

$$e^+e^- \rightarrow V_0V_0$$

and

Anomalous Higgs Sector

Juan Alcaraz
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- $e^+e^- \rightarrow \gamma\gamma$ channel

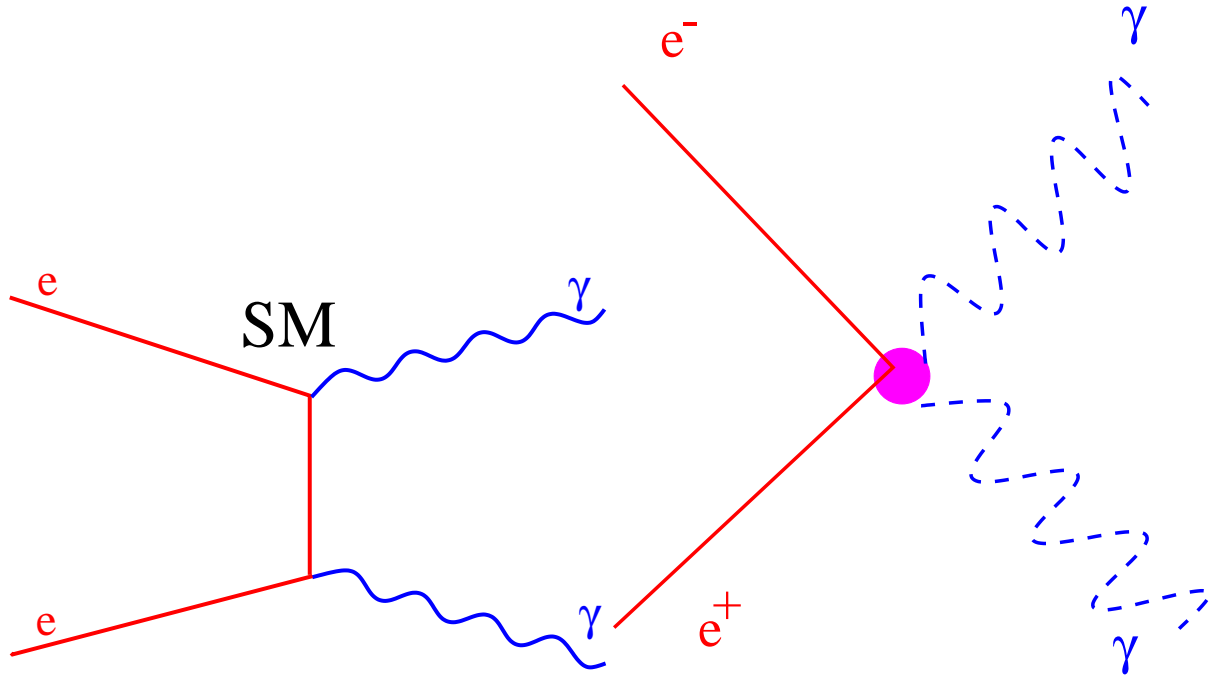
- $e^+e^- \rightarrow Z\gamma$ channel

- $e^+e^- \rightarrow ZZ$ channel

- $e^+e^- \rightarrow H\gamma$ channel

- Summary

Deviations from QED through contact interactions



$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega} \right)_{\text{QED}} \left(1 + \frac{\lambda}{\Lambda_6^4} \frac{s^2}{\alpha} \sin^2\theta \right)$$

Physical examples:

$$m_{e^*} = \left(\frac{\alpha}{4} \right)^{1/4} \Lambda_6$$

$$M_{\text{gravity}} = \left(\frac{1}{2\pi} \right)^{1/4} \Lambda_6$$

\sqrt{s} -independent angular distributions and analysis

- $\sigma_{\text{QED}} \propto \frac{1}{s}$
(≈ 1.5 pb for $\sqrt{s} = 500$ GeV, 15° cut)
- Limit on $\Lambda_6 \approx 12 [\text{Lum}]^{1/8} [\sqrt{s}]^{3/4}$
(95% CL, energies in GeV, luminosity in pb^{-1})

