Higgs production in e and real gamma collision

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QFThep 2013, June 29, Saint Petersburg Area, Russia

Outline

1. Introduction motivations
2. Higgs production in e and real γ collision in SM
3. Two-photon and Z-photon fusion diagrams
4. W-related and Z-related diagrams
5. Numerical analysis
6. Summary

1. Introduction and motivations

- A Higgs particle was found at the LHC

  Is it the SM Higgs boson , a SUSY Higgs boson,

  a Higgs boson of a different model?

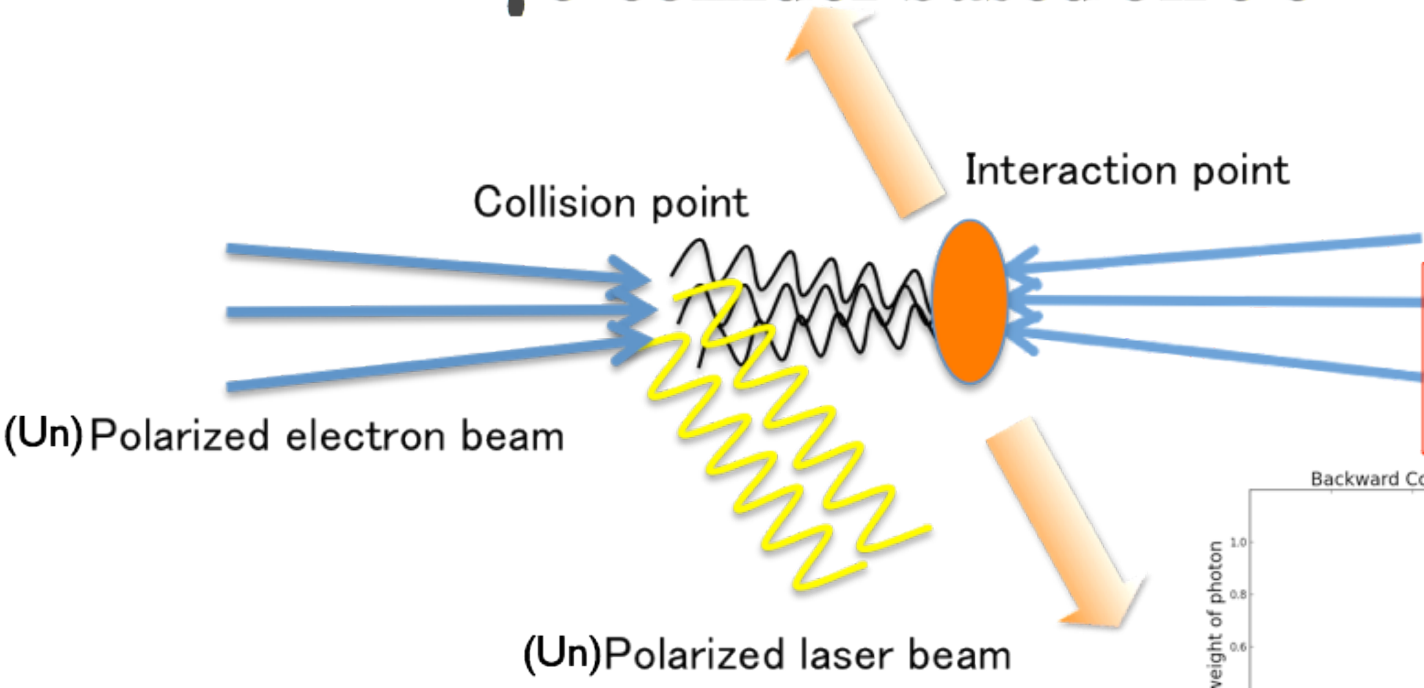
- Future linear collider : ILC
  - $\mathbf{e^+e^-}$ collider: $\sqrt{\mathbf{s}} = \mathbf{250}\ \mathrm{GeV} \cdots$
  - might be constructed in Japan ???

