Higgs Self Coupling Measurement

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SLAC
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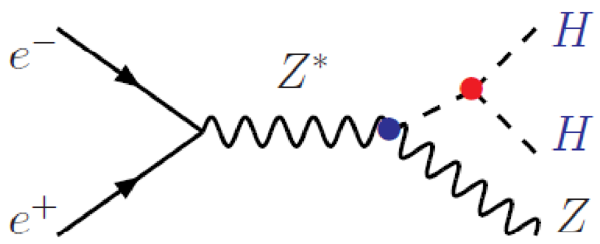
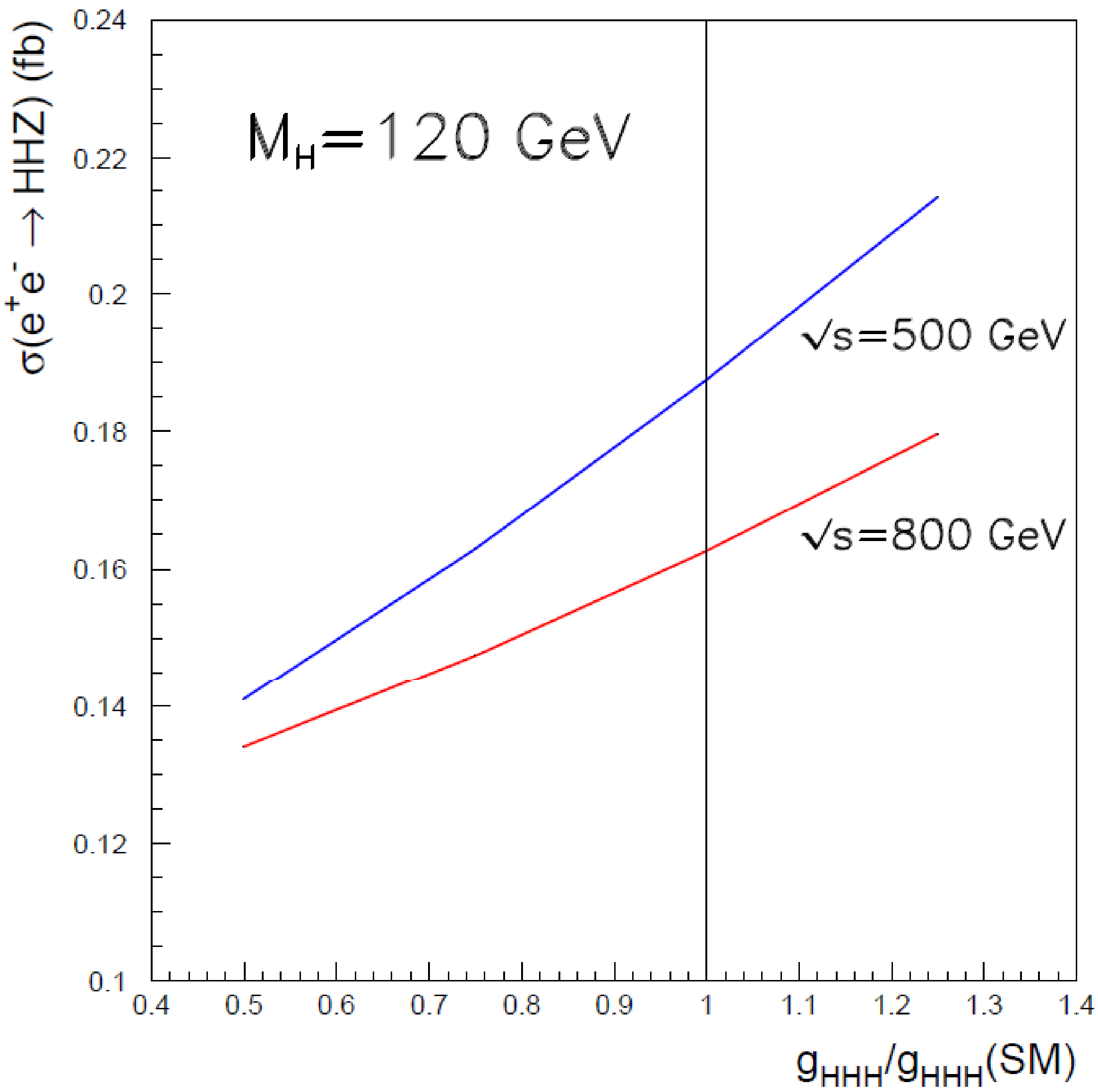
$$e^+e^- \to ZHH \to q\bar{q}b\bar{b}b\bar{b}$$





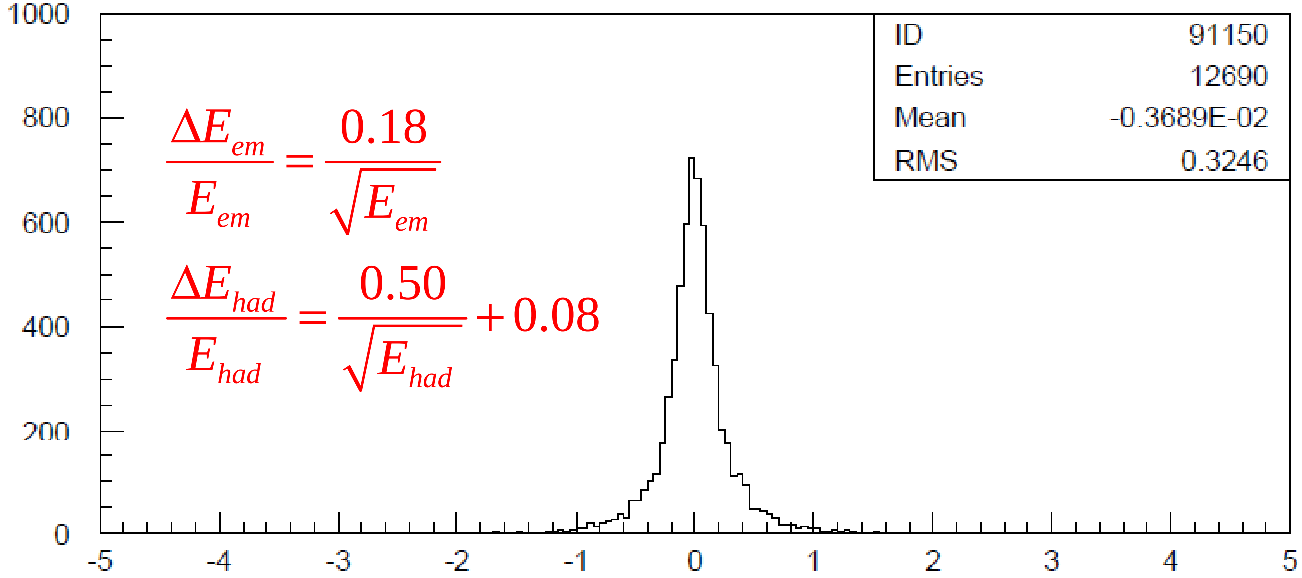
Plan for Analyis

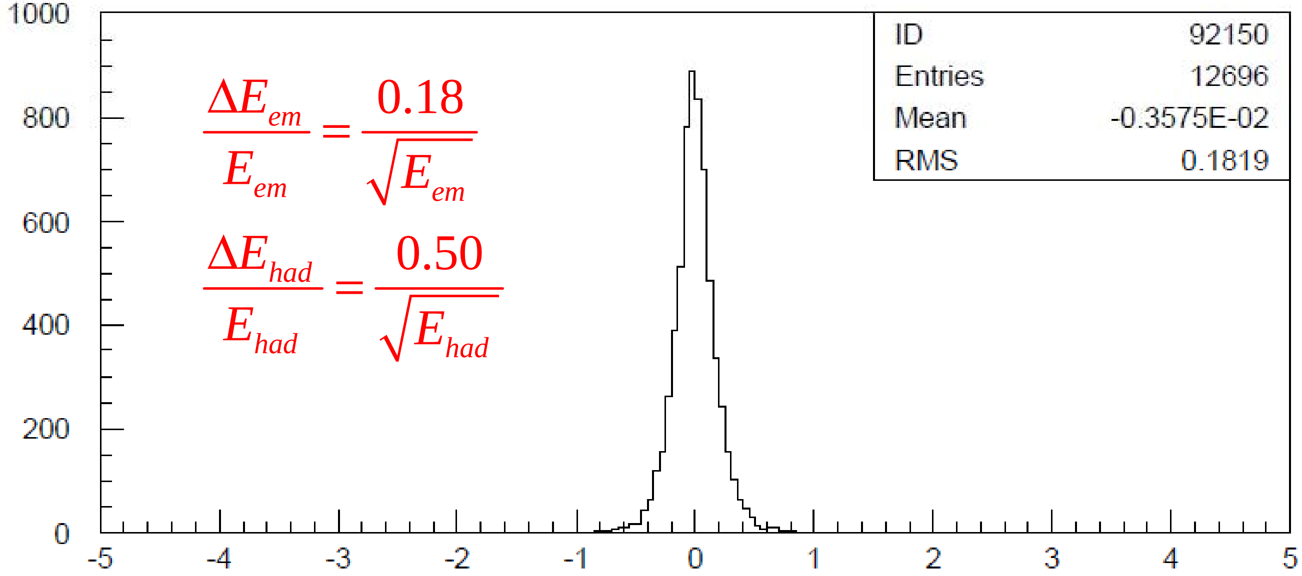
- Perform analysis on qqbbbb channel only at E_{cm}=500 GeV assuming 0% electron polarization. Use org.lcsim Fast MC simulation of baseline SiD. This MC includes a reasonable algorithm for smearing charged track angles, curvature and impact parameters. Calorimeter simulation consists of simple single neutral particle smearing with EM resolution for photons and HAD res for n,$K0_{L.}$
- Scale single particle calorimeter resolutions to get a particular ΔE_{jet} .
- Use org.lcsim ZVTOP for b-tagging
- Perform analysis both with and without final state gluon radiation in signal and background evt generators.

$\sqrt{s} = 500$ GeV

E_{true} is adjusted for neutrinos and particles outside detector acceptance

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





$$\Delta E_{jet} = (E_{rec} - E_{true}) / \sqrt{E_{true}}$$

Drop constant term in single particle resolution for now. Assume negligible contribution from charged particles to jet energy resolution and write

$$\sigma^2 = (1+\lambda(1-r))A_\gamma^2 w_\gamma E_{jet} + (1+\lambda r)A_h^2 w_h E_{jet} = c^2 E_{jet}$$

