Two photon physics with forward detectors

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Two-photon processes – a powerful tool

→ γγ collisions serve as the prototypes of collisions of the other gauge bosons of the Standard Model.

→ Tests of electroweak theory in photon-photon annihilation ($\gamma\gamma \to W^+W^-$, $\gamma\gamma \to$ neutral & charged Higgs bosons; higher order loop processes $\gamma\gamma \to \gamma\gamma$, $Z\gamma$, H^0Z^0 and Z)

→ The high energy γγ and eγ collisions – tests of QCD.

→ Two-photon production of supersymmetric squark and slepton pairs.

→ The eγ collisions allow the study of the photon structure function.

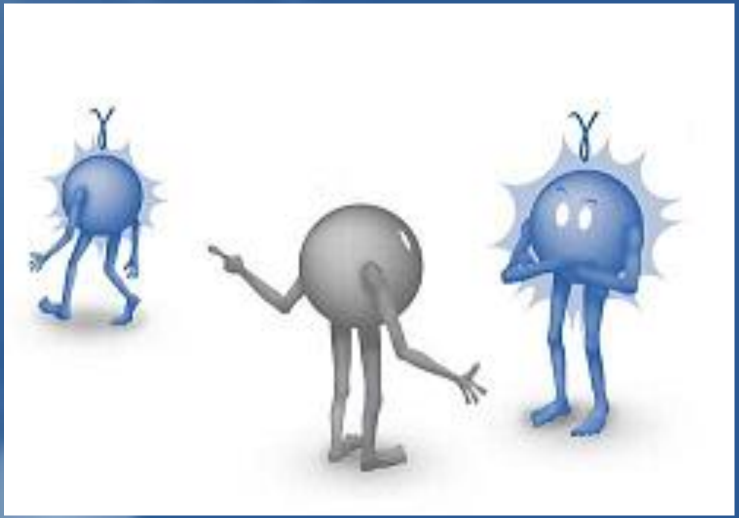
→ …

Two-photon processes ($\gamma\gamma$, $\gamma^*\gamma$, $\gamma^*\gamma^*$ events) provide a comprehensive laboratory for exploring virtually every aspect of the Standard Model and its extensions.

Photons & their interactions

- As a gauge boson of QED, the photon is a massless ($m < 2 \cdot 10^{-16}$eV) and chargeless ($q < 5 \cdot 10^{-30}$e) particle having no internal structure in the common sense.
- In any quantum field theory the existence of interactions means that the photon themself can develop a structure. It can fluctuate for a short period of time into a charged fermion-antifermion pair, carrying the same quantum numbers as the photon.