- Before e+ beams are ready,

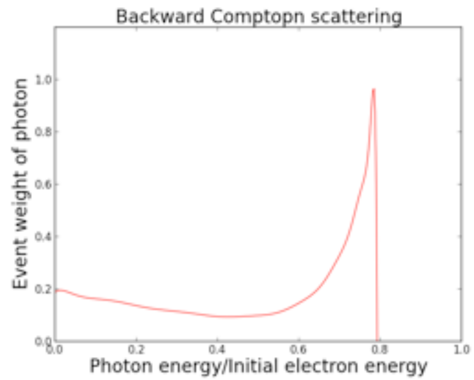
  other options are possible:
  - an $\mathbf{e^-e^-}$ option
  - an $\mathbf{e^-}\gamma$ option

    use one e- beam to produce high energy photons

γe^- collider based on e^-e^-



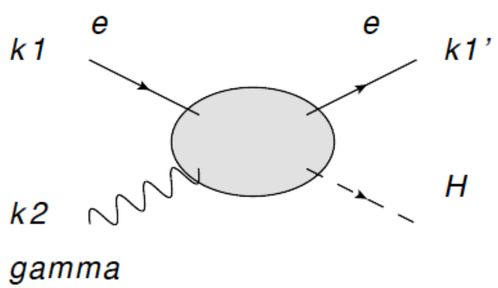
Compton scattering:
$e^- \gamma_{laser} \rightarrow e^- \gamma$
can transfer 80% of e- energy to γ



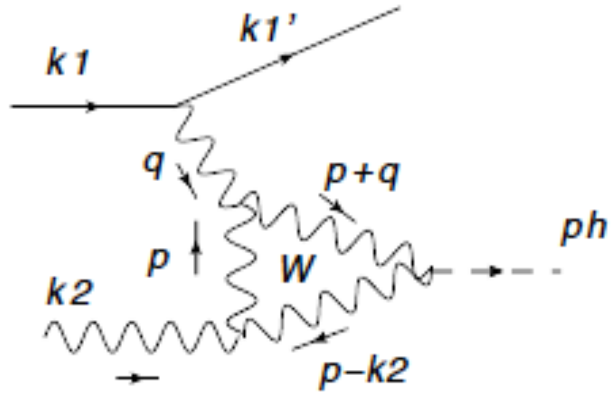
Good test for combining photon science & particle physics!!

2 Higgs production in e- and real γ collision in SM

- Higgs are produced by loop diagrams



an example



$$k_1^2 = {k'_1}^2 = m_e^2 = 0 \; ; \quad p_h^2 = m_h^2,$$

$$\begin{aligned} s &= (k_1 + k_2)^2 = 2k_1 \cdot k_2 \; , \quad t = (k_1 - k'_1)^2 = -2k_1 \cdot k'_1 = q^2, \\ u &= (k_1 - p_h)^2 = (k'_1 - k_2)^2 = -2k'_1 \cdot k_2 = m_h^2 - s - t \\ k_2^2 &= 0 \; , \qquad k_2^\beta \, \epsilon(k_2)_\beta = 0 \end{aligned}$$

3. Two-photon and Z-photon fusion diagrams

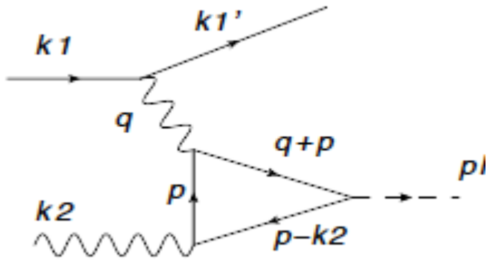
Calculation is done in unitary gauge

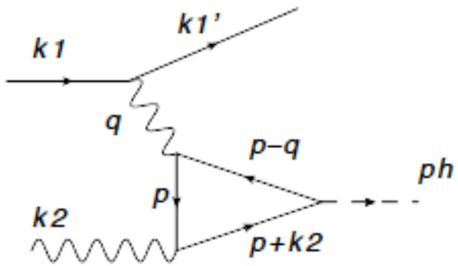
$e \cdot e \cdot \gamma$ coupling : $i(-e)\gamma_\mu$

$t \cdot t \cdot \gamma$ coupling : $i(q_t e)\gamma_\mu$

$e \cdot e \cdot Z$ coupling : $i\dfrac{g}{4\cos\theta_W}\gamma_\mu(f_{Ze}+\gamma_5)$ with $f_{Ze} = -1 + 4\sin^2\theta_W$

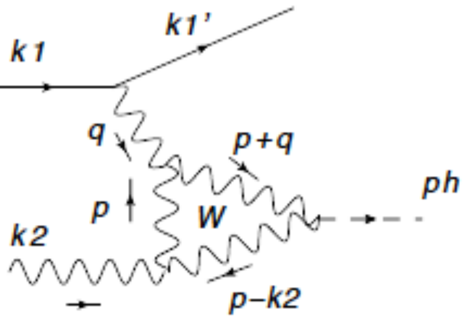
$t \cdot t \cdot Z$ coupling : $i\,\dfrac{g}{4\cos\theta_W}\gamma_\mu\left[f_{Zt}-\gamma_5\right]$ with $f_{Zt} = 1 - \dfrac{8}{3}\sin^2\theta_W$

