Requirements for Jet Energy Resolution

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June 10, 2008

OUTLINE

- Describe a new FastMC tune designed to mimic global behavior of PandoraPFA
- In order to better understand required jet energy resolution, use this FastMC to investigate various contributions to dijet mass resolution
- Revisit some studies of physics error vs jet energy resolution

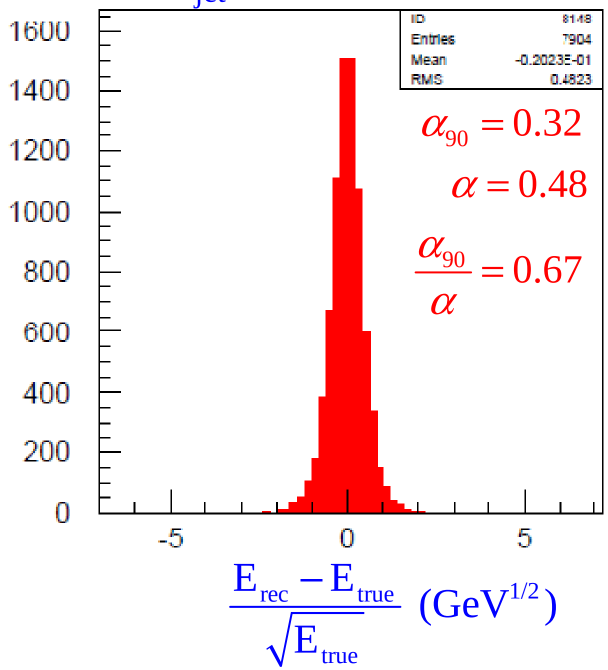
Use the following single particle calorimeter resolutions in FASTMC to mimick PFA jet energy resolution versus jet energy for jet energies 50 GeV < E_{jet} < 250 GeV

$$\frac{\Delta E_{\gamma}}{E_{\gamma}} = \frac{0.18}{\sqrt{E_{\gamma}}}$$

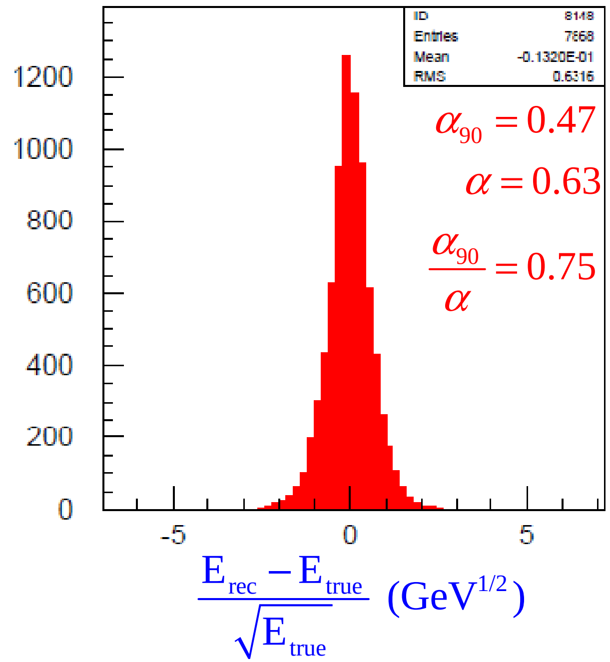
$$\frac{\Delta E_{\pi^+, K^+, p, n, K_L^0}}{E_{\pi^+, K^+, p, n, K_L^0}} = 0.10$$

Tracker used for π^+, K^+, p angles.

$E_{jet} = 100$ GeV



$E_{jet} = 175$ GeV



$$\alpha \equiv \frac{\Delta E_{jet}}{\sqrt{E_{jet}}} \qquad \alpha_{90} \equiv \frac{(\Delta E_{jet})_{90}}{\sqrt{E_{jet}}}$$

where $(\Delta E_{jet})_{90}$ is rms of central 90% core

Behavior of New

FastMC Tune

$$\frac{\Delta E_{\gamma}}{E_{\gamma}} = \frac{0.18}{\sqrt{E_{\gamma}}}$$

$$\frac{\Delta E_{\pi^+, K^+, p, n, K_L^0}}{E_{\pi^+, K^+, p, n, K_L^0}} = 0.10$$

Tracker used for

π^+, K^+, p angles.

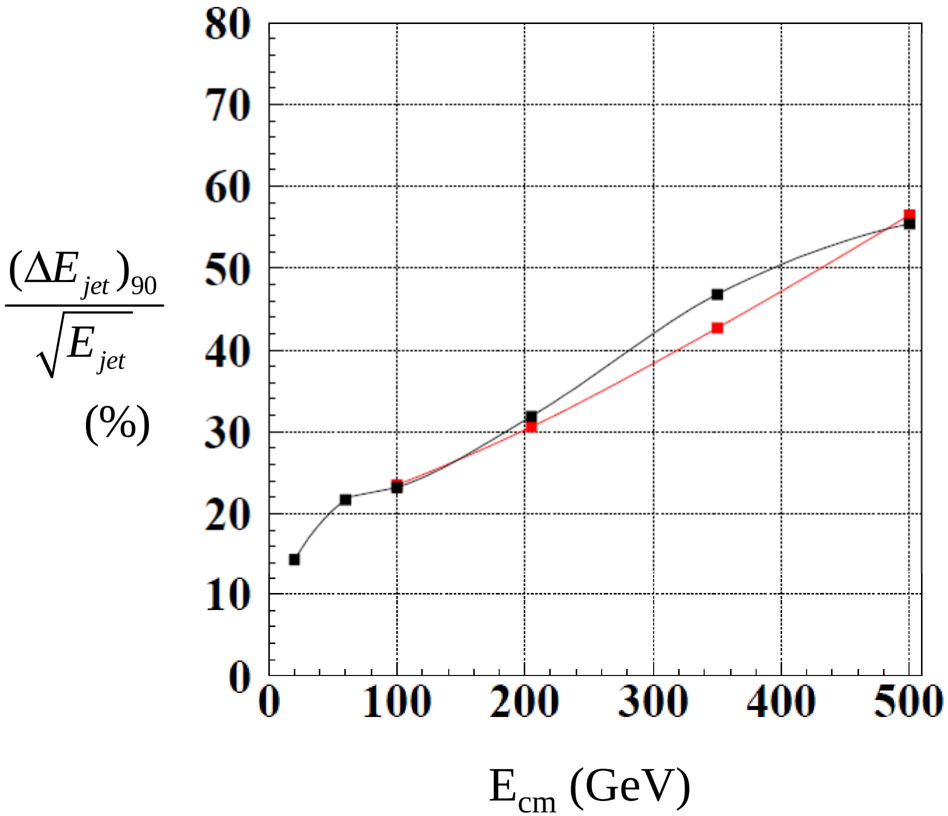
E_{jet} (GeV)	α_{90}	$\frac{(\Delta E_{jet})_{90}}{E_{jet}}$	$\frac{\alpha_{90}}{\alpha}$
10	.14	.046	.75
30	.22	.040	.82
50	.23	.033	.68
102	.32	.031	.68
175	.47	.035	.76
250	.55	.035	.74

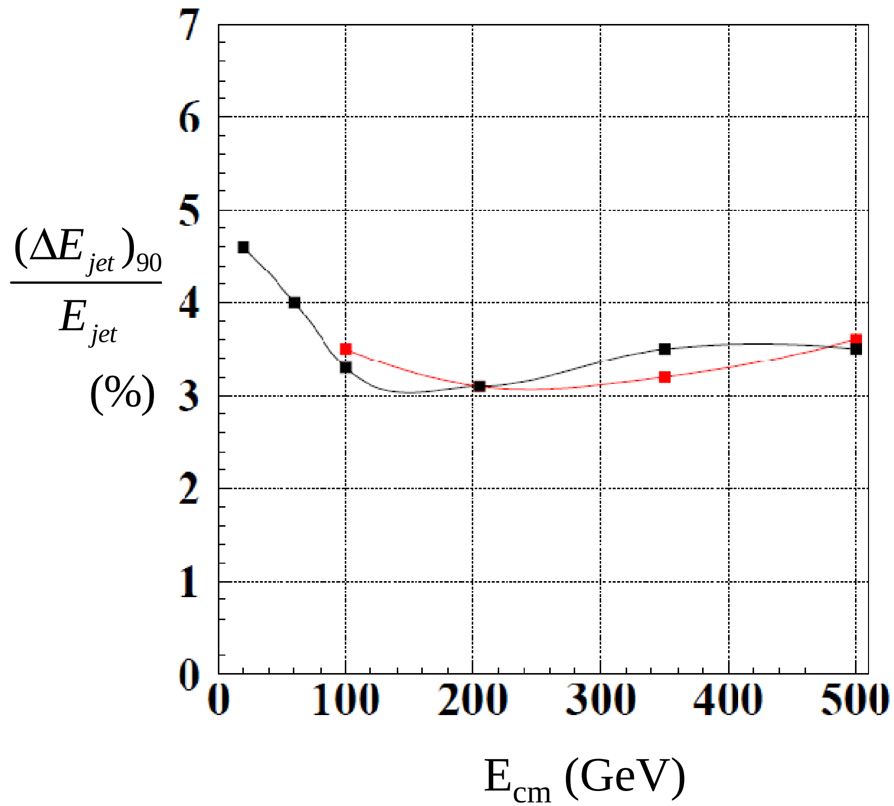
Light quark jets ee→qq

PandoraPFA v02-01 (red line)

FASTMC with (black line)

$$\frac{\Delta E_\gamma}{E_\gamma} = \frac{0.18}{\sqrt{E_\gamma}} \qquad \frac{\Delta E_{\pi^+, K^+, p, n, K_L^0}}{E_{\pi^+, K^+, p, n, K_L^0}} = 0.10$$





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

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

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

Don't include loss of resolution from:

Neutrinos

Particles outside fid. vol.

Particles below tracker/calorimeter energy thresholds

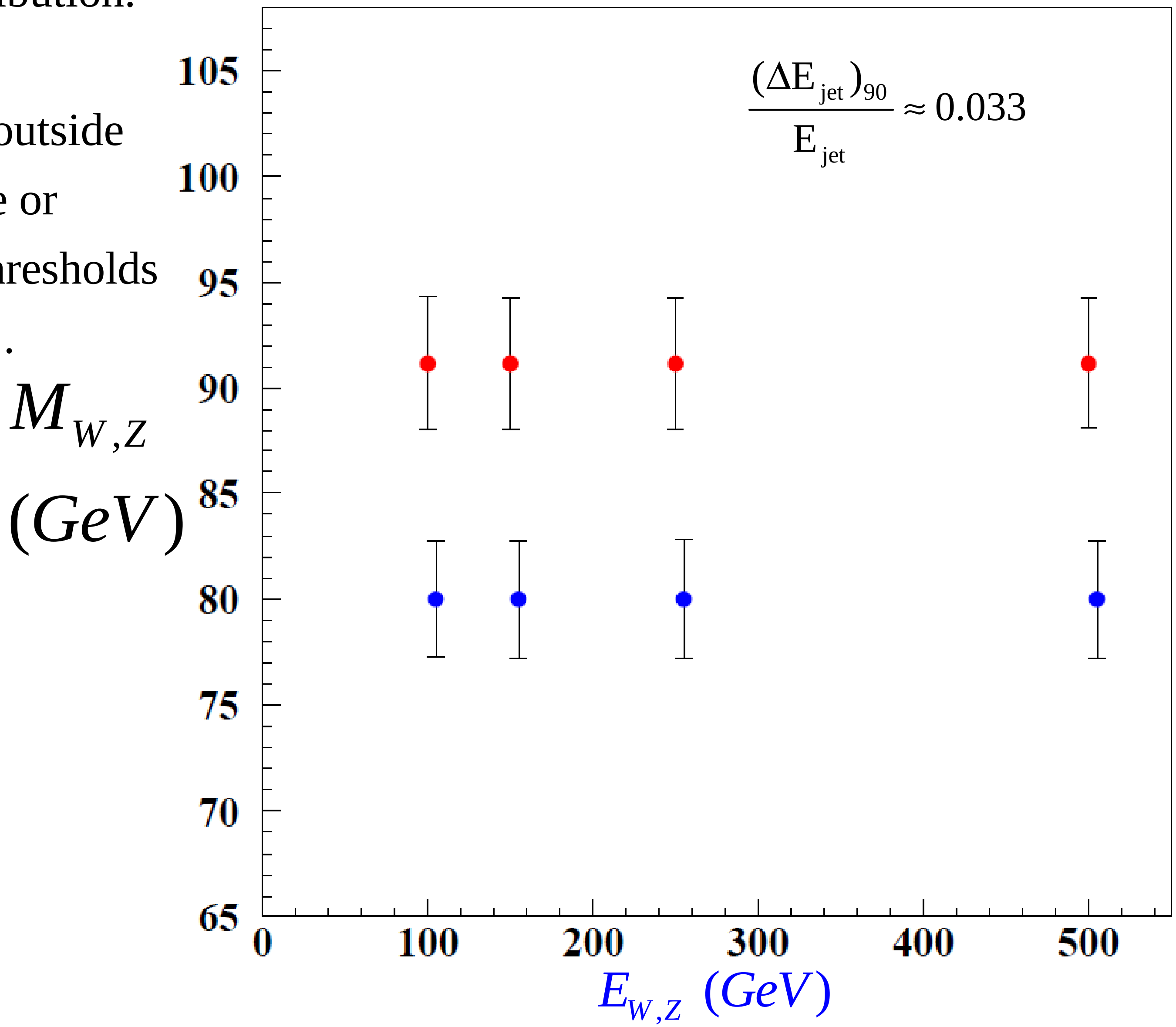
Imperfect V0 finding

Error bars correspond to FastMC full rms for $m_{rec} - m_{true}$ where m_{true} has a Breit-Wigner distribution.