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 λ is given by

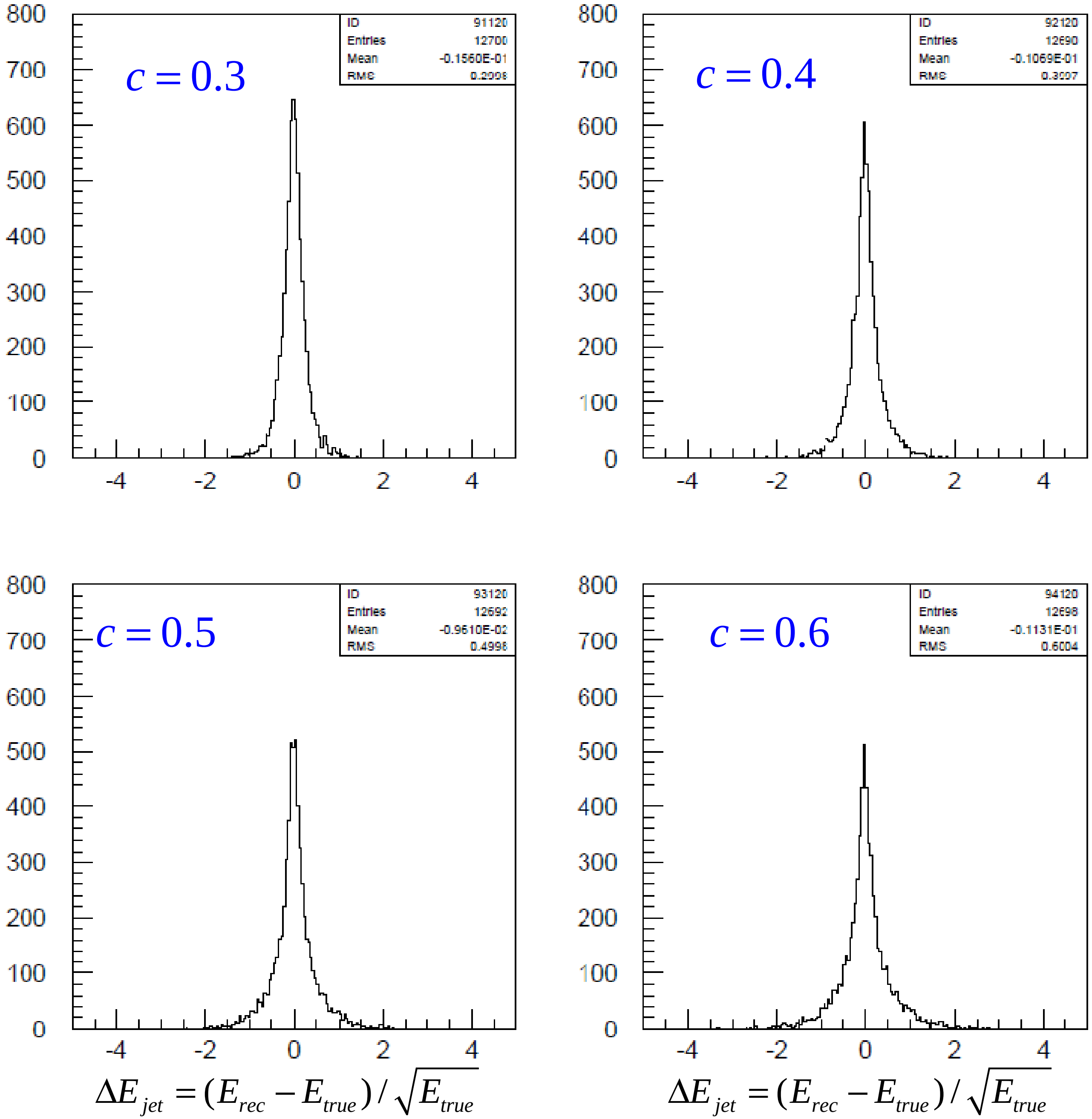
$$\lambda = \frac{c^2 - A_\gamma^2 w_\gamma - A_h^2 w_h}{(1-r)A_\gamma^2 w_\gamma + rA_h^2 w_h}$$

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

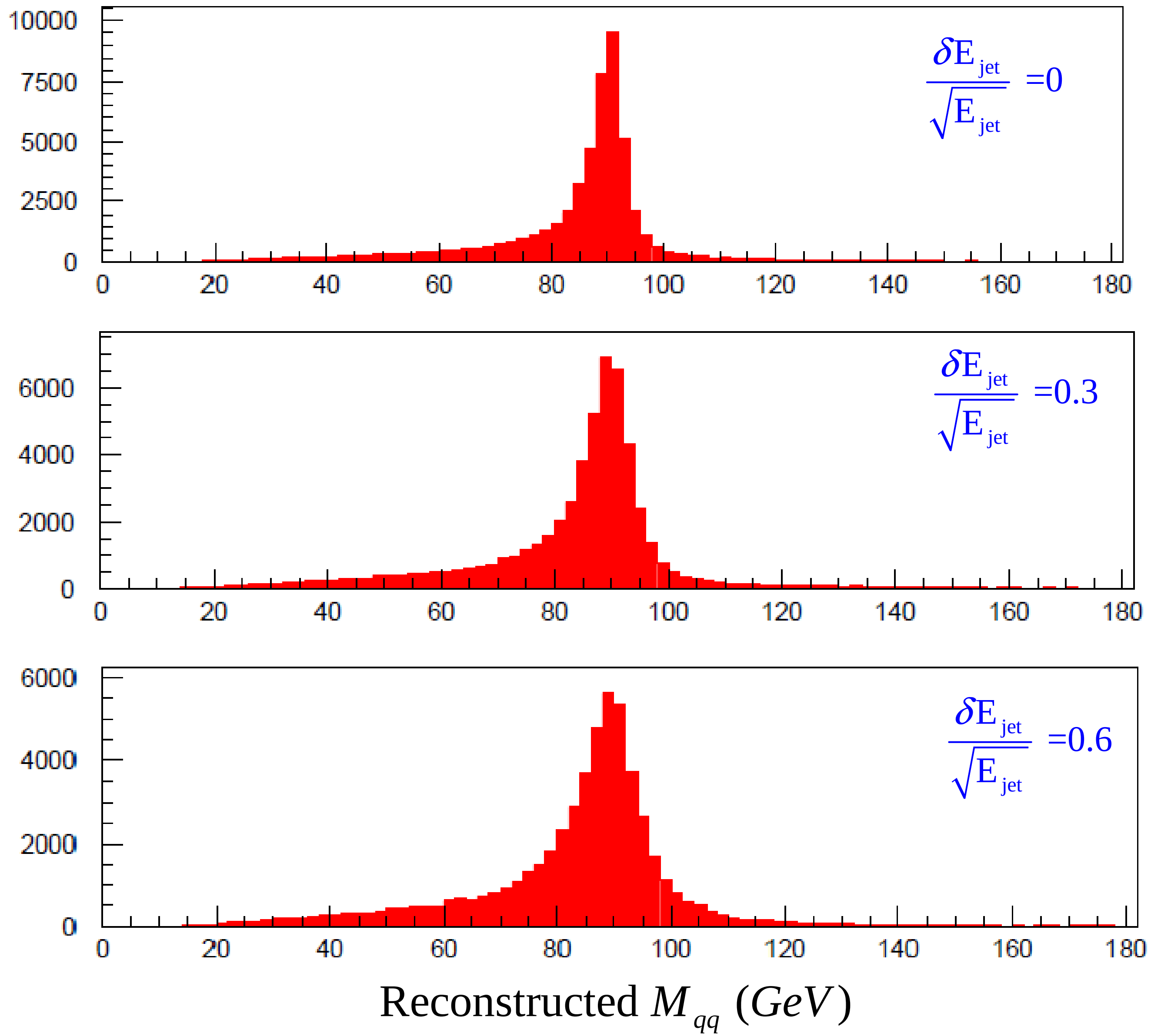
$\sqrt{s} =$ 500 GeV

$r = 1.0$

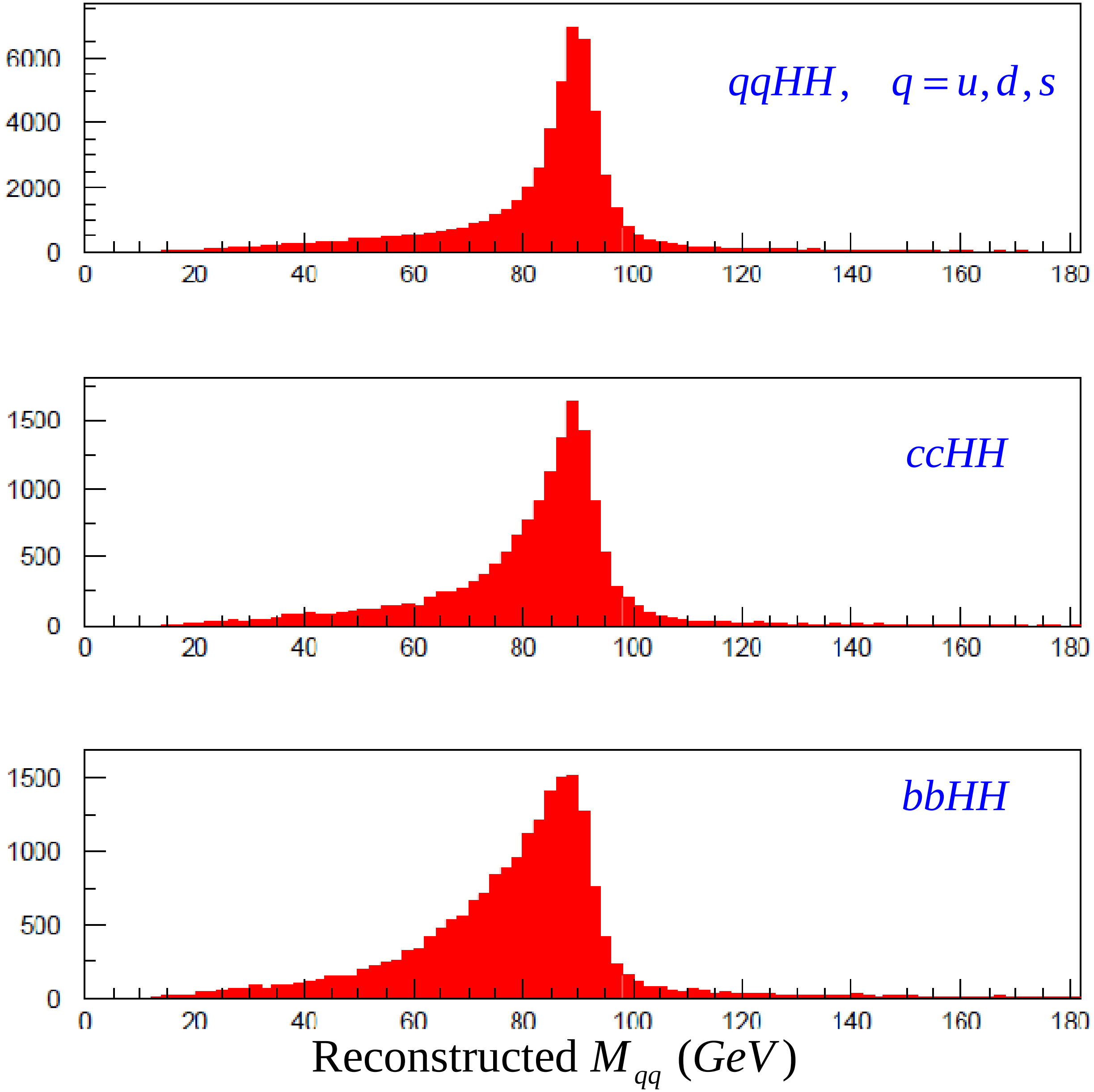
(only degrade had resolution)



$e^+e^- \rightarrow qqHH, \quad q = u, d, s$ non-Gaussian Parameterization



$$e^+e^- \to qqHH, \quad \frac{\delta E_{jet}}{\sqrt{E_{jet}}} = 0.3, \quad \text{non-Gaussian Parameterization}$$



ZHH Preselection

Require:

$$|\cos\theta_{thrust}| < 0.95$$

$$thrust < 0.85$$

$$P_{tot}(z) < 50 \text{ GeV}$$

$$M_{thrust\_hemisphere} > 110 \text{ GeV for at least 1 thrust hemisphere}$$

$$N_{isolated\ leptons} = 0$$

$$6 \le N_{jets} \le 8$$

$$N_{chrg\ tracks} \ge 35$$

$$E_{jet}(photons) / E_{jet}(total) < 0.8 \text{ for all 6 jets}$$

NN_{btag}

- Use udscb jets in ZHH events to train NN_{btag}
- Perform jet analysis on charged and neutral objects allowing number of jets to vary; for each jet perform ZVTOP analysis as implemented in org.lcsim
- Use the following variables in the btag neural net:

  E_{jet}

  E_{vtx}

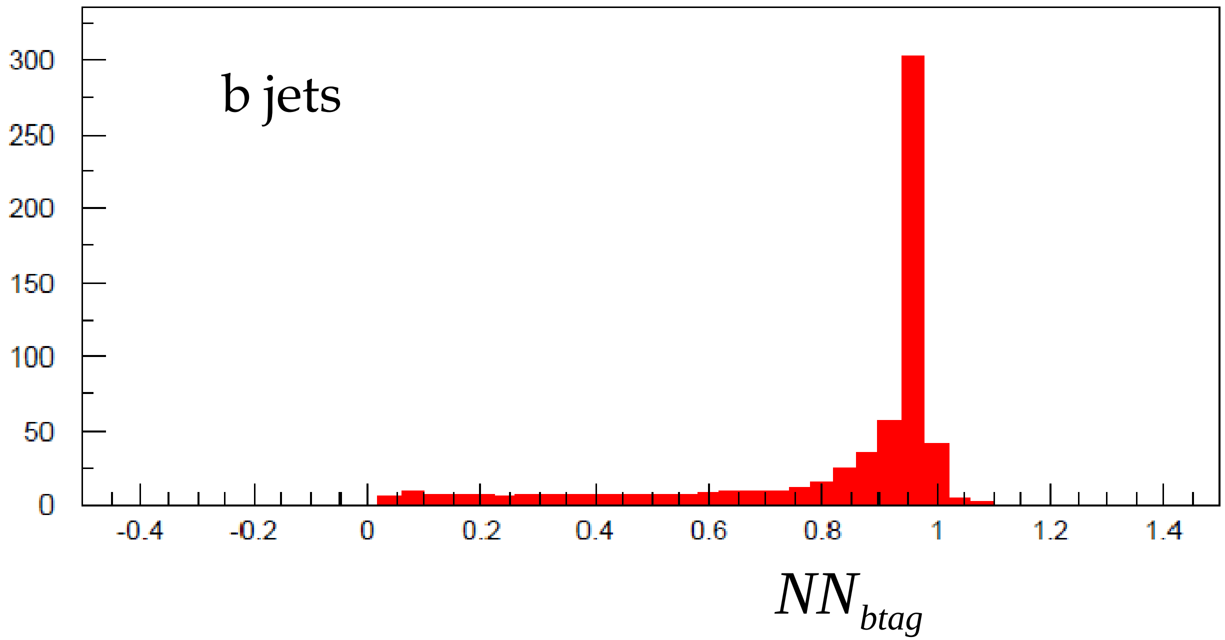
  M_{vtx}

  Pt-Corrected M_{vtx}

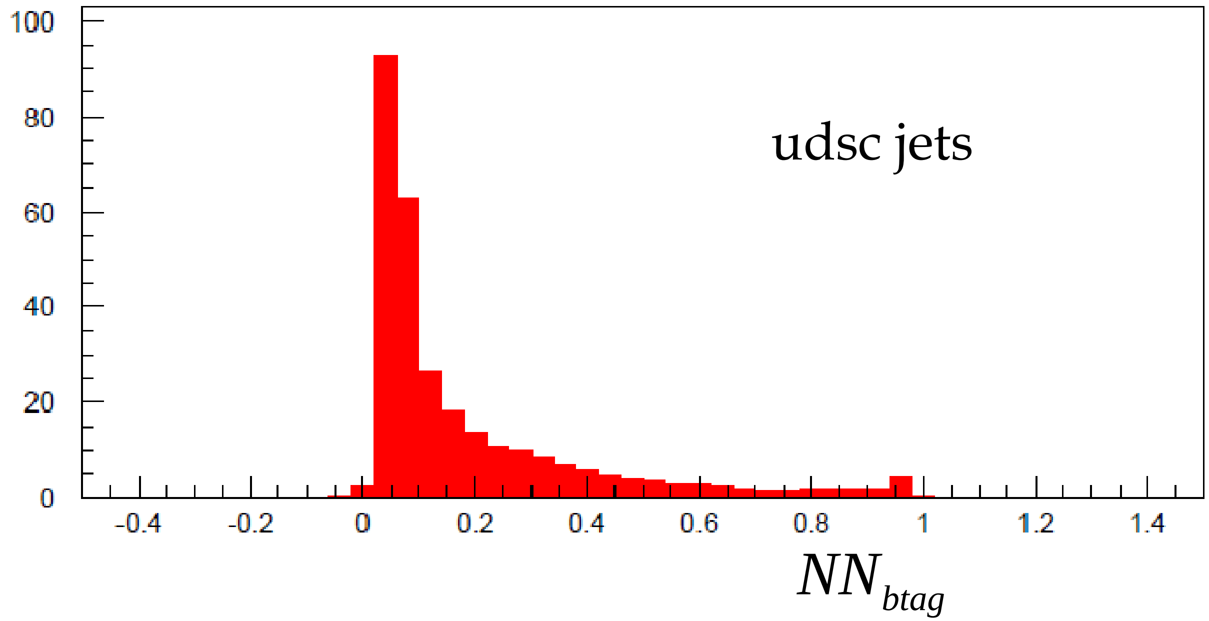
  # Secondary Vertices

  # Unassociated Large Impact Parameter Tracks

ZHH events



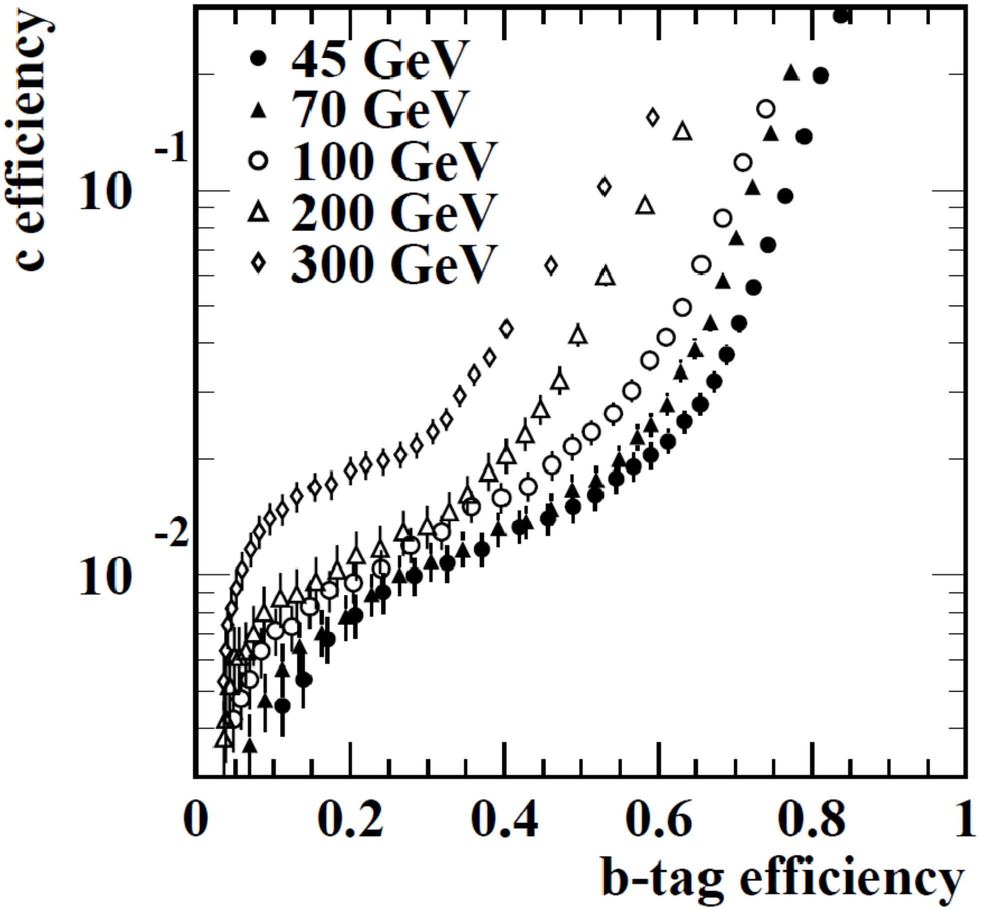
b jets
300
250
200
150
100
50
0
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
NN_{btag}



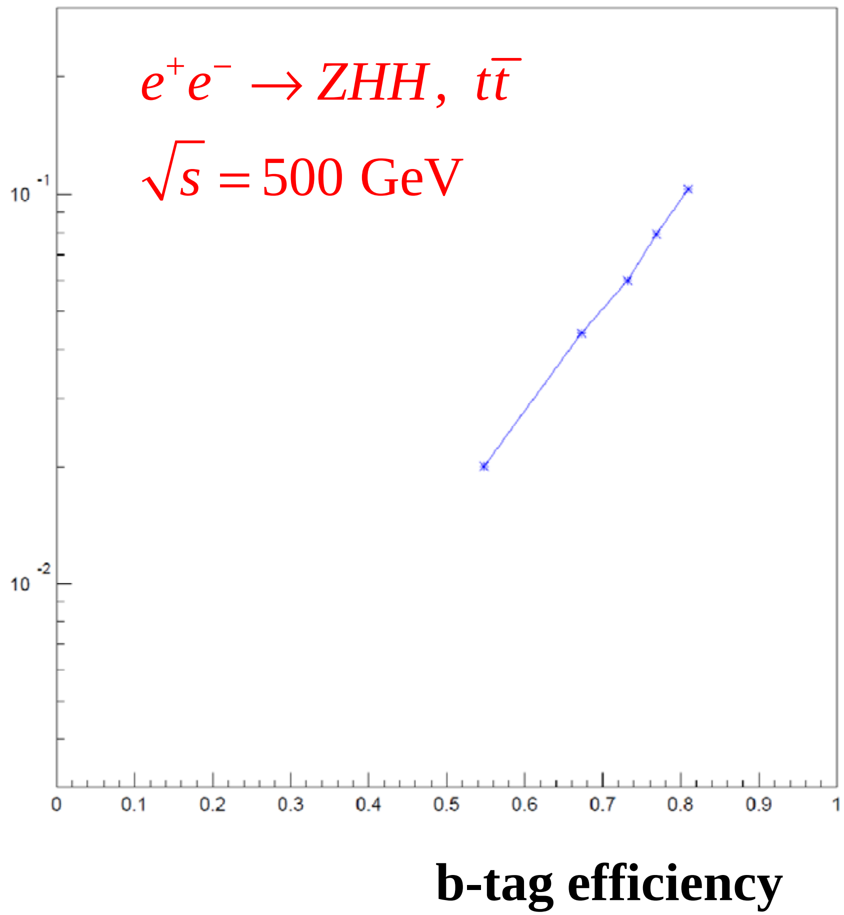
udsc jets
100
80
60
40
20
0
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
NN_{btag}

charm mis-id efficiency versus b-tag efficiency

R. Hawkings, LC-PHSM-2000-021



SiD ZHH Analysis



OLD Neural Net NN_{ZHH}

- Use signal and background events that pass preselection to train NN_{ZHH}
- Use the following variables in the ZHH neural net:

χ^2_{ZHH} $\chi^2_{ZHH\_HHmass}$ $\chi^2_{ZHH\_ZHHmass}$

χ^2_{TT} $\chi^2_{TT\_WWmass}$ $\chi^2_{TT\_TTmass}$

χ^2_{ZZZ} $\chi^2_{ZZH\_ZZHmass}$

χ^2_{ZZ} $\chi^2_{ZH\_ZHmass}$

$NNbtag_j \, , \; j = 1,2,3,4,5,6$

$\min(M_{jet}(k)) \, , \; k = 1,2,3,4,5,6)$

$|\cos\theta_{thrust}|$

$\#$ jets

Old definition χ^2_{ZHH}

- Force charged and neutral objects into 6 jets
- Loop over 45 jet-pair combinations & minimize χ^2_{ZHH}

$$\chi^2_{ZHH} = \chi^2_{ZHH\_ZHHmass} + \sum_{j=3}^{6} \frac{(NNbtag_j - 1)^2}{\sigma^2_{NNbtag}}$$

