Selected problems for Photon Colliders

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

Photon Colliders of next generation

One can discuss 2 variants

- Laser conversion with IR laser or FEL to have $x = 4.8$

- Laser conversion with 1 eV photons (like for ILC) but with conversion coefficient $0.15 \div 0.2$ (no more)

perhaps with static magnetic field between 2 conversion points
(suitable for detector as well)

$\Rightarrow$ High monochromaticity

$$\boxed{\sqrt{s} \sim 1 \div 2\ TeV, \qquad \int \mathcal{L} dt \sim 100\ \text{fb}^{-1}/year}$$

There is standard list of physical problems.

What else?

- Multiple production of SM gauge bosons
- Strong interaction in Higgs sector
- High energy large angle photons to hunt for exotics

Multiple production of SM gauge bosons and higher orders of SM

The high energy **PLC** — single place in future accelerator program where one can measure these processes with high enough accuracy

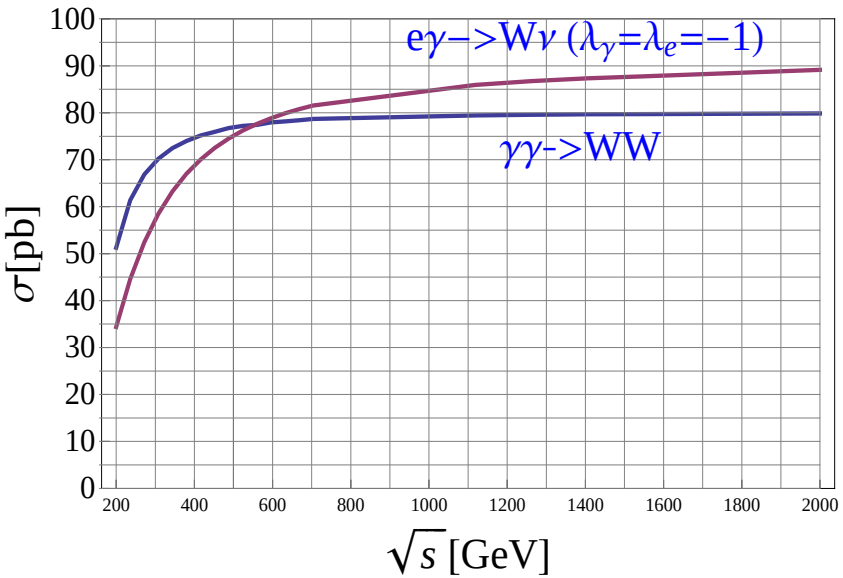
Why interesting?

- High sensitivity to details of SM
- High sensitivity to New Physics via set of anomalous parameters of W and Z interactions
- Fundamental problems of QFT

The most ambitious goal is to find deviations from prediction of $\mathcal{SM}$, obliged by New Physics (and described by anomalies in Effective Lagrangian). There are many anomalies relevant to the gauge boson interactions. Each process react for a number of anomalies. Large variety of processes accessible at Photon colliders allows to separate anomalies from each other.

2-nd order processes

Cross sections provide about 10^7 events per year.



Practically independent on polarization. (Distributions of observables strongly depend on polarization .)

