Requirements for Jet Energy Resolution

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Simple study of $\Delta M_{W,Z}$ versus $E_{W,Z}$ & ΔE_{jet} using FASTMC

$$e^{-}\gamma \rightarrow \nu_e W^{-} \rightarrow \nu_e \bar{u} d$$

$$\nu_e H \rightarrow \nu_e Z \rightarrow \nu_e u \bar{u}$$

No resolution loss from jet-finding, neutrinos,

or particles outside fid. vol.

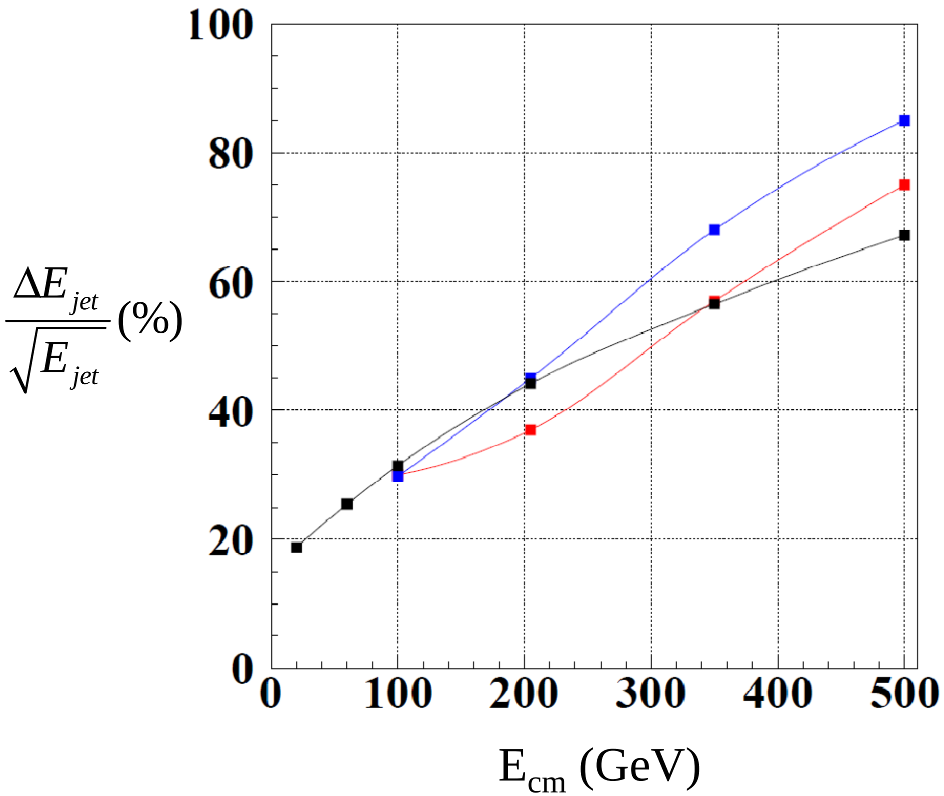
Use the following single particle calorimeter resolutions in FASTMC to mimick PFA jet energy resolution versus jet energy for jet energies 50 GeV < E_{jet} < 250 GeV:

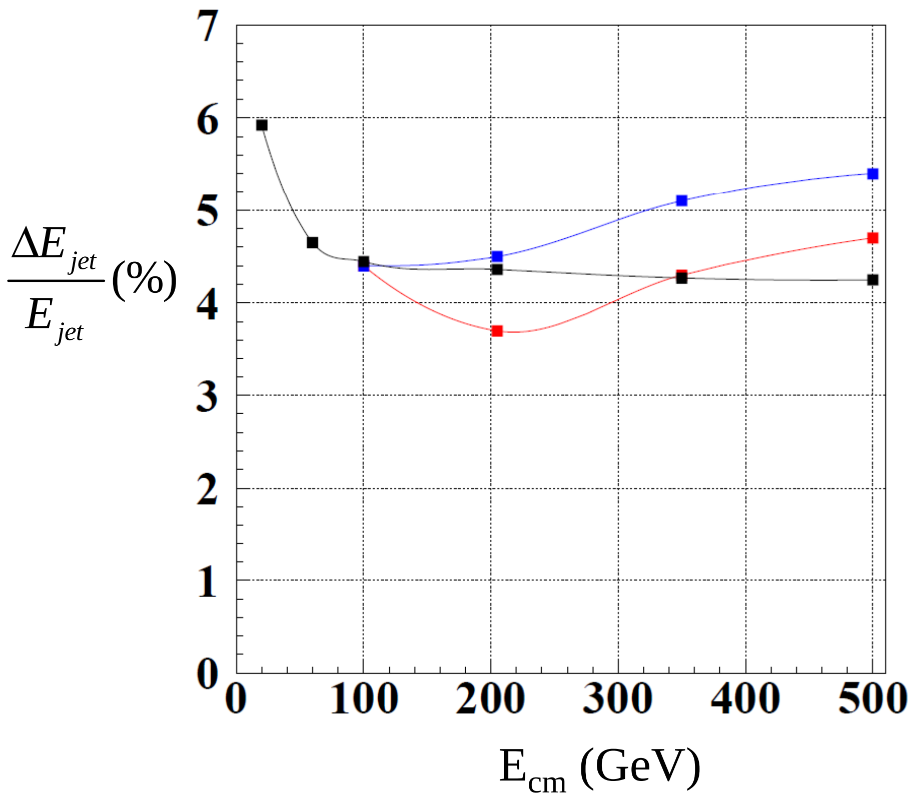
$$\frac{\Delta E_{\gamma}}{E_{\gamma}} = \frac{0.18}{\sqrt{E_{\gamma}}} \qquad \frac{\Delta E_{n,K_L^0}}{E_{n,K_L^0}} = 0.28$$

Light quark jets ee→qq

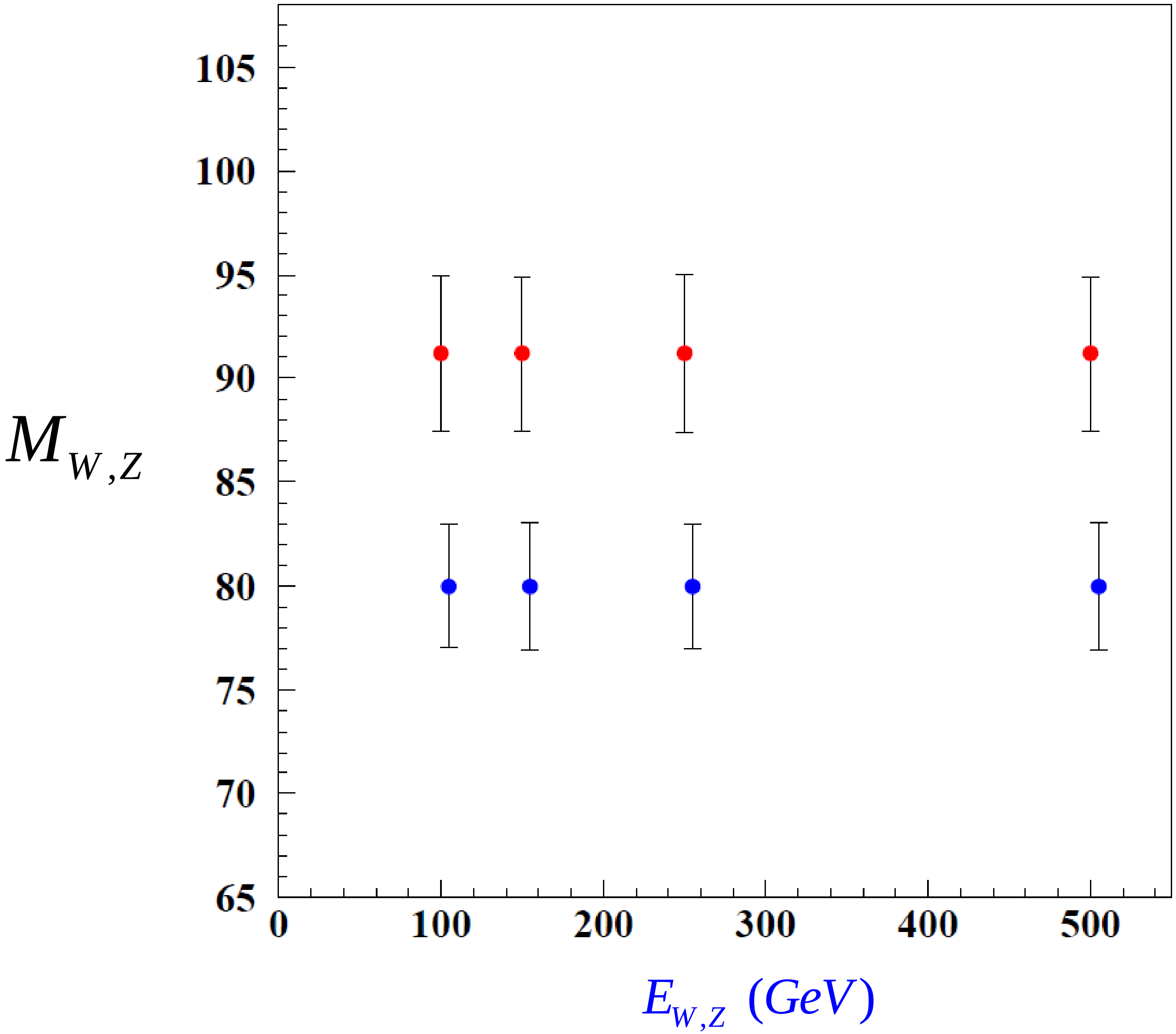
GLD PFA (blue) LDC PFA (red) FASTMC with (black)

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





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



The approximate expression for the two-jet mass M is

$$M \approx 2E_1E_2(1-\cos\theta)$$

$$\frac{\Delta M}{M} \approx \frac{1}{2}\left[\frac{\Delta E_1}{E_1} \oplus \frac{\Delta E_2}{E_2}\right]$$

but the full expression is

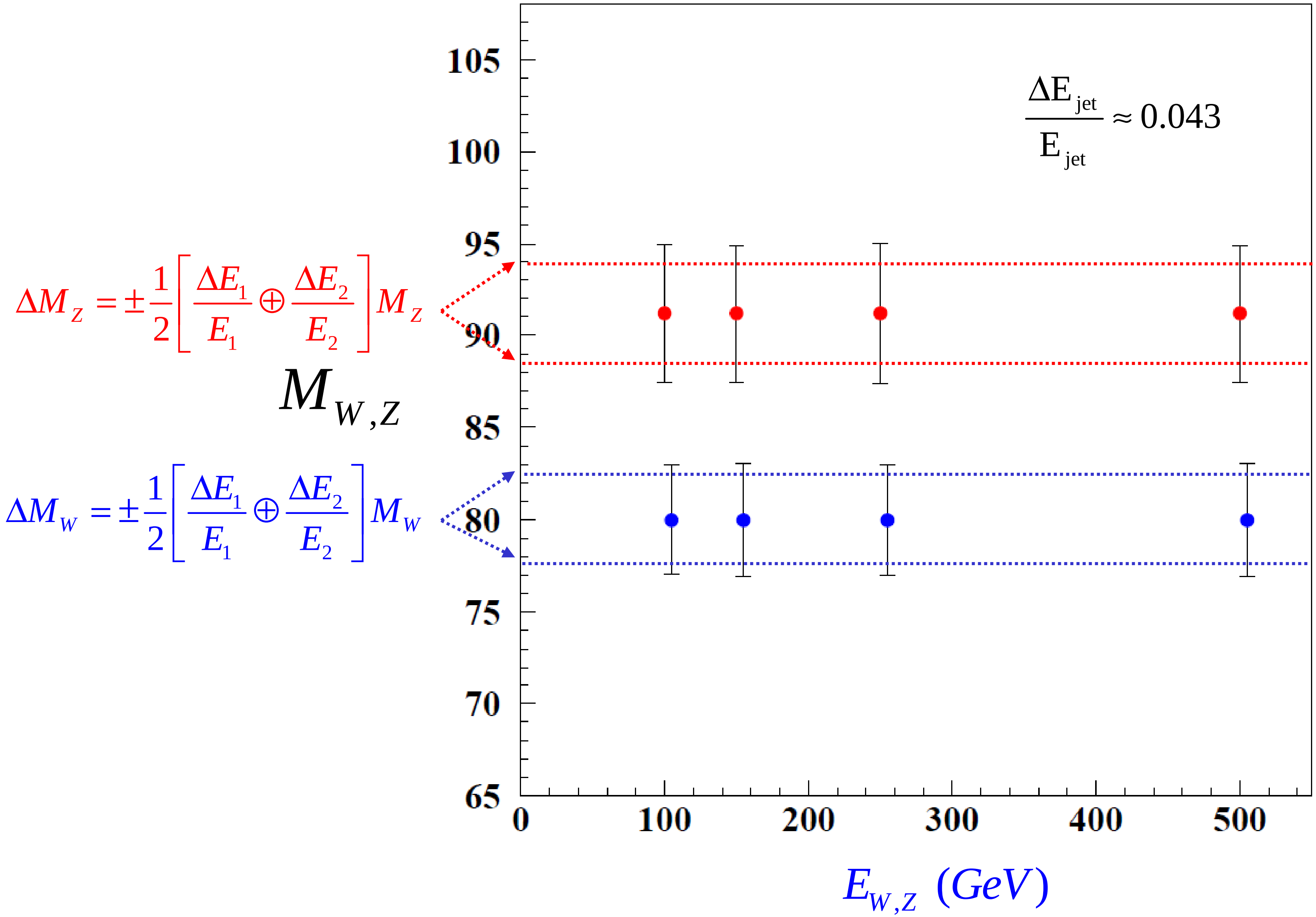
$$M = m_1^2 + m_2^2 + 2E_1E_2(1-\beta_1\beta_2\cos\theta) \quad , \quad \beta_j = \left(1-\frac{m_j^2}{E_j^2}\right)^{\frac{1}{2}}$$