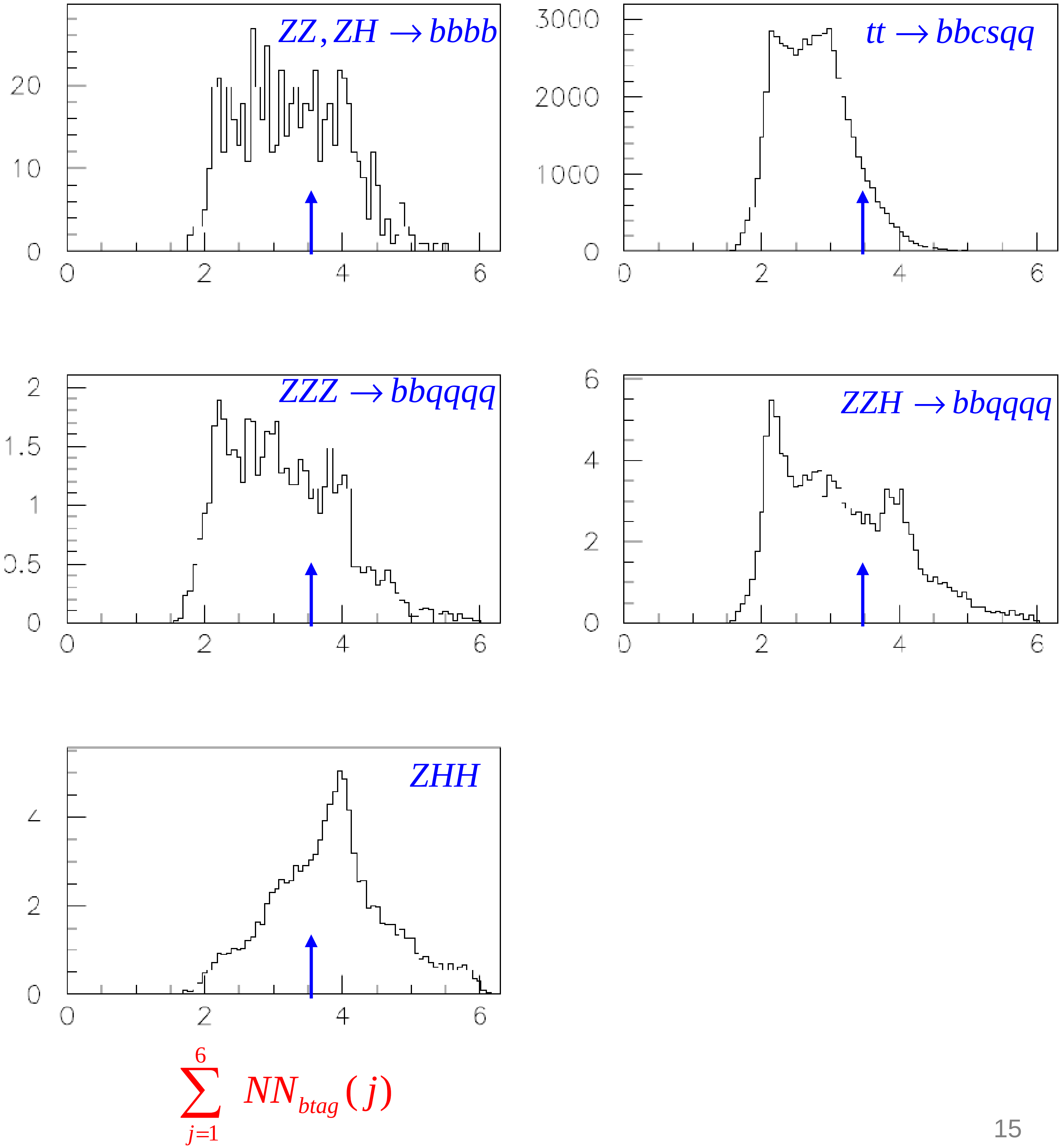
$$\chi^2_{ZHH\_ZHHmass} = \chi^2_{ZHH\_HHmass} + \frac{(M_{12} - M_Z)^2}{\sigma^2_{M_Z}}$$

$$\chi^2_{ZHH\_HHmass} = \frac{(M_{34} - M_H)^2}{\sigma^2_{M_H}} + \frac{(M_{56} - M_H)^2}{\sigma^2_{M_H}}$$

$M_{ij} =$ Mass for jet-pair combination ij

$NNbtag_j =$ btag neural net variable for jet j

New approach:
Instead of variables such as χ^2_{ZHH} , which contain kinematic info for 1 of 45 combinations, feed neural net all jet pair masses where jets are ordered according to jet btag neural net value (jet 1 is the most b-like, jet 2 is 2nd most b-like, etc.)



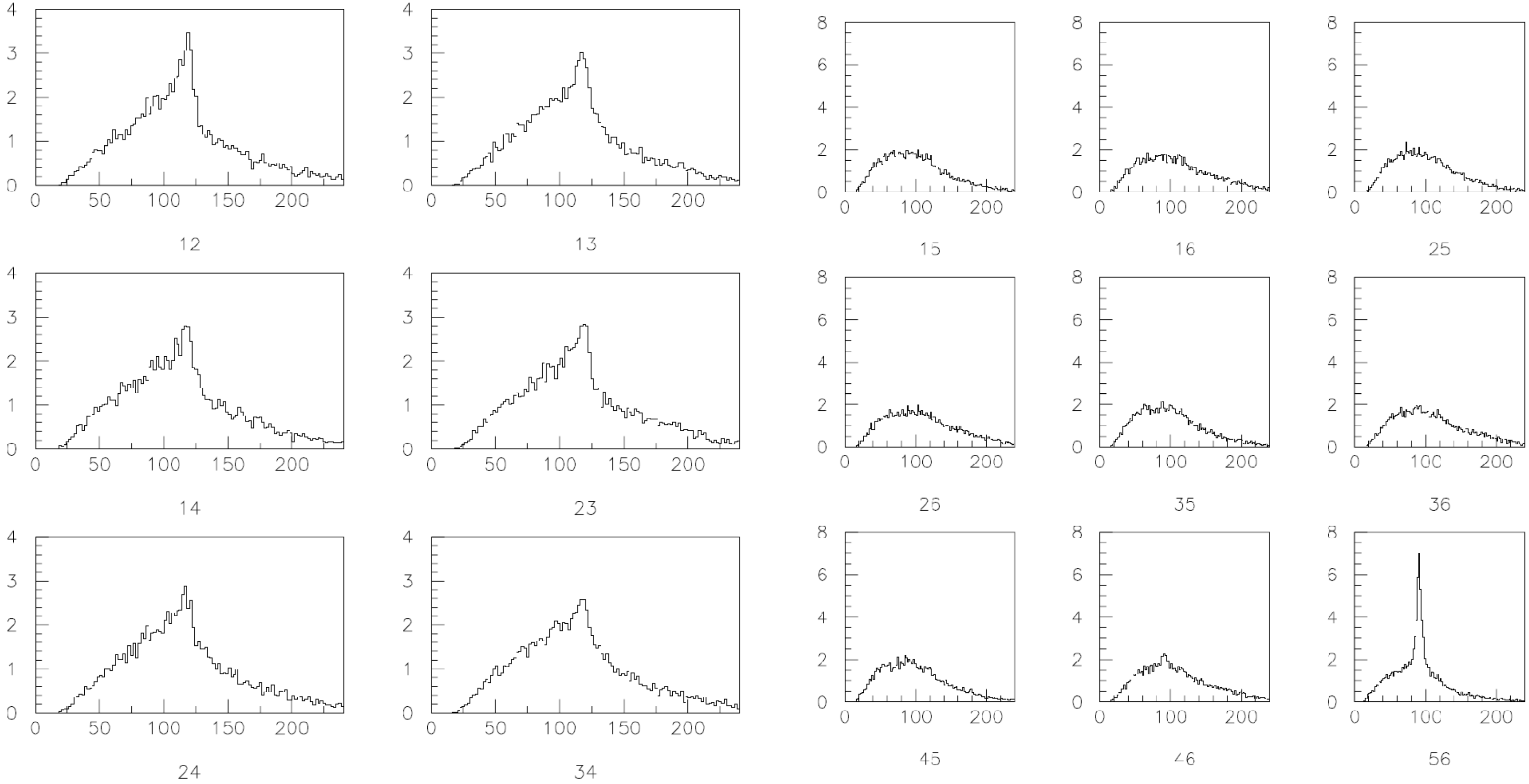
Require

$$\sum_{j=1}^{6} NN_{btag}(j) > 3.5$$

Jet pair masses where jets are ordered according to jet btag neural net value

(jet 1 is the most b-like, jet 2 is 2nd most b-like,etc.) Require $\sum_{j=1}^{6} NN_{btag}(j) > 3.5$

ZHH

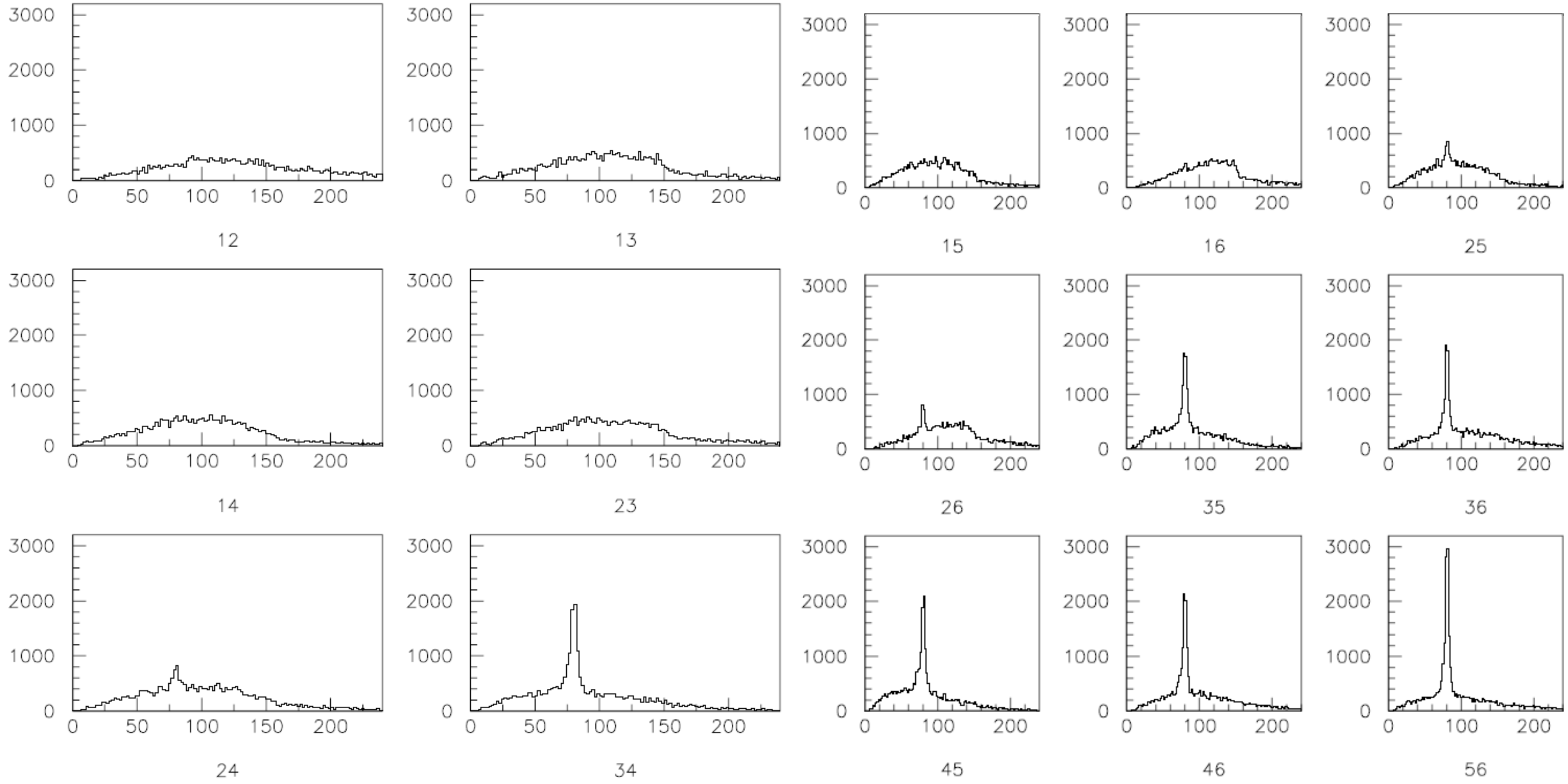


$M_{jk}\,(GeV)$

Jet pair masses where jets are ordered according to jet btag neural net value

(jet 1 is the most b-like, jet 2 is 2nd most b-like,etc.) Require $\sum_{j=1}^{6} NN_{btag}(j) > 3.5$