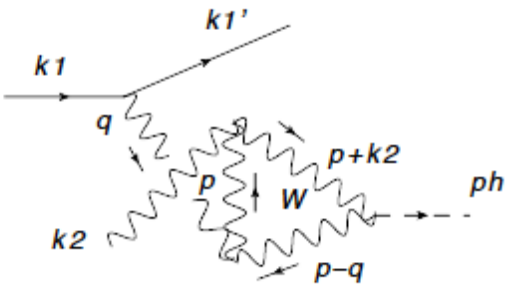


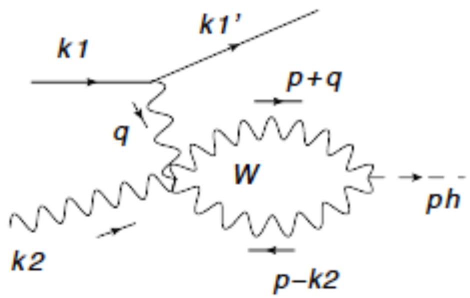


Higgs $\cdot\, t \cdot t$ coupling : $-i\,\dfrac{gm_t}{2m_W}$

Higgs $\cdot\, W \cdot W$ coupling : $igm_W\, g_{\mu\nu}$







$Z_\mu(k_1)$-$W_\nu^+(k_2)$-$W_\lambda^-(k_3)$ coupling: $-ig\cos\theta_W\left[(k_1-k_2)_\lambda g_{\mu\nu} + (k_2-k_3)_\mu g_{\nu\lambda} + (k_3-k_1)_\nu g_{\lambda\mu}\right]$

A_μ-Z_ν-W_α^+-W_β^- coupling: $-ieg\cos\theta_W\left[2g_{\mu\nu}g_{\alpha\beta} - g_{\mu\alpha}g_{\nu\beta} - g_{\mu\beta}g_{\nu\alpha}\right]$

3. Two-photon and Z-photon fusion diagrams

- Contribution of two-photon fusion diagrams
  - Top quark loops:

$$A_{(T)} = \left(\frac{i}{16\pi^2}\right)\left[\overline{u}(k_1')\gamma_\mu u(k_1)\right]\frac{1}{t}\left(g^{\mu\beta} - \frac{2k_2^\mu q^\beta}{m_h^2 - t}\right)\epsilon_\beta(k_2) \times 2e^3 g \frac{q_t^2 m_t^2}{m_W} S_T^a(t, m_t^2, m_h^2)$$

$$\begin{aligned} S_T^a(t, m_t^2, m_h^2) &= 2 - \frac{2t}{m_h^2 - t} B_0(t; m_t^2, m_t^2) + \frac{2t}{m_h^2 - t} B_0(m_h^2; m_t^2, m_t^2) \\ &\quad + \left\{4m_t^2 - m_h^2 + t\right\} C_0(m_h^2, 0, t; m_t^2, m_t^2, m_t^2) \end{aligned}$$

$$B_0(p^2; m_1^2, m_2^2) \equiv \frac{(2\pi\mu)^{4-n}}{i\pi^2} \int \frac{d^n k}{\left[k^2 - m_1^2\right]\left[(k+p)^2 - m_2^2\right]}$$

$$C_0(p_1^2, p_2^2, p_3^2; m_1^2, m_2^2, m_3^2) \equiv \frac{(2\pi\mu)^{4-n}}{i\pi^2} \int \frac{d^n k}{\left[k^2 - m_1^2\right]\left[(k+p_1)^2 - m_2^2\right]\left[(k+p_1+p_2)^2 - m_3^2\right]}$$

  - W boson loops:

$$A_W^{\gamma\gamma} = \left(\frac{i}{16\pi^2}\right)\left[\overline{u}(k_1')\gamma_\mu u(k_1)\right]\frac{1}{t}\left(g^{\mu\beta} - \frac{2k_2^\mu q^\beta}{m_h^2 - t}\right)\epsilon_\beta(k_2) \times (-e^3 g m_W)\ S_{W\,(\mathrm{total})}^a(t, m_W^2, m_h^2)$$