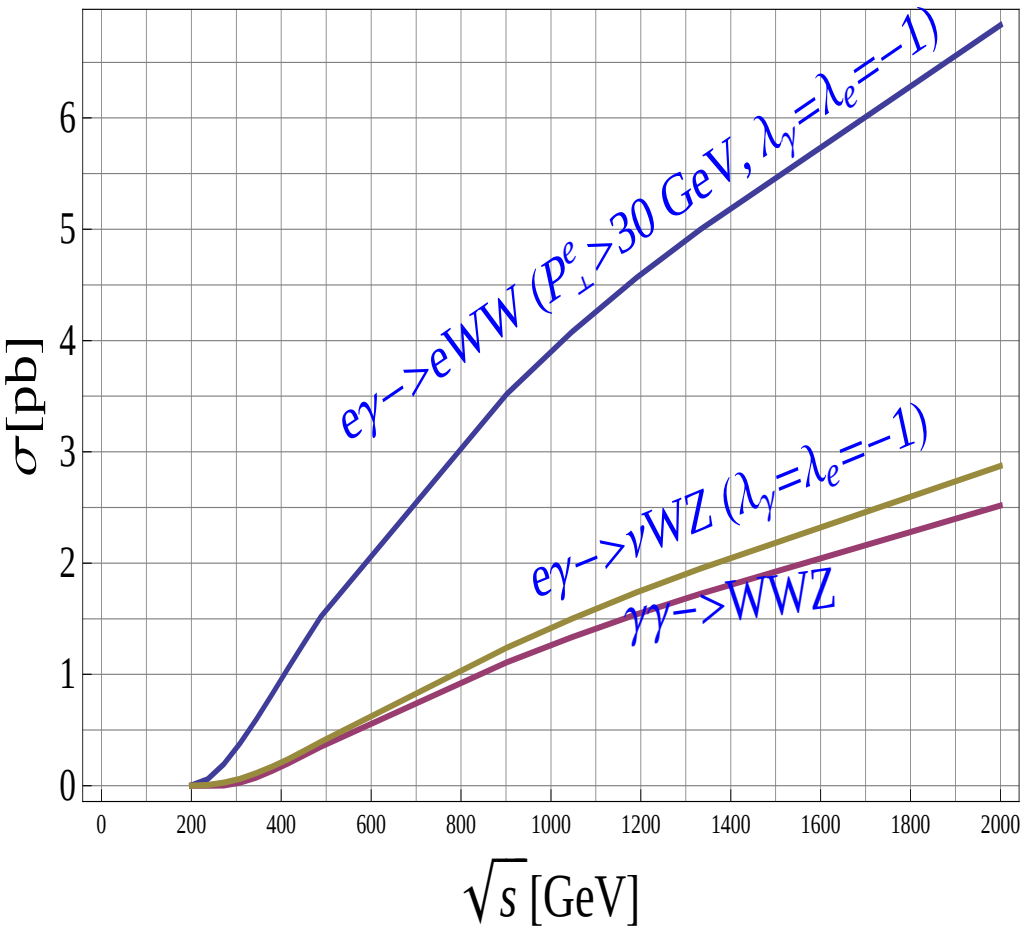
Accuracy enough for study of 2-loop corrections.

The two–loop radiative corrections to $\gamma\gamma \to W^+W^-$ and $e\gamma \to \nu W$ should be considered. They are measurable and sensitive to the problems

(i) construction of S–matrix of theory with unstable particles;

(ii) gluon corrections like Pomeron exchange between quark components of W's.