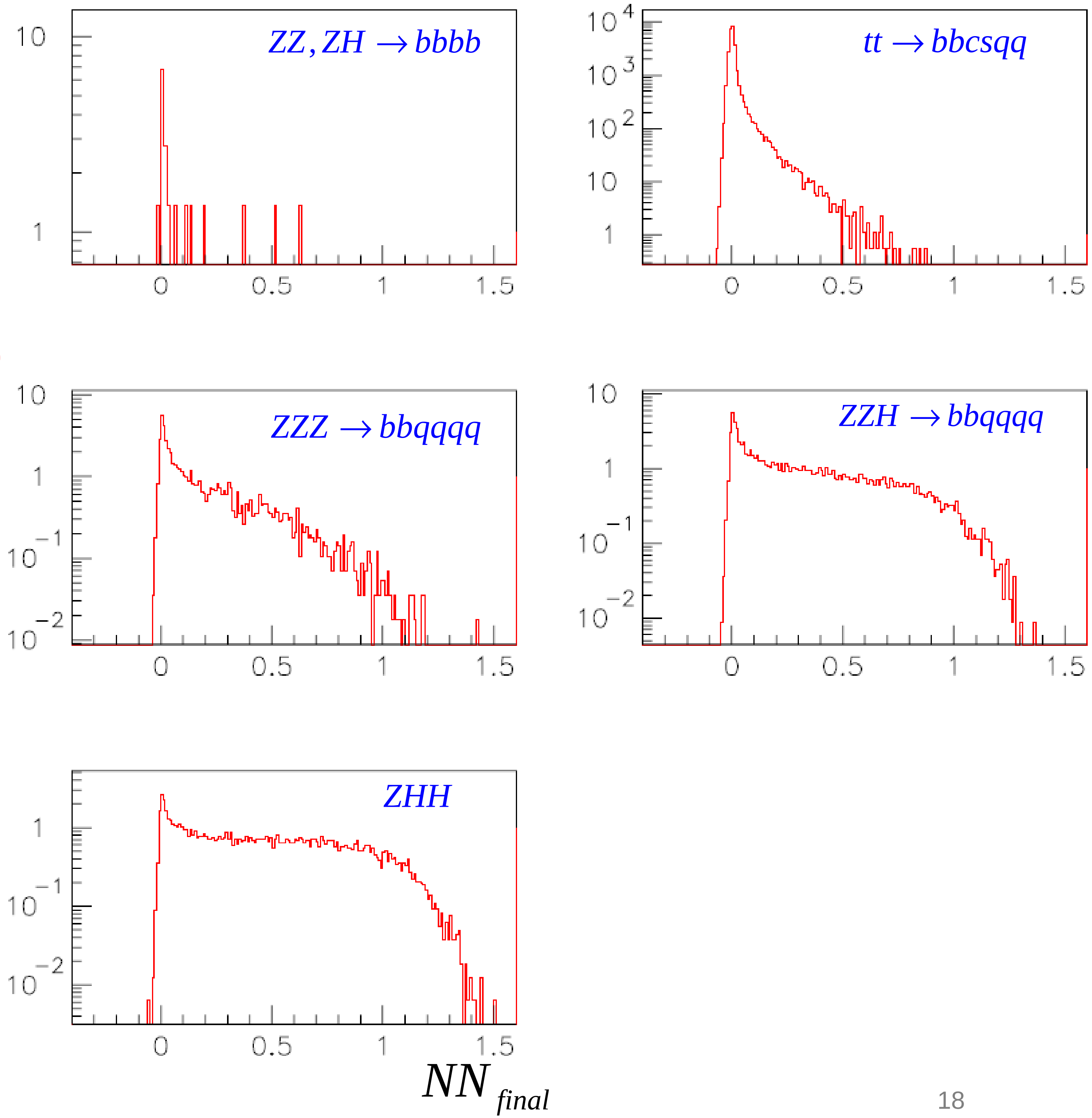
$t\bar{t}$



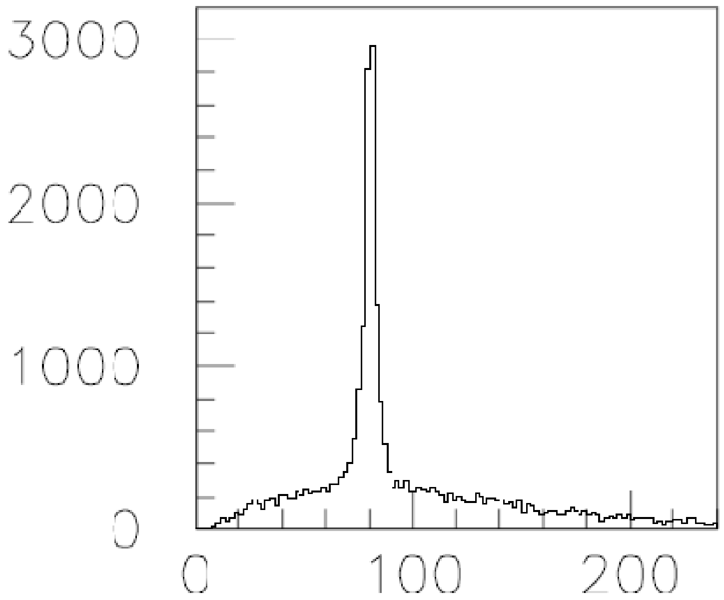
$M_{jk}\,(GeV)$

Neural net based on
b-tag ordered jet pair
masses and χ^2_{HH}, χ^2_{tt},
χ^2_{ZZH}, χ^2_{ZZZ} (only 3
comb. for $\chi^2_{HH}, \chi^2_{ZZZ}$
only 6 comb. for $\chi^2_{tt}, \chi^2_{ZZH}$)

QCD rad turned off



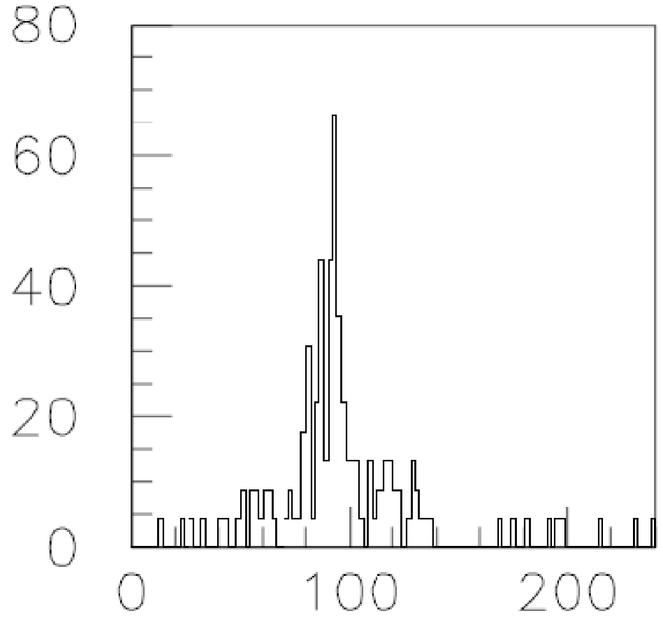
all $t\bar{t}$ with $\sum_{j=1}^{6} NN_{btag}(j) > 3.5$



M_{56} (GeV)

all $t\bar{t}$ with $\sum_{j=1}^{6} NN_{btag}(j) > 3.5$

and $NN_{final} > 0.1$



M_{56} (GeV)