$S_{W\,(\mathrm{total})}^a(t, m_W^2, m_h^2)$: expressed as a linear combination of

$$B_0(t; m_W^2, m_W^2) \qquad B_0(m_h^2; m_W^2, m_W^2) \qquad C_0(m_h^2, 0, t; m_W^2, m_W^2, m_W^2)$$

3. Two-photon and Z-photon fusion diagrams

- Contribution of Z-photon fusion diagrams
  - Top quark loops:

$$A_{(T)} = \left(\frac{i}{16\pi^2}\right)\left[\overline{u}(k_1')\gamma_\mu\left(f_{Ze}+\gamma_5\right)u(k_1)\right]\frac{1}{t-m_Z^2}\left(g^{\mu\beta}-\frac{2k_2^\mu q^\beta}{m_h^2-t}\right)\epsilon_\beta(k_2)\ \times\left(-\frac{eg^3 q_t f_{Zt}}{8\cos^2\theta_W}\right)\frac{m_t^2}{m_W}\ S_T^a(t,m_t^2,m_h^2)$$

  - W boson loops:

$$A_W = \left(\frac{i}{16\pi^2}\right)\left[\overline{u}(k_1')\gamma_\mu\left(f_{Ze}+\gamma_5\right)u(k_1)\right]\frac{1}{t-m_Z^2}\left(g^{\mu\beta}-\frac{2k_2^\mu q^\beta}{m_h^2-t}\right)\epsilon^\beta(k_2)$$
$$\times\left(\frac{eg^3 m_W}{4}\right)\ S^a_{W\,(\mathrm{total})}(t,m_W^2,m_h^2)$$

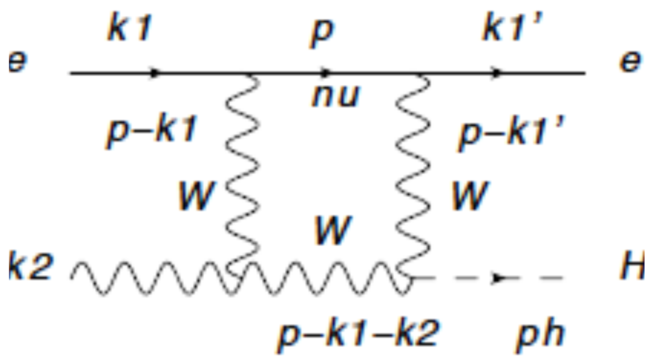
The contribution of two-photon and Z-photon fusion diagrams have the same transition form factors

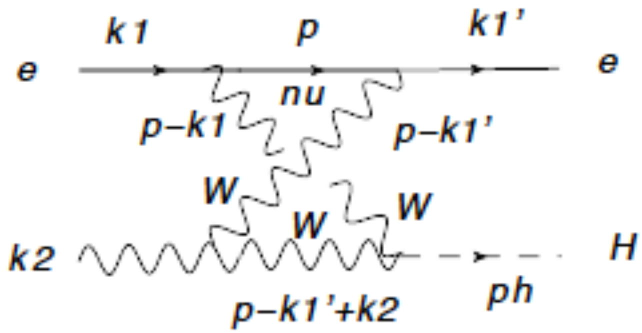
$$S_T^a(t,m_t^2,m_h^2) \qquad S^a_{W\,(\mathrm{total})}(t,m_W^2,m_h^2)$$

