The Little Higgs boson at a photon collider

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The Higgs boson is produced at a photon collider via induced $\gamma\gamma H$ coupling.

$[\gamma\gamma \rightarrow H \rightarrow b\bar{b} \text{ signal}]
\text{Asner et al, hep-ex/011105}$

Expected precisions:

<table>
<thead>
<tr>
<th>$M_H$ (GeV)</th>
<th>$b\bar{b}$ (%)</th>
<th>$WW^*$ (%)</th>
<th>$ZZ^*$ (%)</th>
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<tbody>
<tr>
<td>115</td>
<td>2</td>
<td>5</td>
<td>11</td>
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$\gamma\gamma \to H$ in the Standard Model and beyond

$\gamma\gamma \to H$ comes from the gauge-invariant dim-6 operator

$$\mathcal{L} = \frac{C}{\Lambda^2} H^\dagger H F_{\mu\nu} F^{\mu\nu}$$

induced by $W$ boson and top quark loops in the SM.

Taking $C = e^2/16\pi^2$ (electromagnetic, loop-induced),

$\Lambda_{SM} = 165\ \text{GeV}$. Right scale for $W$ and $t$ loops.

How high a $\Lambda_{new}$ can be probed with a 2% measure of $\gamma\gamma \to H$?

If $C_{new} = C_{SM}$ (weakly coupled new physics):

$\Lambda_{new} = 1.2\ (0.74)\ \text{TeV}$ at 95% CL (5$\sigma$).

If $C_{new} = 1$ (strongly coupled new physics):

$\Lambda_{new} = 48\ (31)\ \text{TeV}$ at 95% CL (5$\sigma$).
The Littlest Higgs model is a new approach to stabilizing the weak scale against radiative corrections, thereby solving the masslessness problem of a light Higgs boson.

**New particles** at the TeV scale cancel off the SM quadratic divergence of the Higgs mass from top $(T)$, gauge $(Z_H)$, and Higgs $(\Phi^0, +, ++)$ loops.

- Higgs is a pseudo-Goldstone boson from global symmetry breaking at scale $\Lambda \sim 4\pi f \sim 10 – 30$ TeV;

- Quadratic divergences cancelled at one-loop level by new states $M \sim gf \sim 1 – 3$ TeV;

- Higgs acquires a mass radiatively at the EW scale $v \sim g^2 f / 4\pi \sim 100 – 300$ GeV.
Corrections to $\gamma \gamma \rightarrow H$ in the Littlest Higgs model

$\gamma \gamma \rightarrow H$ is loop induced: TeV-scale charged particles $W^\pm$, $\phi^{\pm \pm}$ can run in the loops

Higgs couplings to SM particles modified due to mixing of SM and TeV-scale particles and corrections to SM parameters

![Graph](graph.png)

Accessible range found by running over model parameters. Corrections are of order 1.
Corrections to Higgs decays [from mixing between SM scale particles and corrections to couplings]: also $\mathcal{O}(\mu H^2)$.  

- Corrections about the same size in each channel.  
- Best channel from experimental side: $H \to b\bar{b}$.  

Model parameters:

- $f$ – new physics scale.  
- $c$ – $SU(2)_{1,2}$ gauge mixing angle [$Z_H$, $W_H$].  
- $c_t$ – top sector parameter.  
- $x$ – Higgs sector parameter (controls triplet $\Phi$).  
- $c'$ – $U(1)_{1,2}$ gauge mixing angle [$EW'$].  

The best fit favors only one $U(1)$, $c_1 = \frac{1}{\sqrt{2}}$, no $A_H$ part.
Using $\gamma\gamma \rightarrow H \rightarrow b\bar{b}$ to probe the Littlest Higgs

What can be done with the $\gamma\gamma \rightarrow H \rightarrow b\bar{b}$ rate measurement?

- Test the model: probe $\Lambda_{new} \sim 1 - 3$ TeV.

- Search for strongly-coupled UV completion: probe $\Lambda_{new} \sim \text{few}\times10$ TeV.

Must be able to predict the rate for $\gamma\gamma \rightarrow H \rightarrow b\bar{b}$, $R = \frac{\sigma_{\gamma\gamma H \rightarrow b\bar{b}}}{\sigma_{\gamma\gamma H \rightarrow H}}$, with a precision comparable to the photon collider experiment's uncertainty of 2%.

We therefore compute how well each model parameter is measured (at the LHC) in order to contribute no more than the experimental uncertainty to $R$ (i.e., $|\delta R/R_{SM}| \leq 1\%$).
Measure $Z_H (A_H) \rightarrow$ dileptons.

Dilepton invariant mass resolution typically a few percent $\rightarrow$ no problem.
The $\gamma\gamma \to H \to b\bar{b}$ is sensitive to $c_t$ at a $1\%$ level.

Don’t need a measurement of this parameter.
If $f$, $c$ and $c'$ are known, then $x$ can be extracted from 
the current $\delta M_W = 39$ MeV gives good enough precision  
(except for $x \lesssim 0.1$, $f = 1$ TeV).

[Tevatron Run II (2 $\text{fb}^{-1}$) goal: $\delta M_W = 20$ MeV.]
EW precision constraints: $f \gtrsim 1$ TeV $\rightarrow$ want $\gtrsim 6\%$ precision on $f$.

Extract $f$ from $M_{Z_H} = gf/2sc$ and cross section $\propto c^2/f$.

Uncertainty on cross section from statistics: $\delta\sigma/\sigma = 1\%$. 
Summary

Photon collider can measure \( \text{Rate}(\gamma\gamma \rightarrow H \rightarrow b\bar{b}) \) \( m_H = 115 \text{ GeV} \).

\( \text{Rate}(\gamma\gamma \rightarrow H \rightarrow b\bar{b}) \) in the Littlest Higgs model can be calculated from LHC data on model parameters in a region of the parameter space.

Probe the UV completion at \( \sim 10 \text{ TeV} \! \)

- A strongly coupled UV completion contributes at the same order as the TeV-scale particles:
  \( \sim \) several percent for \( f \sim 1 - 3 \text{ TeV} \).

- A weakly coupled UV completion should not affect the collider at an observable level:
  \( \rightarrow \) Measurement is a test of model consistency.