Large angle high energy photons for discovery of New Physics at LHC, ILC, etc.

I. F. Ginzburg
Sobolev Inst. of Mathematics, SB RAS
and Novosibirsk State University
Novosibirsk, Russia

Different exotic models of New Physics - large extra dimensions, point-like monopole, unparticles have common signature – the cross section for $\gamma\gamma$ production grows with energy as ω^6, these photons are produced almost isotropically. Future observations at LHC, ILC, CLIC either give limits for scales of these exotics or allow to see these effects via recording large $p_\perp$ high energy photons.

Common features

In all cases the $\gamma\gamma \to \gamma\gamma$ process (or subprocess) is considered much below new mass scale Λ, the cross section can be written as

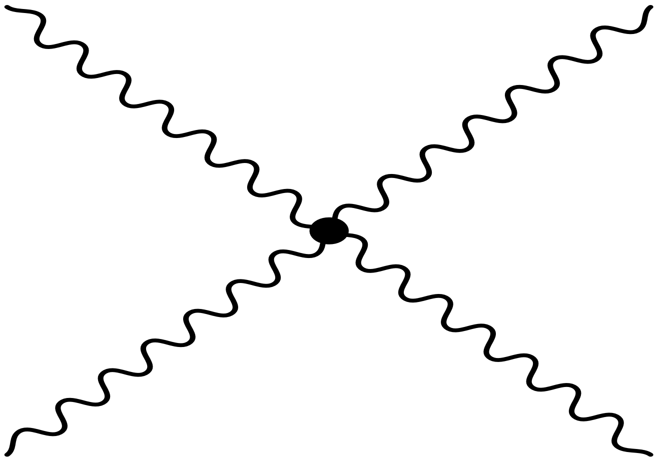
$$\sigma(\gamma\gamma \to \gamma\gamma) = \frac{C}{32\pi s}\left(\frac{s}{4\Lambda^2}\right)^4$$

with specific angular distribution (roughly — isotropic) and polarization dependence.

The wide angle elastic $\gamma\gamma$ scattering has very good signature and small QED background.

The observation of strong elastic $\gamma\gamma$ scattering quickly raised with energy will be signal of one of these mechanisms. The study of polarization and angular dependence at photon collider and partially at e^+e^- collider can discriminate what mechanism works.

All these exotics at modern energies can be treated as an effective point-like interaction with typical interaction of form



$$L \propto \frac{F^{\mu\nu} F^{\alpha\beta} F_{\rho\sigma} F_{\phi\tau}}{\Lambda^4} \ .$$

In different models different orders of field indices is realized. Λ is characteristic mass scale ($\Lambda^2 > s/4$). In all cases s, t and $u-$ channels are essential.

Main features of matrix element (in the photon c.m.s.):

- gauge invariance provides a factor ω for each photon leg;
- to make this factor dimensionless it should be written as $\omega/\Lambda \Rightarrow$ amplitude $\mathcal{M} \propto (\omega/\Lambda)^4 = s^2/(2\Lambda)^4$ (choice of normalization of Λ).

The cross section

$$\sigma_{tot} = \frac{1}{32\pi s}\left(\frac{s}{4\Lambda^2}\right)^4, \qquad \frac{d\sigma}{dp_\perp^2} = \sigma_{tot}\Phi\left(\frac{p_\perp^2}{s}\right)\frac{2dp_\perp^2}{\sqrt{s(s-4p_\perp^2)}}$$