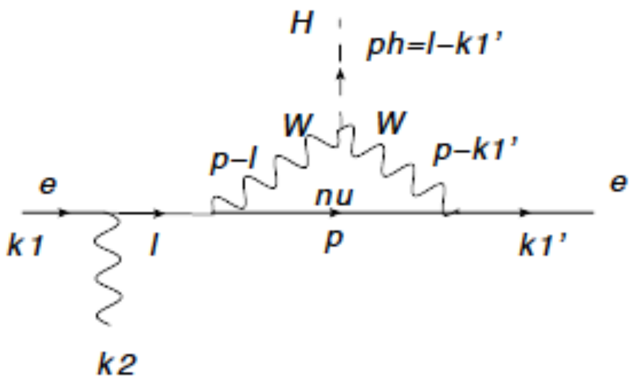
4. W-related and Z-related diagrams

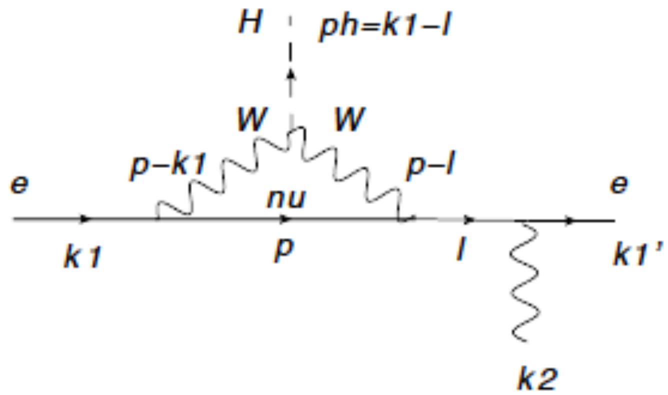
- GRACE gives other contributions to Higgs production in e- γ collision

$e \cdot \nu \cdot W$ coupling : $i\frac{g}{2\sqrt{2}}\gamma_\mu(1-\gamma_5)$





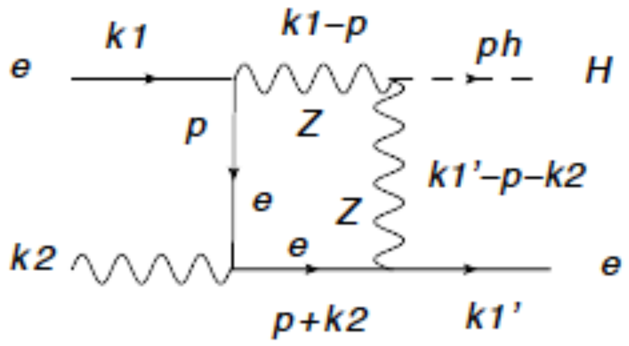


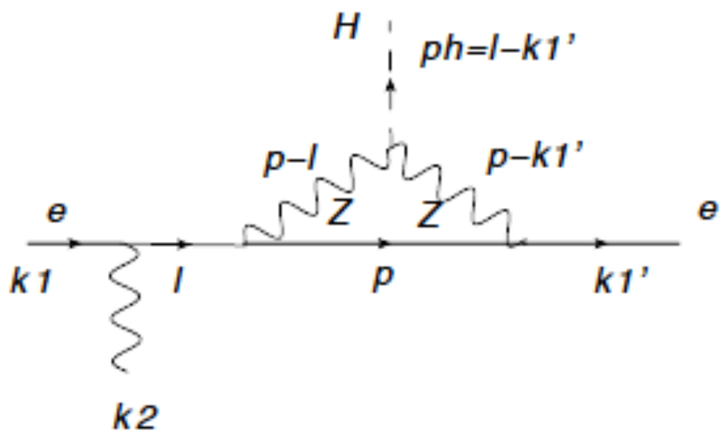


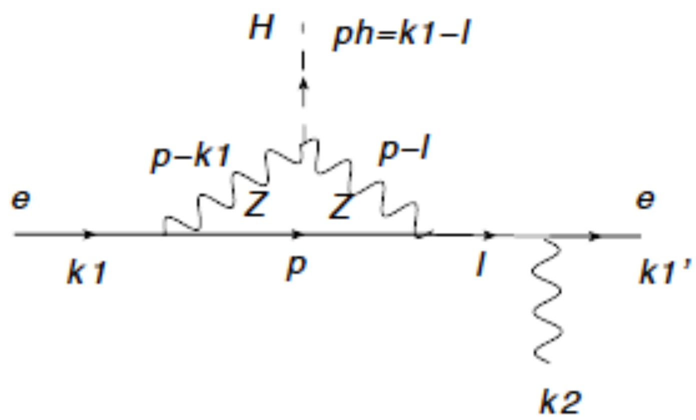
4. W-related and Z-related diagrams

$e \cdot e \cdot Z$ coupling : $i\frac{g}{4\cos\theta_W}\gamma_\mu(f_{Z_e}+\gamma_5)$ with $f_{Z_e} = -1 + 4\sin^2\theta_W$