$$\frac{\Delta M}{M} \approx \frac{1}{2}\left[\frac{\Delta E_1}{E_1} \oplus \frac{\Delta E_2}{E_2} \oplus \frac{\theta\sin\theta}{1-\cos\theta}\frac{\Delta\theta}{\theta} \oplus \frac{1+r^{-1}\cos\theta}{1-\cos\theta}\frac{m_1^2}{E_1E_2}\frac{\Delta m_1}{m_1} \oplus \frac{1+r\cos\theta}{1-\cos\theta}\frac{m_2^2}{E_1E_2}\frac{\Delta m_2}{m_2}\right]$$

$$r = \frac{E_1}{E_2}$$

How important are the $\frac{\Delta\theta}{\theta}$, $\frac{\Delta m_1}{m_1}$, $\frac{\Delta m_2}{m_2}$ terms?

At least in the FASTMC, the $\frac{\Delta\theta}{\theta}$, $\frac{\Delta m_1}{m_1}$, $\frac{\Delta m_2}{m_2}$ terms are not very important:



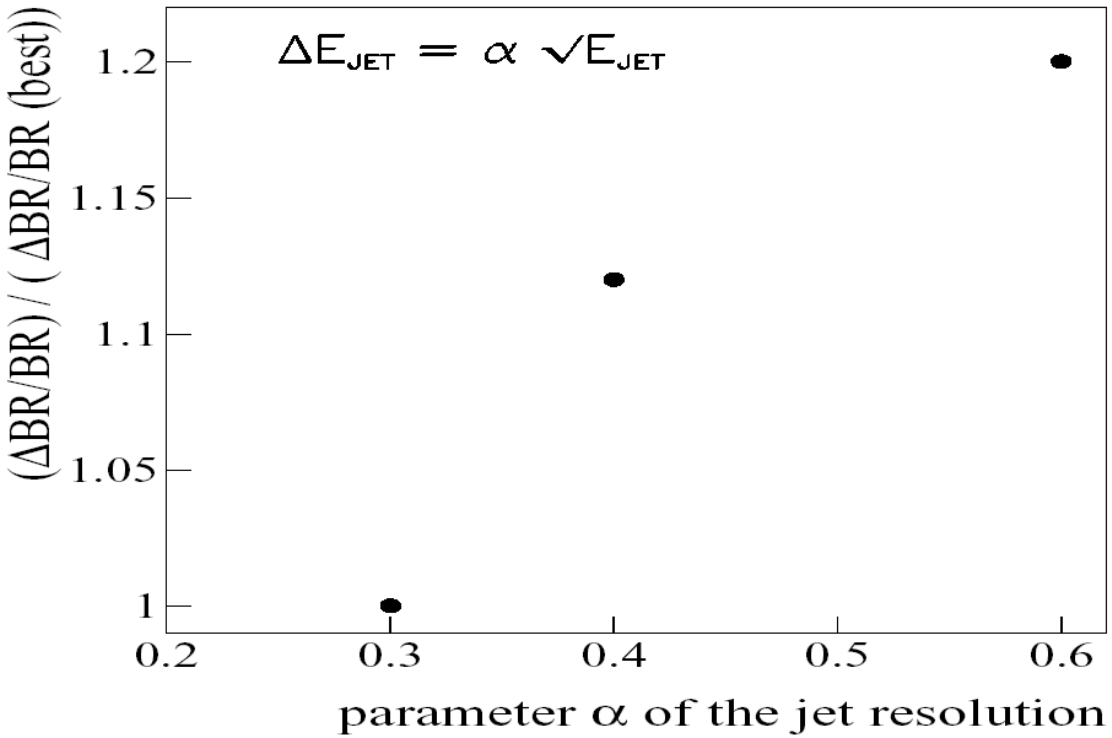
Error on $BR(H \to WW^*)$ from measurement of

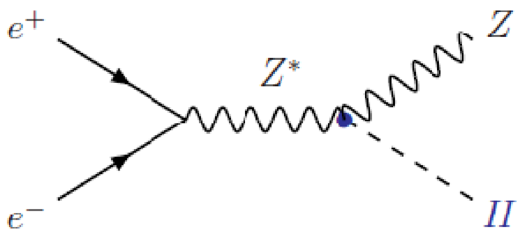
$e^+e^- \to ZH \to q\bar{q}WW^* \to q\bar{q}q\bar{q}l\nu$ at $\sqrt{s} = 360$ GeV, L=500 fb^{-1}