3-rd order processes

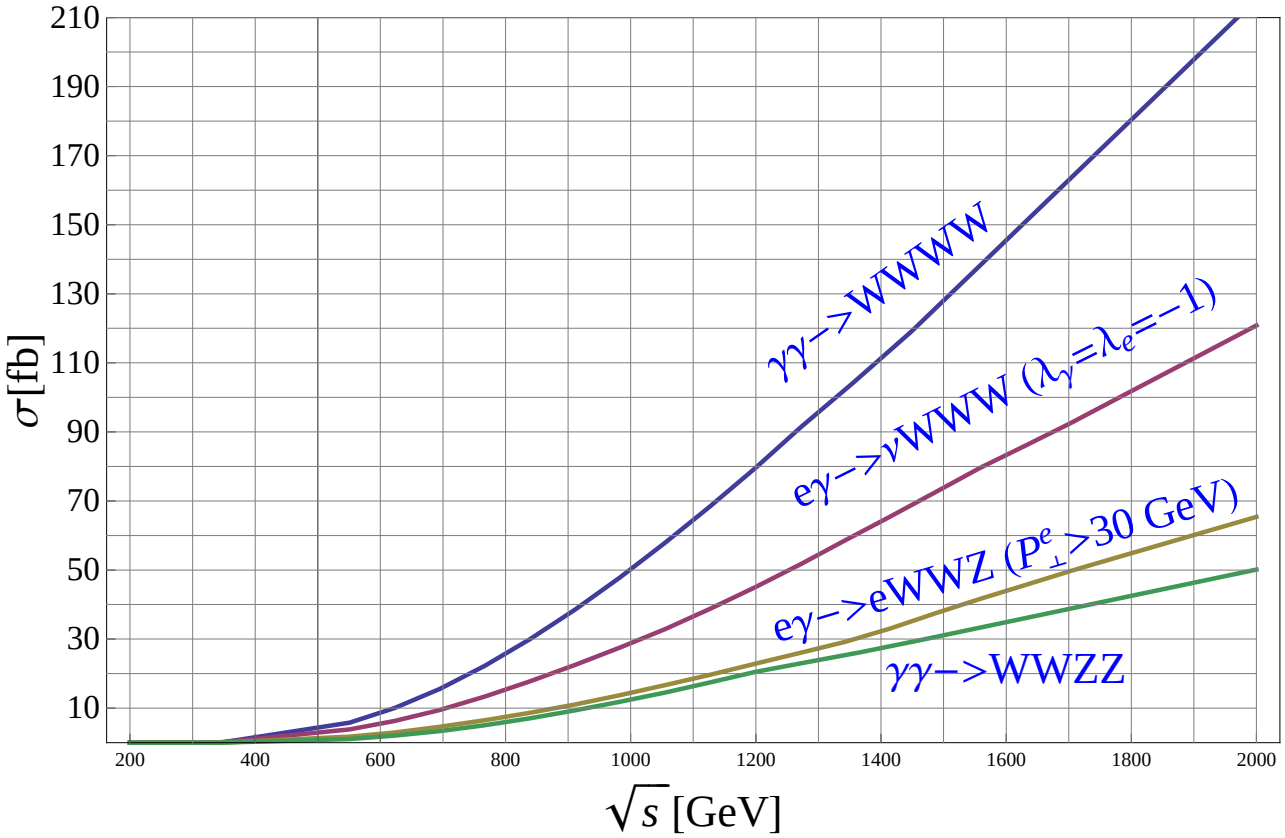


Total cross section $\sigma_{e\gamma\to eWW} \simeq dn_\gamma \otimes \sigma_{\gamma\gamma\to WW}$. At large enough transverse momentum of scattered electron this factorization is violated. So that we present $\sigma_{e\gamma\to eWW}$ only for $p_{\perp e} > 30$ GeV. It allow to separate contribution of $\gamma Z \to WW$ subprocess.

For definiteness, we put $M_H = 140$ GeV

4-th order processes

Cross sections are high enough to see for these processes with 1% precision.