Neutrinos and particles outside FastMC detector volume or below FastMC energy thresholds are not included in m_{true} .

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

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



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?

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

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

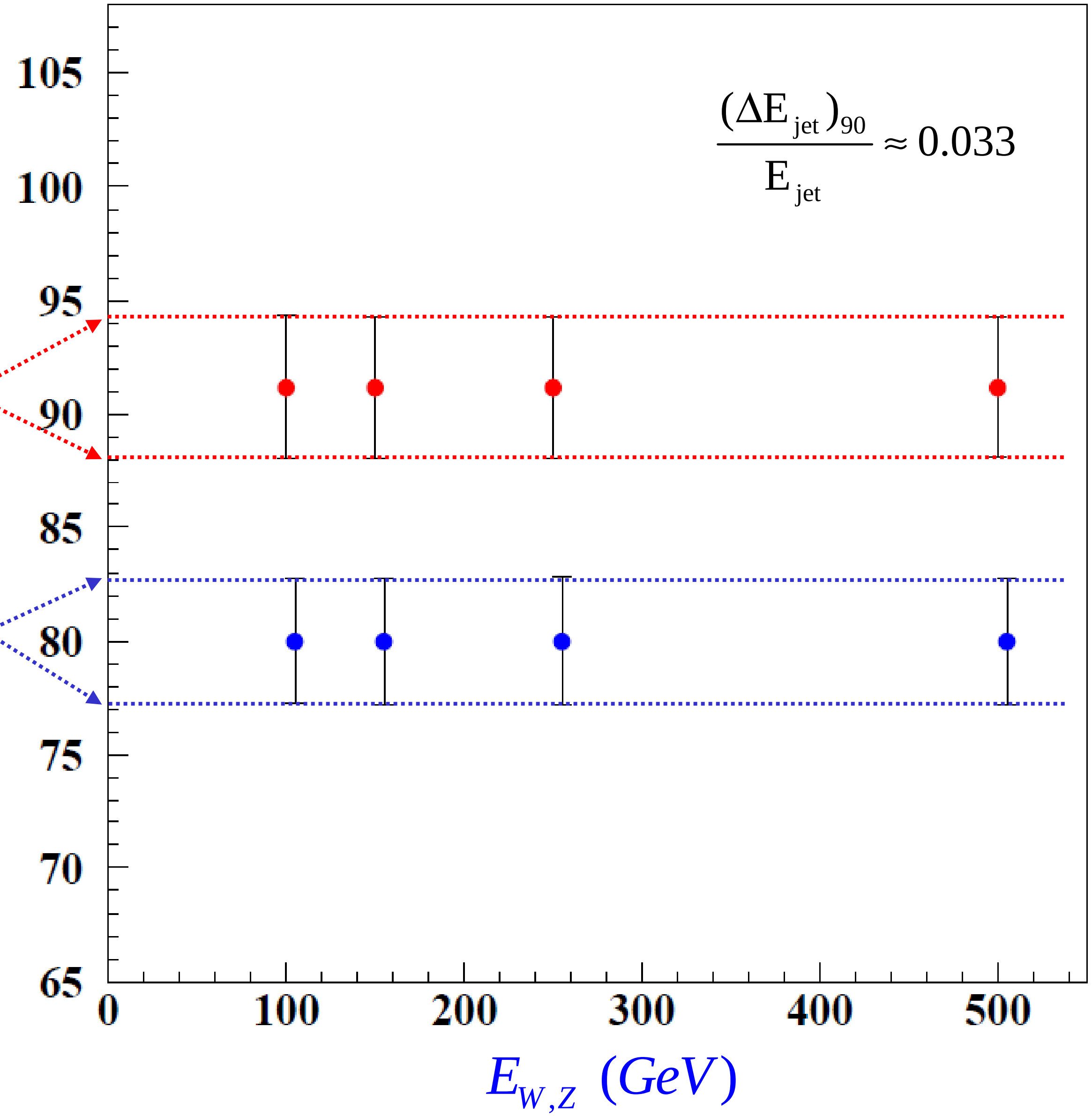
At least in the FASTMC,

the $\frac{\Delta\theta}{\theta}$, $\frac{\Delta m_1}{m_1}$, $\frac{\Delta m_2}{m_2}$ terms are not important.

$$\Delta M_Z = \pm\frac{1}{2}\left[\frac{\Delta E_1}{E_1} \oplus \frac{\Delta E_2}{E_2}\right] M_Z$$

$M_{W,Z}$

$$\Delta M_W = \pm\frac{1}{2}\left[\frac{\Delta E_1}{E_1} \oplus \frac{\Delta E_2}{E_2}\right] M_W$$



Full rms is used for $\frac{\Delta E_j}{E_j}$:

$$\frac{\Delta E_j}{E_j} = \frac{(\Delta E_{jet})_{90}}{E_{jet}} \frac{1}{0.68} = 0.049$$

Force event into 4 jets.

Form dijet pairs and select pair that minizes

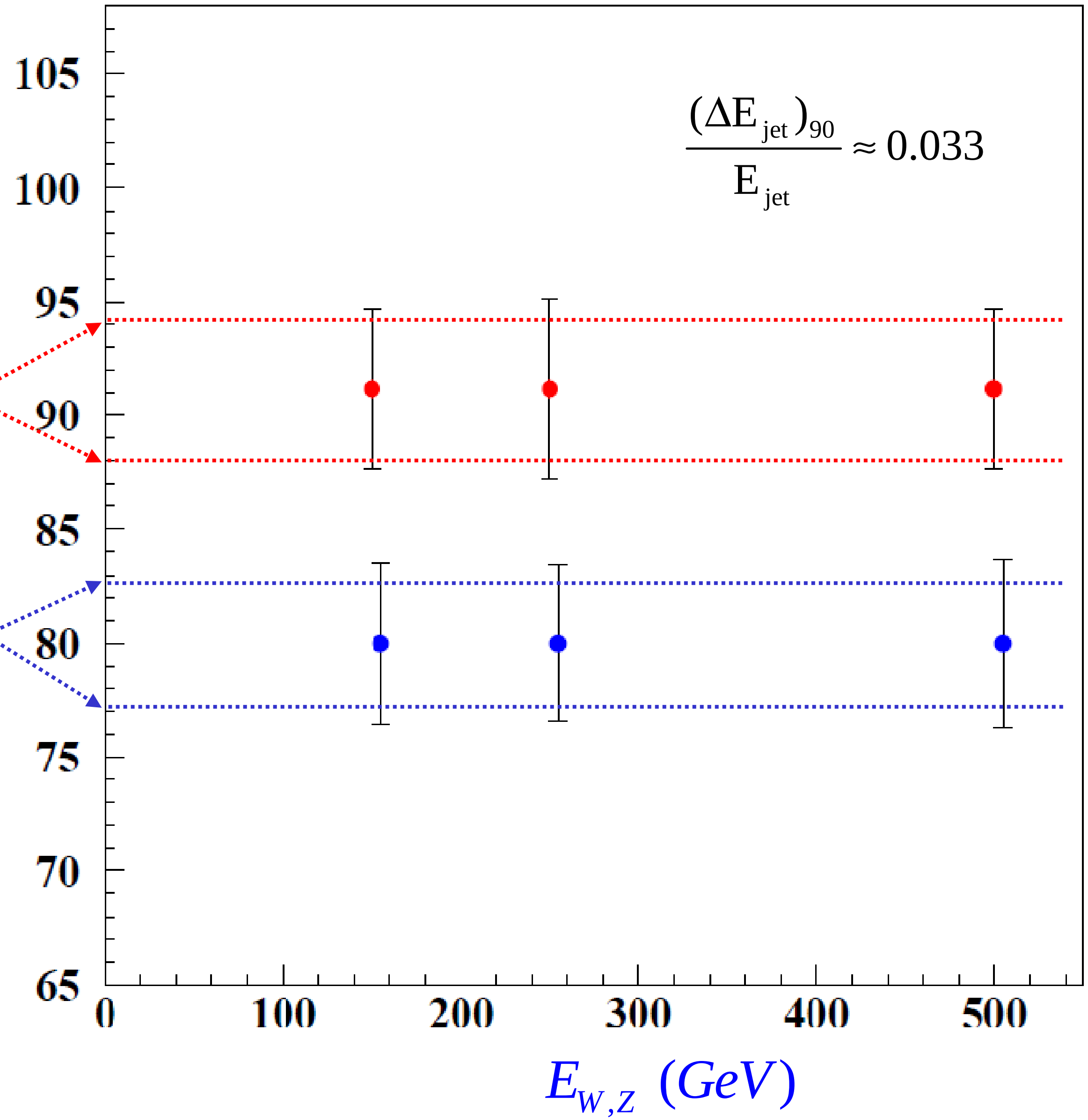
$$\sum \frac{(m_{ij} - M_W)^2}{\sigma_W^2} + \frac{(m_{kl} - M_Z)^2}{\sigma_Z^2}$$

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

Back to back W Z $\to$ 4 jets $(\theta_{WZ} = \pi)$ no gluon radiation

$$\Delta M_Z = \pm \frac{1}{2}\left[\frac{\Delta E_1}{E_1} \oplus \frac{\Delta E_2}{E_2}\right] M_Z$$

$$\Delta M_W = \pm \frac{1}{2}\left[\frac{\Delta E_1}{E_1} \oplus \frac{\Delta E_2}{E_2}\right] M_W$$



Force event into 4 jets.