J.-C. Brient, LC-PHSM-2004-001

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

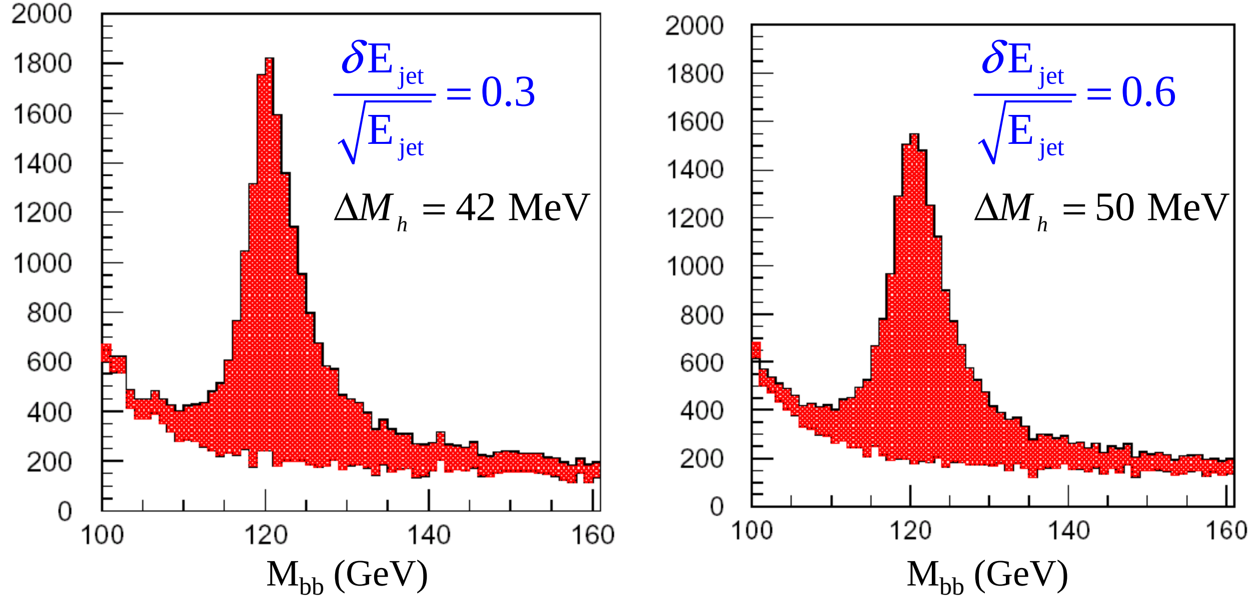
equiv to $1.4\times$ Lumi

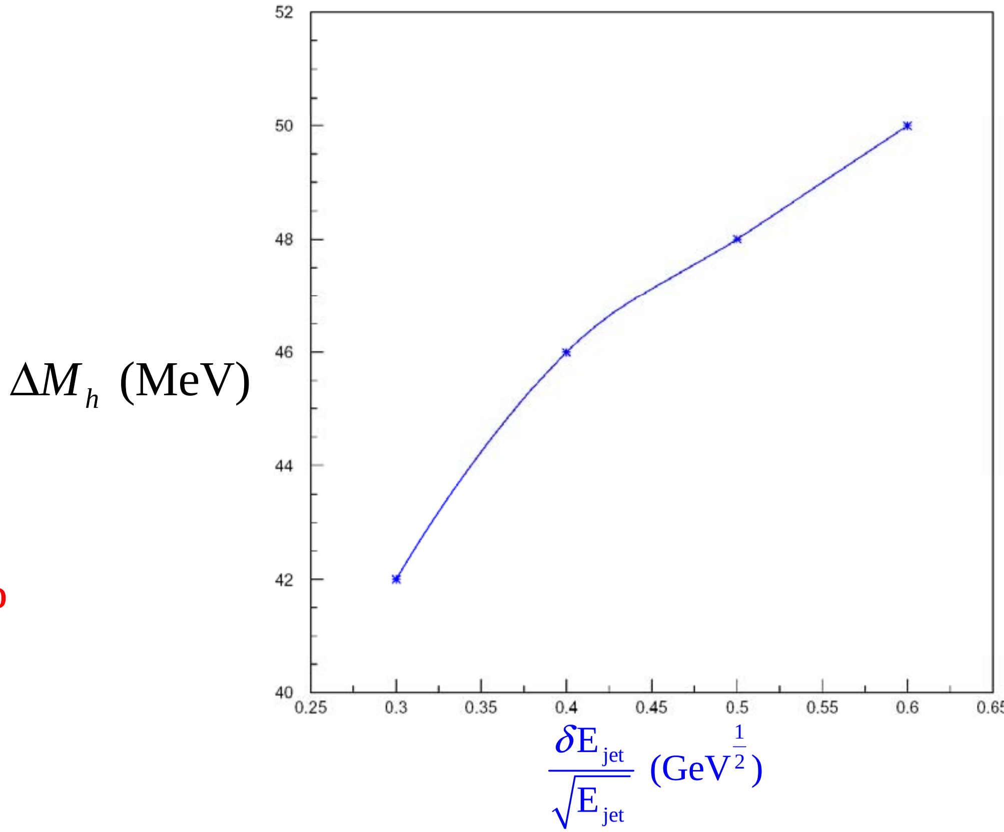




$$e^+e^- \rightarrow ZH$$
$$\rightarrow qqb\bar{b}$$

$$\sqrt{s} = 350\ GeV$$
$$L = 500\ fb^{-1}$$





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

equiv to $1.4\times$ Lumi

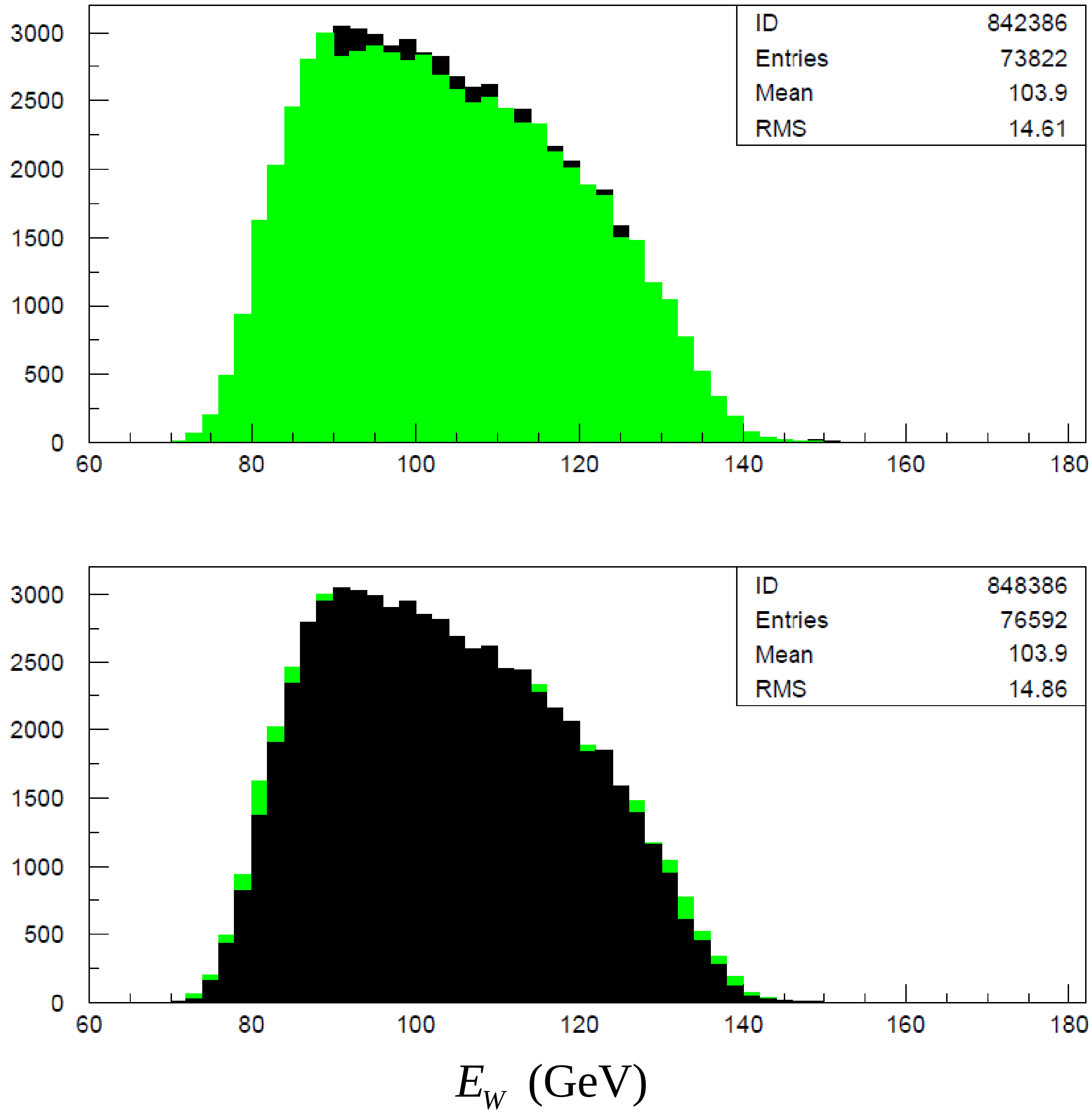
$$e^+e^- \rightarrow \tilde{\chi}_1^+\tilde{\chi}_1^- \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0 W^+W^- \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0 qqqq$$

$M_{\tilde{\chi}_1^0} = 106.2$ GeV

$\sqrt{s} = 500$ GeV

$M_{\tilde{\chi}_1^+} = 198.4$ GeV

$M_{\tilde{\chi}_1^+} = 200.4$ GeV



Due to W mass the energy spectrum doesn't shift to left or right as in slepton case but instead get wider or narrower $\Rightarrow$ all energies contribute to mass meas.

$$e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 W^+W^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 qqqq$$

$M_{\tilde{\chi}_1^+} = 199.4$ GeV

$M_{\tilde{\chi}_1^0} = 106.2$ GeV

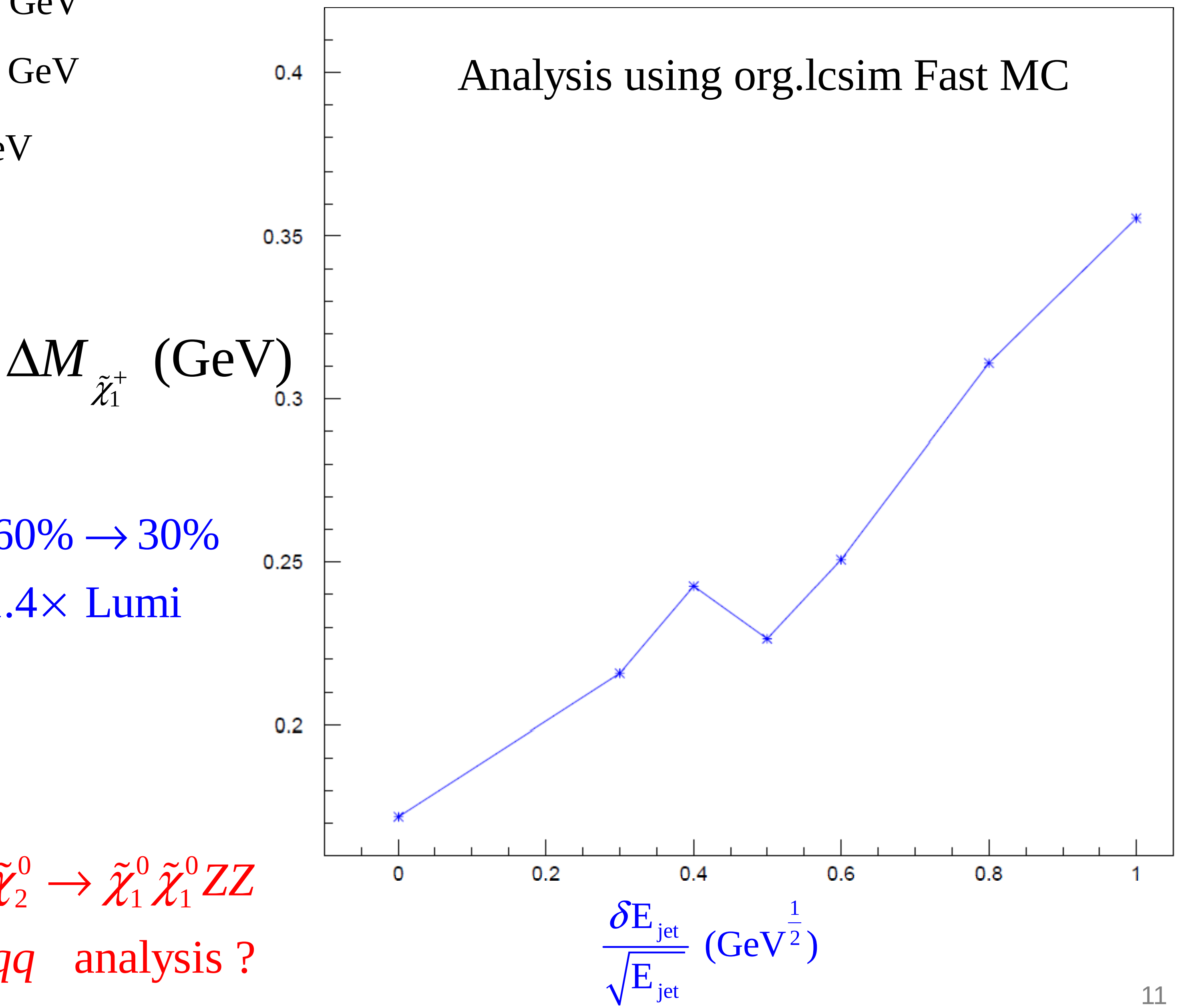
$\sqrt{s} = 500$ GeV

$L = 500\ fb^{-1}$

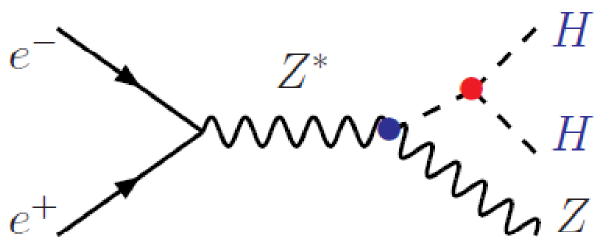
$\Delta E/\sqrt{E} = 60\% \to 30\%$

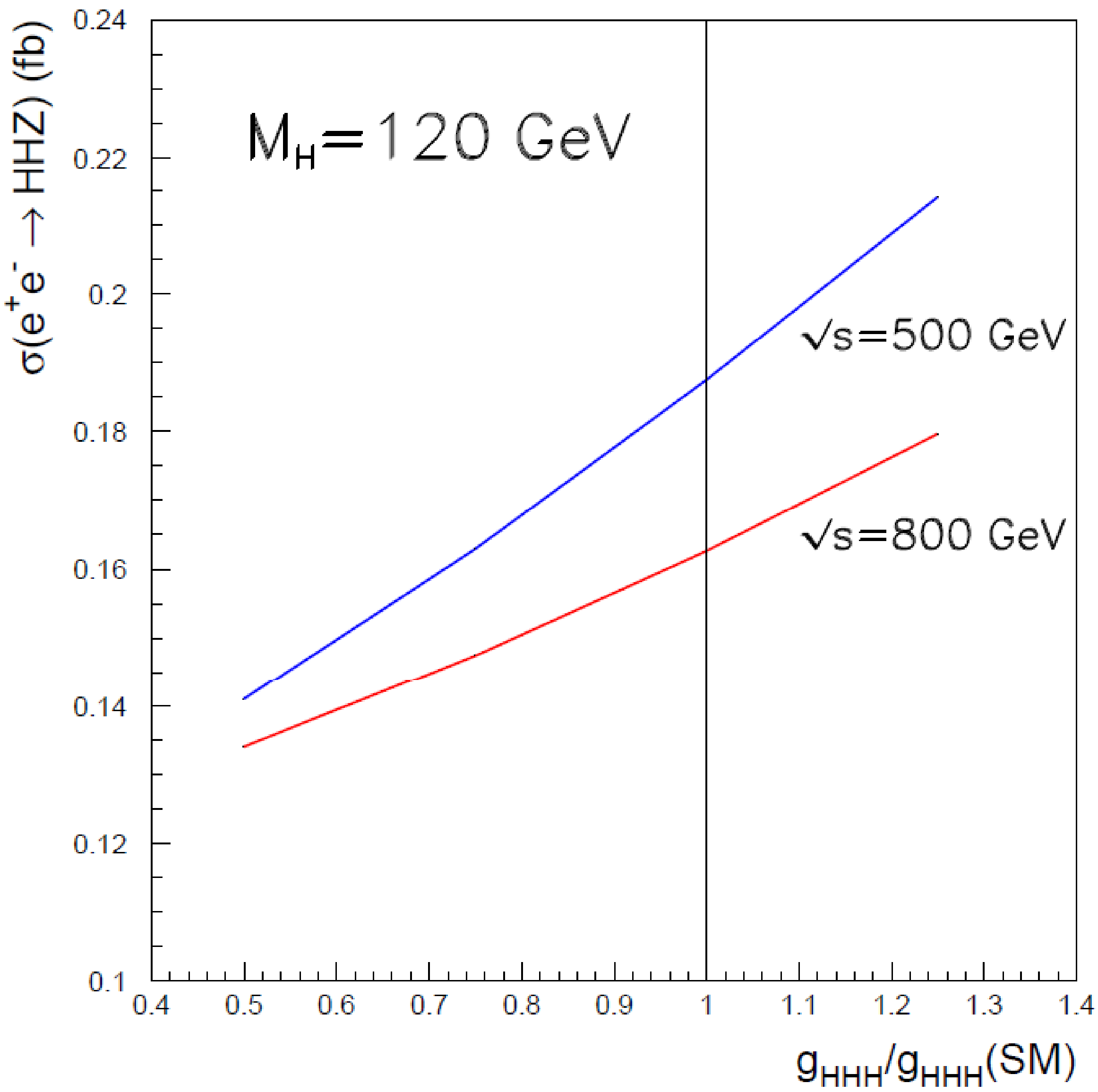
equiv to $1.4\times$ Lumi

$e^+e^- \to \tilde{\chi}_2^0\tilde{\chi}_2^0 \to \tilde{\chi}_1^0\tilde{\chi}_1^0 ZZ \to \tilde{\chi}_1^0\tilde{\chi}_1^0 qqqq$ analysis ?