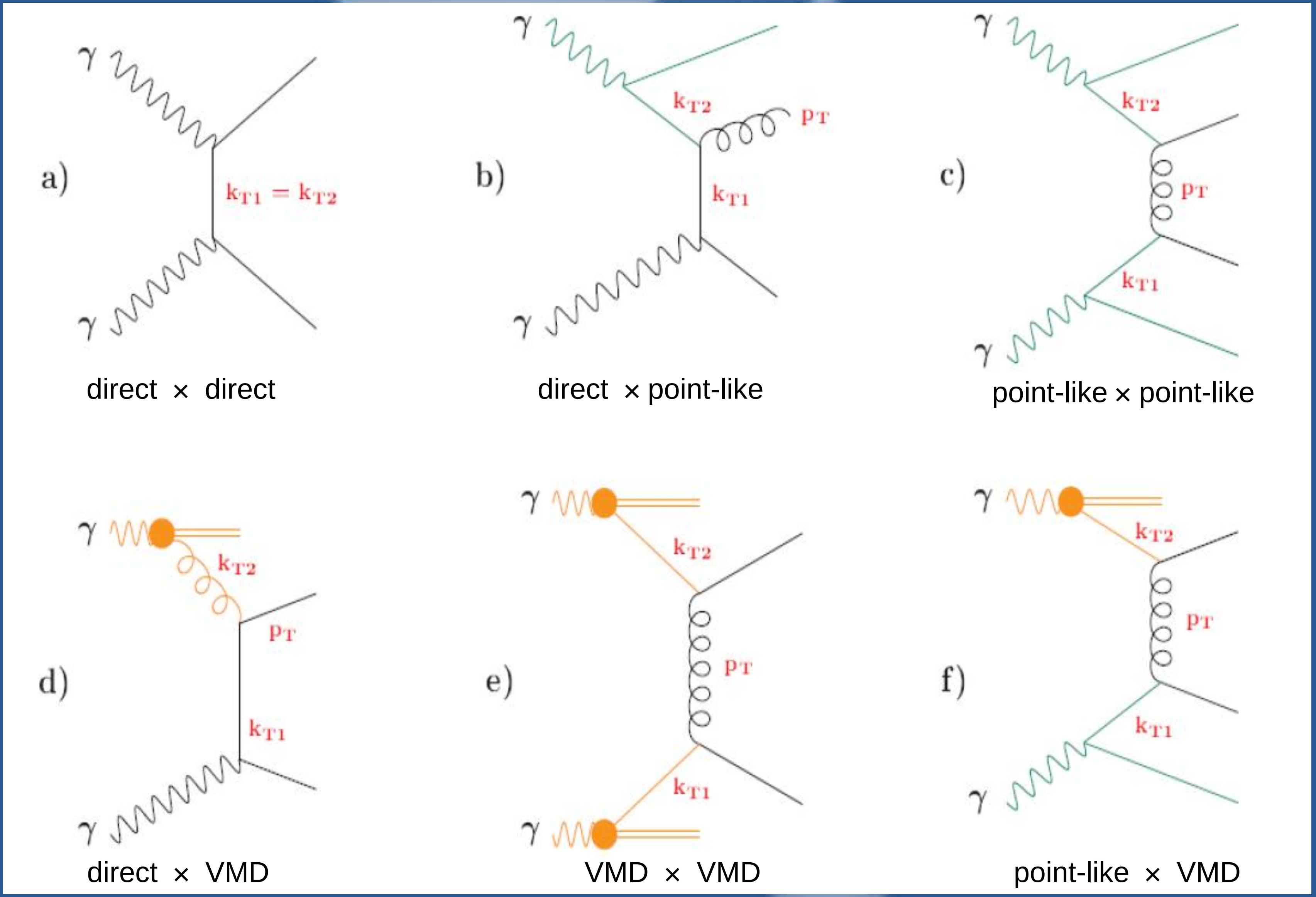
- *Direct* photon – if it interacts with another object as a whole quantity.
- *Resolved* photon – if it interacts through one of the fermions produced in the quantum fluctuation.



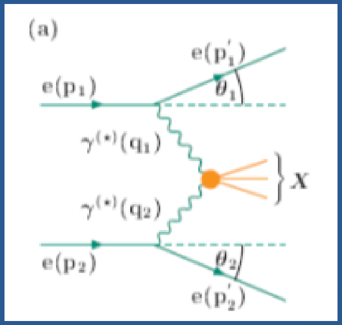
Photons & their interactions (II)

- If photon fluctuates into a pair of leptons, the process can be completely calculated within QED. Much more complicated situation – when it fluctuates into a pair of quarks (QCD interactions).
- Vector Meson Dominance (VMD) model – the photon turns first into a hadronic system with quantum numbers of a vector meson ($J^{CP}=1^{--}$) and the hard interaction takes place between partons of the vector meson and a probing object.
- *Hadron-like* and *point-like* contribution to the photon structure.

Event classes in the process γγ→hadrons



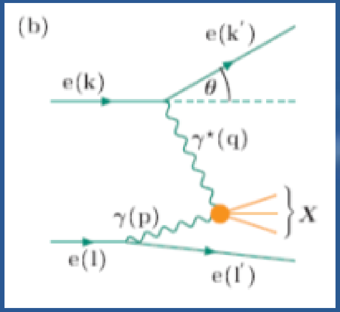
Two photon interactions at e^+e^- colliders (I)



