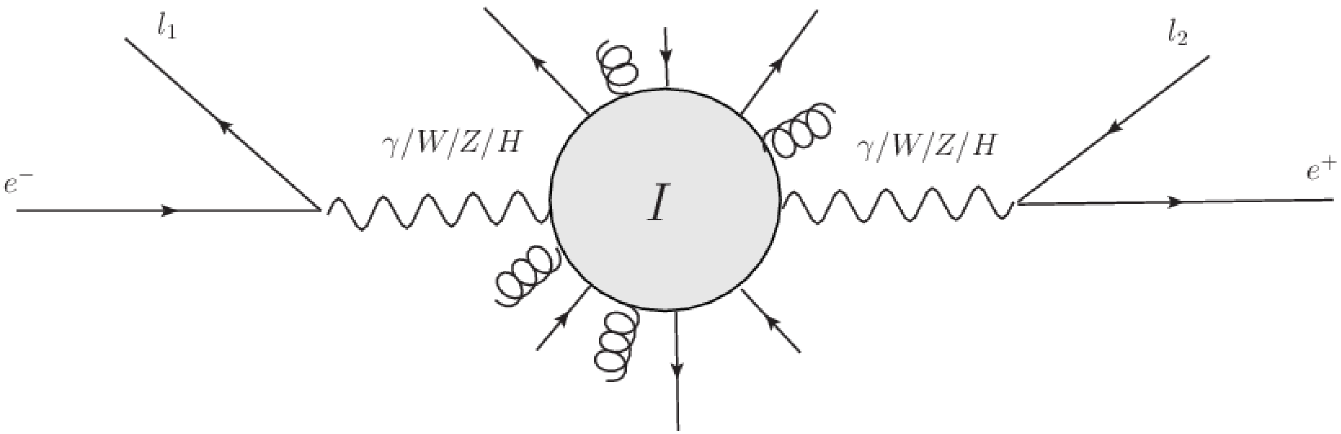


$$\Delta Q_5 = 2n_f(N_L - N_R)$$

Key features in hard scattering:

- Factorisation
- Can be calculated from QCD-instanton perturbation theory (Ringwald, Schrempp)
- There is a dynamic cutoff for instanton size $\rho < Q^{-1}$, where Q is the hard scattering scale.

QCD-instanton induced process at CLIC



Chirality violating subprocess $\gamma^* + \gamma^* \rightarrow 2\, n_f (q_R + \bar{q}_R) + n_g g$

- Key differences of QCD-Instanton induced final states in comparison to pQCD final states

- **Flavour democratic**
- **Isotropic**
- **High average multiplicity**
- **Poisson distribution of gluons**
- **Specific correlation moments**
- **Others non-investigated yet**

Confront these final states with pQCD predictions to find QCD-instanton enhanced regions

The QCD-instanton induced events in DESY were modelled by the Monte Carlo generator QCDINS (Chekanov)

References

1. R. Jackiw and C. Rebbi. *Vacuum periodicity in a Yang-Mills quantum theory.* Phys. Rev. Lett., 37:172–175, 1976.
2. Moch, S.; Ringwald, A. & Schrempp, F. *Instantons in deep inelastic scattering: The Simplest process*. Nucl.Phys., 1997, B507, 134-156.
3. S. Chekanov et al. *Search for QCD-instanton induced events in deep inelastic e p scattering at HERA.* Eur. Phys. J., C34:255–265, 2004.
4. Kashkan, V. I.; Kuvshinov, V. I. & Shulyakovsky, R. G. *QCD-instantons: experimental signatures and Monte-Carlo simulation.* Proceed. of CERN-CMS-week (December 6-18, 1999, Geneva, Switzerland), 1999.
5. Kashkan, V. I., Kuvshinov, V. I. & Shulyakovsky, R. G. *Effect of hadronization on the form of correlation moments for instanton processes and possibility of discovering them experimentally*. Phys. Atom. Nucl., 2002, 65, 925-928

OTHER IDEARS

- **QCD New nonperturbative QCD phenomena V. Kuvshinov**
-
- 1).Colour Dissipation by Propagation Through QCD Vacuum
- 2). Critical energy for order-chaos transition
  3).Quantum Chaos Criterium

- **QED. Luminosity** for photon colliders taking into account
- - the nonlinear contributions in the inverse Compton scattering,
- - polarization of colliding electrons
- - polarization of photon of laser wave. **Pairs, Higgs boson production**
  M.Galynskii
- .

- **SM. Multi-boson interactions. Higgs production at CLIC V. Gilewsky**

- **Technique proposal for CLIC Gilewsky**

  RF-cavities, optical alignment systems (for accelerator)
  slow control system (for accelerator and detector), mechanics
  Experience in production of support structures for toroidal
  magnets, plates for TileCal at some Minsk plants and LVPS for ATLAS

Thank you for the attention!