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

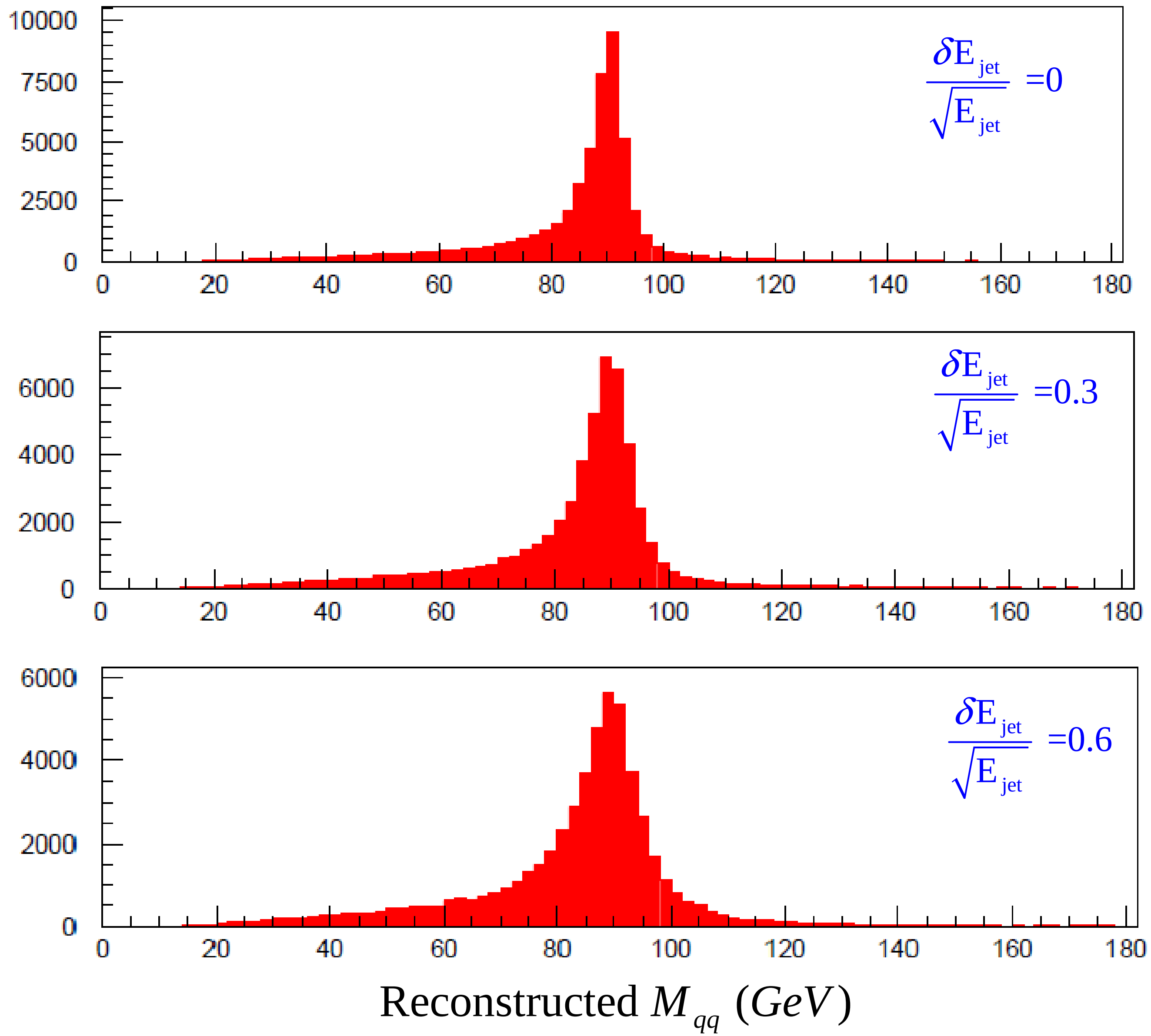




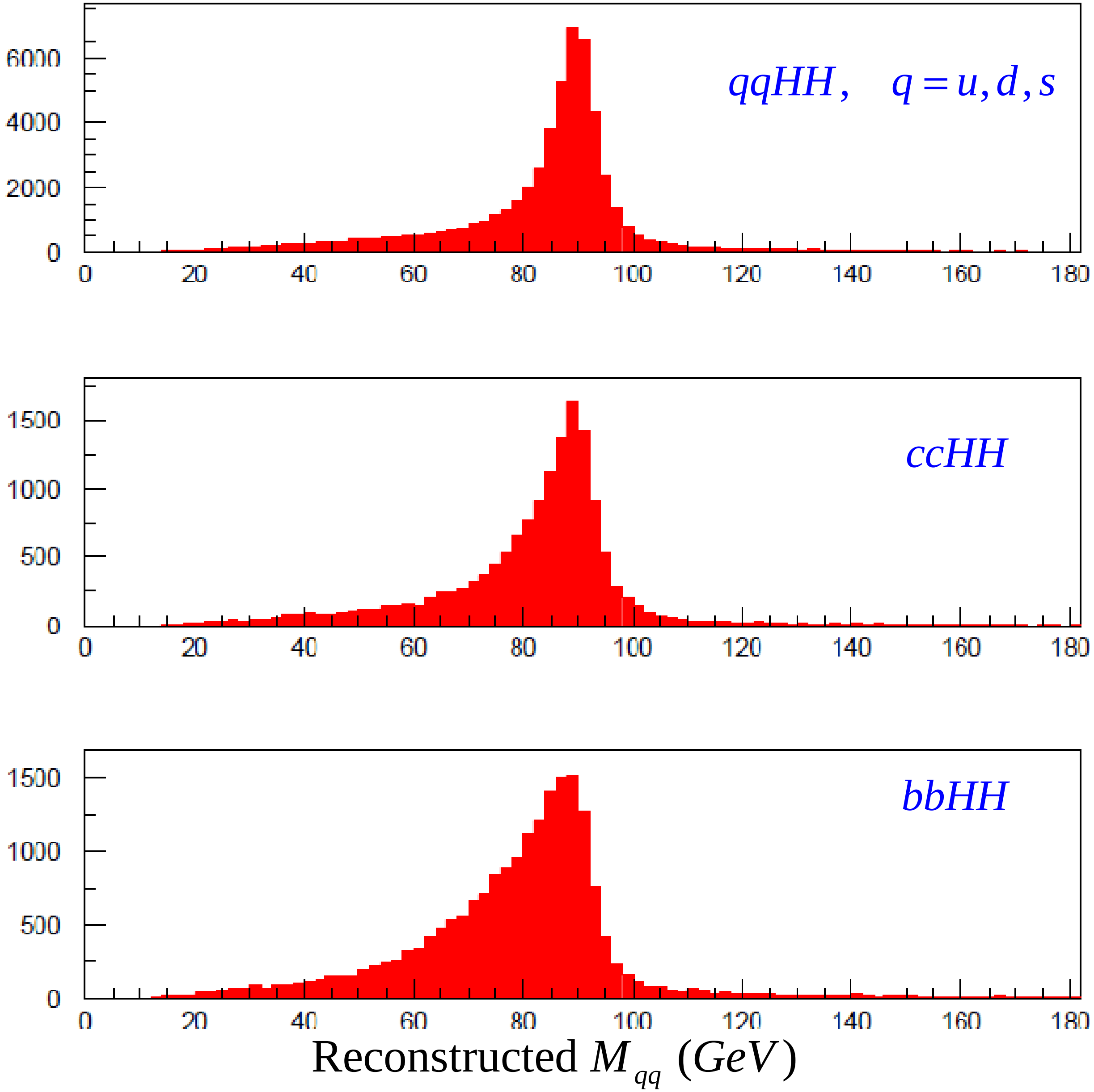
Plan for ZHH Analysis

- 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.

$e^+e^- \to qqHH, \quad q = u, d, s$ 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:

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

$$thrust < 0.85$$

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

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

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

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

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

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

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}

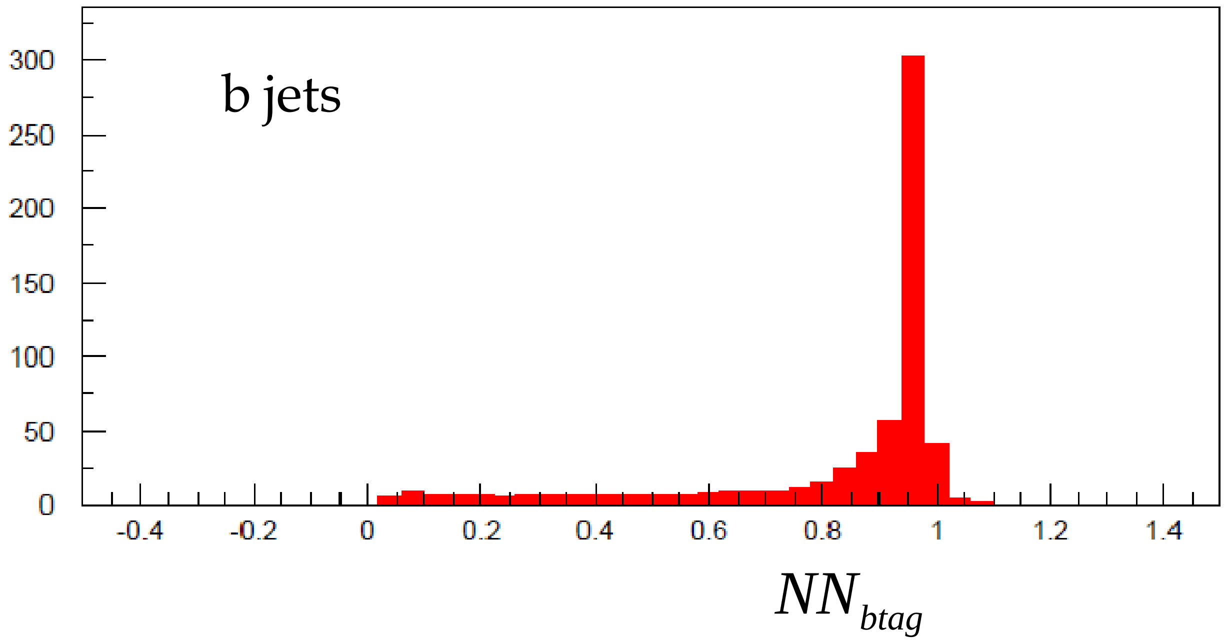
M_{vtx}

Pt-Corrected M_{vtx}

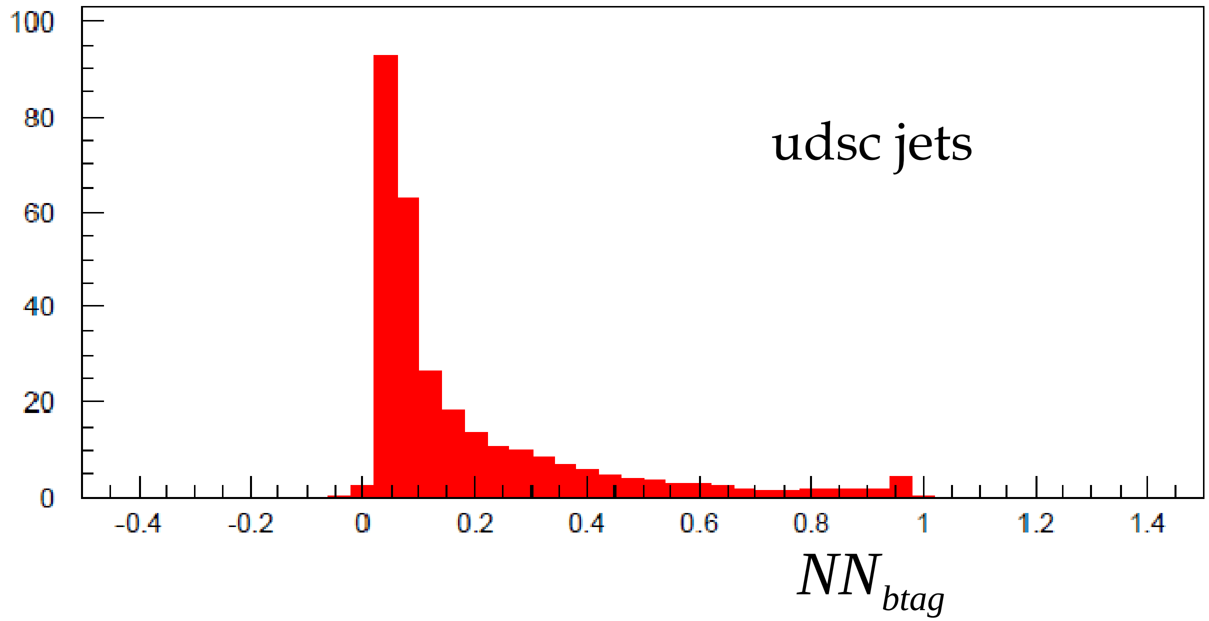
\# Secondary Vertices

\# Unassociated Large Impact Parameter Tracks

ZHH events



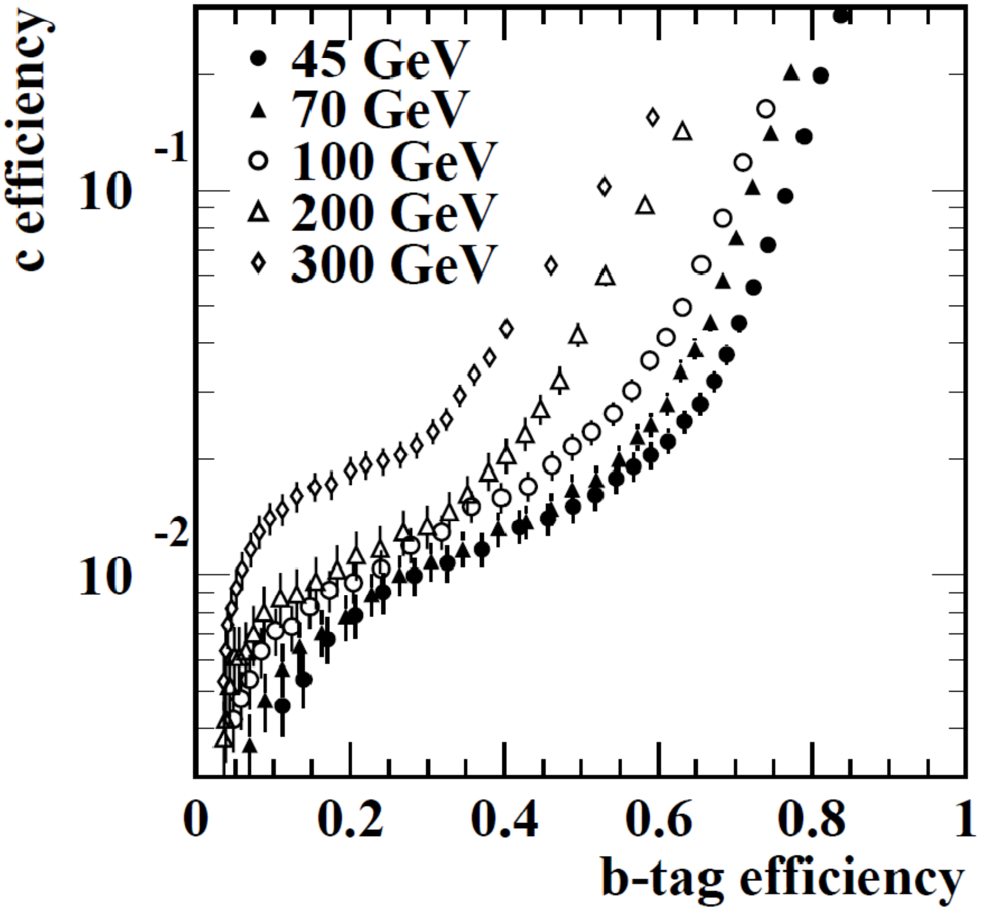
b jets
300
250
200
150
100
50
0
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
NN_{btag}



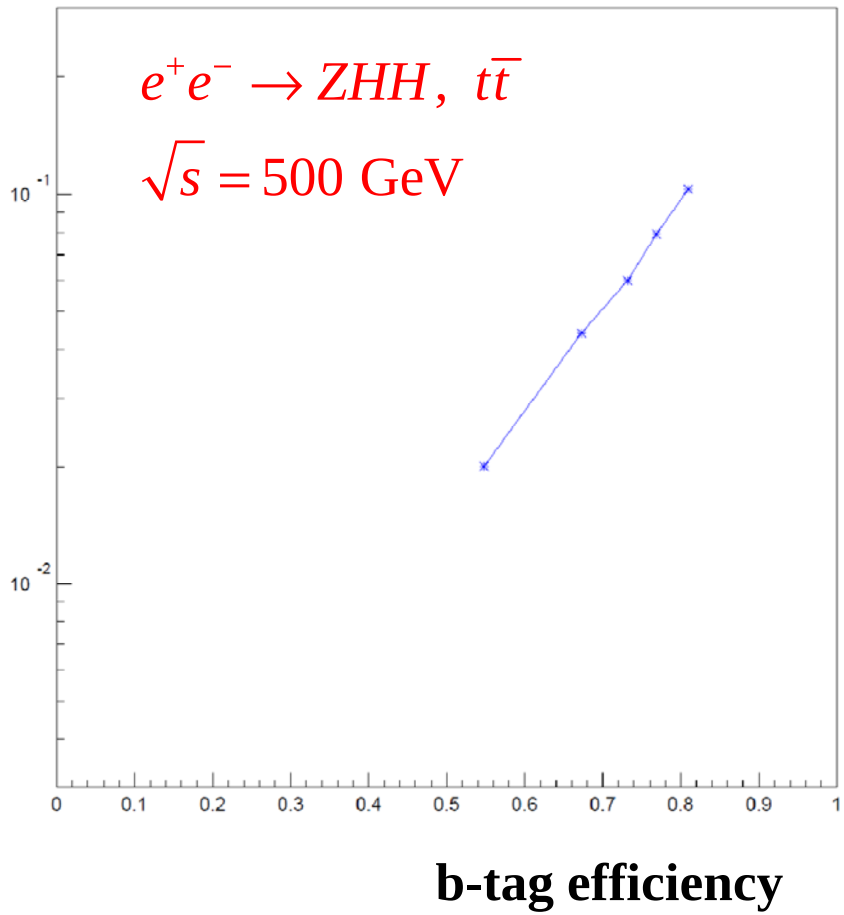
udsc jets
100
80
60
40
20
0
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
NN_{btag}