General diagram

$e^+e^- \longrightarrow e^+e^-X$ → the classical way to investigate photon's structure at e^+e^- colliders

virtualities of the photons: $Q_i^2 \equiv -q_i^2 = -(p_i - p_i')^2$



Deep inelastic eγ scattering

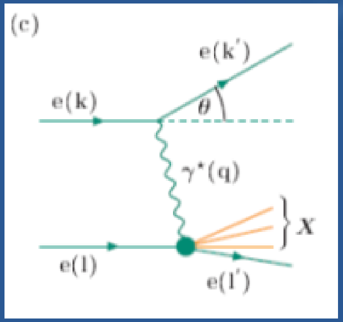
The usual dimensionless variables of deep inelastic scattering

$$x = \frac{Q_i^2}{2q_1 \cdot q_2}$$

fraction of parton momentum with respect to the target photon

$$y = \frac{q_1 \cdot q_2}{p_1 \cdot q_2}$$

the energy lost by the inelastically scattered electrons

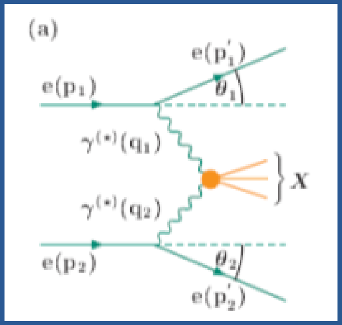


Deep inelastic ee scattering

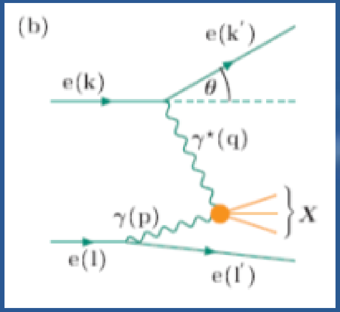
The hadronic (leptonic) invariant mass squared:

$$W^2 \equiv S_{\gamma\gamma} = (q_1 + q_2)^2$$

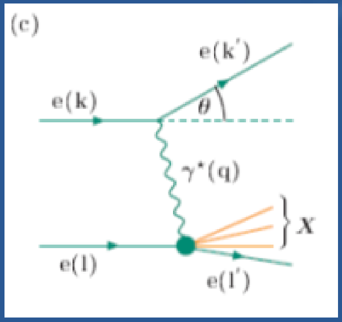
Two photon interactions at e^+e^- colliders (II)



General diagram



Deep inelastic eγ scattering



Deep inelastic ee scattering

$e^+e^- \longrightarrow e^+e^-X$

Experimentally the kinematical variables are obtained from the four-vectors of the tagged electrons and the hadronic final state:

$$Q_i^2 = 4E_\mathrm{b}E_i' \sin^2(\theta_i/2),$$

$$y_{\mathrm{e}i} = 1 - \frac{E_i'}{E_\mathrm{b}} \cos^2(\theta_i/2),$$

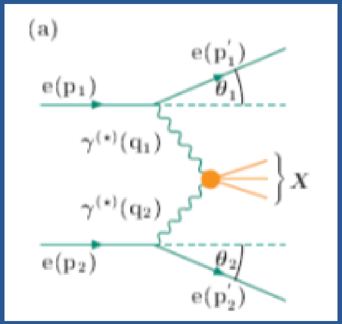
$$x_i = \frac{Q_i^2}{Q_1^2 + W^2 + Q_2^2},$$

$$z_i = \frac{Q_i^2}{y_{\mathrm{e}i} s_{\mathrm{ee}}} = \frac{E_i' \sin^2(\theta_i/2)}{E_\mathrm{b} - E_i' \cos^2(\theta_i/2)}.$$

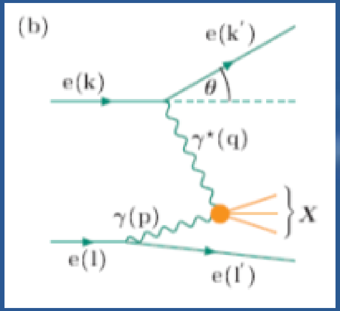
$$W^2 = \left(\sum_h E_h\right)^2 - \left(\sum_h \vec{p}_h\right)^2 .$$

E_b (E_i') – energy of the beam electrons (the scattered electrons)
E_h ($\vec{p}_h$) – energies (momenta) of final state particles

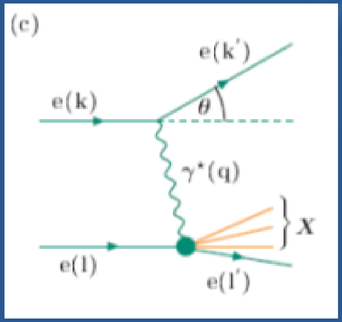
Two photon interactions at e^+e^- colliders (III)