Strong interaction in Higgs sector via charge asymmetry in $e\gamma \to eWW$

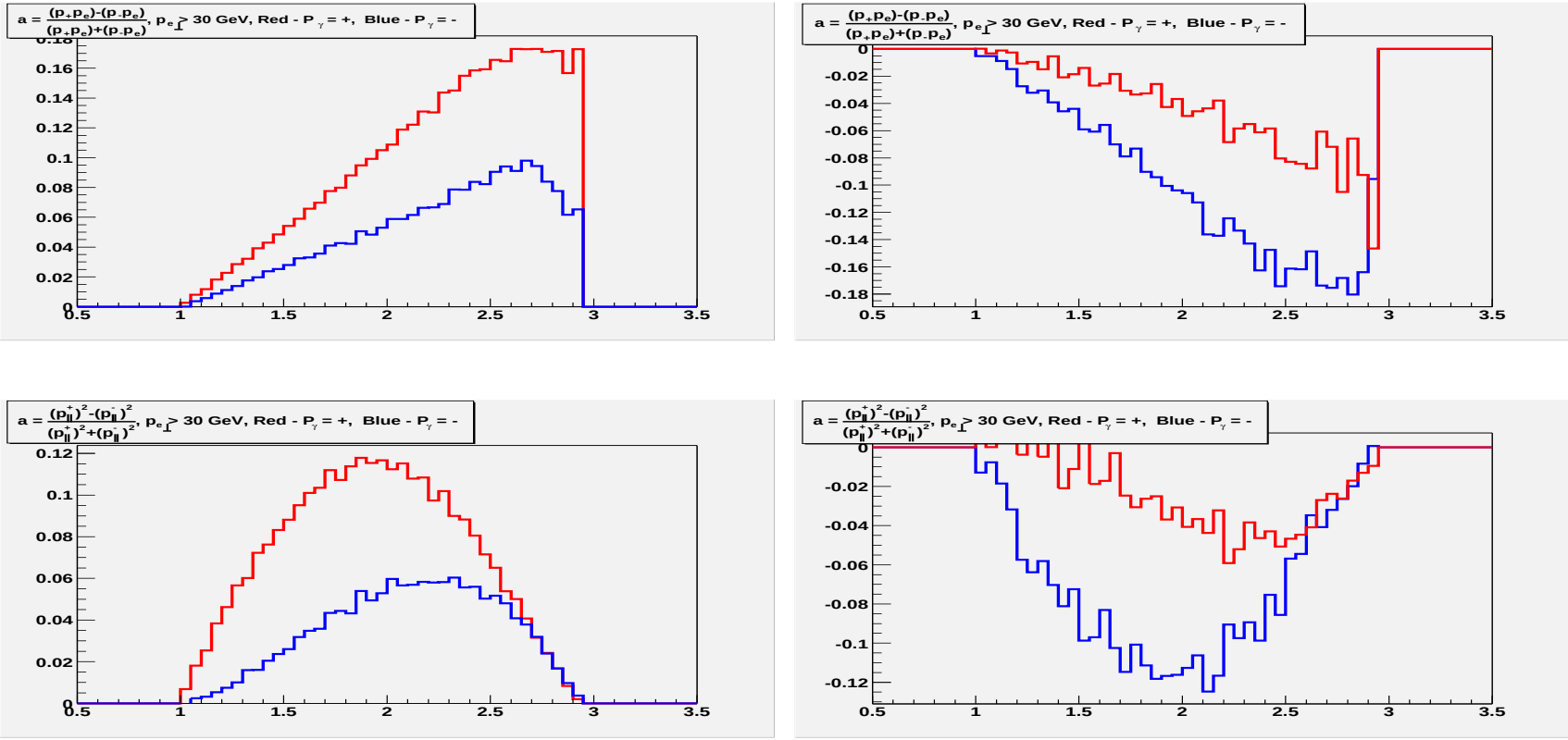
The diagrams of the process are subdivided into three types,

a) $e \to e\gamma^*(Z^*) \otimes \boxed{\gamma + \gamma^*(Z^*) \to WW}$, subprocess is modified by strong interaction in Higgs sector (denoted 2-gauge).

b) $e\gamma \to e\gamma^*(Z^*) \otimes \boxed{\gamma^*(Z^*) \to WW}$, subprocess is modified by strong interaction in Higgs sector (denoted 1-gauge).

c) $\gamma \oplus \boxed{e \to W\nu \to We}$

Interference of 2-gauge and 1- gauge diagrams result in charge asymmetry of produced W due to different C-parity of final WW system in contributions with γ and due to indefinite C-parity for contributions with Z^*.



SM: in variables $v_1 = \dfrac{\langle (p^+ - p^-) p_e \rangle}{\langle (p^+ + p^-) p_e \rangle}$ (up), $v_2 = \dfrac{\langle (p_\parallel^+)^2 - (p_\parallel^-)^2 \rangle}{\langle (p_\parallel^+)^2 + (p_\parallel^-)^2 \rangle}$ (down), complete (left) and without 1-gauge contribution (right).