with smooth and model dependent function $\Phi(p_\perp^2/s)$ and

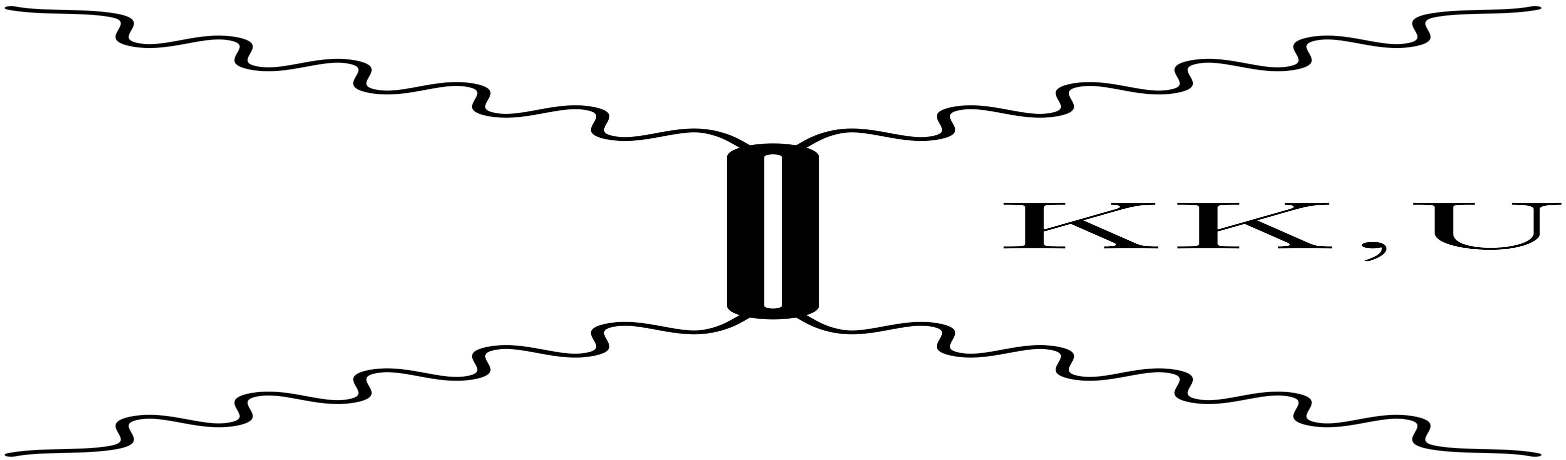
$$\int \Phi\left(\frac{p_\perp^2}{s}\right)\frac{2dp_\perp^2}{\sqrt{s(s-4p_\perp^2)}} = 1\,.$$

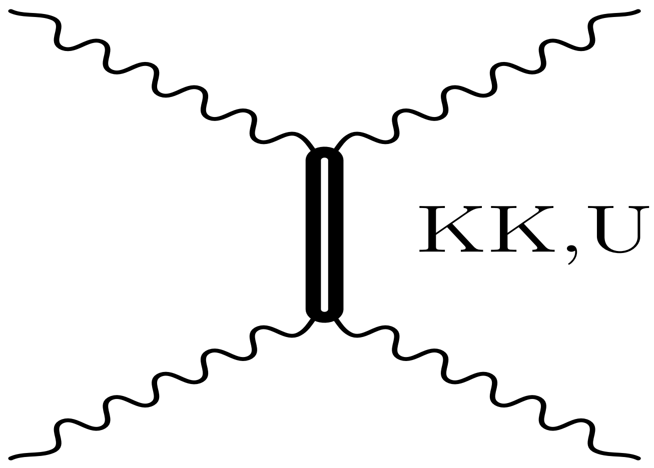
For large extra dimensions and monopoles entire s dependence is given by mentioned $s^4/(2\Lambda)^8$, for unparticles additional factor $(s/4\Lambda^2)^\delta$ is added.

Extra dimensions, unparticles

H. Davoudiasi, K. Cheung,... 1998 – 2000 →, Georgi, ... (2007)

Typical diagram





In both cases s, t and u − channels are essential.

Extra dimensions (LED)

E.g.: Gravity propagates in the $(4+n)$–dimensional bulk of space-time, while gauge and matter fields are confined to the (3+1)–dimensional world volume. The extra n dimensions are compactified with scale R which gives Kaluza–Klein excitations having masses $\pi n/R$. The corresponding scale **Λ** in our world is assumed to be $\sim$ few TeV. The particles of our world interact via the set of these Kaluza-Klein excitations having spin 2 or 0. For example, for the processes $AB \to AB$ or $A\bar{A} \to B\bar{B}$ it describes by an effective Lagrangian $\mathcal{L}_{eff} = T^{\mu\nu}(A\bar{A})T_{\mu\nu}(B\bar{B})/\Lambda^4$, where $T^{\mu\nu}(A\bar{A})$ is stress-energy tensor of $A\bar{A}$ state. Partial model dependent coefficients are accumulated in the definition of Λ. For photons $(A = B = \gamma)$ scattering amplitude

$$\Rightarrow \;\; \mathcal{M}_{\gamma\gamma\to\gamma\gamma} \approx \frac{F^{\mu\nu}F_{\nu\alpha}F^{\alpha\beta}F_{\beta\mu}}{\Lambda^4} \; + \; permutations\,.$$

After averaging over polarizations for tensorial KK excitations (stress-energy tensor!)