General diagram



Deep inelastic eγ scattering



Deep inelastic ee scattering

$e^+e^- \longrightarrow e^+e^-X$

When the virtualities of the exchanged photons differ significantly the following notation is used:

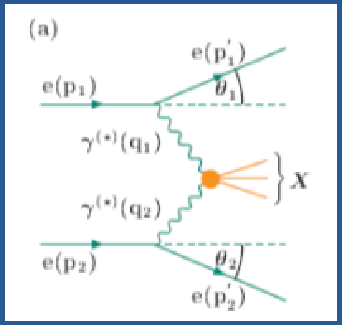
$$Q^2 \equiv -q^2 = \max(Q_1^2, Q_2^2)$$

$$P^2 \equiv -p^2 = \min(Q_1^2, Q_2^2)$$

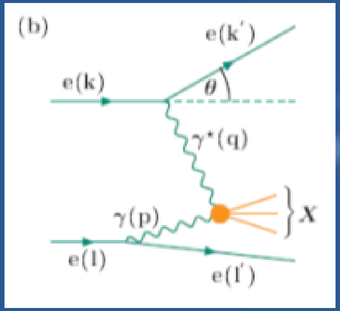
Then: $W^2 = Q^2({}^1/_x - 1) - P^2$

x, y refer to the photon with higher virtuality.

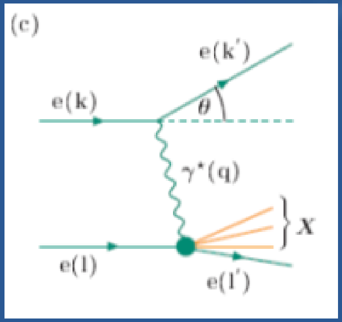
Two photon interactions at e^+e^- colliders (IV)



General diagram



Deep inelastic eγ scattering



Deep inelastic ee scattering

$e^+e^- \longrightarrow e^+e^-X$

From the experimental point of view three event classes are distinguished:

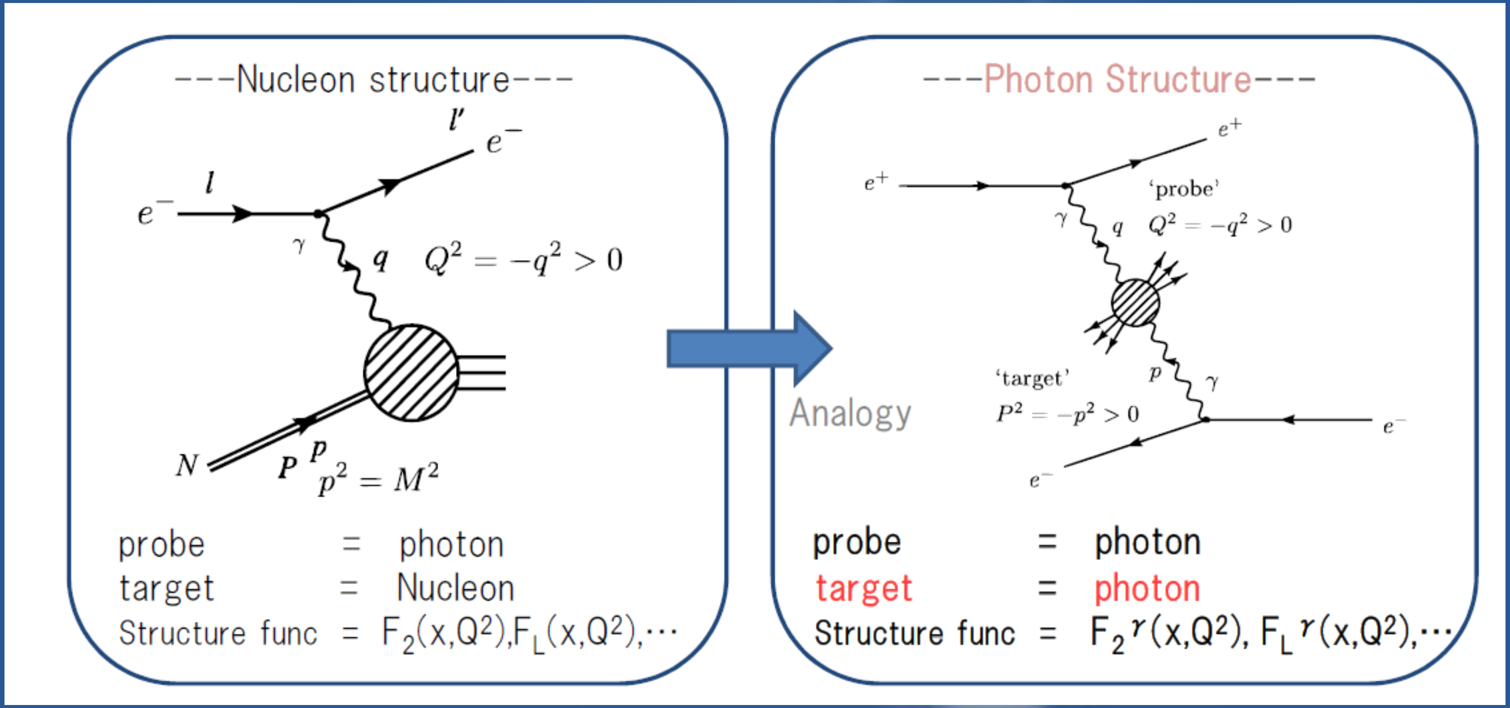
- anti-tagged → the structure of quasi-real photon can be studied in terms of total cross-sections, jet production and heavy quark production;
- single-tagged → deep-inelastic electron scattering off a quasi-real photon;
- double-tagged → highly virtual photon collisions