Form dijet pairs and select pair that minizes

$$\sum \frac{(m_{ij}-M_W)^2}{\sigma_W^2} + \frac{(m_{kl}-M_Z)^2}{\sigma_Z^2}$$

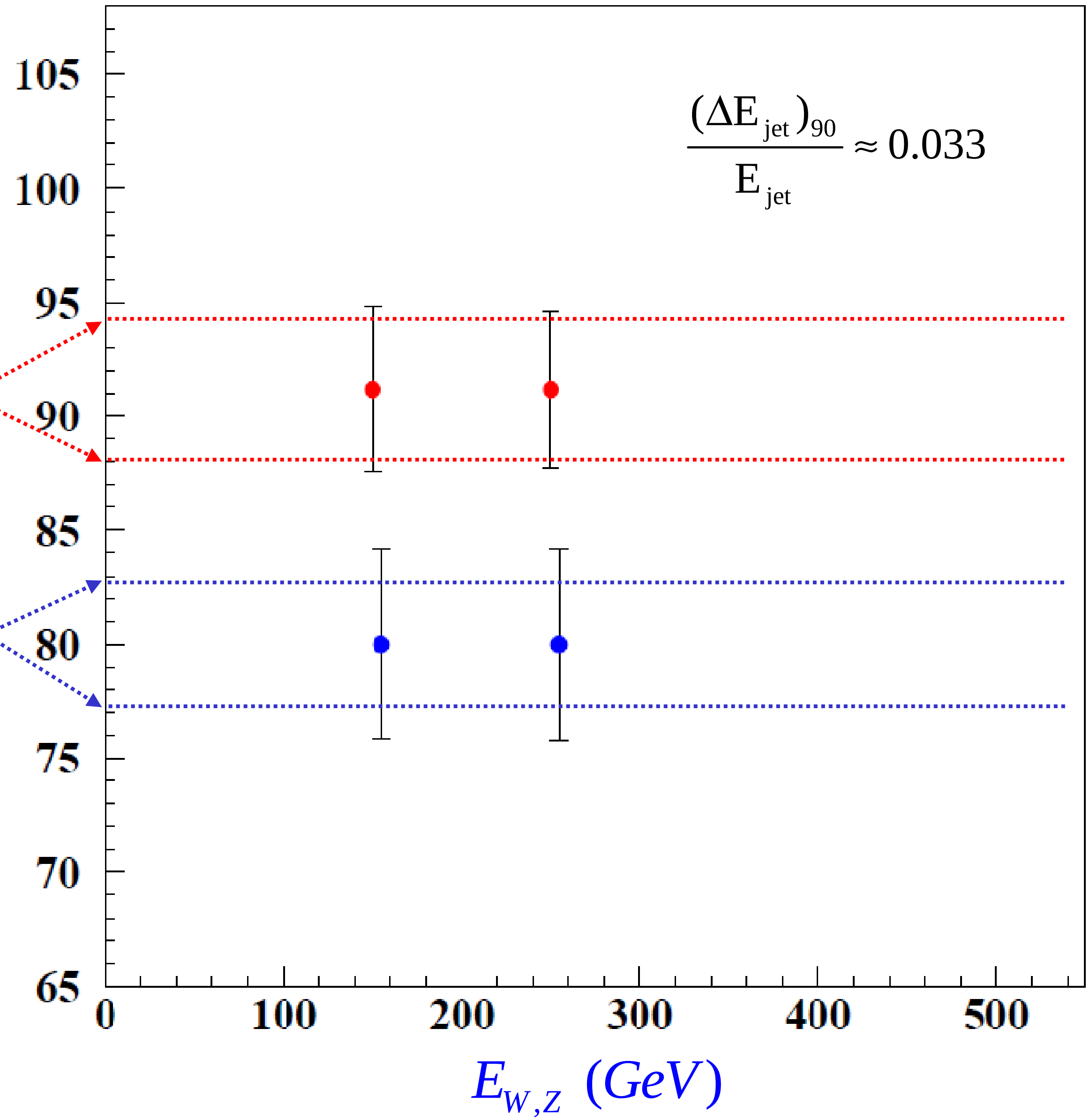
$$e^-\gamma \rightarrow \nu_e W^- Z \rightarrow \nu_e \bar{u} d u \bar{u}$$

Collinear W Z $\rightarrow$ 4 jets (θ_{WZ}=0) no gluon radiation

$$\Delta M_Z = \pm\frac{1}{2}\left[\frac{\Delta E_1}{E_1} \oplus \frac{\Delta E_2}{E_2}\right] M_Z$$

$M_{W,Z}$

$$\Delta M_W = \pm\frac{1}{2}\left[\frac{\Delta E_1}{E_1} \oplus \frac{\Delta E_2}{E_2}\right] M_W$$



Force event into 4 jets.

Form dijet pairs and select pair that minizes

$$\sum \frac{(m_{ij} - M_W)^2}{\sigma_W^2} + \frac{(m_{kl} - M_Z)^2}{\sigma_Z^2}$$

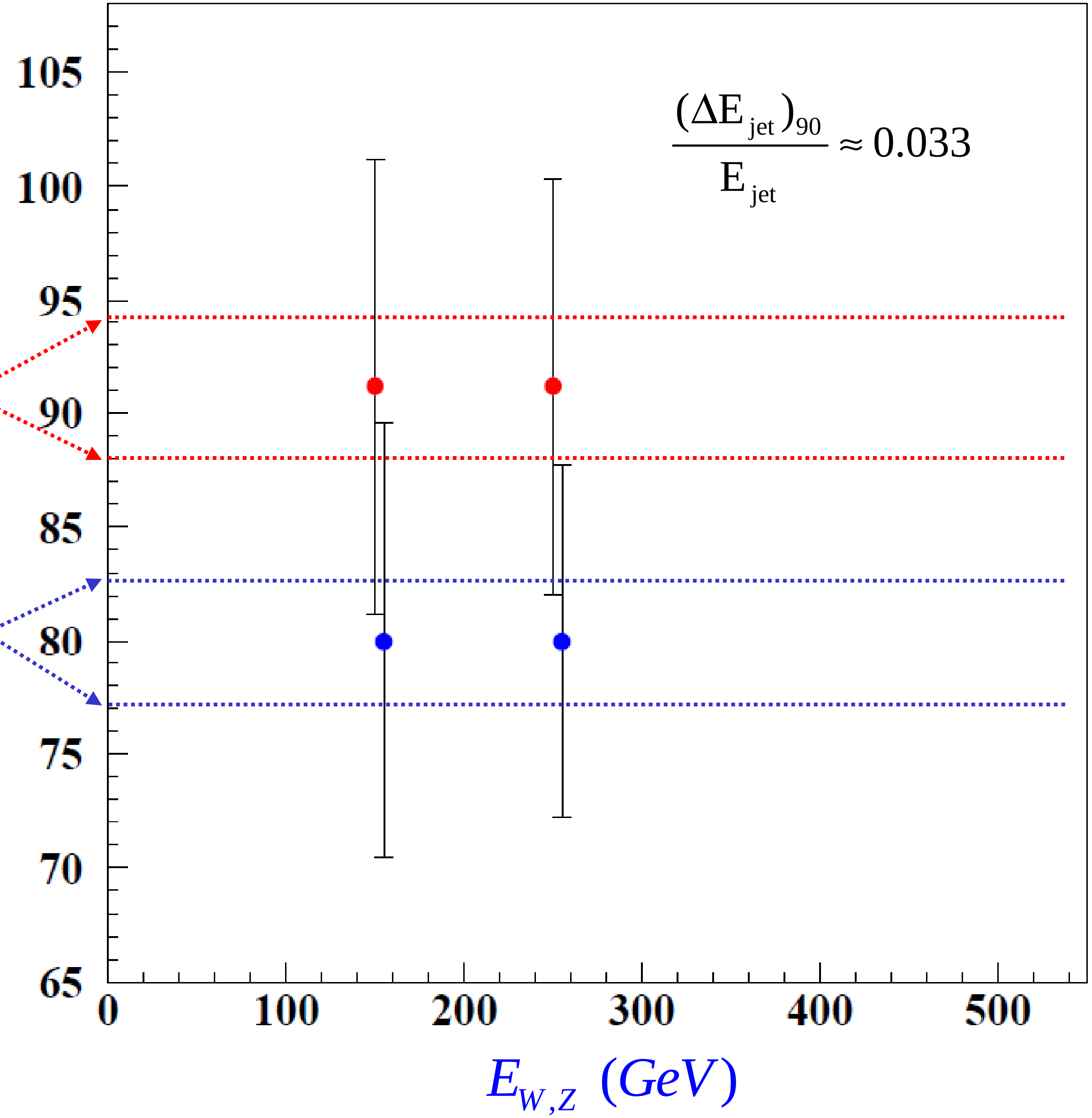
$$e^- \gamma \rightarrow \nu_e W^- Z \rightarrow \nu_e \bar{u} d u \bar{u}$$

Back to back W Z $\rightarrow$ 4 jets ($\theta_{WZ} = \pi$) yes gluon radiation

$$\Delta M_Z = \pm \frac{1}{2} \left[\frac{\Delta E_1}{E_1} \oplus \frac{\Delta E_2}{E_2} \right] M_Z$$

$$M_{W,Z}$$

$$\Delta M_W = \pm \frac{1}{2} \left[\frac{\Delta E_1}{E_1} \oplus \frac{\Delta E_2}{E_2} \right] M_W$$



$e^{-}\gamma \to \nu_e W^{-}$

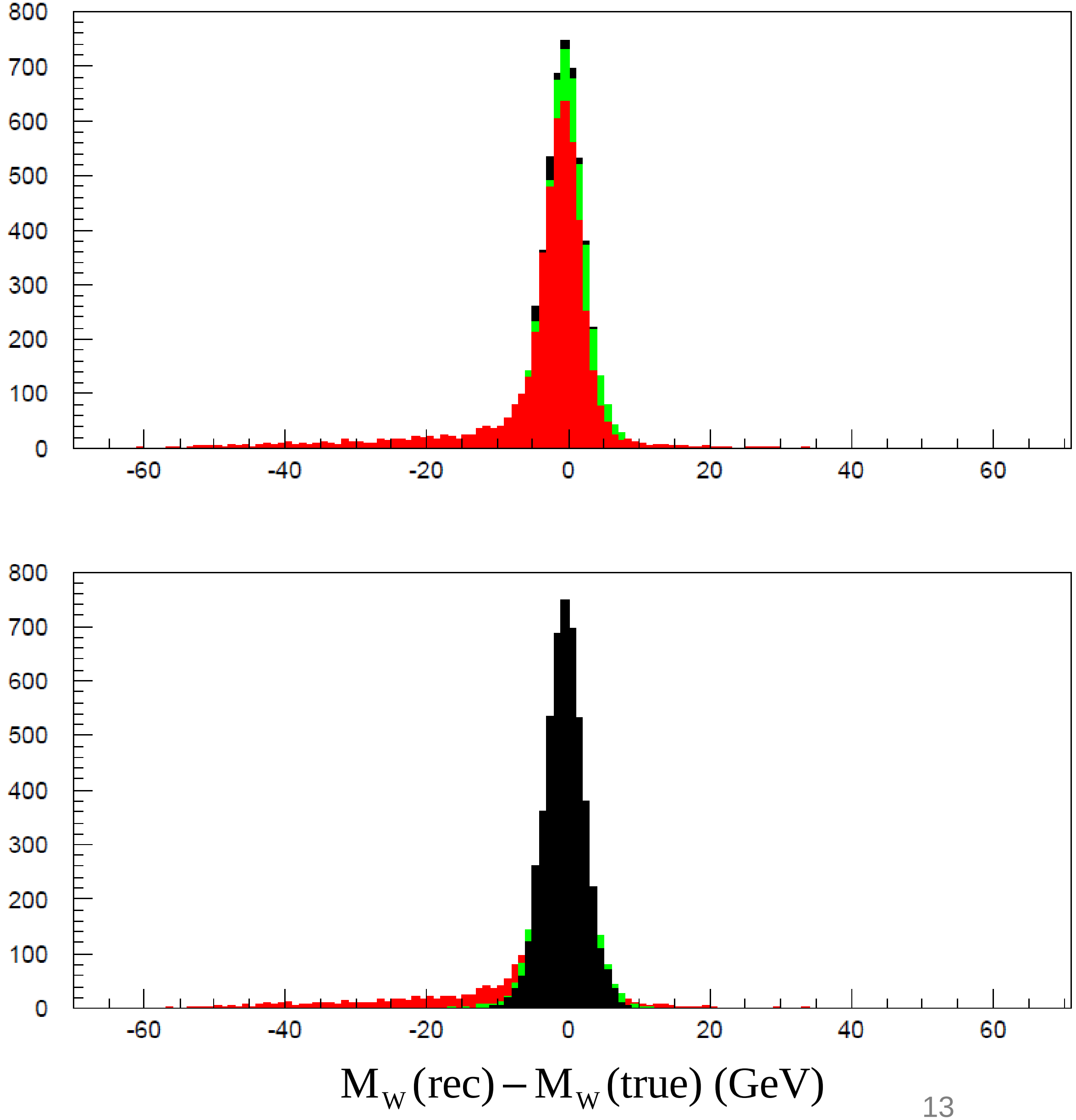
$e^{-}\gamma \to \nu_e W^{-} Z \quad \theta_{WZ} = \pi$ no gluons

$e^{-}\gamma \to \nu_e W^{-} Z \quad \theta_{WZ} = \pi$ yes gluons

$$\frac{(\Delta E_{jet})_{90}}{E_{jet}} \approx 0.033$$

$$E_W = 150 \text{ GeV}$$

Gluon radiation creates a long tail but core width is more or less maintained



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

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

We have been assuming perfect V0 finding in the plots shown so far.