$BR(H \to b\bar{b})=0.678$

$e^+e^- \to ZHH$

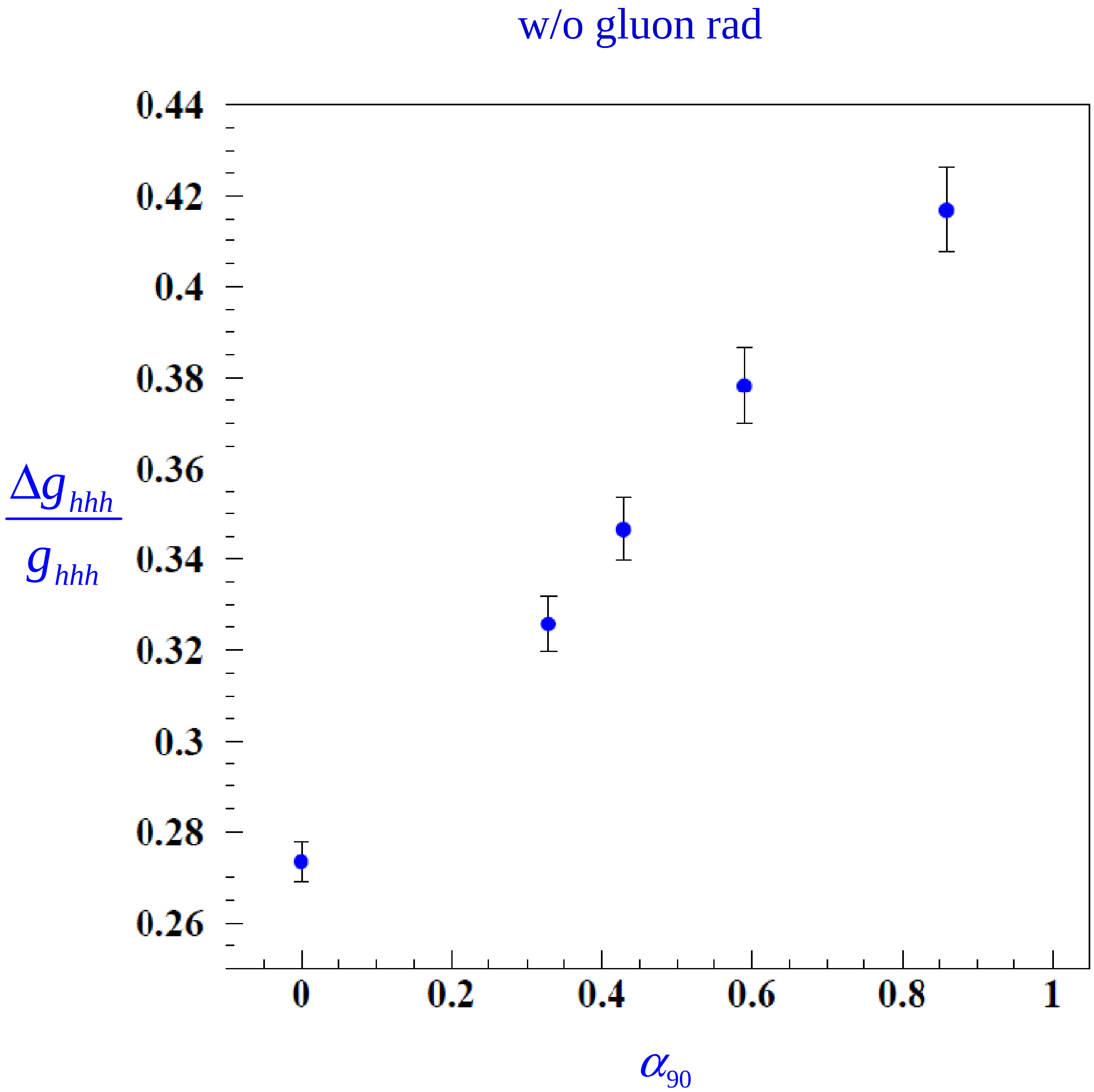
$\to qqb\bar{b}b\bar{b}$

$\sqrt{s} = 500\ GeV$

$L = 2000\ fb^{-1}$

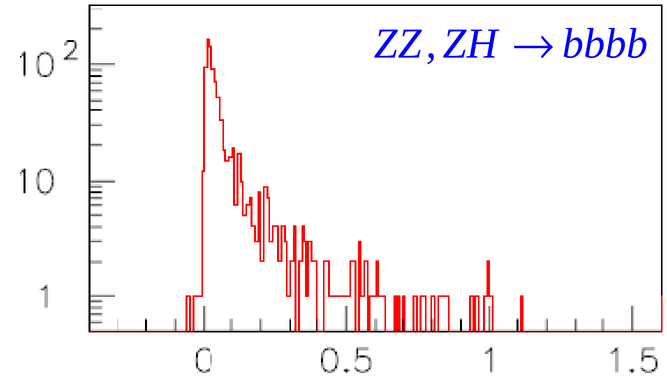
$\Delta E/\sqrt{E} = 60\% \to 30\%$

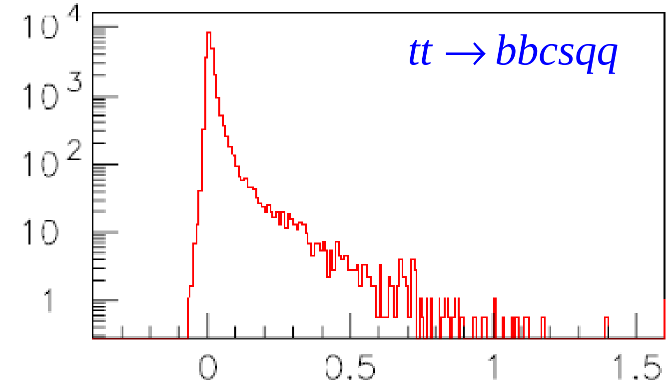
equiv to $1.4\times$ Lumi

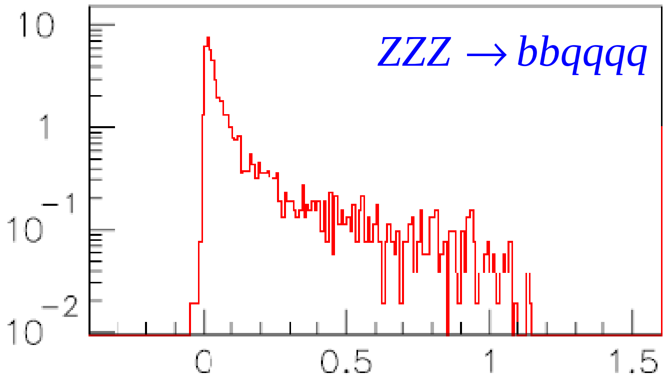


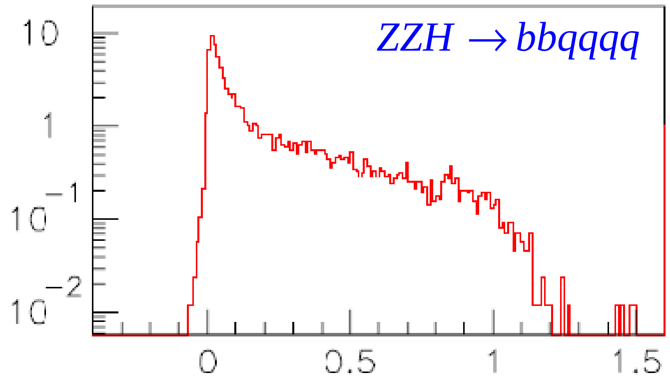
Neural net based on b-tag ordered jet pair masses and χ^2_{HH}, χ^2_{tt}, χ^2_{ZZH}, χ^2_{ZZZ} (only 3 comb. for $\chi^2_{HH}, \chi^2_{ZZZ}$ only 6 comb. for $\chi^2_{tt}, \chi^2_{ZZH}$)