Photon structure function

Deep inelastic eγ scattering

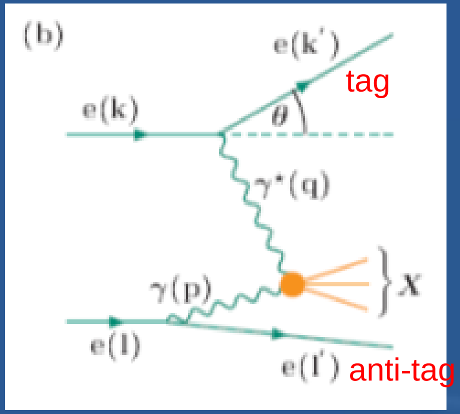
Analogy with studies of the proton structure functions at HERA

HERA LC



Photon structure function

Using single-tagged $\gamma\gamma$ events: deep inelastic $e\gamma$ scattering



The single-tagged events - one scattered electron tagged in the detector $\gamma\gamma$ process – deep inelastic electron scattering on a quasi-real photon. The flux of quasi-real photons can be calculated using Equivalent Photon Approximation (EPA).

The unpolarised $e\gamma$ DIS cross-section:

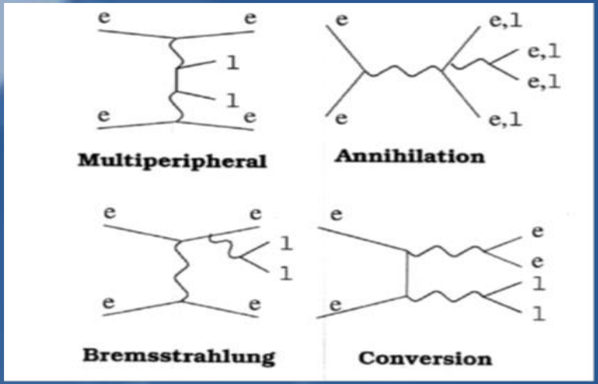
$$\frac{d\sigma(e\gamma \to eX)}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4} \cdot \left[\{1 + (1-y)^2\}F_2^\gamma(x,Q^2) - y^2 F_L^\gamma(x,Q^2)\right]$$

Structure functions of the quasi-real photon

If the photon momentum *p* is known, then Q^2, x, y, and W^2 are fixed by energy and angle of the tagged outgoing electron. If *p* is unknown, the determination of x has to proceed via calorimetric measurements of the hadronic final state.

QED structure function of the photon

QED processes:



The measurements of the QED photon structure functions at e^+e^- colliders are possible by studying the process $e^+e^- \to e^+e^- l^+l^-$ in deep inelastic photon scattering regime.

It is expected that the most clean measurement can be performed with $\mu^+\mu^-$ final state, because this process has large cross-section & is almost background free.

