Towards a Study of $\Delta g_{HHH}$ vs. Jet Energy Resolution and Other SiD Performance Parameters

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\[ e^+ e^- \rightarrow ZH \rightarrow q\overline{q} b\overline{b} \]

\[ \sqrt{s} = 350 \text{ GeV} \]
\[ L = 500 \text{ fb}^{-1} \]

\[ \Delta E/\sqrt{E} = 60\% \rightarrow 30\% \text{ equiv to } 1.4 \times \text{ Lumi} \]
Standard Model:

\[ M^2_H = 2 \lambda v^2 = -2 \mu^2 \]

\[ g_{HHH} = -6 \mu^2 / v \]

\[ e^+ e^- \rightarrow ZHH \rightarrow q\bar{q}b\bar{b}b\bar{b} \]

\[ \sqrt{s} = 500 \text{ GeV}, \quad L = 1000 \text{ fb}^{-1} \]

\[ \Delta E / \sqrt{E} = 60\% \rightarrow 30\% \]

equiv to \ 4 \times \text{ Lumi}

C. Castanier et al. hep-ex/0101028
$M_H = 120$ GeV

$\sigma(e^+e^- \rightarrow HHZ)$ (fb)

$\sqrt{s} = 500$ GeV

$\sigma(e^+e^- \rightarrow HHZ)$ (fb)

$\sqrt{s} = 800$ GeV

$g_{HHH}/g_{HHH}(SM)$
Not All $e^+e^- \rightarrow ZHH$ Diagrams Contain the HHH Coupling
SIMDET Analysis for $\sqrt{s} = 800$ GeV, 1 ab$^{-1}$ by Battaglia, Boos, Yao

$\frac{g_{HHH}}{g_{SM}} = 1.25$

$\frac{g_{HHH}}{g_{SM}} = 1.00$

$\frac{g_{HHH}}{g_{SM}} = 0.75$

$\frac{g_{HHH}}{g_{SM}} = 0.50$

hep-ph/0111276
\( \sqrt{s} = 500 \text{ GeV} \)

\[
\frac{g_{HHH}^{SM}}{g_{HHH}^{SM}} = 1.25
\]

\[
\frac{g_{HHH}^{SM}}{g_{HHH}^{SM}} = 1.00
\]

\[
\frac{g_{HHH}^{SM}}{g_{HHH}^{SM}} = 0.75
\]

\( e^+ e^- \rightarrow ZHH \)

\( \text{True } M_{HH} \text{ (GeV)} \)
Plan for Analysis

- We need to assign jets to parent bosons as best we can to suppress background to ZHH and to optimize $M_{HH}$ resolution. Use ZVTOP for b-tagging and for a vertex charge analysis to distinguish b from bbar. Try to use H mass constraints ($\Delta M_H = 60$ MeV).

- At $M_H=120$ GeV the $bb$ BR is 70% so that only 50% of ZHH events are $Zbbb$. We should therefore try to include other Higgs decays in analysis. Also include $ZHH \rightarrow l^+l^-HH$, $\nu\nu HH$.

- Perform analysis with baseline SiD. Then vary $\Delta E_{jet}$, vtx detector parameters, tracker parameters.
Progress with Tools

• LCIO Reconstructed Particles can be successfully read out in JAVA, C++ and FORTRAN.
• There is an interface from LCIO reconstructed particles to SIMDET common block so that SIMDET-based analysis code can be run on LCIO files with reconstructed particles (see http://www-sid.slac.stanford.edu/BenchMarking/ for details)
• The org.lcsim Fast MC is working, and the relationship between single particle energy resolution and jet energy resolution is now understood; features have been added to allow users to easily vary the jet energy resolution.
Perfect PFA : What theory predicts

- Jet energy resolution
  \[ \sigma^2(E_{\text{jet}}) = \sigma^2(\text{ch.}) + \sigma^2(\gamma) + \sigma^2(h^0) + \sigma^2(\text{conf.}) \]

- Excellent tracker:
  \[ \sigma^2(\text{ch.}) \ll \sigma^2(\gamma) + \sigma^2(h^0) + \sigma^2(\text{conf.}) \]

- Perfect PFA: \( \sigma^2(\text{conf.}) = 0 \)

\[ \sigma^2(E_{\text{jet}}) = \lambda_{\gamma}^2 E_{\gamma} + \lambda_{h}^2 E_{h} = w_{\gamma} \lambda_{\gamma}^2 E_{\gamma \text{jet}} + w_{h0} \lambda_{h}^2 E_{h \text{jet}} \]

\[ \frac{\sigma(E_{\gamma \text{jet}})}{E_{\gamma \text{jet}}} = A_{\gamma} / \sqrt{E_{\gamma \text{jet}}} \]