Higgs $\cdot Z \cdot Z$ coupling : $i\frac{g m_Z}{\cos\theta_W} g_{\mu\nu}$







4. W-related and Z-related diagrams

- Contribution of W-related diagrams

$$A^{W}_{e\gamma\to eH} = \frac{eg^3 m_W}{4} \times \left[\overline{u}(k_1')\ F^{W}_{(e\gamma\to eH)\beta}\ (1-\gamma_5)u(k_1)\right]\epsilon(k_2)^{\beta}$$

$$F^{W}_{(e\gamma\to eH)\beta} = \left(k_{1_\beta}\not{k}_2 - \frac{s}{2}\gamma_\beta\right) S^{(W)(k_{1_\beta})}_{(e\gamma\to eH)}(s,t,m_h^2,m_W^2) + \left(k'_{1_\beta}\not{k}_2 + \frac{u}{2}\gamma_\beta\right) S^{(W)(k'_{1_\beta})}_{(e\gamma\to eH)}(s,t,m_h^2,m_W^2)$$

where

$S^{(W)(k_{1_\beta})}_{(e\gamma\to eH)}(s,t,m_h^2,m_W^2)$ and $S^{(W)(k'_{1_\beta})}_{(e\gamma\to eH)}(s,t,m_h^2,m_W^2)$

expressed as a linear combination of

$$B_0(s;0,m_W^2) \quad B_0(u;0,m_W^2) \quad B_0\left(t;m_W^2,m_W^2\right) \quad B_0\left(m_h^2;m_W^2,m_W^2\right)$$

$$C_0\left(0,0,s;m_W^2,m_W^2,0\right) \quad C_0\left(0,0,u;m_W^2,m_W^2,0\right) \quad C_0\left(0,0,t;m_W^2,0,m_W^2\right)$$

$$C_0\left(0,s,m_h^2;m_W^2,0,m_W^2\right) \quad C_0\left(0,u,m_h^2;m_W^2,0,m_W^2\right) \quad C_0\left(0,t,m_h^2;m_W^2,m_W^2,m_W^2\right)$$

$$D_0\left(0,0,0,m_h^2;s,t;m_W^2,m_W^2,0,m_W^2\right) \quad D_0\left(0,0,0,m_h^2;t,u;m_W^2,0,m_W^2,m_W^2\right)$$

4. W-related and Z-related diagrams

- Contribution of Z-related diagrams

$$A^{Z}_{e\gamma\to eH} = -\frac{eg^3 m_Z}{16\cos^3\theta_W} \times \left[\overline{u}(k_1')\, F^{Z}_{(e\gamma\to eH)\beta}\, (f_{Ze}+\gamma_5)^2 u(k_1)\right]\epsilon(k_2)^{\beta}$$

$$F^{Z}_{(e\gamma\to eH)\beta} = \left(k_{1_\beta}\not{k}_2 - \frac{s}{2}\gamma_\beta\right) S^{(Z)(k_{1_\beta})}_{(e\gamma\to eH)}(s,t,m_h^2,m_Z^2) + \left(k'_{1_\beta}\not{k}_2 + \frac{u}{2}\gamma_\beta\right) S^{(Z)(k'_{1_\beta})}_{(e\gamma\to eH)}(s,t,m_h^2,m_Z^2)$$

where

$S^{(Z)(k_{1_\beta})}_{(e\gamma\to eH)}(s,t,m_h^2,m_Z^2)$ and $S^{(Z)(k'_{1_\beta})}_{(e\gamma\to eH)}(s,t,m_h^2,m_Z^2)$

: expressed as a linear combination of

$B_0(s;0,m_Z^2)$ $\quad B_0(u;0,m_Z^2)$ $\quad B_0\left(m_h^2;m_Z^2,m_Z^2\right)$

$C_0\left(0,0,s;m_Z^2,0,0\right)$ $\quad C_0\left(0,0,u;m_Z^2,0,0\right)$ $\quad C_0\left(0,s,m_h^2;m_Z^2,0,m_Z^2\right)$ $\quad C_0\left(0,u,m_h^2;m_Z^2,0,m_Z^2\right)$

$D_0\left(0,0,0,m_h^2;s,u;m_Z^2,0,0,m_Z^2\right)$

- Collinear divergences appear in $C_0\left(0,0,s;m_Z^2,0,0\right)$ $C_0\left(0,0,u;m_Z^2,0,0\right)$ $D_0\left(0,0,0,m_h^2;s,u;m_Z^2,0,0,m_Z^2\right)$

