Benchmarking Status and Goals

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SLAC

Apr 10, 2007

Full MC Detector Simulation and Event Reconstruction

Full MC Detector Simulation and Event Reconstruction of

$$e^+e^- \rightarrow ZH \rightarrow \mu^+\mu^- X$$

by Norm Graf

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

Backgrounds: $e^+e^- \rightarrow ZZ^* \rightarrow \mu^+\mu^- X, \quad |\cos\theta_\mu| < 0.8$

$\gamma\gamma \rightarrow e^+e^-$ (overlay)

$\gamma\gamma \rightarrow \mu^+\mu^-$ (overlay)

$\gamma\gamma \rightarrow$ hadrons (overlay)

Detector response of latest baseline SiD is simulated with GEANT4

Digitization simulated using GEANT4 hits as input
(level of detail varies from one subsystem to the next: ccd, si μ-strip, calorimeters)

Digitized hits are fed to clustering algorithms which create tracker hits or calorimeter clusters

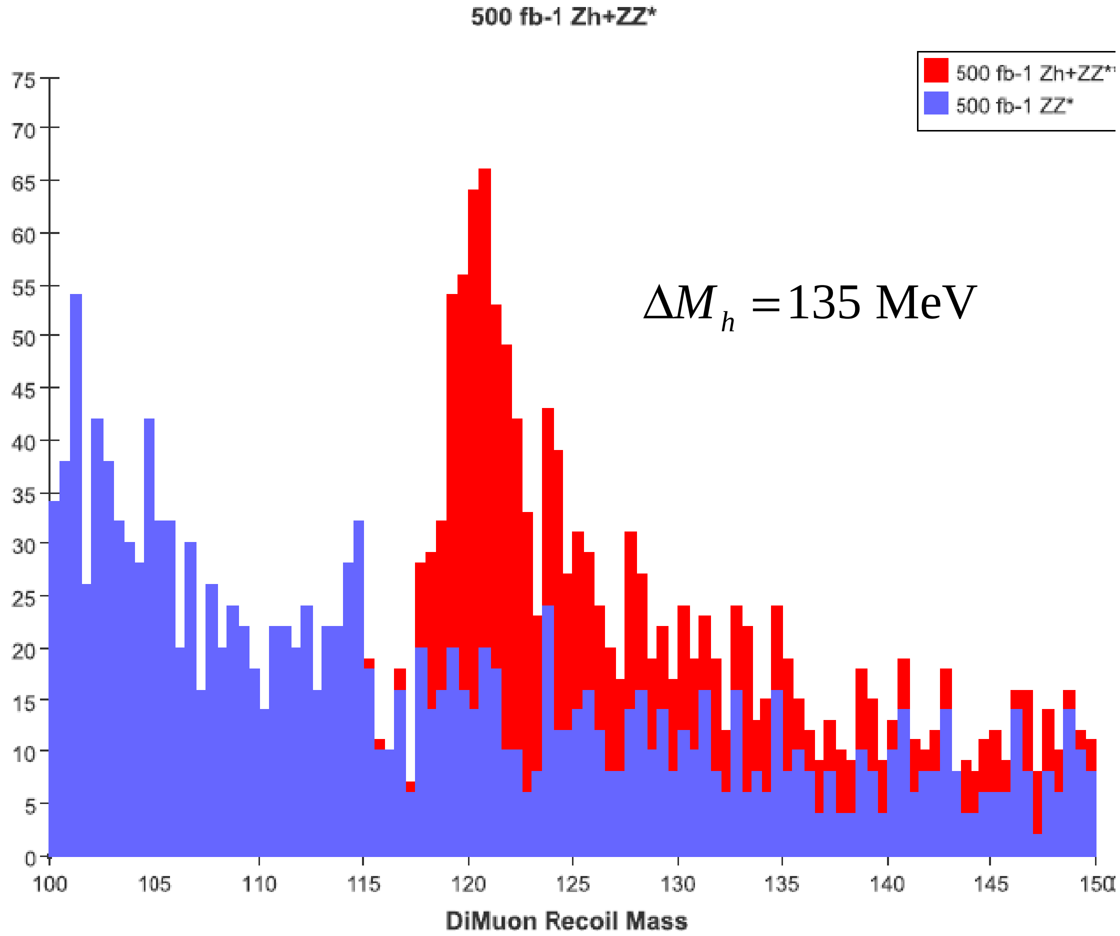
Isolated MIP clusters in EM, Had, & μ calorimeters identify muons and seed track finding in si μ-strip.