Typically \( w_\gamma = 25\% ; w_{h0} = 13\% \)

I find \( w_\gamma = 28\% ; w_{h0} = 10\% \)

\[ A_\gamma = 11\% ; A_{h0} = 34\% \]

\[ \Rightarrow \frac{\sigma(E_{\gamma \text{jet}})}{E_{\gamma \text{jet}}} = 12\% / \sqrt{E_{\gamma \text{jet}}} \]

\[ A_\gamma = 11\% ; A_{h0} = 50\% \]

\[ \Rightarrow \frac{\sigma(E_{\gamma \text{jet}})}{E_{\gamma \text{jet}}} = 17\% / \sqrt{E_{\gamma \text{jet}}} \]
$\sqrt{s} = 500 \text{ GeV}$

$e^+ e^- \rightarrow u \bar{u}$

$E_{\text{true}}$ is adjusted for neutrinos and particles outside detector acceptance.

\[
\frac{\Delta E_{\text{em}}}{E_{\text{em}}} = \frac{0.18}{\sqrt{E_{\text{em}}}}
\]

\[
\frac{\Delta E_{\text{had}}}{E_{\text{had}}} = \frac{0.50}{\sqrt{E_{\text{had}}}} + 0.08
\]

$\Delta E_{\text{jet}} = \frac{(E_{\text{rec}} - E_{\text{true}})}{\sqrt{E_{\text{true}}}}$
Drop constant term in single particle resolution for now. Assume negligible contribution from charged particles to jet energy resolution and write

\[ \sigma^2 = (1 + \lambda(1-r))^2 A^2 \gamma \gamma E_{jet} + (1 + \lambda r)^2 A^2_h w_h E_{jet} = c^2 E_{jet} \]

where \( c = 0.3, 0.4, 0.5, 0.6 \)

\( r = \) hadronic resolution degradation fraction

\( r = 1 \) to only degrade hadronic resolution

\( r = 0 \) to only degrade em resolution

\( A_\gamma = 0.18 \quad A_h = 0.50 \quad w_\gamma = 0.28 \quad w_h = 0.10 \)

Given a desired jet energy resolution \( c \) the parameter \( \lambda \) is given by

\[
\lambda = \frac{c^2 - A^2 \gamma \gamma - A^2_h w_h}{(1-r)A^2 \gamma \gamma + rA^2_h w_h}
\]
\[ \sqrt{s} = 500 \text{ GeV} \]

\[ e^+ e^- \rightarrow u\bar{u} \]

\[ r = 1.0 \]
(only degrade had resolution)
\[ \sqrt{s} = 500 \text{ GeV} \]

\[ r = 0.5 \]

(degrade em & had resolutions with equal wgt)

\[ e^+ e^- \rightarrow u\bar{u} \]

\[ \Delta E_{\text{jet}} = \frac{(E_{\text{rec}} - E_{\text{true}})}{\sqrt{E_{\text{true}}}} \]
$\sqrt{s} = 100$ GeV

$e^+ e^- \rightarrow uu$

$r = 1.0$

(only degrade had resolution)

$$\Delta E_{\text{jet}} = \frac{E_{\text{rec}} - E_{\text{true}}}{\sqrt{E_{\text{true}}}}$$
\[ \sqrt{s} = 100 \text{ GeV} \]

\[ e^+ e^- \rightarrow u\bar{u} \]

\[ c = 0.3 \quad c = 0.4 \]

\[ r = 0.5 \quad \text{(degrade em & had resolutions with equal wgt)} \]

\[ \Delta E_{\text{jet}} = \frac{(E_{\text{rec}} - E_{\text{true}})}{\sqrt{E_{\text{true}}}} \]
\[ \sqrt{s} = 1000 \text{ GeV} \]

\[ e^+ e^- \rightarrow uu \]

\[ \Delta E_{\text{jet}} = \frac{(E_{\text{rec}} - E_{\text{true}})}{\sqrt{E_{\text{true}}}} \]

\[ r = 1.0 \]

(only degrade had resolution)
$\sqrt{s} = 1000$ GeV

$r = 0.5$

(degrade em & had resolutions with equal wgt)
Next Steps

• Finish FORTRAN/C to JAVA interface so that hep.lcd ZVTOP can be called from FORTRAN90 analysis code.

• Incorporate Higgs Mass Constraints into Jet Energy Fitting Algorithm for 6 Jets (Currently it only has Beam Energy-Momentum Constraints)

• Start Optimizing Neural Network Analyses