Now go to the opposite extreme and completely turn off V0 finding.

$$\Delta M_Z = \pm \frac{1}{2}\left[\frac{\Delta E_1}{E_1} \oplus \frac{\Delta E_2}{E_2}\right] M_Z$$

$$\Delta M_W = \pm \frac{1}{2}\left[\frac{\Delta E_1}{E_1} \oplus \frac{\Delta E_2}{E_2}\right] M_W$$

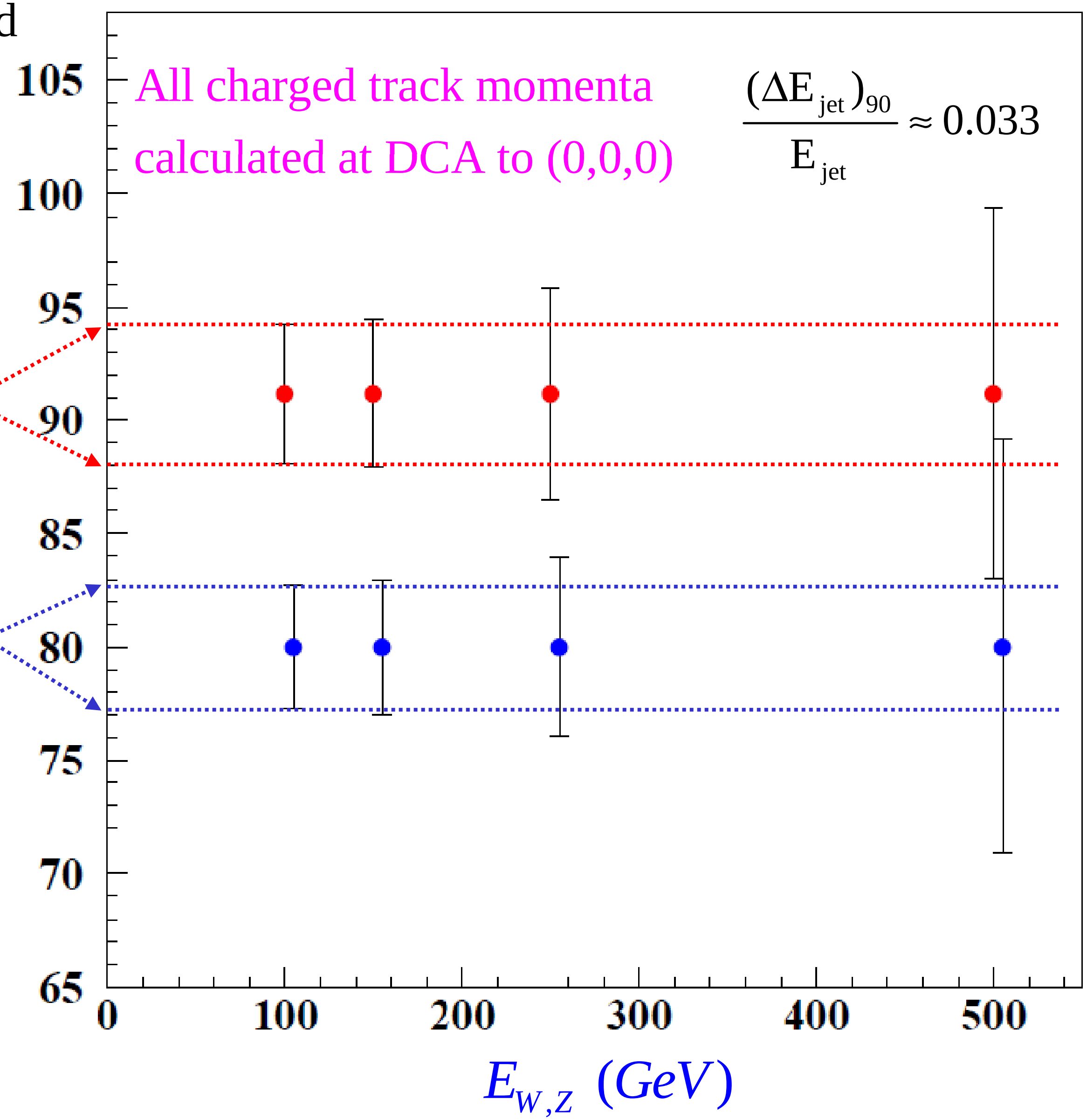


Table of W,Z Mass Resolution Effects
All entries are full rms in GeV

Source of Error	$E_W = 150$ ΔM_W	$E_Z = 150$ ΔM_Z	$E_W = 250$ ΔM_W	$E_Z = 250$ ΔM_Z
PFA Jet Energy	2.8	3.1	2.8	3.1
Jet Angle/Mass	< 0.5	< 0.5	< 0.5	< 0.5
Jet Finding, $\theta_{WZ} = \pi$	2.2	1.7	2.0	2.5
Jet Finding, $\theta_{WZ} = 0$	3.1	1.9	3.1	1.5
Gluon Rad.	9.2	9.5	7.2	8.6
Intrinsic Width	2.1	2.5	2.1	2.5
No V0 Finding	1.2	1.1	2.8	3.5

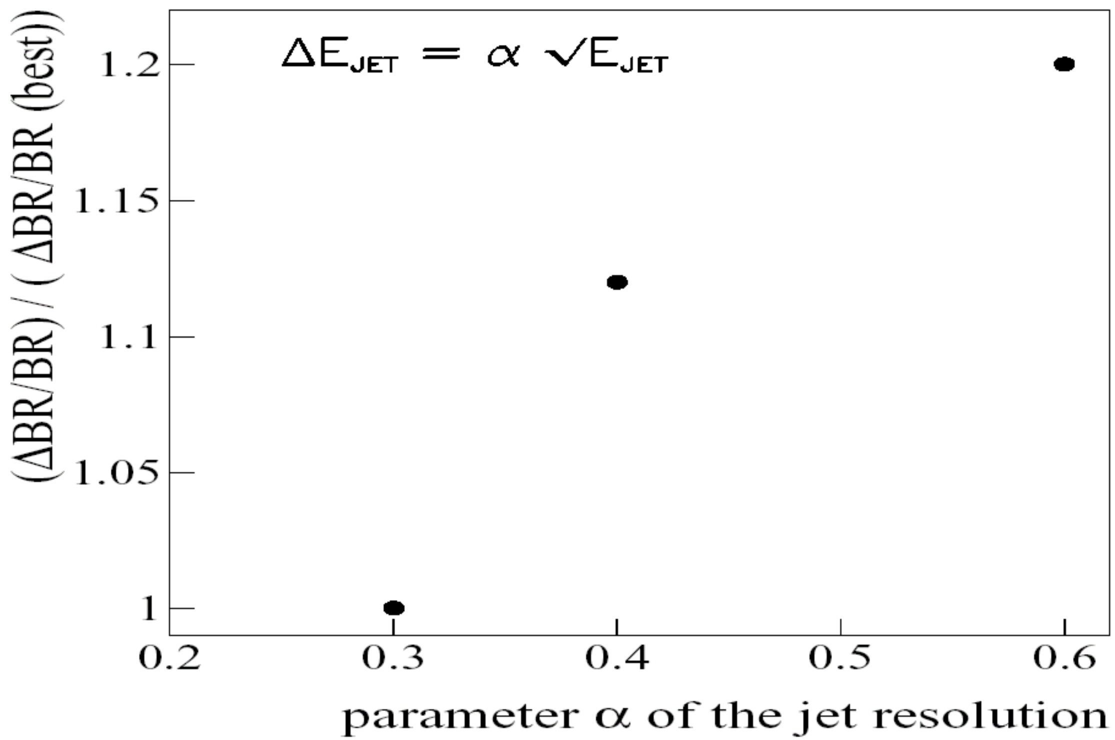
Error on $BR(H \rightarrow WW^*)$ from measurement of

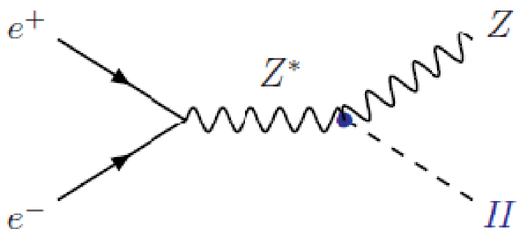
$e^+e^- \rightarrow ZH \rightarrow q\bar{q}WW^* \rightarrow q\bar{q}q\bar{q}l\nu$ at $\sqrt{s} = 360$ GeV, L=500 fb^{-1}

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

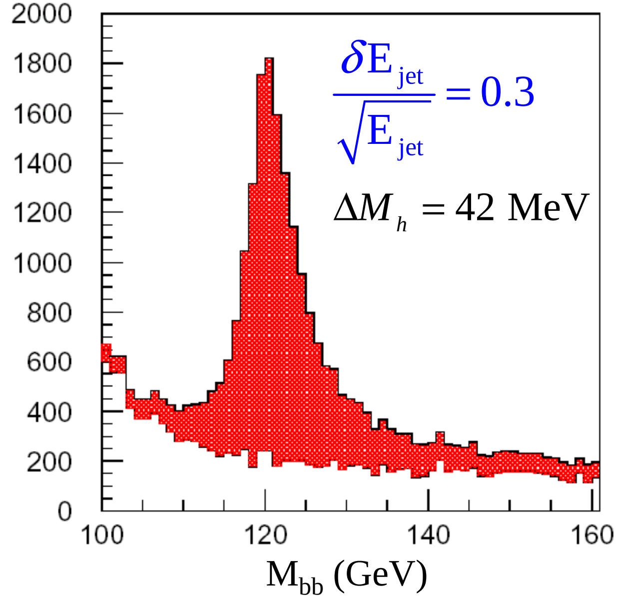
$\Delta E/\sqrt{E} = 60\% \rightarrow 30\%$