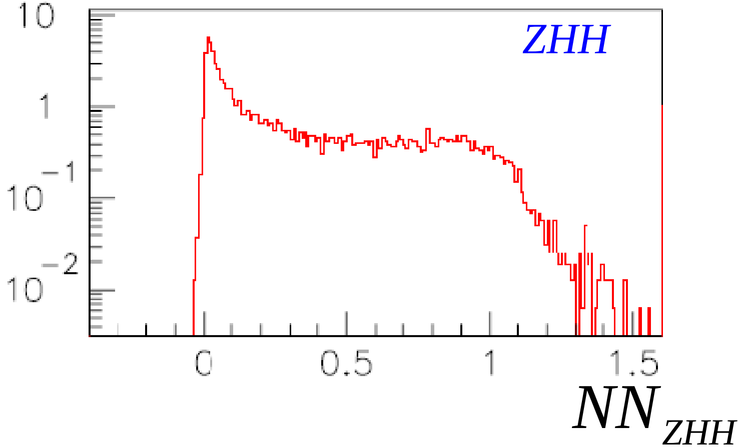
QCD rad turned on











with gluon rad

$BR(H \to b\bar{b})=0.678$

$e^+e^- \to ZHH$

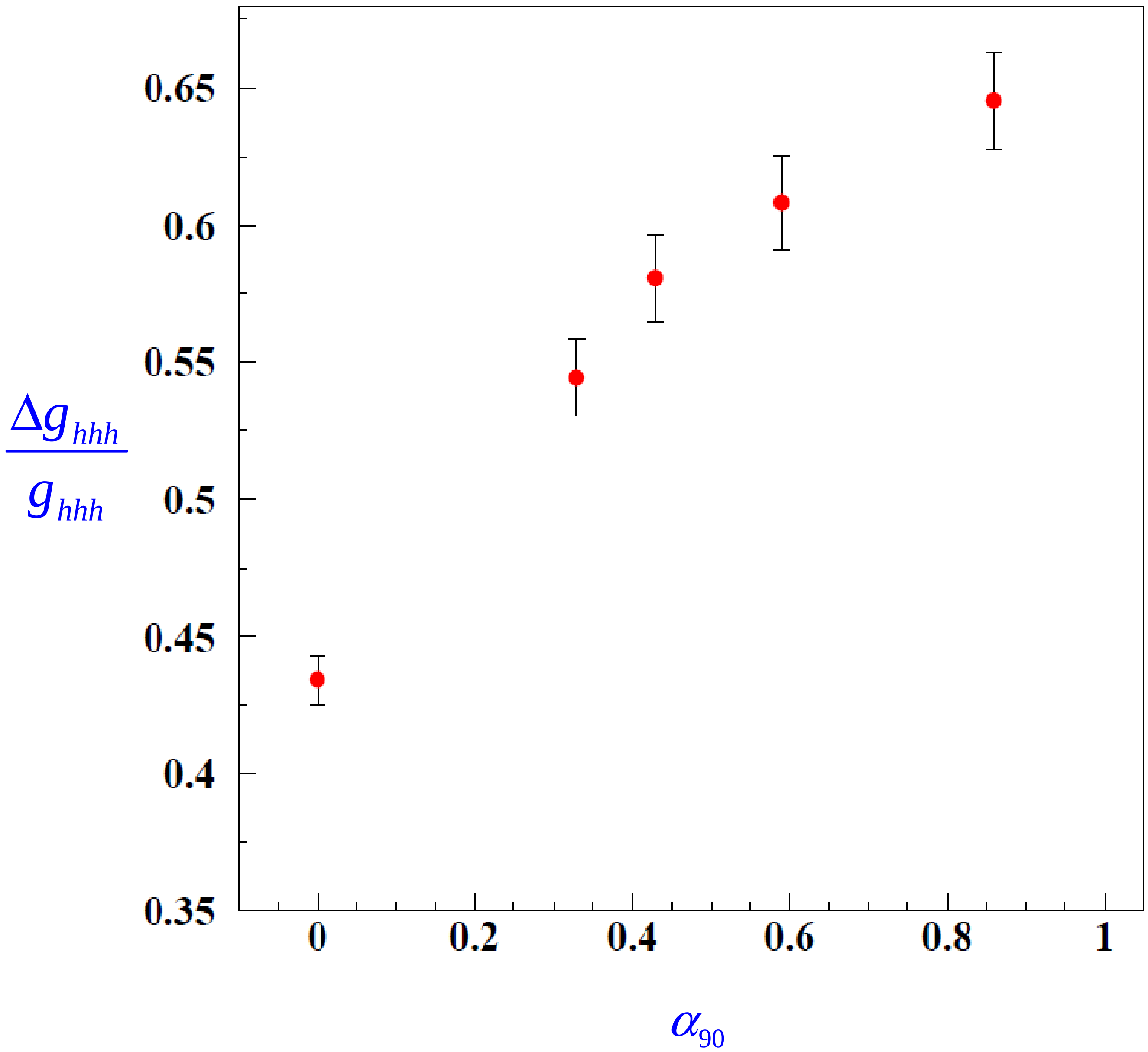
$\to qqb\bar{b}b\bar{b}$

$\sqrt{s} = 500\ GeV$

$L = 2000\ fb^{-1}$

$\Delta E/\sqrt{E} = 60\% \to 30\%$

equiv to $1.35\times$ Lumi



$\mathrm{BR}(H \to b\bar{b}) = 0.678$

$e^+e^- \to ZHH$

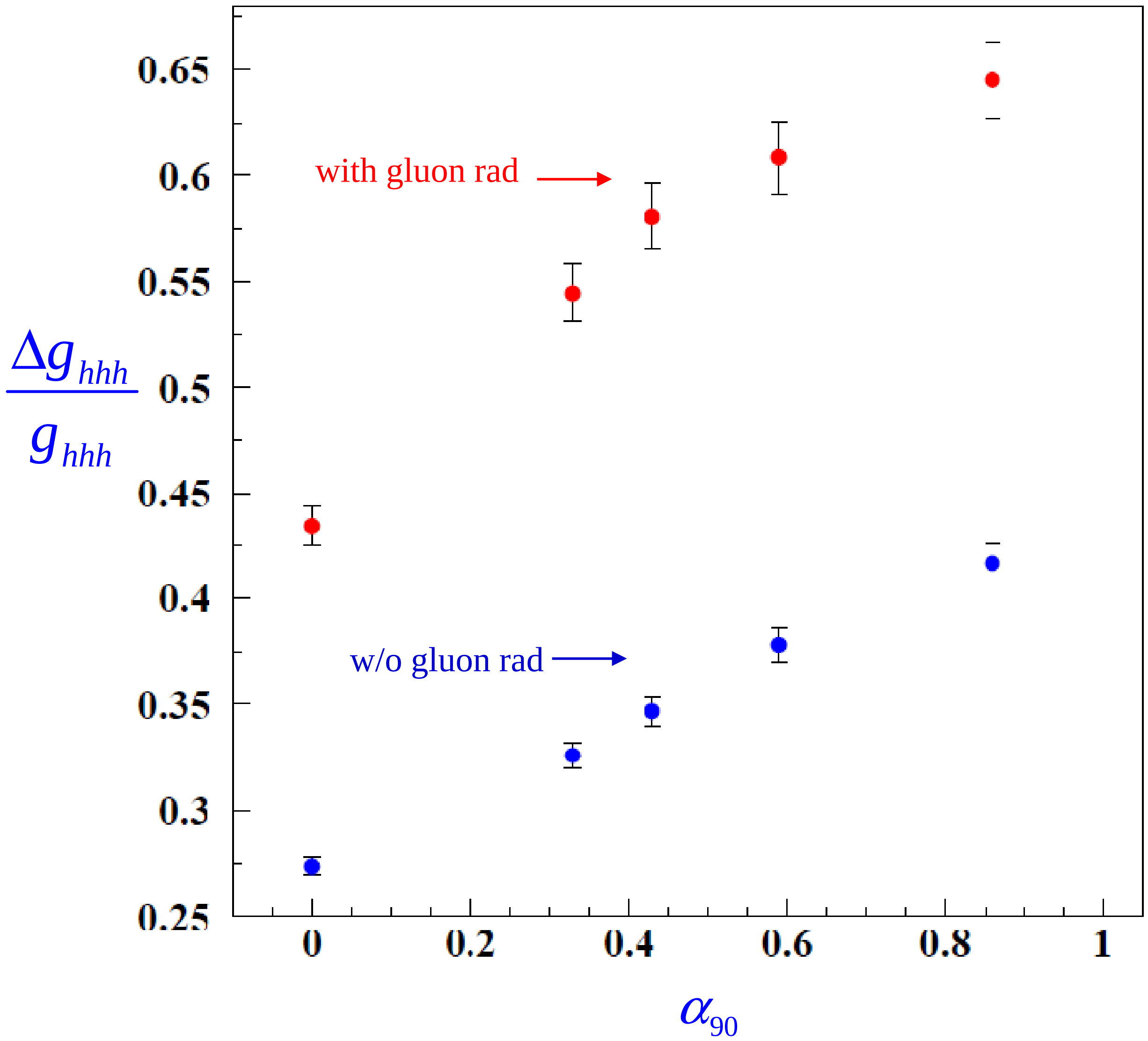
$\to qqb\bar{b}b\bar{b}$

$\sqrt{s} = 500\ GeV$

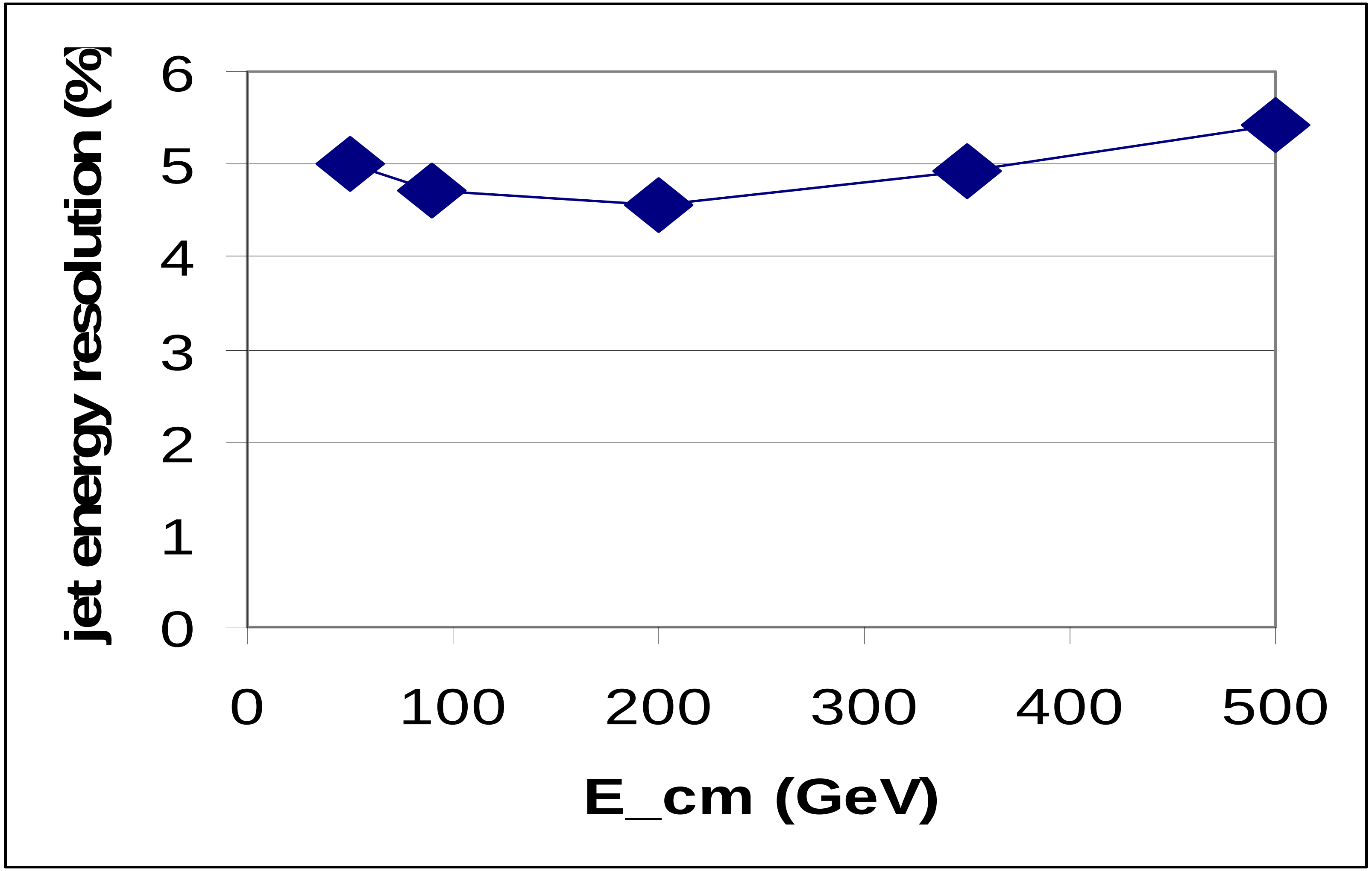
$L = 2000\ fb^{-1}$

$\Delta E/\sqrt{E} = 60\% \to 30\%$

equiv to $1.4\times$ Lumi



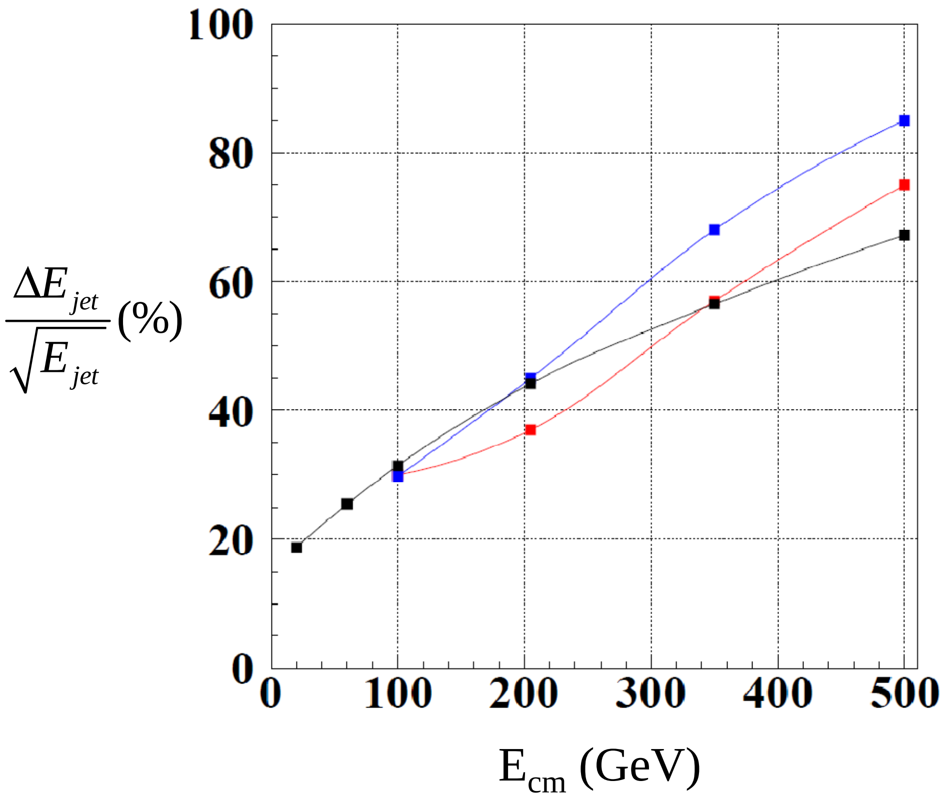
Light quark jets ee→qq GLD-PFA

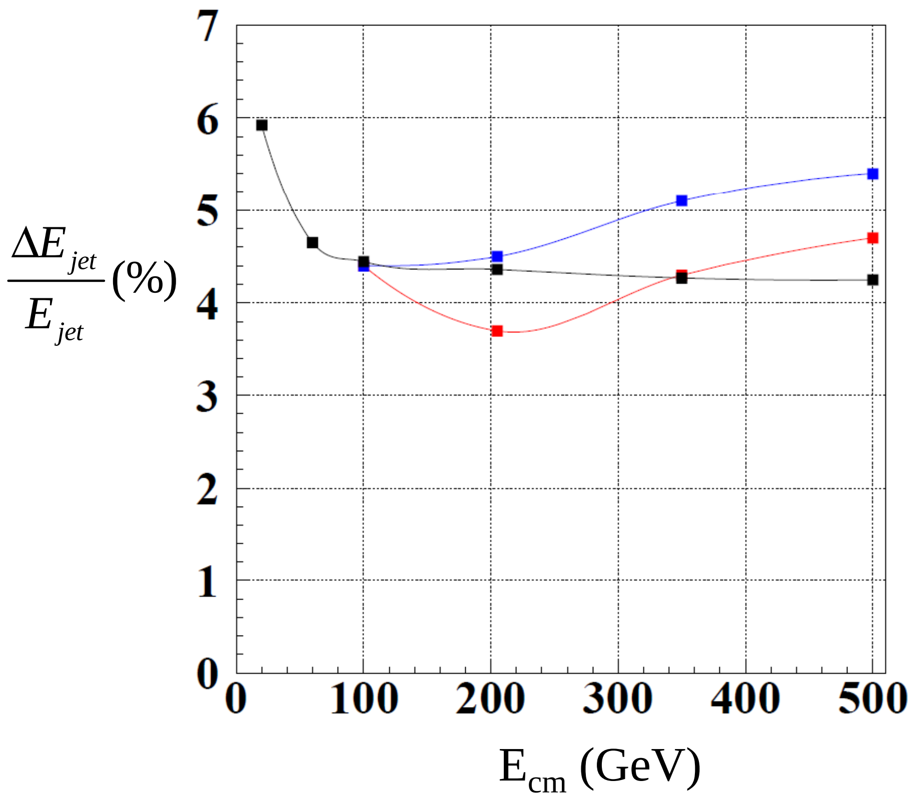


Light quark jets ee→qq

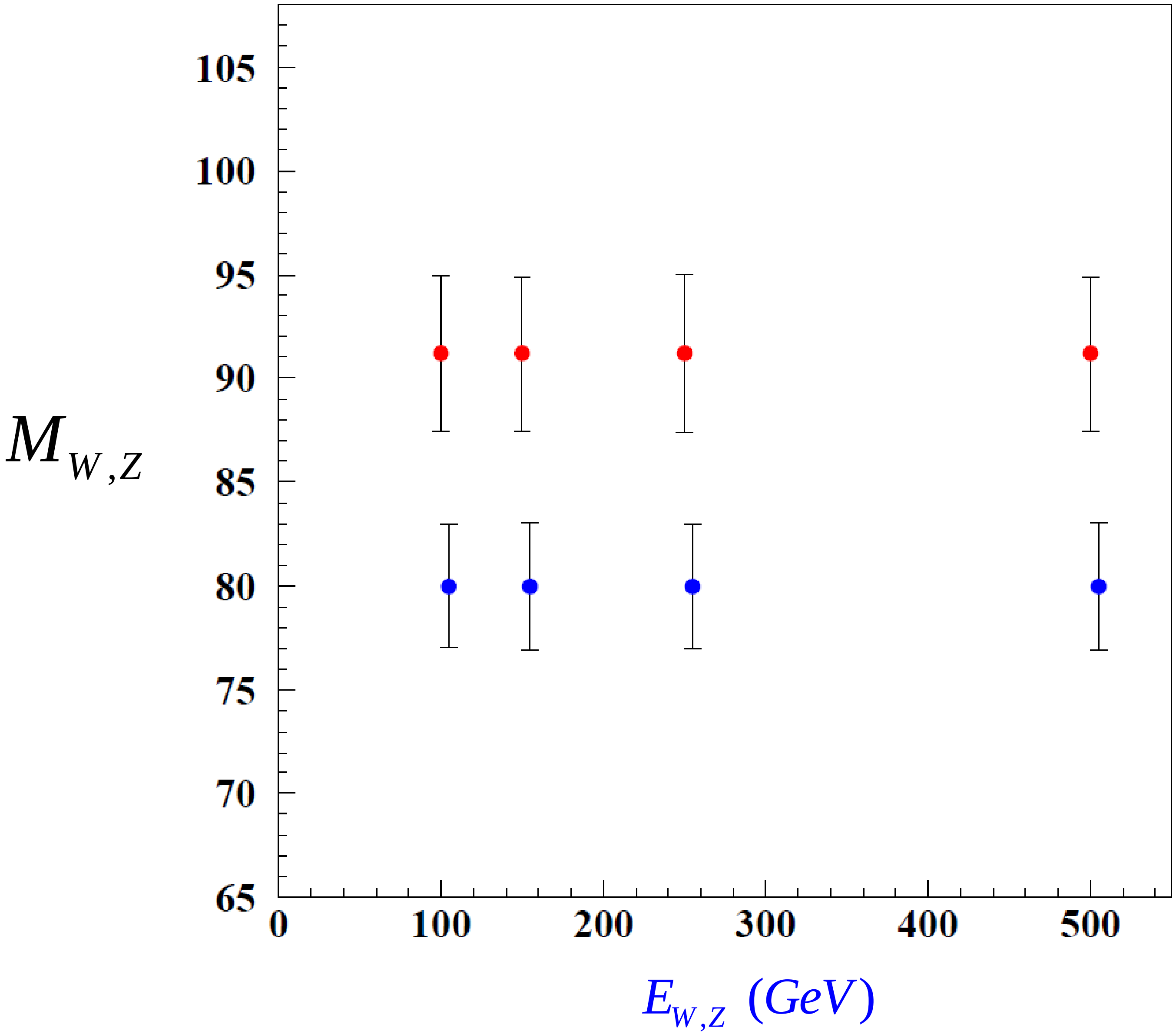
GLD PFA — LDC PFA — FASTMC with

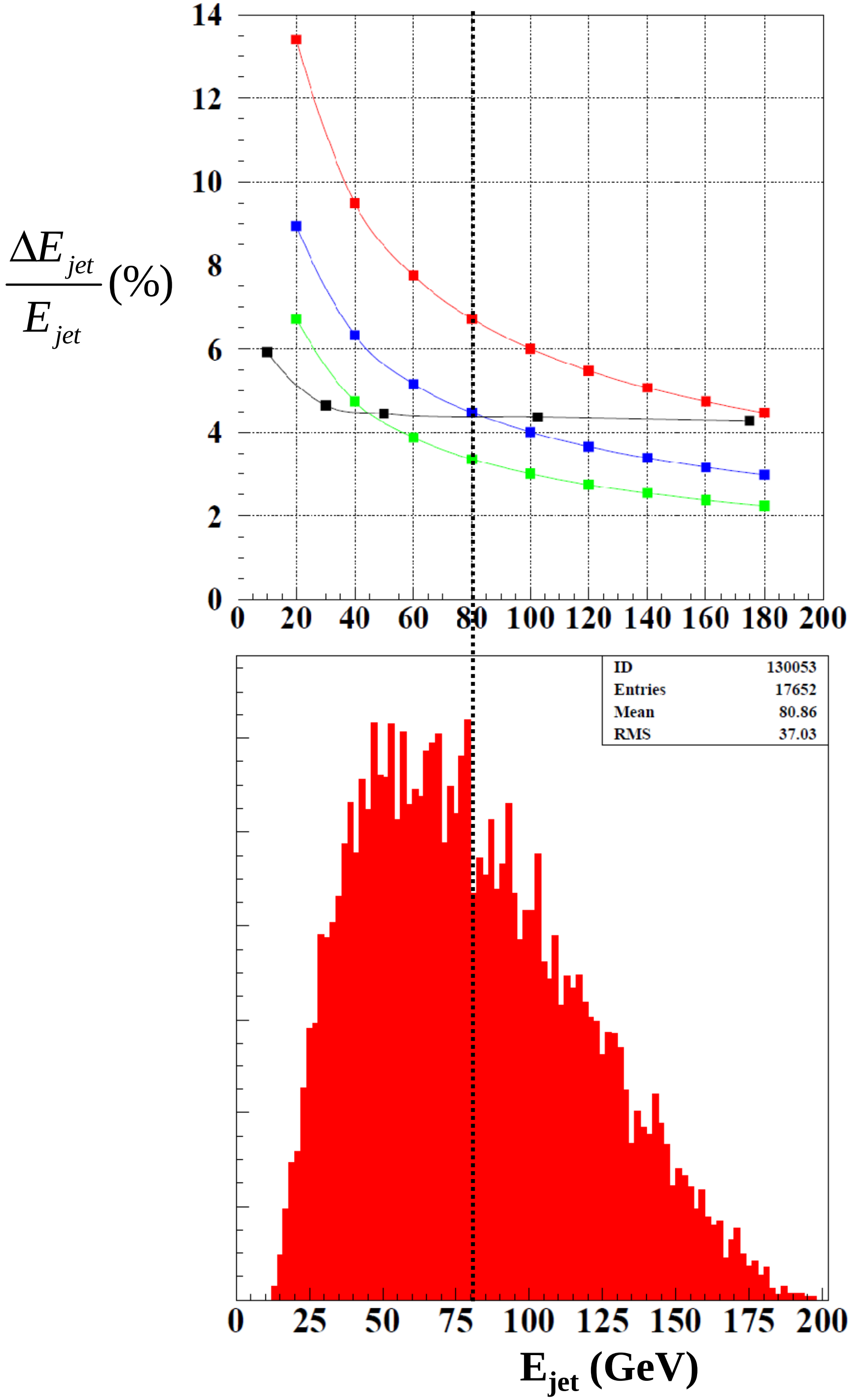
$$\frac{\Delta E_\gamma}{E_\gamma} = \frac{0.18}{\sqrt{E_\gamma}} \qquad \frac{\Delta E_{n,K_L^0}}{E_{n,K_L^0}} = 0.28$$





$$\frac{\Delta E_{jet}}{E_{jet}} \approx 0.043$$ (see FASTMC plot on previous page)





$$\frac{\Delta E_{jet}}{E_{jet}} = \frac{0.6}{\sqrt{E_{jet}}}$$

$$\frac{\Delta E_{jet}}{E_{jet}} = \frac{0.4}{\sqrt{E_{jet}}}$$

$$\frac{\Delta E_{jet}}{E_{jet}} = \frac{0.3}{\sqrt{E_{jet}}}$$

$\frac{\Delta E_{jet}}{E_{jet}} \approx$ PFA Current Status

True Jet Energy Distribution for

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

at $\sqrt{s} = 500$ GeV

Analysis must be redone with $\frac{\Delta E_{jet}}{E_{jet}}$ that reflects current PFA status.

For now replot triple Higgs coupling error vs. $\frac{\Delta E_{jet}}{E_{jet}}$ using existing results with $\frac{\Delta E_{jet}}{E_{jet}} \equiv \frac{\alpha_{90}}{\sqrt{80}}$

$BR(H \to b\bar{b})=0.678$