$\sqrt{s} = 500$ GeV with 10 fb^{-1} :

$$\frac{\Delta\sigma_{\text{QED}}}{\sigma_{\text{QED}}} \approx 0.8\% \text{ (stat.) (15}^\circ \text{ cut)}$$

$$\Lambda_6 > 4 \text{ TeV } (\lambda = 1, 95\% \text{ CL})$$

$\sqrt{s} = 500$ GeV with 100 fb^{-1} :

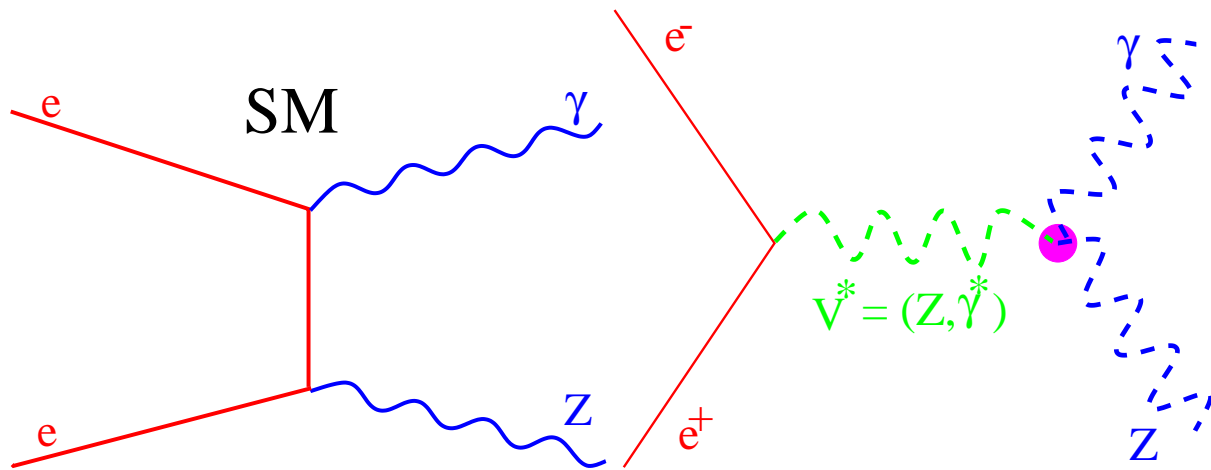
$$\frac{\Delta\sigma_{\text{QED}}}{\sigma_{\text{QED}}} \approx 0.3\% \text{ (stat.) (15}^\circ \text{ cut)}$$

$$\Lambda_6 > 5.4 \text{ TeV } (\lambda = 1, 95\% \text{ CL})$$

$$m_{e^*} > 1.1 \text{ TeV } (\lambda = 1, 95\% \text{ CL})$$

$$M_{\text{gravity}} \gtrsim 3 \text{ TeV } (\lambda = 1, 95\% \text{ CL})$$

Anomalous $ZZ\gamma$, $Z\gamma\gamma$ couplings in $e^+e^- \rightarrow Z\gamma$:



8 possible anomalous terms: h_i^Z, h_i^γ ; $i = 1, 4$

$h_1, h_2 \rightarrow$ CP violating

$h_3, h_4 \rightarrow$ CP conserving

SM expectation: $h_3^Z \approx 2 \cdot 10^{-4}$ at 1 loop

$SU(2)_L \times U(1)_Y$ extensions: dim-8 operators,
which can be large for $\Lambda_{\text{new}} \lesssim 3 \text{ TeV}$

DIM-8 deviations: $\sim v^2/\Lambda^4$ (tree level)

DIM-6 deviations: $\sim 1/(16\pi^2\Lambda^2)$ (1 loop)

Main signature: γ excess at large polar angles

15000 PYTHIA $e^+e^- \rightarrow Z\gamma$ events (SIMDETV3):

- $\sigma = 6.4 \text{ pb}$

$e^+e^- \rightarrow Z\gamma \rightarrow q\bar{q}\gamma$ event selection:

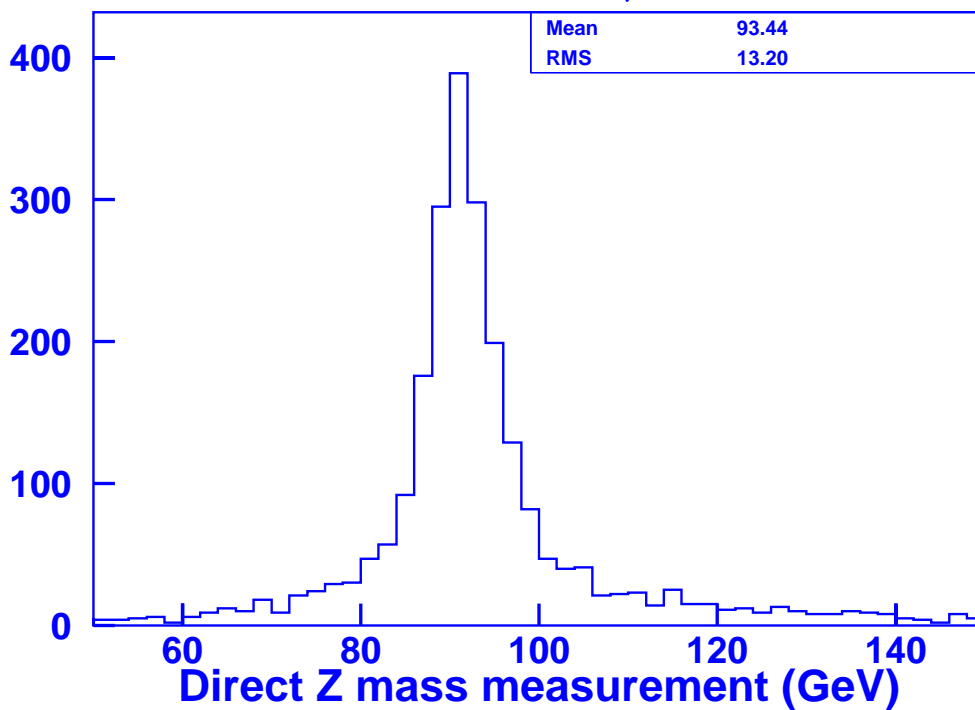
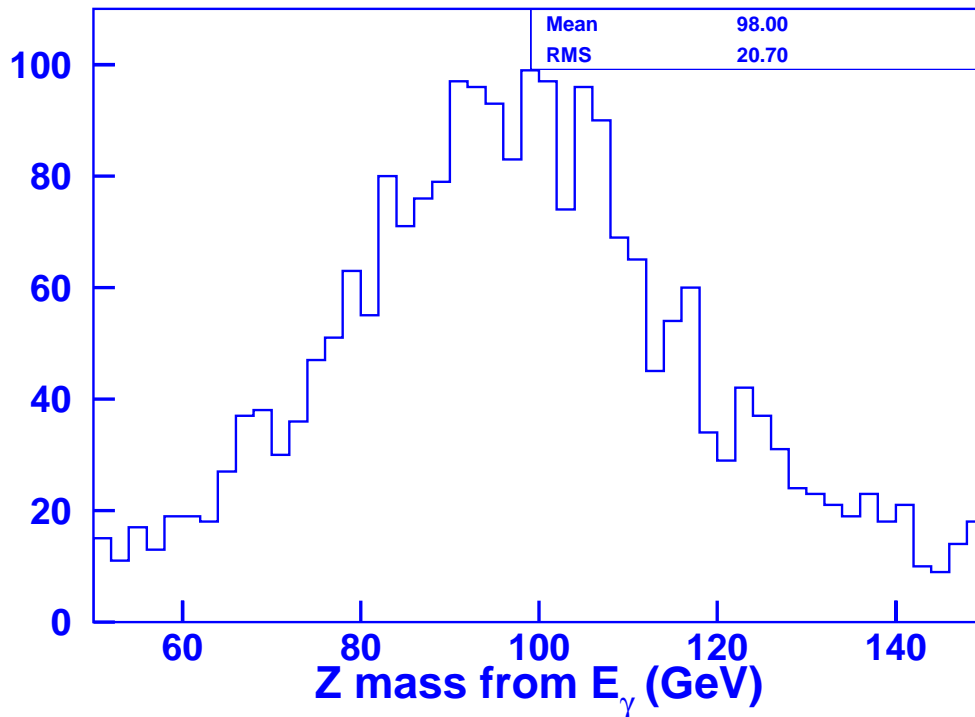
- Track multiplicity cut
- $|\cos\theta_\gamma| < 0.8$
- Neutral object with $E_{ECAL} > 225 \text{ GeV}$