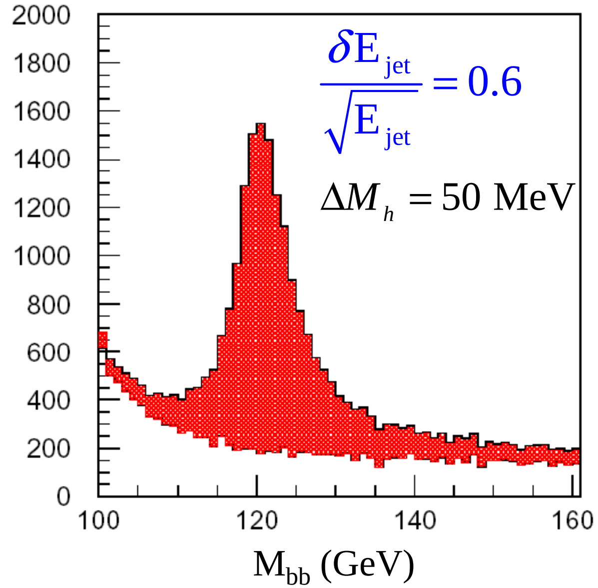
equiv to $1.4\times$ Lumi



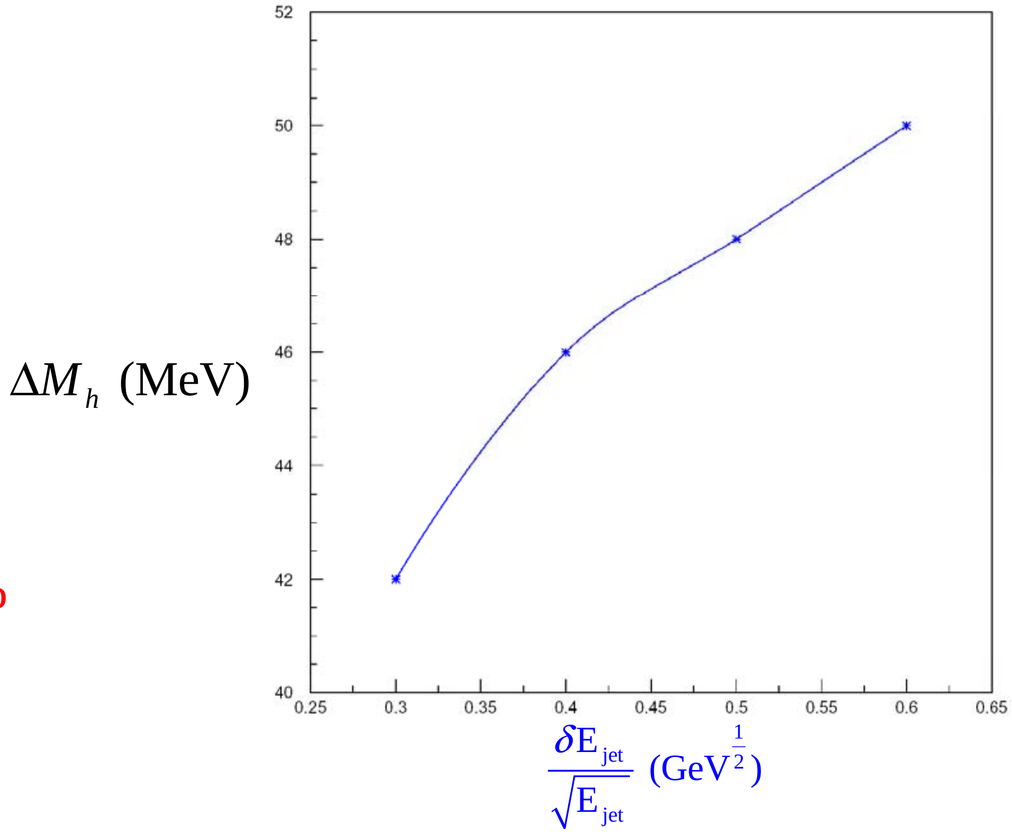


$$e^+e^- \to ZH$$
$$\to qqb\bar{b}$$





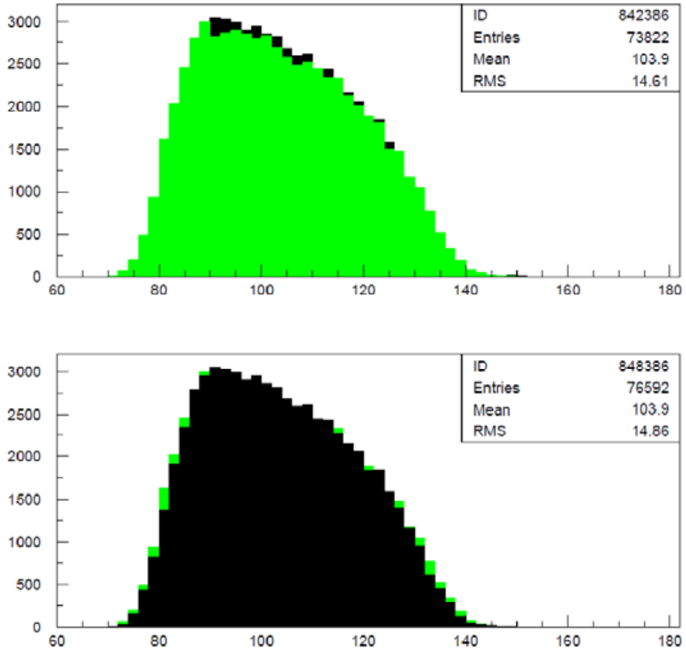
$$\sqrt{s} = 350\ GeV$$
$$L = 500\ fb^{-1}$$



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

equiv to $1.4\times$ Lumi

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



E_W (GeV)

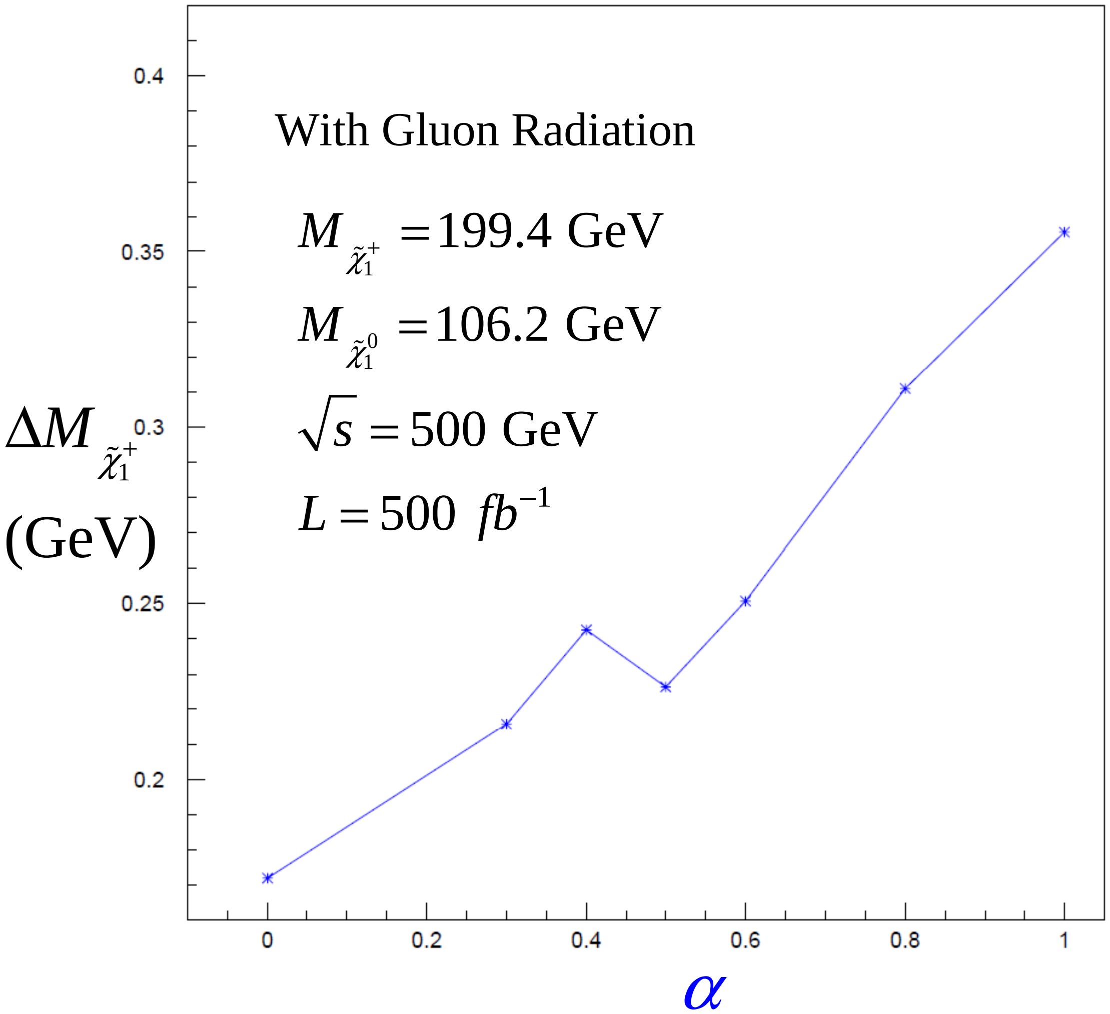
$M_{\tilde{\chi}_1^+} = 198.4$ GeV (black)

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

Force event into 4 jets.

Form dijet pairs and select pair that minizes

$$\sum \frac{(m_{ij} - M_W)^2}{\sigma_W^2} + \frac{(m_{kl} - M_W)^2}{\sigma_W^2}$$



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

equiv to $1.4\times$ Lumi

The full rms α was used in plotting physics error vs jet energy resolution for the last two analyses (and probably the first one too).

The eff. luminosity gain in going from $0.6/\sqrt{E}$ to $0.3/\sqrt{E}$ changes when one uses α_{90} as the jet energy resolution variable:

$$\text{Eff. Lumi Gain} = \left(\frac{\sigma_{.6}}{\sigma_{.3}}\right)^2 \left[\frac{1+\left(2\dfrac{\sigma_{.3}}{\sigma_{.6}}-1\right)\left(\dfrac{\alpha_{90}}{\alpha}-1\right)}{1+\left(2-\dfrac{\sigma_{.6}}{\sigma_{.3}}\right)\left(\dfrac{\alpha_{90}}{\alpha}-1\right)}\right]^2$$

where $\sigma_{.3}$ and $\sigma_{.6}$ are the physics errors for α= .3 and .6 resp.

Assuming $\dfrac{\sigma_{.6}}{\sigma_{.3}} = 1.2$

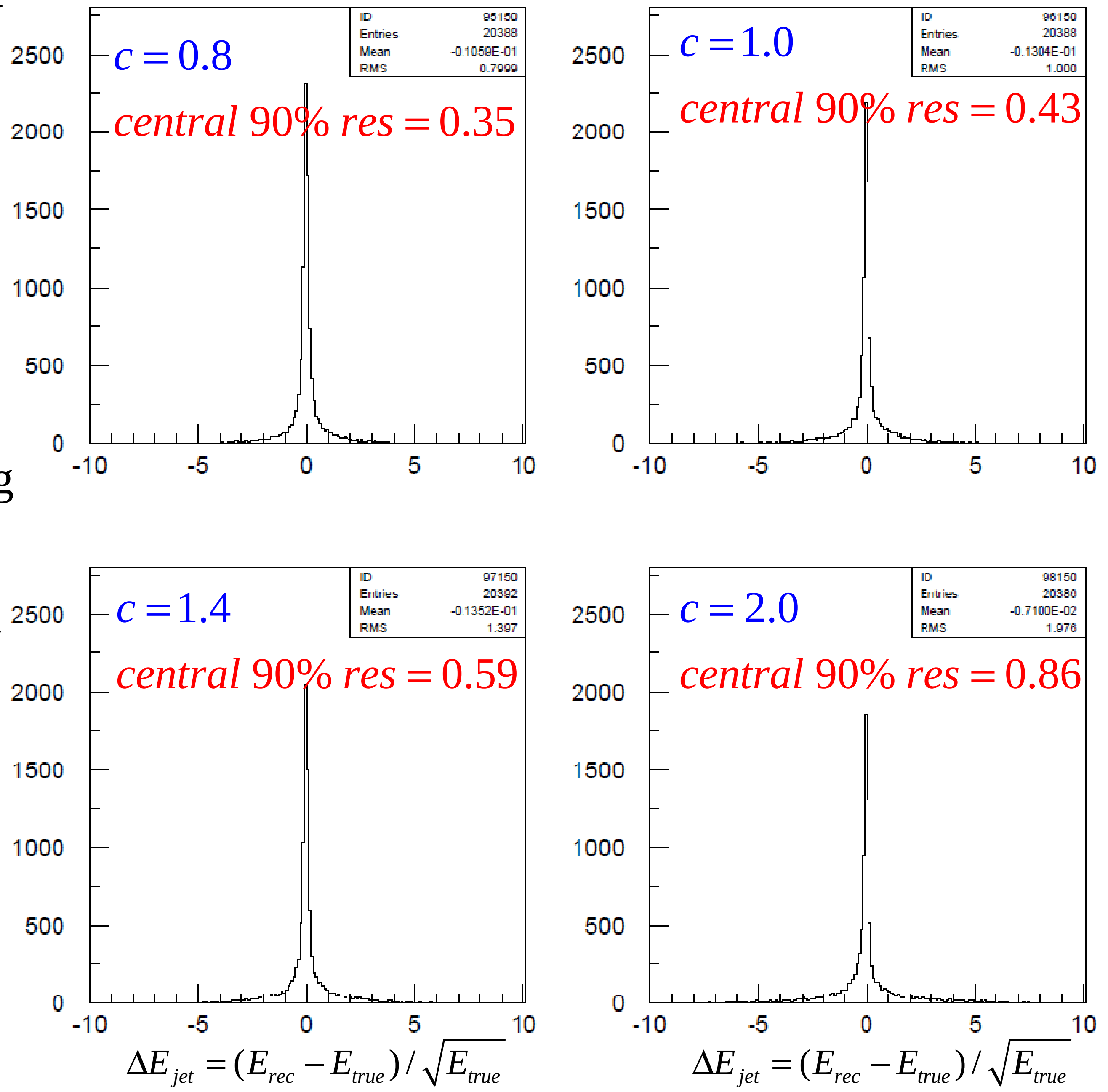
eff lumi gain = 1.4 (1.6) (1.9) for $\dfrac{\alpha_{90}}{\alpha} = 1.00\ (0.68)\ (0.43)$