$e^+e^- \to ZHH$

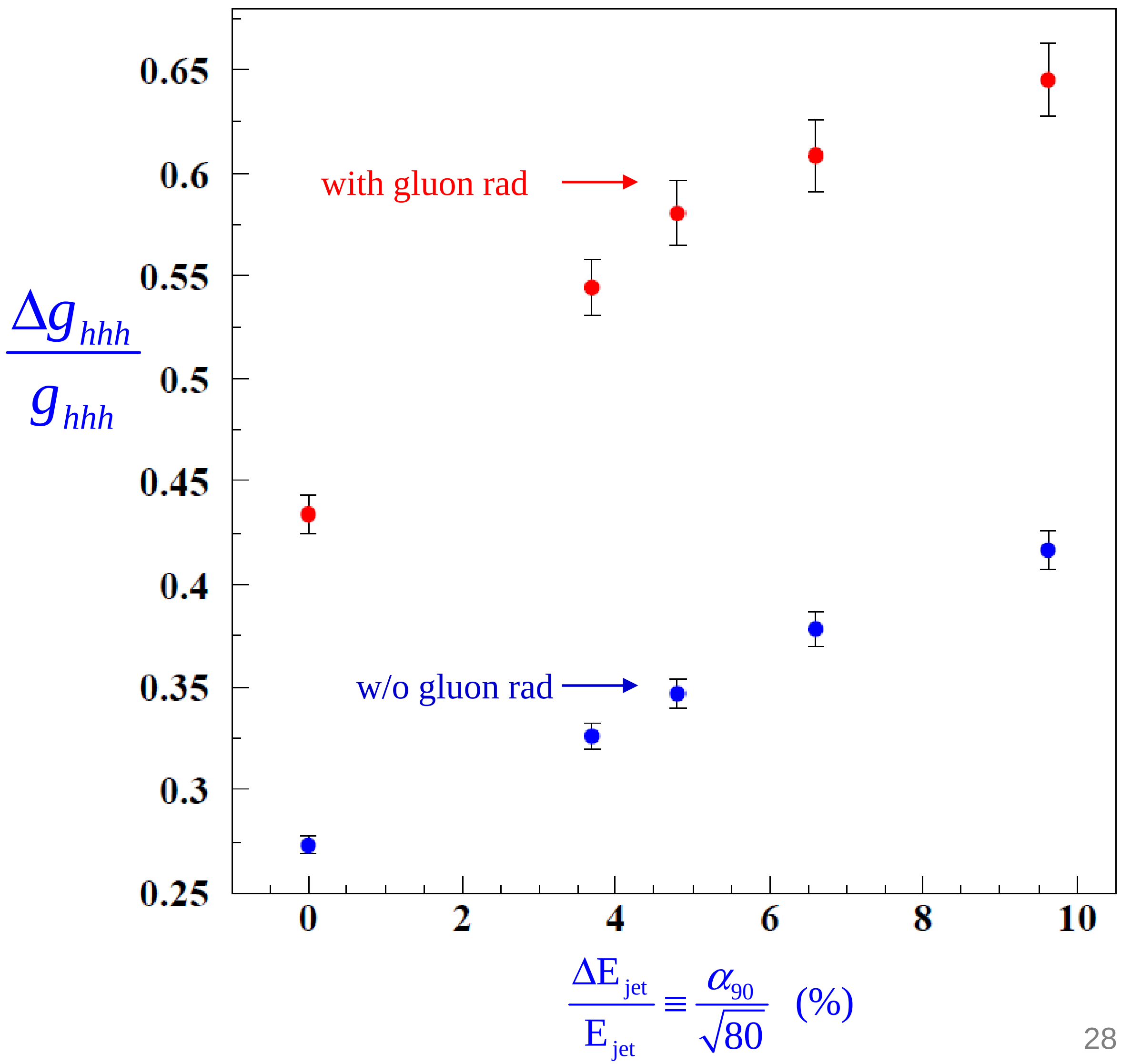
$\to qqb\bar{b}b\bar{b}$

$\sqrt{s} = 500\ GeV$

$L = 2000\ fb^{-1}$

$\Delta E/\sqrt{E} = 60\% \to 30\%$

equiv to 1.4× Lumi



Conclusions

- The error on the coupling g_{HHH} varies between 32 % and 38% as the jet energy resolution is varied between 30% to 60% over sqrt(E) assuming no gluon radiation, Ecm=500 GeV, L=2000 fb^{-1}, and the final state ZHH→qqbbbbb. This corresponds to an effective luminosity gain of 40% as the jet energy resolution is improved from 60% to 30% over sqrt(E). By increasing BR(H→bb) from 0.687 to 0.853, and adding the contribution from ZHH→llbbbb, this particular result replicates the TESLA TDR result.
- When final state gluon radiation is switched on, the error on g_{HHH} deteriorates to a range of 53 % to 62% for jet energy resolutions between 30% to 60% over sqrt(E). This problem may be solved with a more sophisticated jet algorithm and better b/c tagging. Note that we currently force reconstructed particles into 6 jets, which may not be the best approach in the presence of hard gluon radiation. Better b/c tagging, as well as b/bbar discrimination, can reduce combinatorics and provide b/c weighted jet energy corrections.

Conclusions (cont.)

- Results from the study of the Higgs self coupling error versus jet energy resolution at E_{cm}=500 GeV do not reflect the ultimate precision on the Higgs self coupling. In addition to improvement to the analysis of ZHH→qqbbbb, methods have and will be developed to exploit other Higgs decay modes. Also, analysis at E_{cm}=1000 GeV will lead to a significant improvement. A precision of 10% can eventually be achieved when data at E_{cm}=500 GeV and 1000 GeV are combined.