  but they are cancel out when they are added

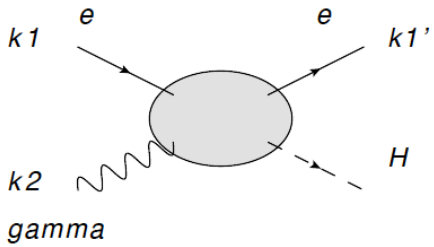
5. Numerical analysis

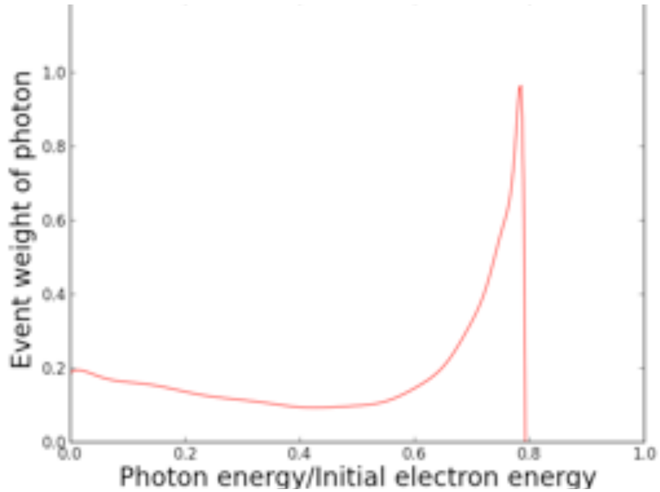
A preliminary numerical analysis has been done,
but we need a more detailed analysis

- Compton scattering:
  $e^- \gamma_{laser} \to e^- \gamma$
- can transfer 80% of e- energy to γ

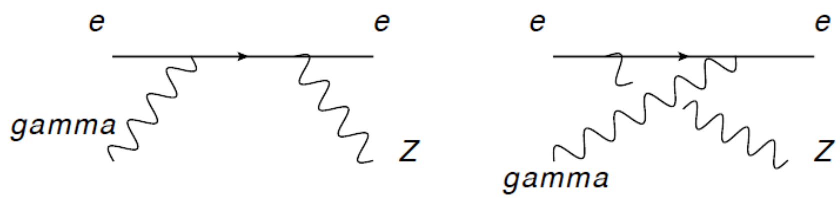
Since a photon beam has a energy band,
we examine a missing energy spectrum

$$\frac{d\sigma}{dE_{\rm miss}} \qquad E_{\rm miss} = \sqrt{(k_1 + k_2 - k_1')^2}$$