charm mis-id efficiency versus b-tag efficiency

R. Hawkings, LC-PHSM-2000-021



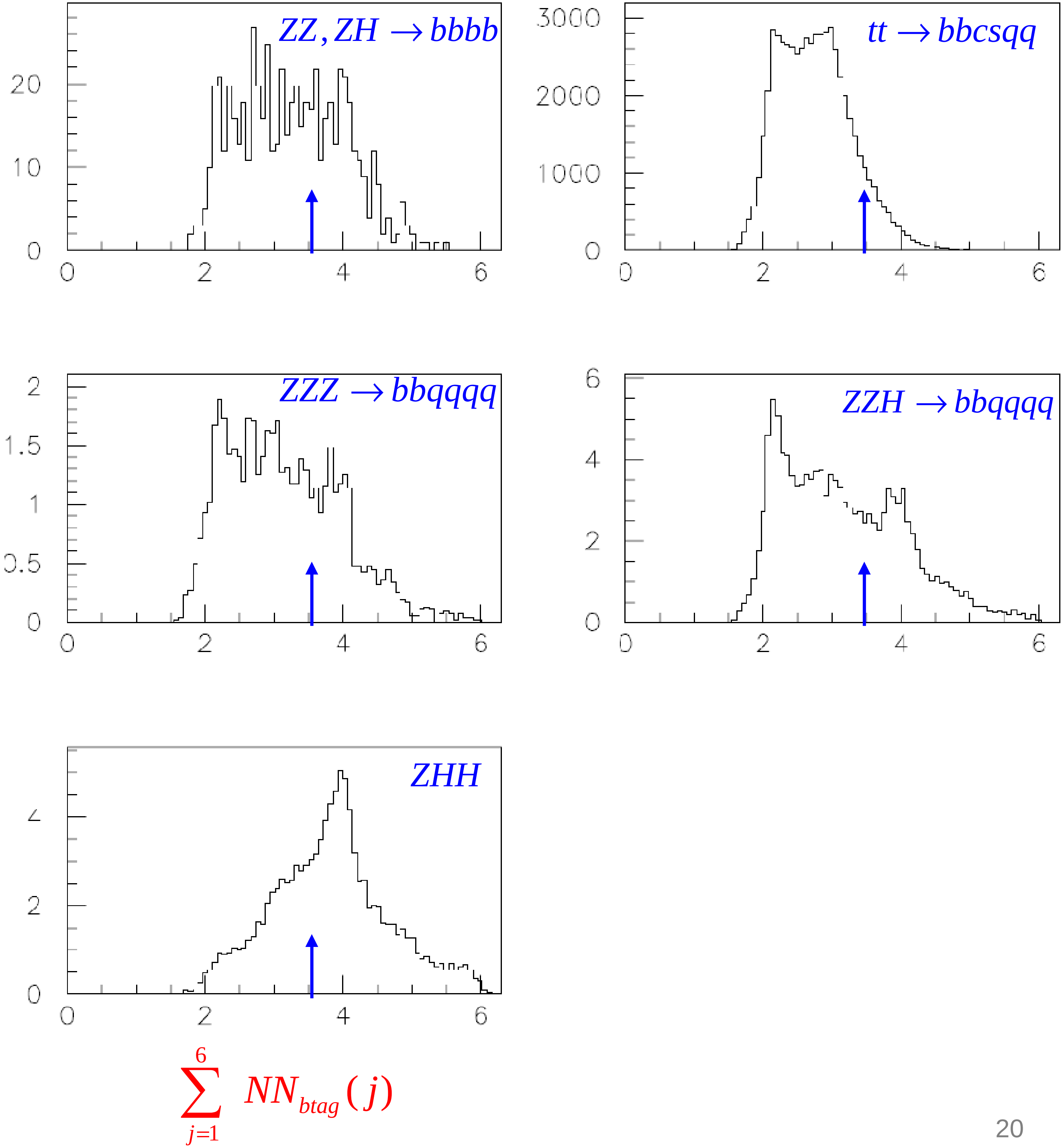
SiD ZHH Analysis



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

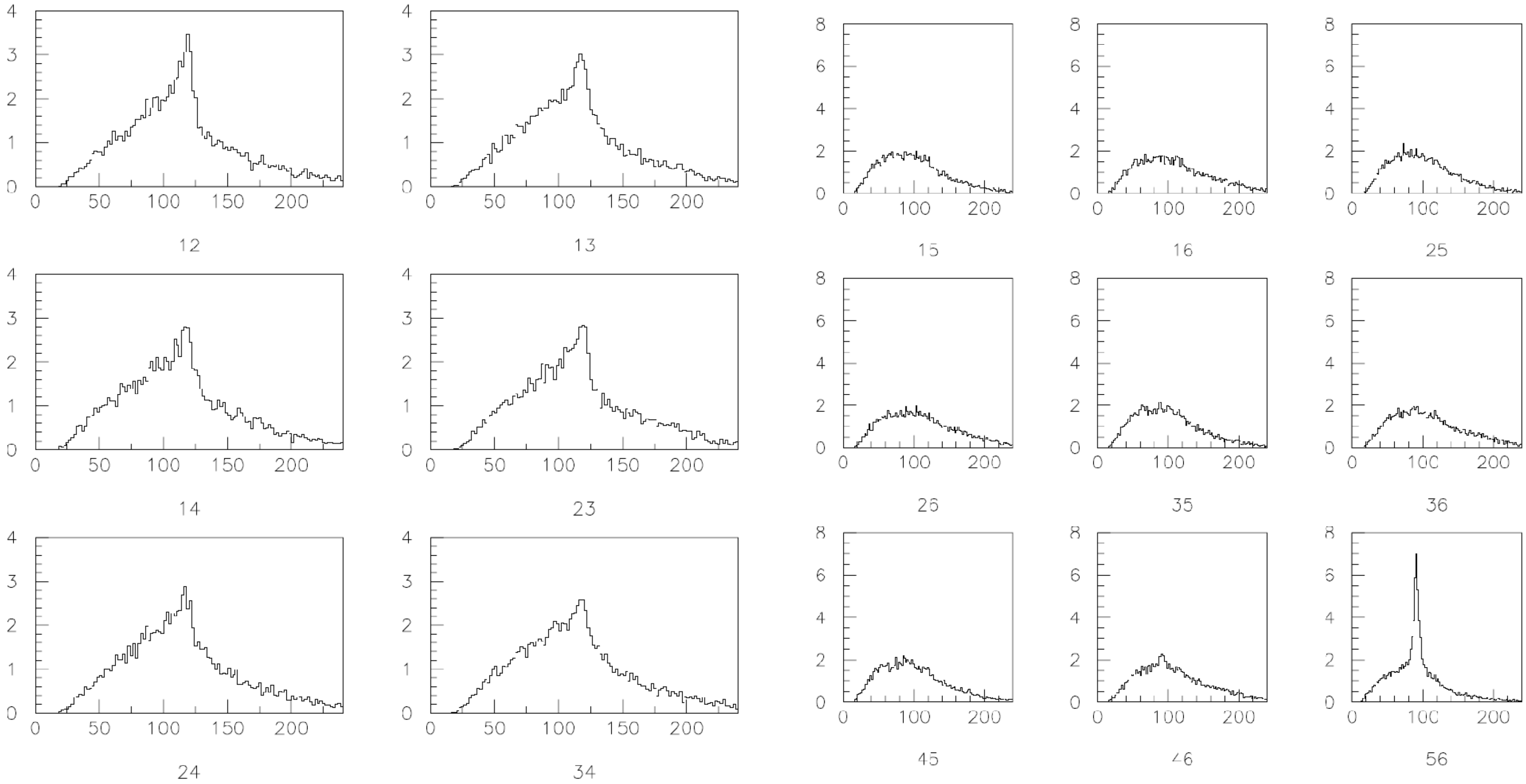
$$\sum_{j=1}^{6} NN_{btag}(j) > 3.5$$



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

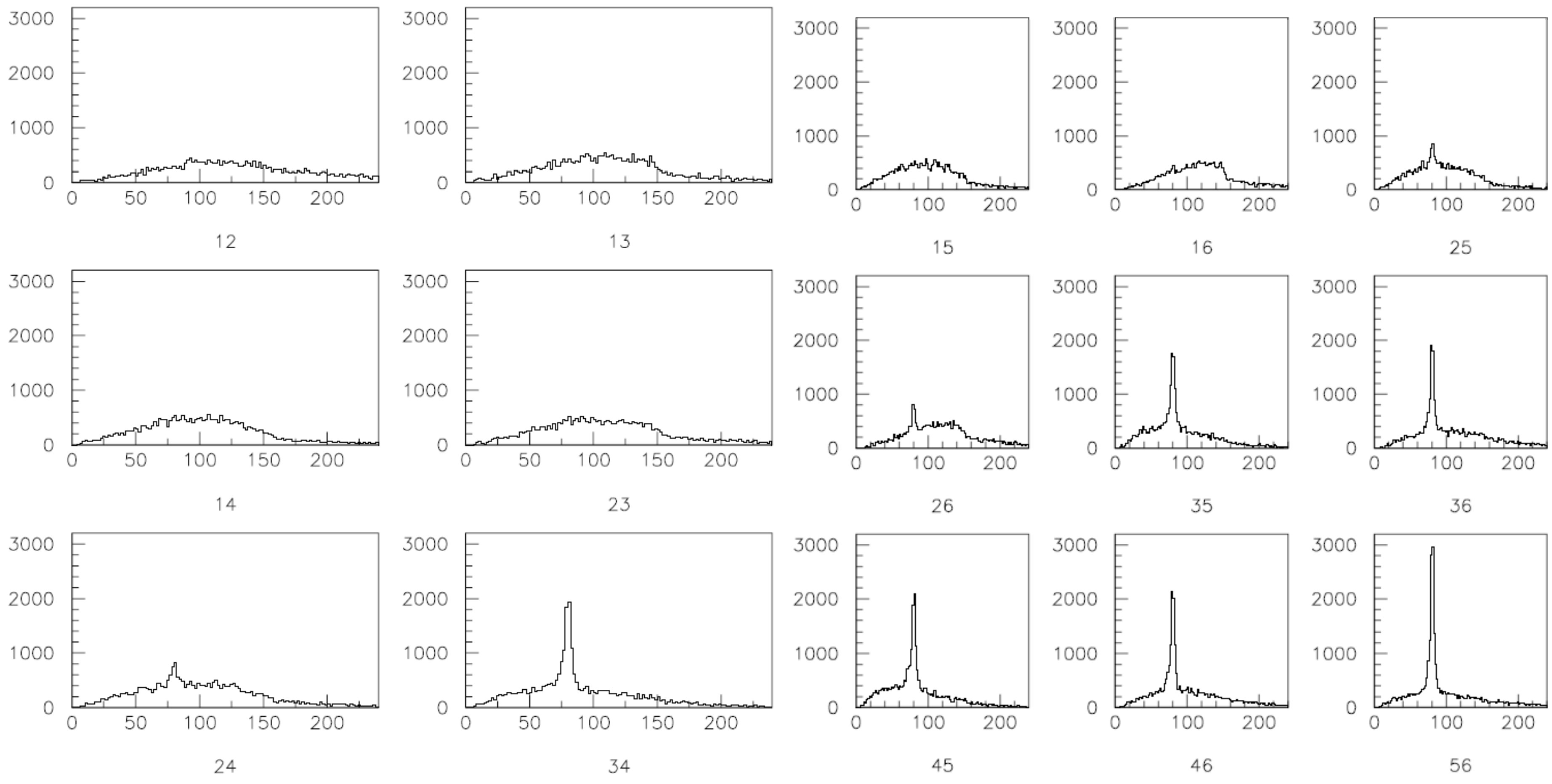


$M_{jk}\ (GeV)$

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