Cross section measurement:

- Acceptance: $(16.6 \pm 0.3)\%$
- $\Delta\sigma/\sigma = 1.5\%$ for 10 fb^{-1}
- $\Delta\sigma/\sigma = 0.5\%$ for 100 fb^{-1}

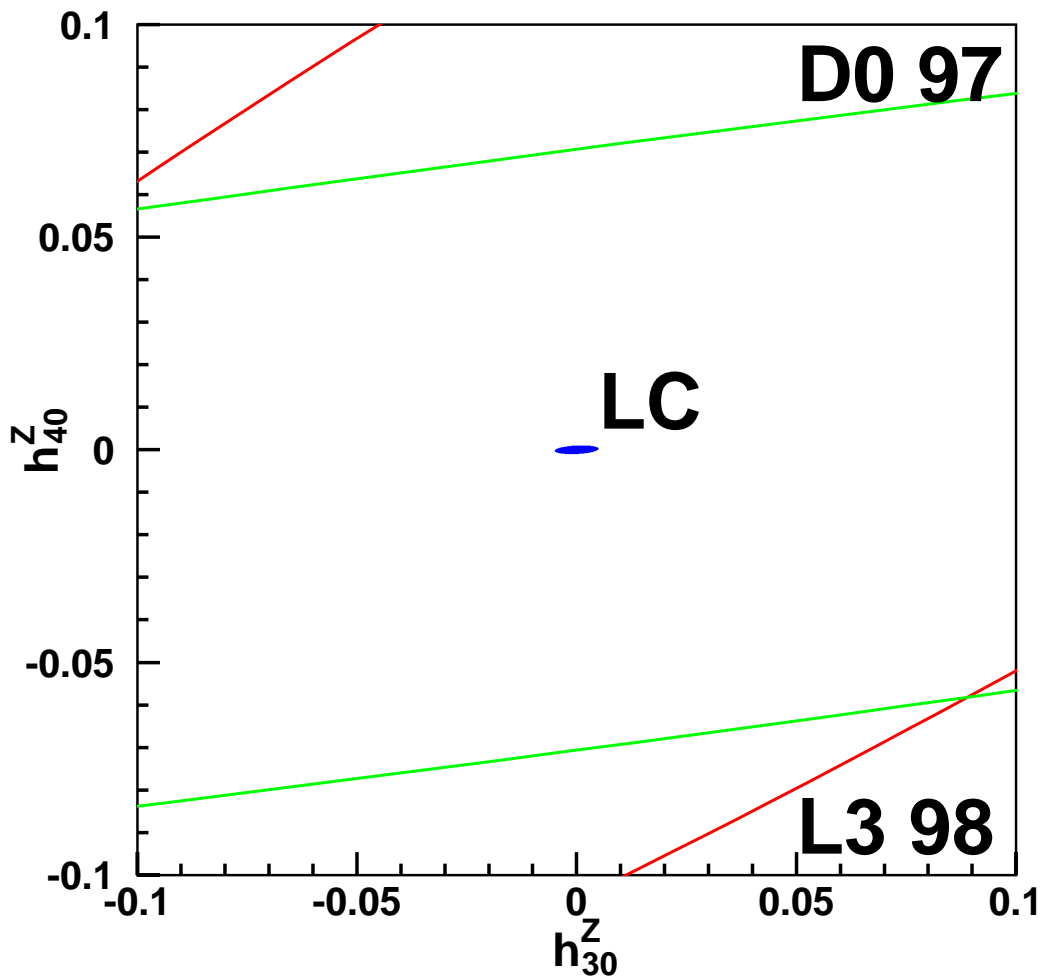
Expected sensitivity on $ZZ\gamma$ anomalous couplings:

- $|h_3^Z| > 0.0085$ at 95% CL with 10 fb^{-1}
- $|h_3^Z| > 0.005$ at 95% CL with 100 fb^{-1}