For e^+e^- final state $\longrightarrow$ the cross-section is even higher, but the number of different Feynman diagrams contributing to this process makes the analysis more difficult

For $\tau^+\tau^-$ final state $\longrightarrow$ low statistics, the final state can be only identified by detecting the products of τ decays

Event selection

At first we are concentrating on single-tagged events with electron measured in LumiCal . The optimal choice of the selection cuts to find a high efficiency for signal events is on going. They will include among others cuts like :

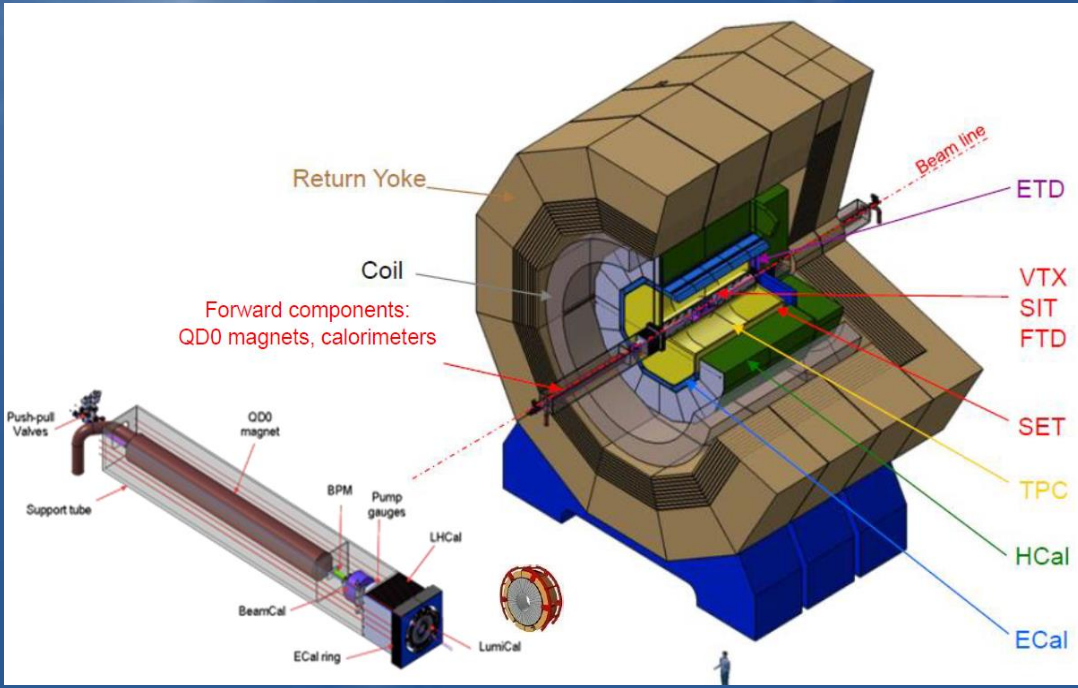
An electron candidate observed with energy $E_{tag} > 0.8E_b$ and polar angle in the range $31 < \theta < 77$ mrad.

There must be no deposit energy with value $E_a > 0.2E_b$ in the detector on the opposite side (an anti-tag cut applied for possible electron candidates in the hemisphere opposite to the tag electron) – low virtuality of the quasi-real photon

At least 3 tracks originated from the hadronic final state have to be present

The visible invariant mass W_{vis} of the hadronic system should be in some range $W_{low} < W_{vis} < W_{upper}$
The upper limit should reduce expected background of annihilation events.
Not yet defined precisely.

The W_{vis} will be reconstructed from tracks measured in tracking detectors together with energy depositions –clustrers in electromagnetic and hadronic calorimeters of the main detector ILD



Now and future prospects

- We learned how to use the ILCSoft (Mokka, Marlin) and DIRAC (event generation

  and date processing – grid environment)
- The beginning of the simulations in order to see what information can be obtained among others from LumiCal, BeamCal, LHCal detectors.
- For the time being we use the existing data generated for DBD in Whizard 1.95.
- We intend to generate the data using the latest version of Whizard and then other generators (e.g. Pythia, Twogam, Phojet).
- Researching the possibility to measure the photon structure function using forward detectors.

Future : studies of other two-photon processes at linear collider (ILC/CLIC)