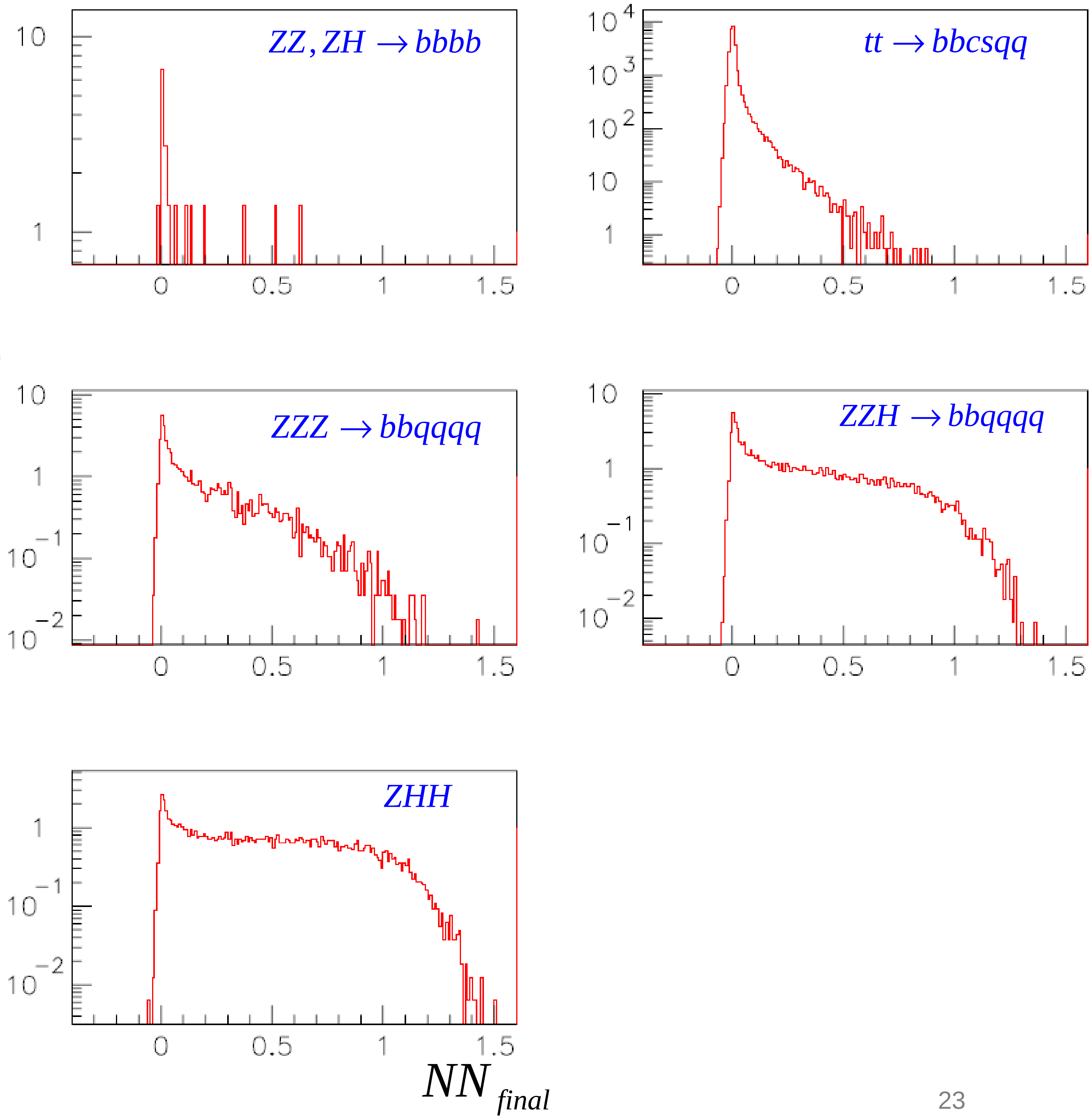
$t\bar{t}$



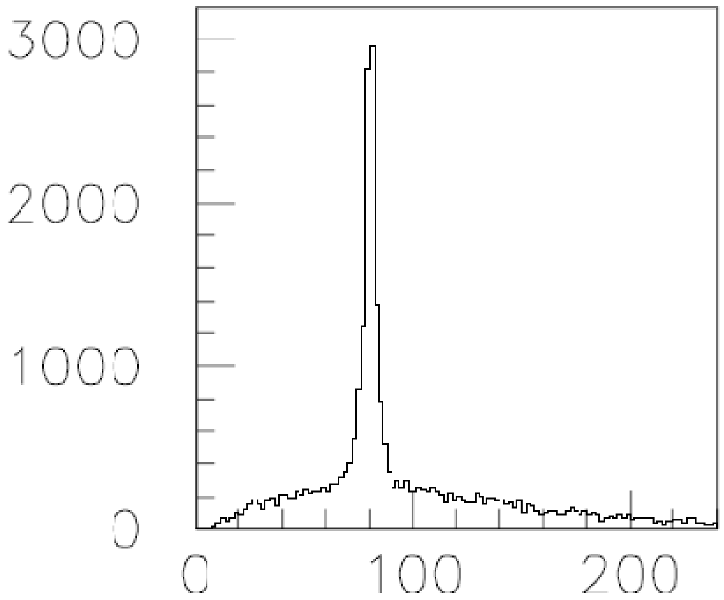
$M_{jk}\ (GeV)$

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



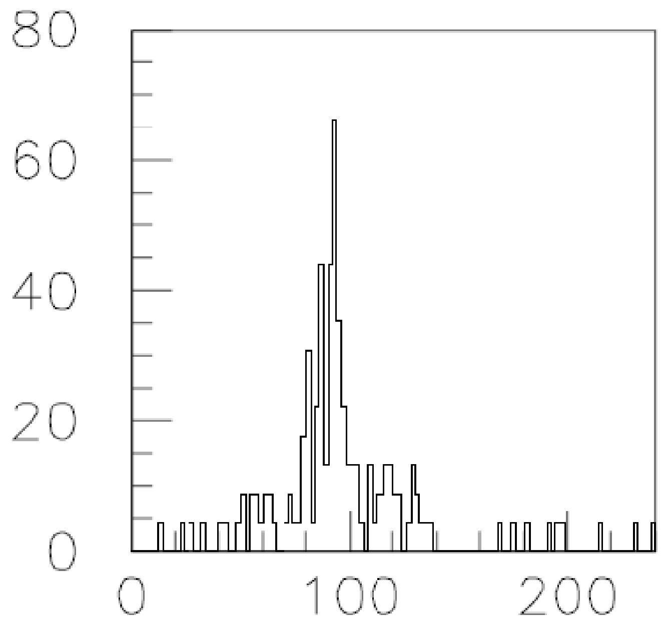
all $t\bar{t}$ with $\sum_{j=1}^{6} NN_{btag}(j) > 3.5$



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

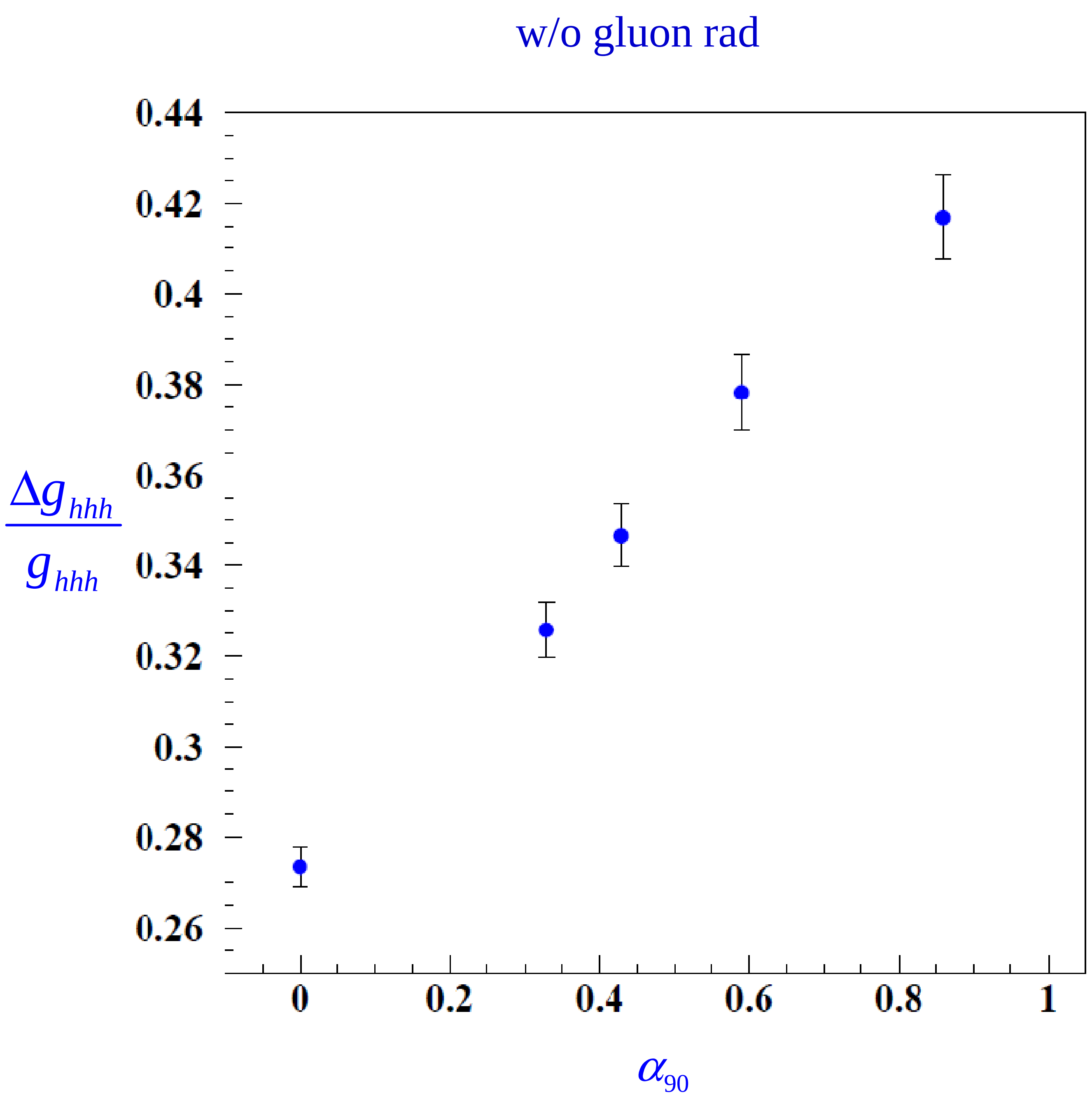
$$e^+e^- \to ZHH$$
$$\to qqb\bar{b}b\bar{b}$$