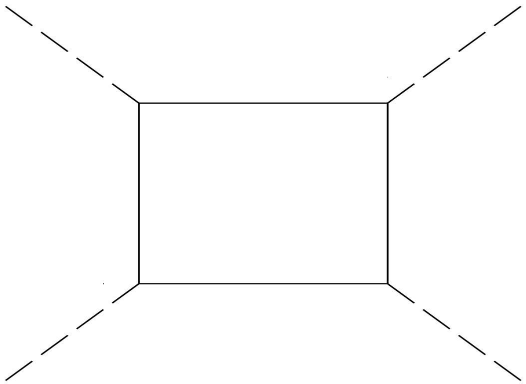
$$\Phi \propto 2\left(1 - \frac{p_\perp^2}{\hat{s}}\right)^2 = \frac{(3+\cos^2\theta)^2}{8} = \frac{\hat{s}^4 + \hat{t}^4 + \hat{u}^4}{2\hat{s}^4}$$

Point–like Dirac monopole.

I.F.G., S.L.Panfil (1983), I.F.G., A.Shiller (1998-2000)

This monopole existence would explain mysterious quantization of an electric charge. There is no place for it in modern theories of our world but there are no precise reasons against its existence.

Let M is monopole mass. At $s \ll M^2$ the electrodynamics of monopoles is expected to be similar to the standard QED with effective perturbation parameter $g\sqrt{s}/(4\pi M)$ where $g = n/(2e)$.



The effect is described by monopole loop $\Rightarrow$ it is calculated within QED. the coefficient and details of angular and polarization dependence depend strong on spin of monopole J, e.g., $A(J=1)/A(J=0) \approx 1900$.

Here

$$\mathcal{L}_{4\gamma} = \frac{1}{36}\left(\frac{g}{\sqrt{4\pi}M}\right)^4 \left[\frac{\beta_+ + \beta_-}{2}\left(F^{\mu\nu}F_{\mu\nu}\right)^2 + \frac{\beta_+ - \beta_-}{2}\left(F^{\mu\nu}\tilde{F}_{\mu\nu}\right)^2\right].$$

After averaging over polarizations

$$\Phi \propto \left(1 - \frac{p_\perp^2}{\hat{s}}\right)^2 = \left(\frac{\hat{s}^2 + \hat{t}^2 + \hat{u}^2}{\hat{s}^2}\right)^2$$

The cross section is given the same eq. as for LED with $\Lambda = (M/n)a_J$, where quantity a_J depends on monopole spin J,

$$a_0 = 0.177,\ a_{1/2} = 0.125,\ a_1 = 0.069.$$

Unparticles.

Introduced H.Georgi in March 2007. Now 130 papers in hep.

For our goal: This model contain unparticle $\mathcal{U}$ − object, describing particle scattering via propagator which has no poles at real axis, correspondent to particles. This propagator behaves (in the scalar case) as $(-p^2)^{d_U-2}$ where scalar dimension d_u is not integer or half-integer. The interaction carried by unparticle has form $\frac{F^{\mu\nu}F_{\mu\nu}\mathcal{U}}{\Lambda^{2d_U}}$ with some phase factor. Here Λ is characteristic scale, which is large enough to don't contradict modern data. It accumulate other real coefficients. For matrix element it gives (C.F. Chang et al.)

$$\mathcal{M} = \frac{F^{\mu\nu}F_{\mu\nu}F^{\rho\tau}F_{\rho\tau}}{\Lambda^{4d_U}}(-P^2)^{d_U-2} + permutations\,.$$

$$|\mathcal{M}|^2 = C\frac{s^{2d_U} + |t|^{2d_U} + |u|^{2d_U} + \cos(d_u\pi)[(s|t|)^{d_U} + (s|u)^{d_U}] + (tu)^{d_U}}{\Lambda^{4d_U}}$$

How to see

At all type of colliders initial photons are non-monochromatic. Their energy distribution for i-th type of source is given by spectrum $dn_i(\omega)$. The observed cross section is given by convolution

$$d\sigma = \int dn_i(\omega_1) d\sigma(\hat{s}) dn_j(\omega_2)\,.$$

For all cases except Photon Colliders

$$dn_i(\omega) = \frac{\alpha}{\pi} \frac{n_i(\omega, Q^2)}{\omega} \frac{dQ^2}{Q^2} \equiv \frac{\alpha}{\pi} \frac{n_i(y, Q^2)}{y} \frac{dQ^2}{Q^2}\,,$$

where $\boxed{\boldsymbol{\omega = yE}}$ and Q^2 are photon energy and virtuality.
Since in the dominant integration region $Q_i^2 \ll \hat{s}$, the transverse motion of initial photons can be neglected with good accuracy.

$$\Rightarrow\ \hat{s} = 4\omega_1\omega_2$$

.