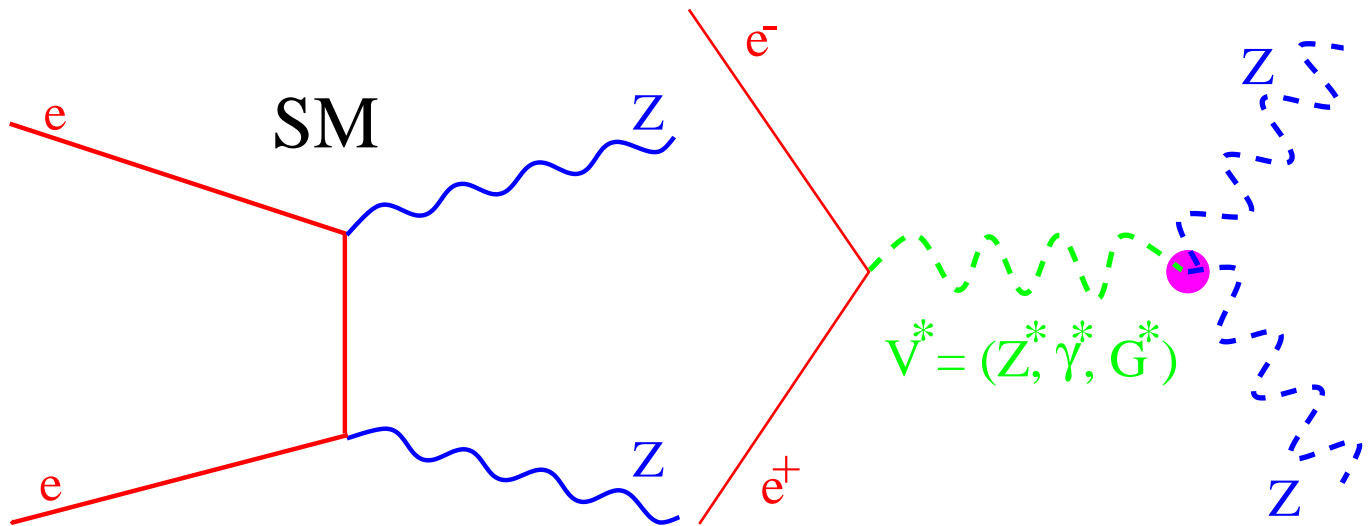
Best resolution from the hadronic system

Sensitivity at the e^+e^- linear collider (100 fb^{-1})



- Testing anomalous contributions ~ 10 times SM
- Conservative estimate: full phase space analysis and beam polarization not considered

Anomalous contributions to $e^+e^- \rightarrow ZZ$:



4 anomalous ZZV_0 couplings: $f_i^Z, f_i^\gamma; i = 4, 5$

$f_4 \rightarrow$ CP violating ($\sim g_4$ in WWV_0)

$f_5 \rightarrow$ CP conserving ($\sim g_5$ in WWV_0)