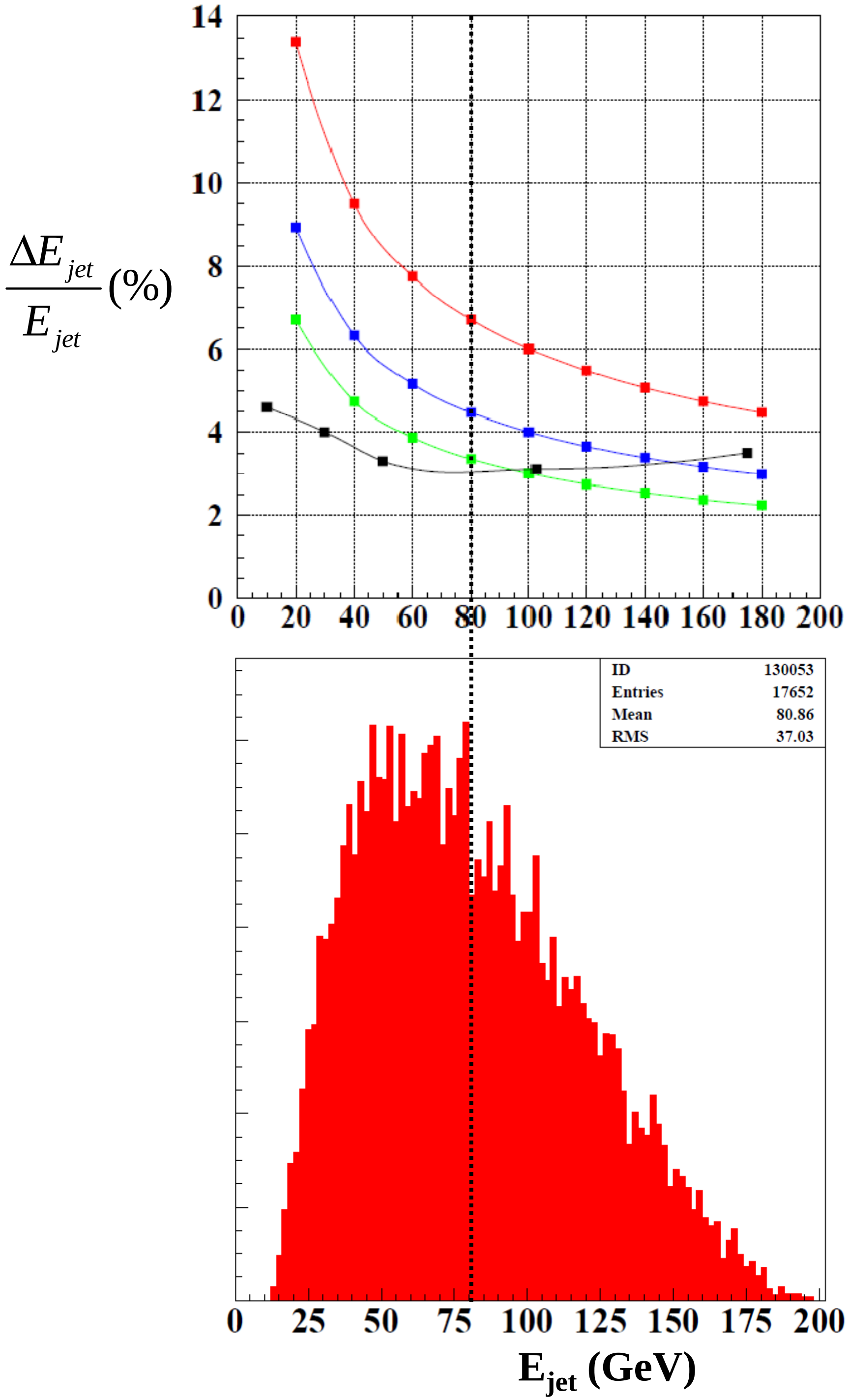
$$e^+e^- \rightarrow u\bar{u}$$

$\sqrt{s} =$ 500 GeV

org.lcsim FastMC used for chargino analysis always took tracker momentum for chg hadrons - peakier than Pandora PFA and the new org.lcsim FastMC

$$\frac{\alpha_{90}}{\alpha} \approx 0.43$$





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

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

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

$\frac{\Delta E_{jet}}{E_{jet}} \approx$ 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

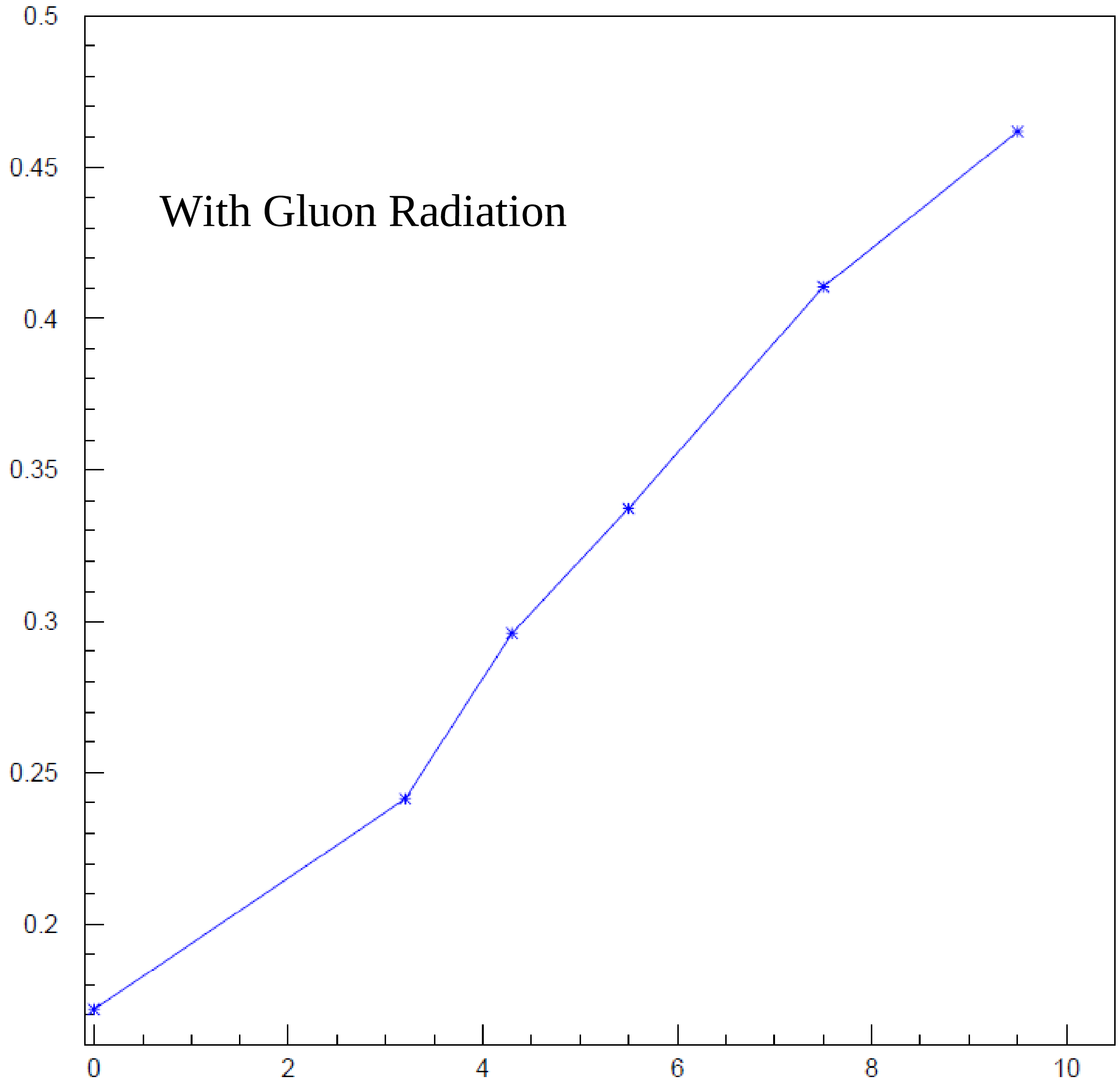
$$e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 W^+W^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 qqqq$$

$M_{\tilde{\chi}_1^+} = 200.0$ GeV

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

$\sqrt{s} = 500$ GeV

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



$\Delta M_{\tilde{\chi}_1^+}$ (GeV)

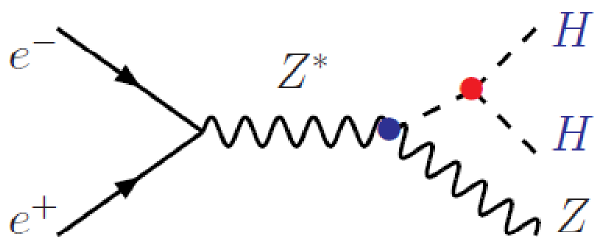
$\left(\frac{\Delta E_{jet}}{E_{jet}}\right)_{90}$ (%)

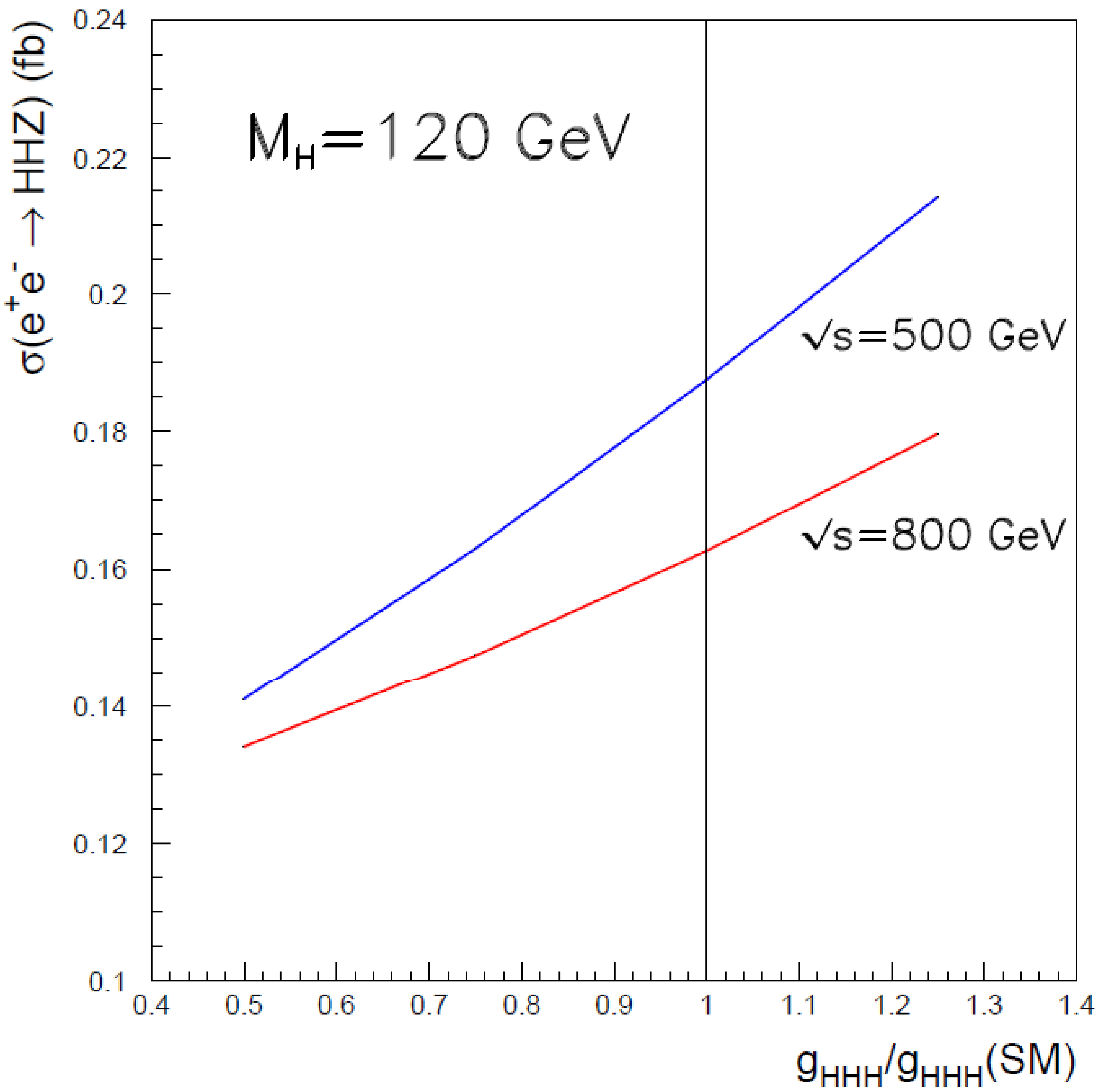
$\left(\frac{\Delta E_{jet}}{E_{jet}}\right)_{90} = .06 \to .03$