High sensitivity to interrelation 2-gauge and 1-gauge contributions $\Rightarrow$ to the phase of strong Higgs interaction.

The unique source of information about $HZ\gamma$ coupling $e\gamma \to eH$ process.

The process is described by diagrams with photon exchange in t–channel, Z exchange and boxes. First two contain contributions of $H\gamma\gamma$ and $HZ\gamma$ vertices. This subdivision is gauge invariant with accuracy $\sim m_e/M_Z$. Box contributions are very small. Even in $\mathcal{SM}$ when transverse momentum of electron $p_\perp \geq 30$ GeV, contributions of $H\gamma\gamma$ and $HZ\gamma$ items are roughly equal. The cross sections for left–hand and right–hand polarized electrons $\sigma^L \propto (J_\gamma + J_Z)^2$ and $\sigma^R \propto (J_\gamma - J_Z)^2$ strongly different and their difference $\Delta\sigma = \sigma^L - \sigma^R \propto Re(J_\gamma^* J_Z)$ become relatively large.

It shows that the $HZ\gamma$ coupling could be extracted good even in $\mathcal{SM}$.

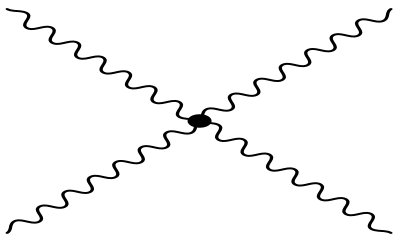
Large angle high energy photons for exotics

Different exotic models of New Physics - large extra dimensions, point-like monopole, unparticles have common signature – the cross section for $\gamma\gamma \to \gamma\gamma$ production grows with energy as ω^6, these photons are produced almost isotropically. Future observations either give limits for scales of these exotics or allow to see these effects via recording large $p_\perp \sim 0.5 \div 0.7 E_e$ photons.

All these models seem hardly probable to ME

Common features

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



$$L \propto \frac{F^{\mu\nu}F^{\alpha\beta}F_{\rho\sigma}F_{\phi\tau}}{\Lambda^4}, \quad (\Lambda^2 \gg s/4).$$

In different models different orders of field indices are realized.

Λ is characteristic mass scale.

In all cases s, t and u – channels are essential.

In the extra dimension case point correspond exchange by heavy KK excitations (via stress-energy tensor).

In the unparticle case point correspond exchange by heavy unparticle.

In the point-like monopole case point correspond exchange by loop of heavy monopoles (like electron loop in QED – see Heisenberg, Euler)

Matrix element (in the photon c.m.s.):

- gauge invariance provides 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

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

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

H. Davoudiasi, K. Cheung,... 1998 – 2000 →

$$\mathcal{M}_{\gamma\gamma\to\gamma\gamma} \propto \langle \frac{T_{ab}T^{ab}}{\Lambda^4} \rangle \approx \frac{F^{\mu\nu}F_{\nu\alpha}F^{\alpha\beta}F_{\beta\mu}}{\Lambda^4} + \; permutations\,,$$

T_{ab} – stress-energy tensor.

After averaging over polarizations for tensorial KK excitations

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

At ILC energies interference with $\gamma\gamma \to WW$ is essential $\Rightarrow \gamma\gamma \to WW$ is better for discovery.

At $E_e = 1$ TeV the $\gamma\gamma \to \gamma\gamma$ process dominates.

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 $g\sqrt{s}/(4\pi M)$. 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 extra dimensions 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 (H.Georgi, 2007).

Model contains 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. The characteristic scale Λ is large enough to don't contradict modern data. It accumulate other coefficients. For matrix element it gives (C.F. Chang et al.)

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

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

Discovery limits

Tevatron D0	175 GeV
LHC	2 TeV
$\gamma\gamma$ (100 fb^{-1})	$3E_e$
e^+e^- LC (1000 fb^{-1})	$2E_e$