The relevant scale for the virtuality dependence of the $\gamma\gamma \to \gamma\gamma$ subprocess cross section is given by our scale parameter Λ. Since $Q^2 \ll \hat{s} \ll \Lambda^2$, it is safely neglected.

Finally, we have

$$\sigma(AB \to AB\gamma\gamma) = RE^6 \left(\frac{\alpha}{\pi}\right)^2 \int dn_A(y_1) dn_B(y_2) (y_1 y_2)^3 \,,$$

For e^+e^- collider (ILC, CLIC)

$$dn_e(y) = \frac{\alpha}{\pi}\frac{dy}{y}\int\limits_{Q^2_{min}}^{Q^2_{max}} \frac{dQ^2}{Q^2}\left[1 - y + \frac{1}{2}y^2 - (1-y)\frac{Q^2_{min}}{Q^2}\right],$$

$$Q^2_{min} = \frac{m_e^2 y^2}{1-y}, \qquad Q^2_{max} \approx \hat{s},$$

$$\Rightarrow \quad dn(y_i) = \frac{\alpha}{\pi}\left(1 - y_i + \frac{1}{2}y_i^2\right) L - (1 - y_i), \qquad L = \ln\frac{4E^2}{m_e^2}.$$

For hadron collider (Tevatron, LHC) the photon flux density is a sum over elastic and inelastic contributions:

$$n(y, Q^2) = (D_{\text{el}} + D_{\text{in}}) + \frac{y^2}{2}(C_{\text{el}} + C_{\text{in}})\,.$$

In the individual contributions the quantity Q^2 is limited kinematically from below (m_p is the proton mass):

$$Q^2 > Q^2_{\text{min}} = (M_X^2 - m_p^2)\frac{y}{1-y} + m_p^2\frac{y^2}{1-y}\,.$$

M_X is the effective mass of the system produced in the $\gamma^* p$ collision,
in the elastic case $M_X = m_p$,
in the inelastic case via Bjorken variable $M_X^2 = m_p^2 + Q^2(1-x)/x$.

The elastic contribution is written via standard proton form factors G_E and G_M

$$C_{\text{el}}(Q^2) = G_M^2(Q^2)\,,$$

$$D_{\text{el}}(Q^2) = (1-y)\frac{4m_p^2 G_E^2(Q^2) + Q^2 G_M^2(Q^2)}{4m_p^2 + Q^2}\left(1 - \frac{Q^2_{\text{min}}}{Q^2}\right)\,.$$

The inelastic contribution is written via standard structure functions

$$C_{\text{in}}(Q^2) = \frac{2}{Q^2}\int dM_X^2\, F_1(M_X^2, Q^2)\,,$$

$$D_{\text{in}}(Q^2) = \frac{(1-y)}{Q^2}\int dM_X^2\, xF_2(M_X^2, Q^2)\left(1 - \frac{Q^2_{\text{min}}}{Q^2}\right).$$

We used standard approximations GRV and MRSS.

At hadron collider, like LHC, Tevatron and e^+e^- ILC, CLIC initial photons are virtual photons emitted by an initial proton or electron both without excitation of proton or with it. Therefore, for C independent on s, maximum of cross section is obtained in a maximum of function $\omega^3 dn(\omega)$, where $dn(\omega)$ – spectrum of equivalent photons. Simple calculations (*I.F.G., A.Shiller (1998)*) result in

	$\frac{\langle\omega\rangle}{E}$	$\frac{\langle\Delta\omega\rangle}{\langle\omega\rangle}$
e^+e^- ILC, CLIC	$8/11 \approx 0.7$	0.283
pp, $p\bar{p}$ LHC Tevatron	0.314	0.45

In this region QED process $e^+e^- \to \gamma\gamma$ must be taken into account for background.

Discovery limits

Tevatron D0	175 GeV
LHC	2 TeV
$\gamma\gamma$ (100 fb^{-}1)	3E_e
e^+e^- ILC (100 fb^{-}1)	1.5E

Nearest Future

For Large Extra Dimensions and unparticles – to add another initial state in addition to $\gamma\gamma$. For Large Extra Dimensions this procedure is unambiguous (return to stress-energy tensor), for unparticle it demands introduction of new couplings.

For e^+e^- new channel is $e^+e^- \to \gamma\gamma$. Here we expect to see almost isotropic back to back monochromatic photons with $\omega = E$. It will be very clean signature.

For LHC we should see for photons with $E \sim 0.3E$ or more. In this region quark pdf is finite while antiquark pdf is negligible. So that one must to see for $gg \to \gamma\gamma$ process (gluon pdf is not small in this region).