equiv to $2.1\times$ Lumi

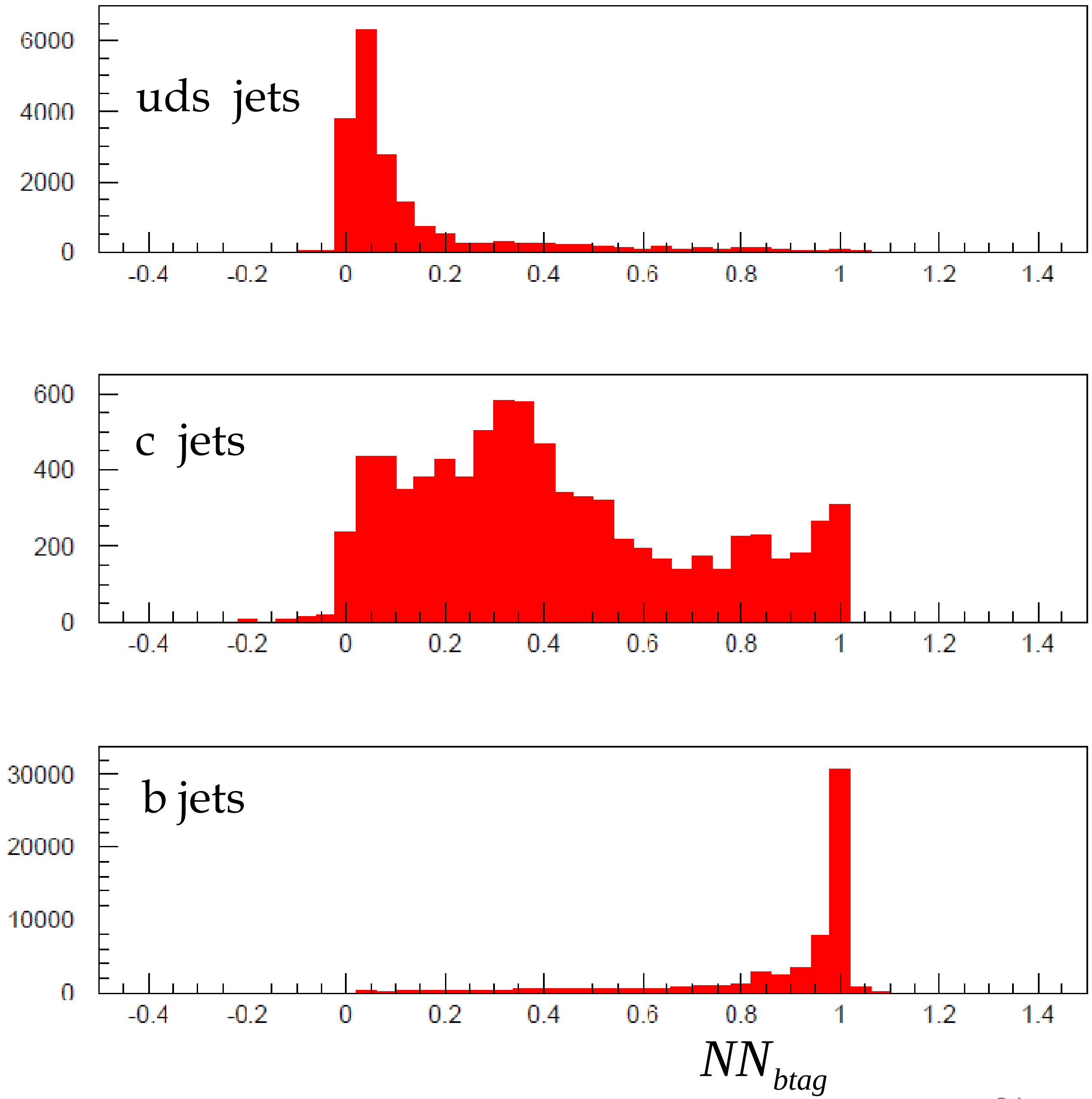
New org.lcsim FastMC described on pp 2-5 was used.

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

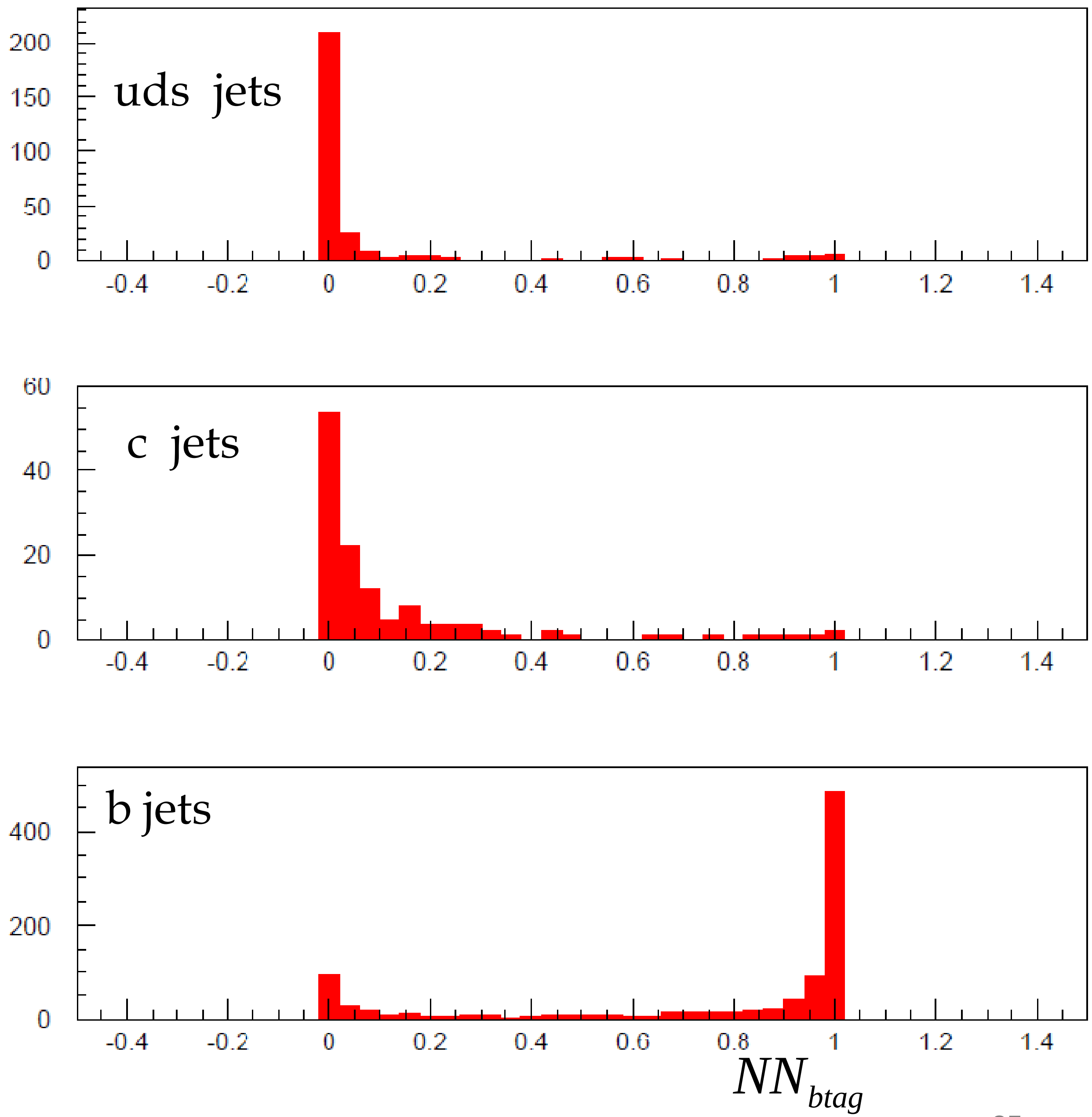




ZHH events My btag NN



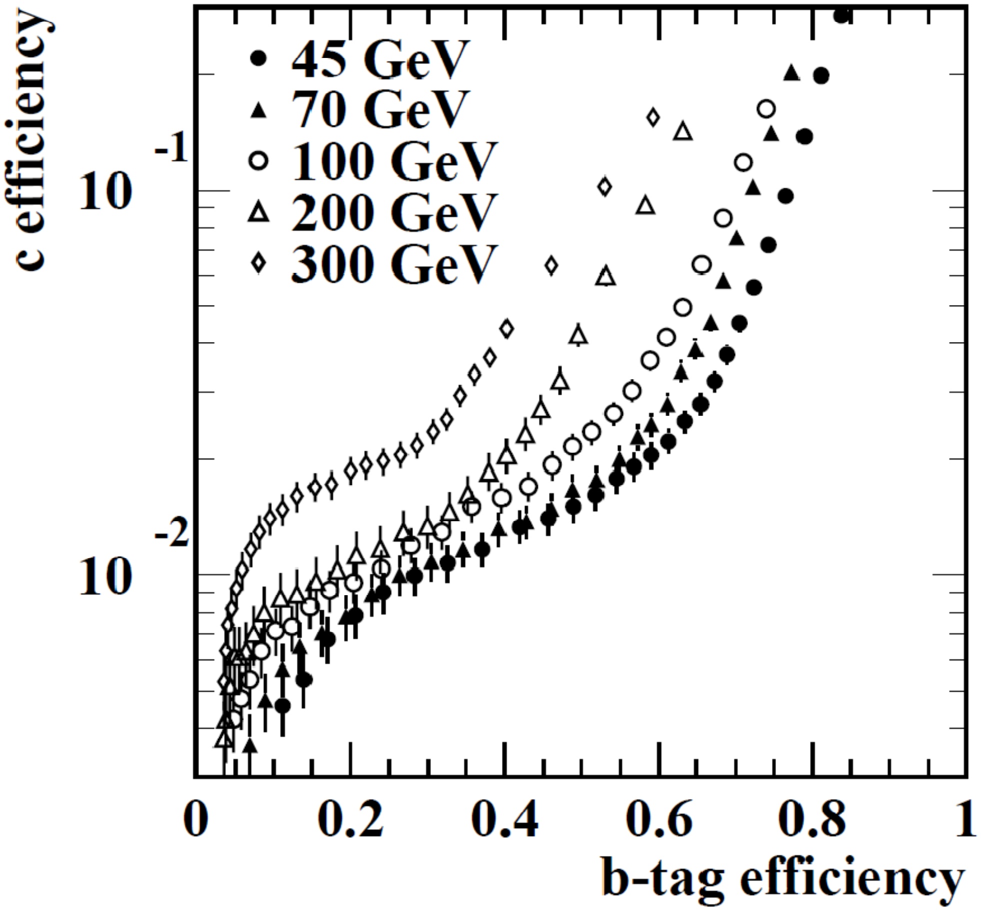
ZHH events   LCFI btag NN   much improved performance but 5s/ev*