$\sqrt{s} = 500\ GeV$

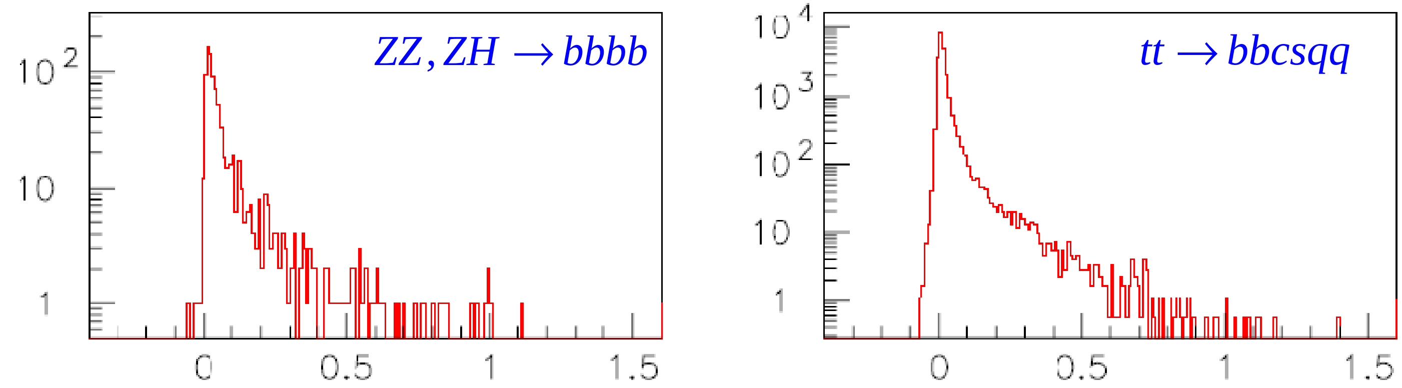
$L = 2000\ fb^{-1}$

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

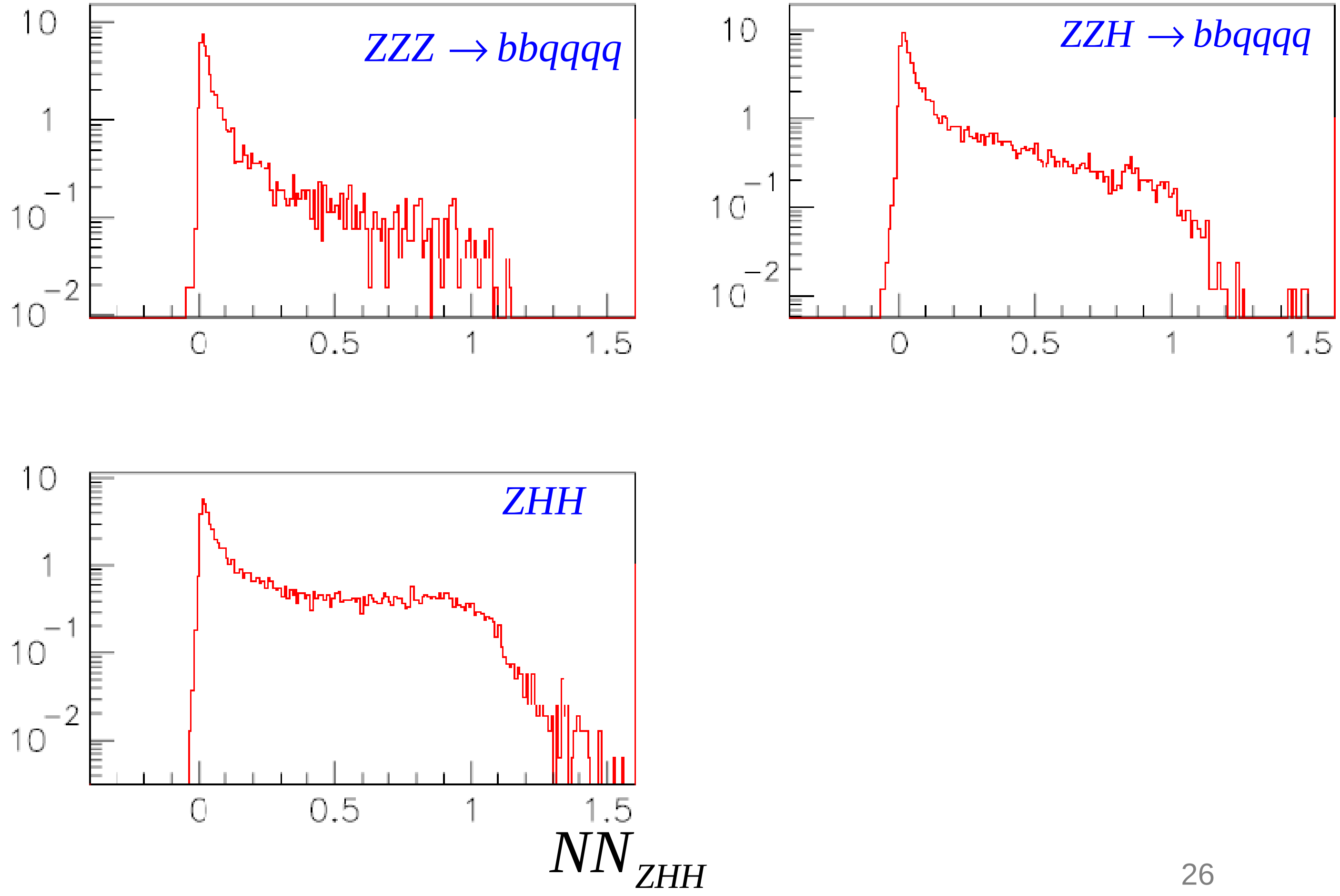
equiv to $1.4\times$ Lumi



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



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

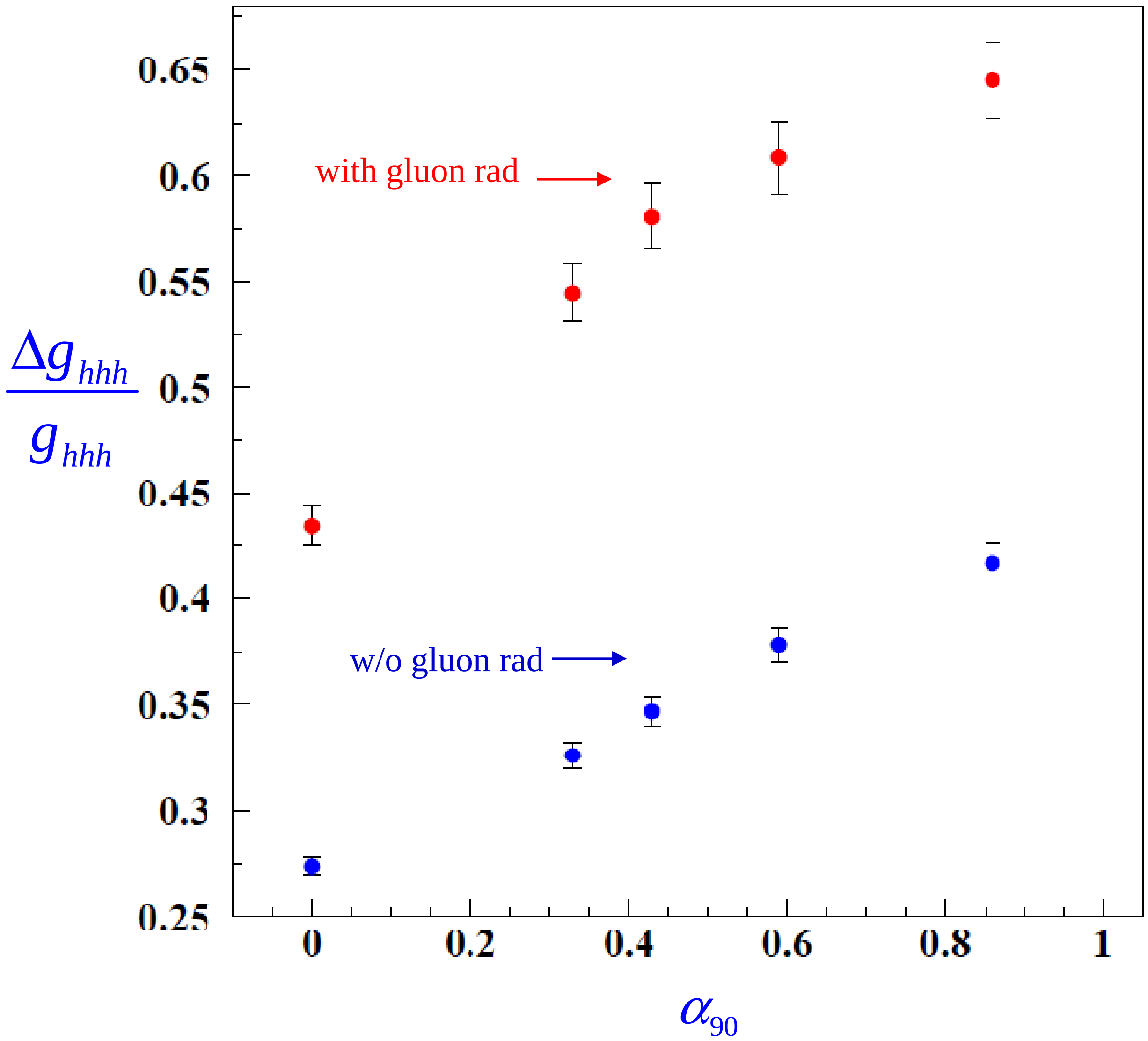
$e^+e^- \to ZHH$
$\to qqb\bar{b}b\bar{b}$

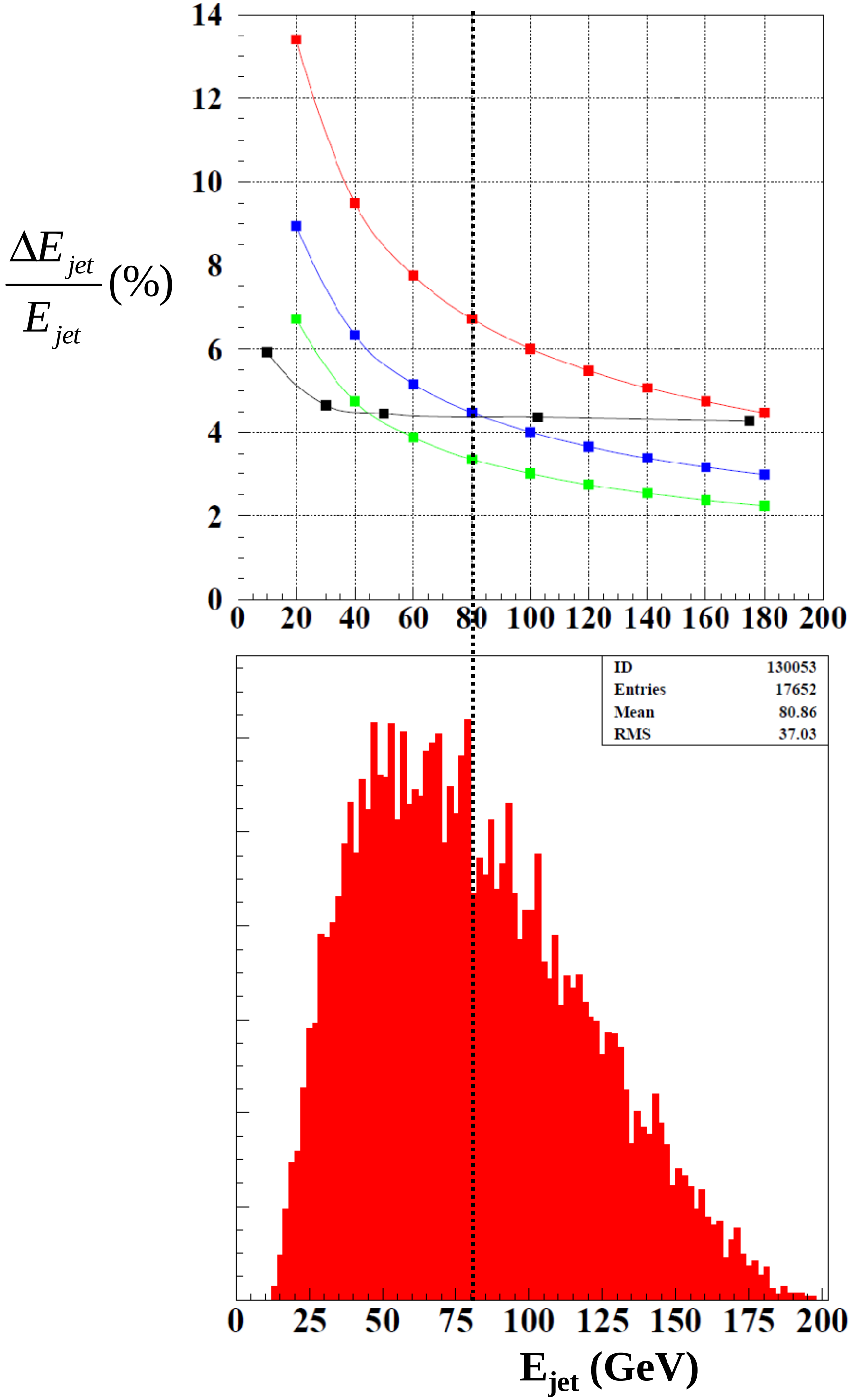
$\sqrt{s} = 500\ GeV$

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

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

equiv to $1.4\times$ Lumi





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

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

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

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

True Jet Energy Distribution for

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

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 $\frac{\Delta E_{jet}}{E_{jet}} \equiv \frac{\alpha_{90}}{\sqrt{80}}$

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

$e^+e^- \to ZHH$

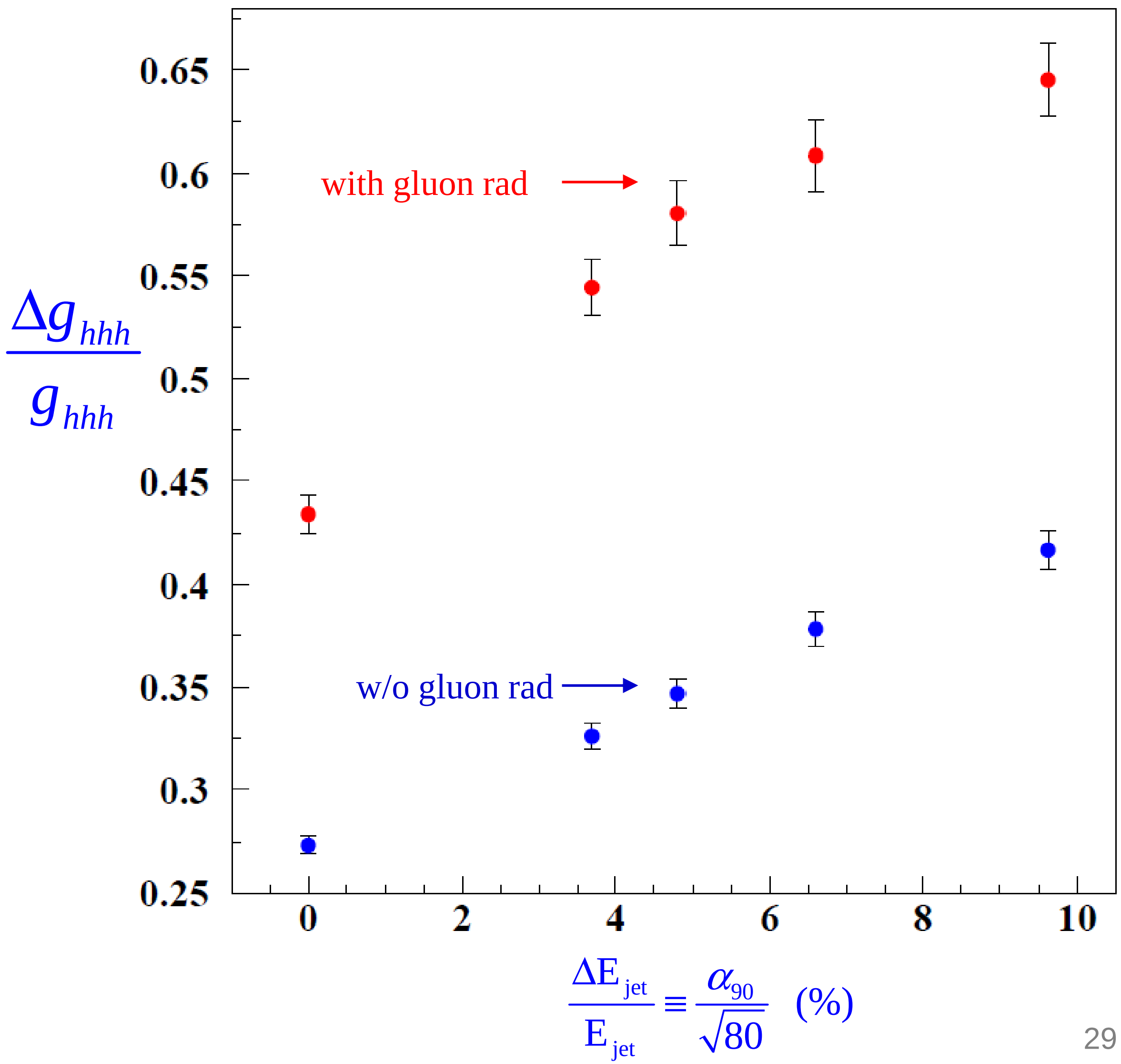
$\to qqb\bar{b}b\bar{b}$

$\sqrt{s} = 500\ GeV$

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

$\Delta E_{jet}/E_{jet} = .067 \to .033$

equiv to 1.4× Lumi



ZHH Conclusions

- The error on the coupling g_{HHH} varies between 32 % and 38% as the jet energy resolution is varied between 3.3% and 6.7% 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 6.7% to 3.3%.
- 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 3.3% and 6.7% 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.

ZHH Conclusions (cont.)

- The Ecm=500 GeV ZHH study is an interesting detector benchmark study. However, results from this study of the Higgs self coupling error do not reflect the ultimate precision on the Higgs self coupling. In addition to improvement to the analysis of ZHH$\rightarrow$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.