SM expectation: zero at tree level

Gravity at low energies: virtual graviton exchange

Main anomalous signature: excess of ZZ events

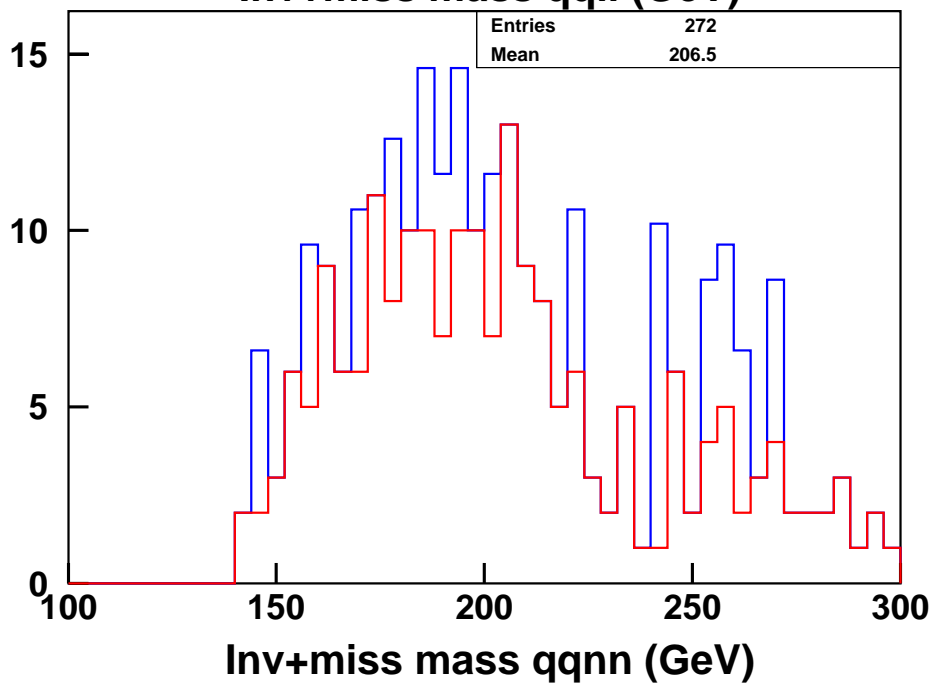
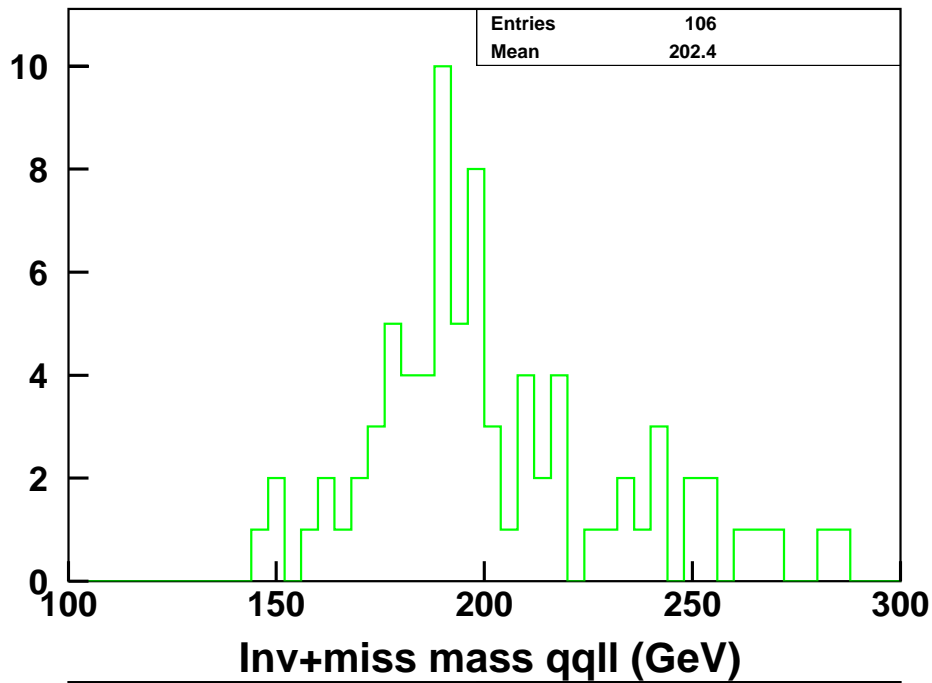
Only “clean” channels studied
PYTHIA used (technically simpler)
2000 events simulated (SIMDETV3)

$e^+e^- \rightarrow q\bar{q}\ell^+\ell^-$ selection:

- Track multiplicity cut
- 2 leptons with $70 \text{ GeV} < M_{\ell^+\ell^-} < 150 \text{ GeV}$
- Recoiling mass (measured from $\ell^+\ell^-$) $> 50 \text{ GeV}$
- $|\cos\theta_e| < 0.8$ for electrons (PYTHIA)

$e^+e^- \rightarrow q\bar{q}\nu\bar{\nu}$ selection:

- Track multiplicity cut
- $70 \text{ GeV} < M_{q\bar{q}} < 150 \text{ GeV}$
- Recoiling mass (measured from $q\bar{q}$) $> 50 \text{ GeV}$
- $E_T > 20\% E_{\text{vis}}$ (reject $q\bar{q}\gamma$)
- No e, μ in the “empty” hemisphere (reject WW)