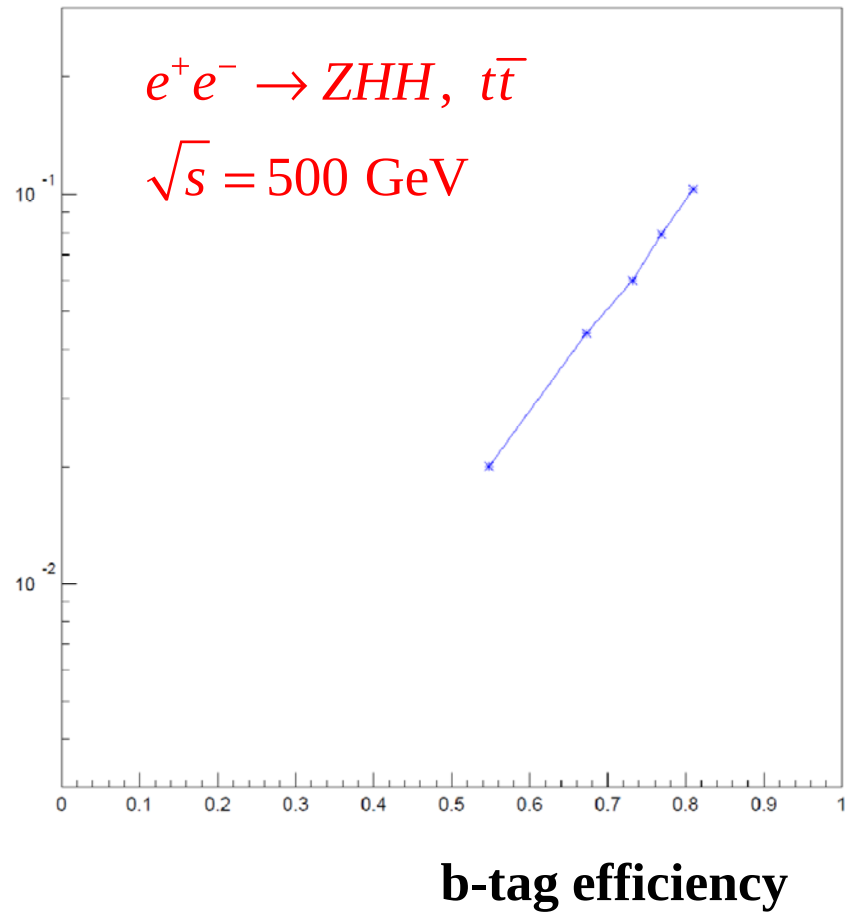
*Recently improved
to 0.6s/ev thanks
to Ben Jeffery

charm mis-id efficiency versus b-tag efficiency

R. Hawkings, LC-PHSM-2000-021



SiD ZHH Analysis



New org.lcsim FastMC described on pp 2-5 was used for black points

Old org.lcsim FastMC with $\alpha/\sqrt{E}$ jet energy dependence used for red and blue points

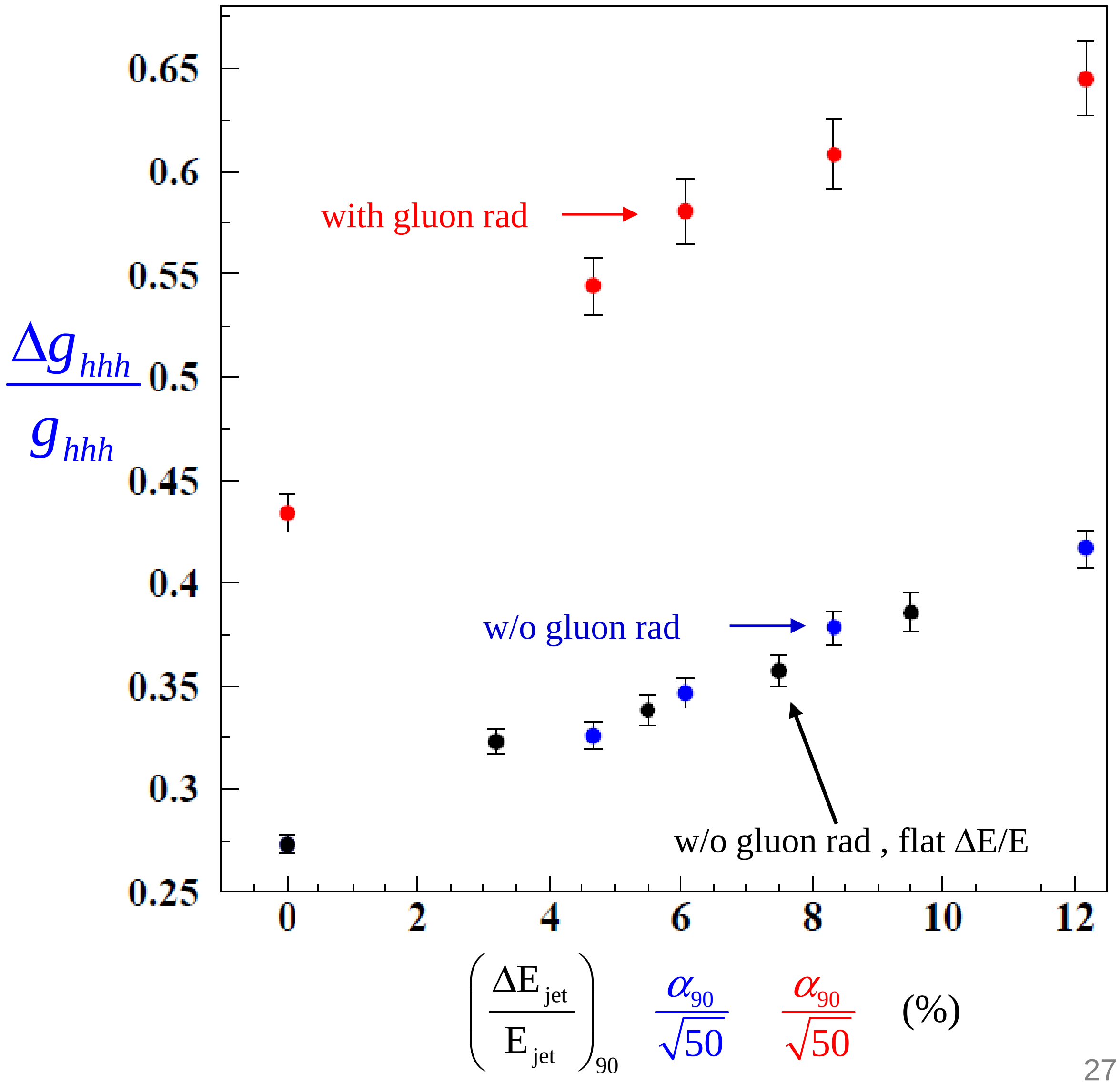
BR($H \to b\bar{b}$)=0.678

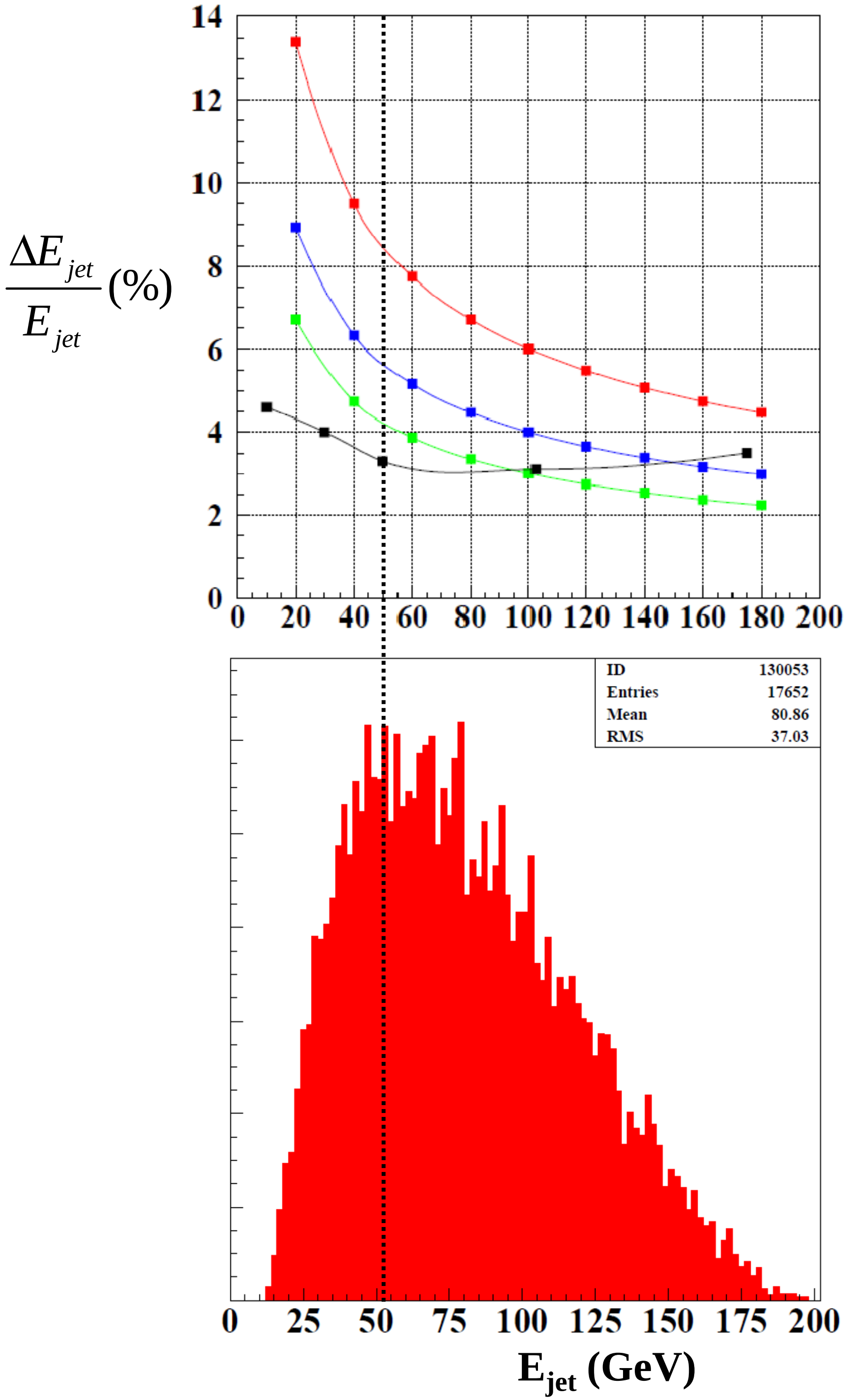
$e^+e^- \to ZHH$
$\to qqb\bar{b}b\bar{b}$

$\sqrt{s} = 500\ GeV$

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

$\Delta E_{jet}/E_{jet} = .06 \to .03$
equiv to $1.3\times$ 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

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

at $\sqrt{s} = 500$ GeV

Summary

- Single particle resolution parameters of the org.lcsim FastMC have been tuned to give a reasonable approximation to PandoraPFA v02-01. Using this new FastMC tune several studies were performed/updated.
- Dijet mass resolution for single W,Z bosons appears to be dominated by PFA jet energy resolution – angle and jet mass errors are small. For $\Delta E_{jet}/E_{jet}=0.033$ the mass resolutions are 2.8 (3.1) GeV for W (Z).
- Jet finding in final states with two massive bosons produces a dijet mass sys error of 2 - 2.5 GeV in the absence of gluon rad. This is about the size of the W,Z intrinsic widths.

Summary cont.

- Gluon radiation creates a long tail in the dijet mass distribution for events with two massive bosons. This blows up the rms, but the core width is approx maintained.
- Various jet resolutions variables have been used in the past when quoting physics error vs jet resolution. The choice of variable can affect the lumi gain. Also, jet energy response of detector was often dominated by a $1/\sqrt{E_{jet}}$ term which isn't seen in PFA studies. Redoing these studies using the new org.lcsim FastMC single particle tune and a consistent jet resolution variable $(\Delta E_{jet}/E_{jet})_{90}$ leads to different conclusions regarding the effective luminosity gain.