Main background

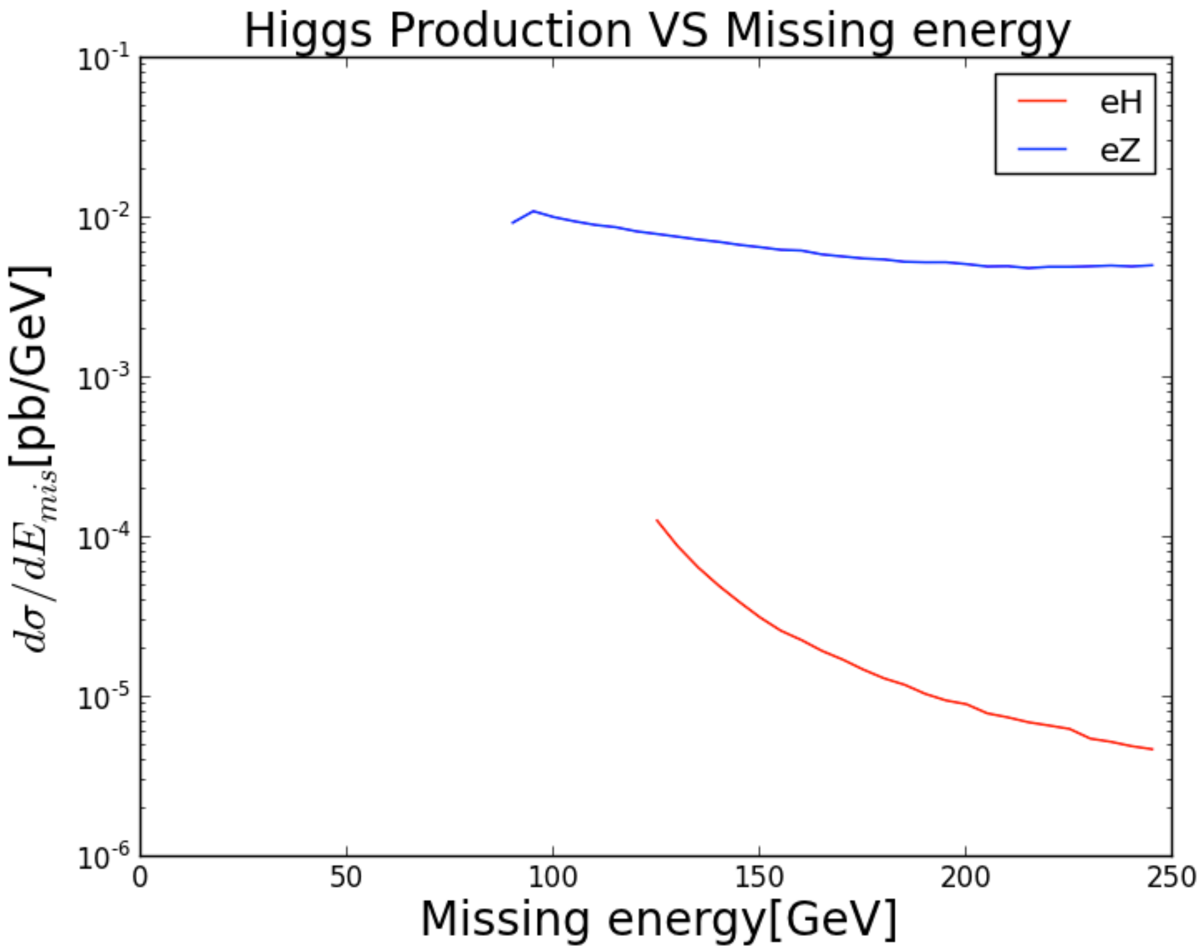


5. Numerical analysis

$E_e = 125\text{GeV}$

$E_\gamma = 0.8 \times E_e$ or less

Preliminary



5. Numerical analysis

- A background $e + \gamma \Longrightarrow e + Z$ is too large
  We need to consider Higgs decay channels,
  for an example, detection of the final states with $e \text{ and two } \gamma \text{ s}$

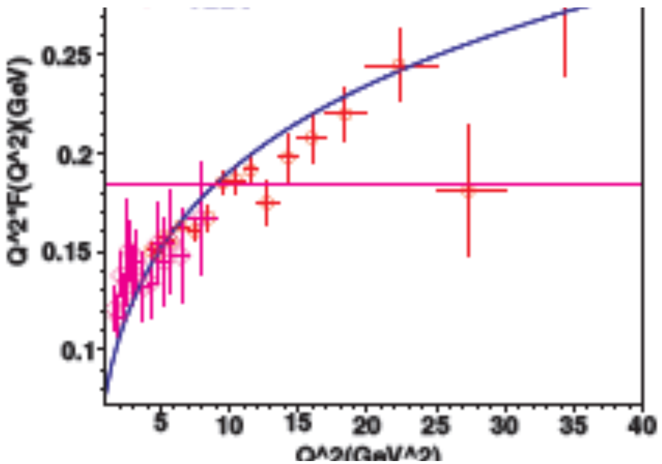
6. Summary

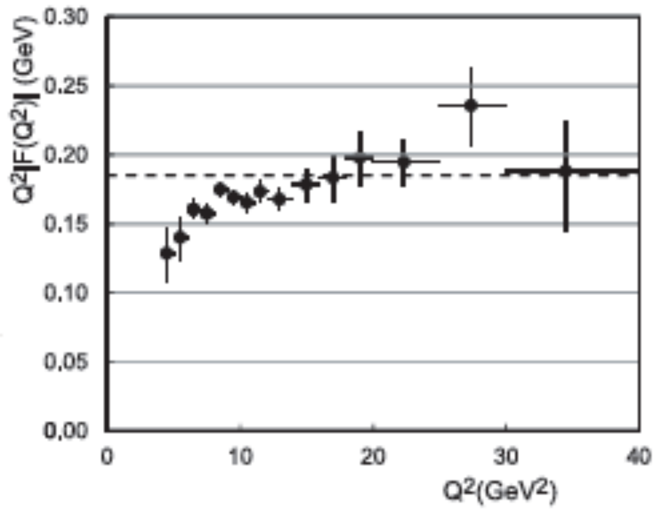
- Higgs production in $\mathbf{e}^{-}\gamma$ collision was investigated in SM.
- The EW one-loop contributions to the amplitude $e + \gamma \Longrightarrow e + H$ were obtained in analytical form.
- A preliminary numerical analysis was performed for the cross section vs missing energy.

- A more detailed analysis for this Higgs production process is necessary.

Thank you

$\gamma\gamma^*(Q^2) \to \pi^0$ transition form factor





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