Dominant background: WW for $q\bar{q}\nu\bar{\nu}$
Higgs signal NOT CONSIDERED

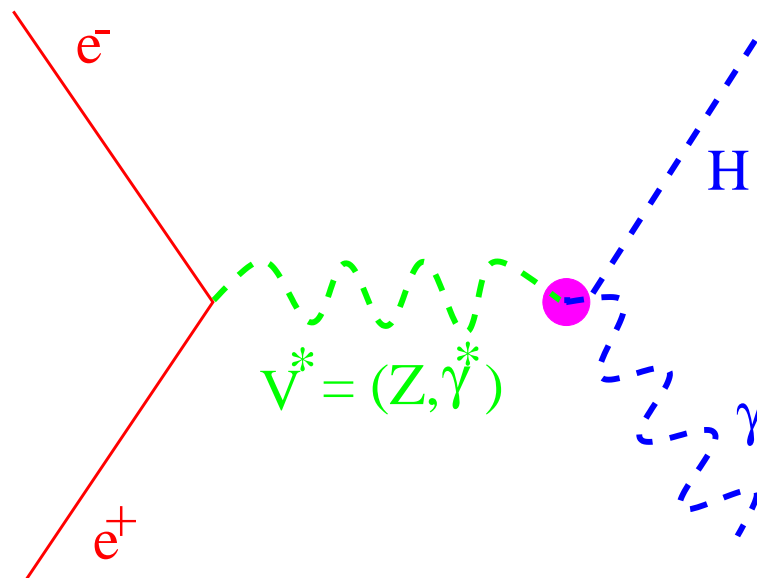
Results:

- $\sigma = 0.7$ pb (PYTHIA $e^+e^- \rightarrow Z/\gamma Z/\gamma$)
- Acceptance: $(17.5 \pm 0.9)\%$
- WW background: $(29 \pm 6)\%$ (from $q\bar{q}\nu\bar{\nu}$)
- $q\bar{q}\gamma$ background: $(0.7 \pm 0.4)\%$ (from $q\bar{q}\nu\bar{\nu}$)
- $t\bar{t} \rightarrow b\bar{b}\ell^+\ell^-\nu\bar{\nu}$ contribution not studied yet
- $\Delta\sigma/\sigma = 3.5\%$ for 10 fb^{-1}
- $\Delta\sigma/\sigma = 1.1\%$ for 100 fb^{-1}

Expected sensitivity on anomalous effects:

- 10 fb^{-1} : $|f_5^Z| < 0.009$ (95% CL)
- 100 fb^{-1} : $|f_5^Z| < 0.005$ (95% CL)
- 100 fb^{-1} : $M_{\text{gravity}} \gtrsim 3 \text{ TeV}$ ($\lambda = 1$, 95% CL)
- Huge improvement with respect to LEP2

Anomalous $H\gamma\gamma$, $HZ\gamma$ couplings in $e^+e^- \rightarrow H\gamma$:

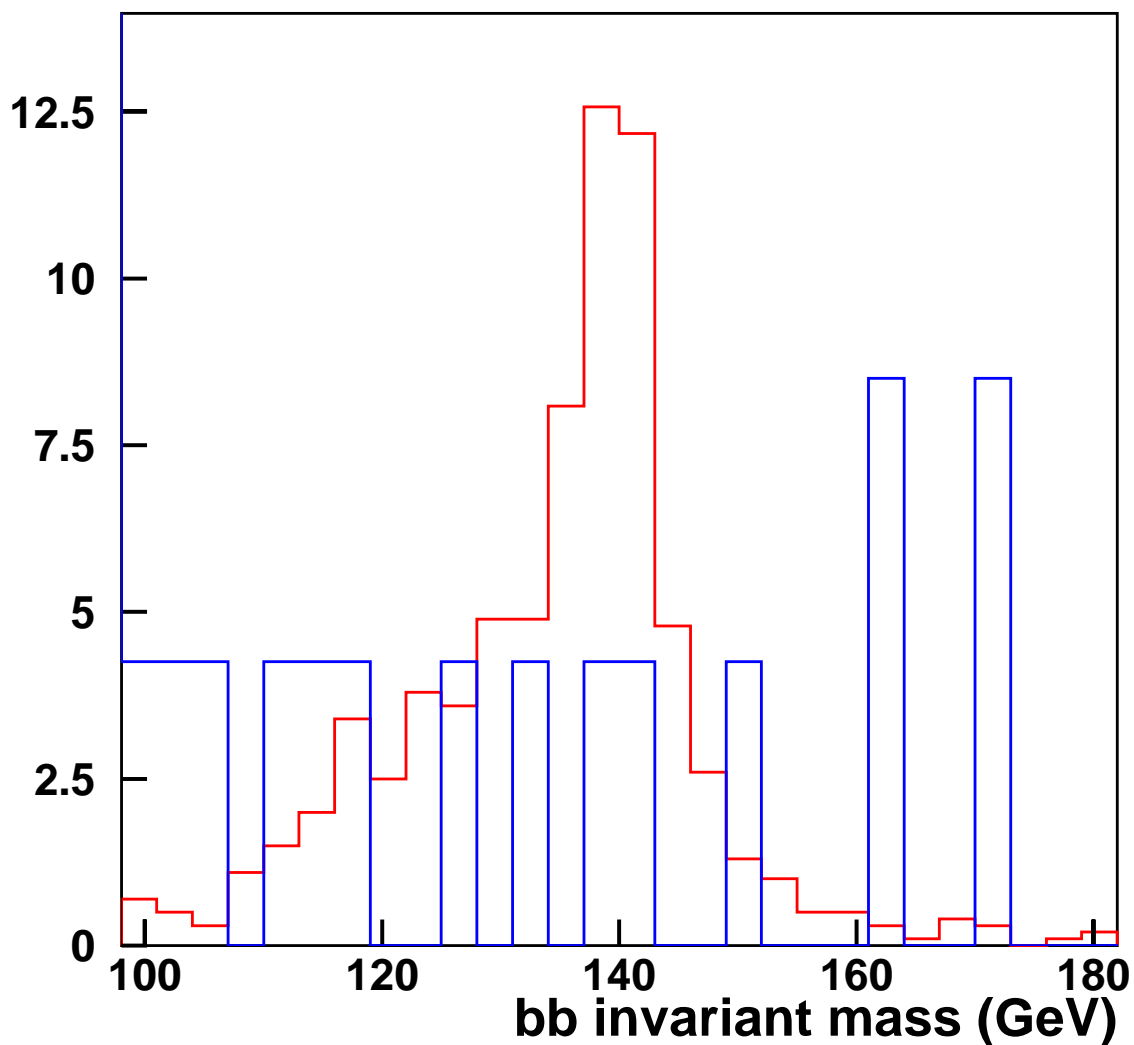


- SM expectation: zero at tree level
- DIM 6 operators in $SU(2)_L \times U(1)_Y$ extensions
- Some of them manifest only in H production
- Some of them modify the WWV_0 couplings
- Differential cross-section $\sim (1 + \cos^2\theta_\gamma)$
- Signatures: monochromatic photons, $H \rightarrow \gamma\gamma$
- Anomalous cross-section \sim constant at high \sqrt{s}
- Optimal places for study: $e\gamma, \gamma\gamma$ colliders
- Dominant $H \rightarrow b\bar{b}$ decay if $m_H < 2 m_W$ (LEP2)
- Dominant $H \rightarrow WW$ decay if $m_H > 2 m_W$

Studies underway: $e^+e^- \rightarrow b\bar{b}\gamma$ at $\sqrt{s} = 500$ GeV

$m_H = 140$ GeV

$H\gamma\gamma$, $HZ\gamma$ couplings ≈ 10 times SM, 10 fb^{-1}



Higgs signal + background

- $e^+e^- \rightarrow \gamma\gamma$ with 100 fb^{-1} :
 - $\Delta\sigma/\sigma \sim 0.3\%$
 - $\Lambda_6 > 5.4 \text{ TeV}$
 - $m_{e^*} > 1.1 \text{ TeV}$
 - $M_{\text{gravity}} > 3.4 \text{ TeV}$
- $e^+e^- \rightarrow Z\gamma$ with 100 fb^{-1} :
 - $\Delta\sigma/\sigma \sim 0.5\%$
 - $|h_3^Z| > 0.005$
 - Test couplings $\sim 10 \times \text{SM}$
- $e^+e^- \rightarrow ZZ$ with 100 fb^{-1} :
 - $\Delta\sigma/\sigma \sim 1.1\%$
 - $|f_5^Z| > 0.005$
 - $M_{\text{gravity}} \gtrsim 3 \text{ TeV}$
- Studies of the $e^+e^- \rightarrow H\gamma$ channel underway:
 - Enhanced if anomalous couplings are present
 - Not competitive with $e\gamma$, $\gamma\gamma$ options