Full MC Detector Simulation and Event Reconstruction of

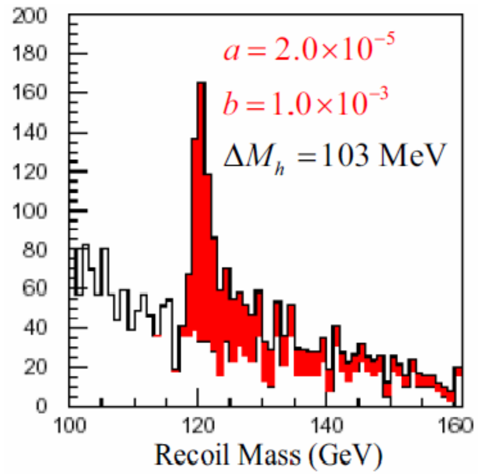
$$e^+e^- \rightarrow ZH \rightarrow \mu^+\mu^- X$$

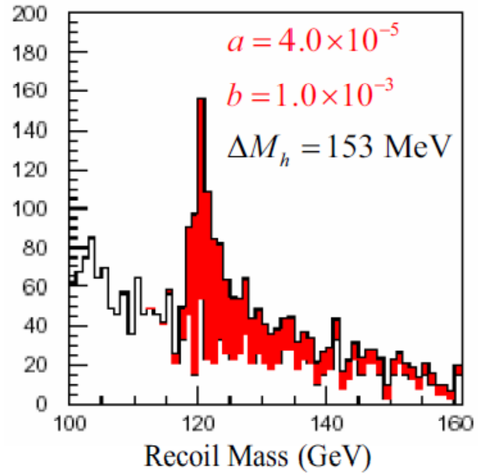
by Norm Graf

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



Old FASTMC study:

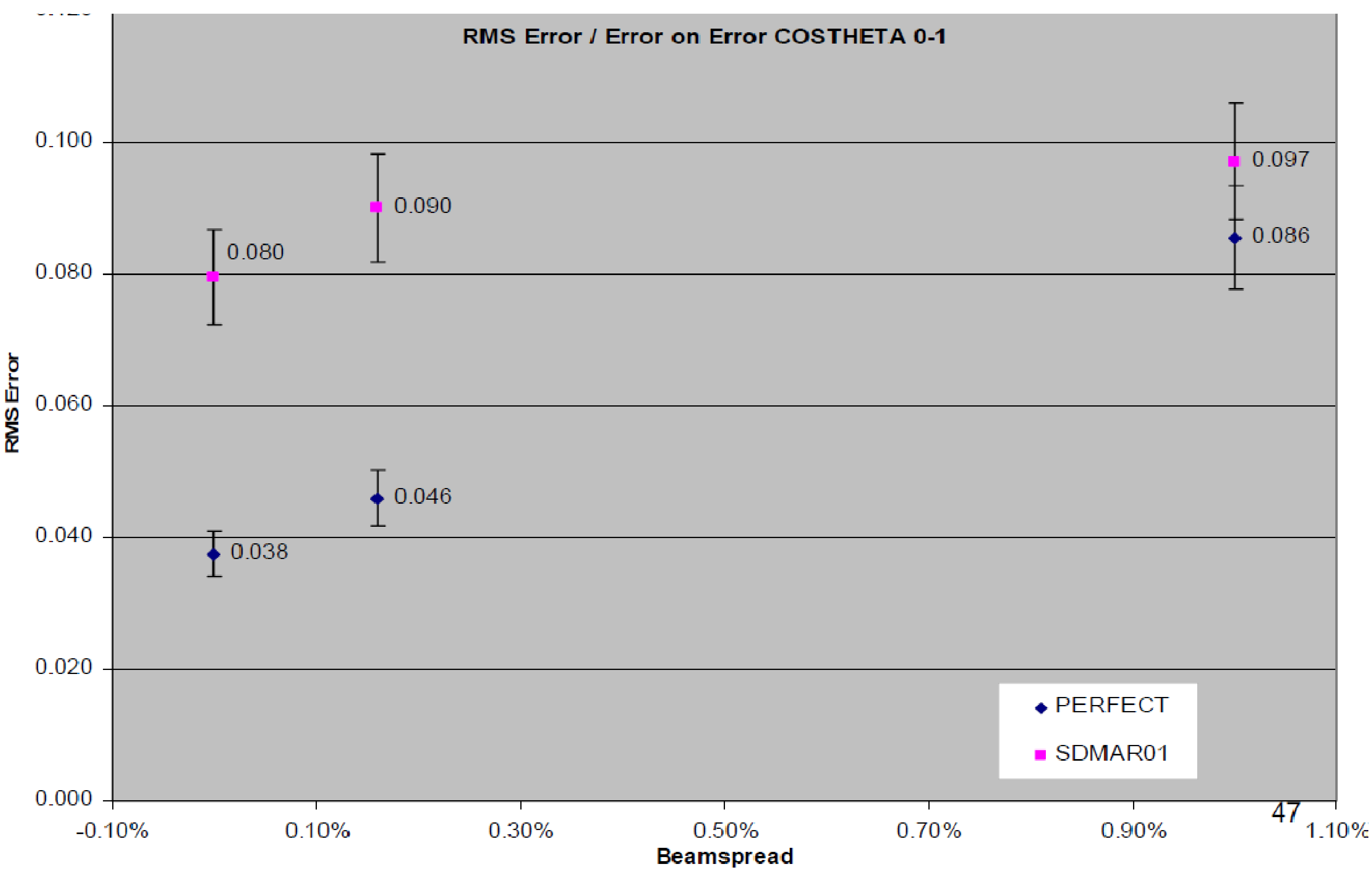




Tracker Performance Studies

SPS1a Selectron Mass Measurement at 1 TeV B. Schumm et al.

SDMAR01: $a = 2.1\times10^{-5}$ $b = 1.0\times10^{-3}$ $\frac{\delta p_t}{p_t^2} = a \oplus \frac{b}{p_t \sin\theta}$



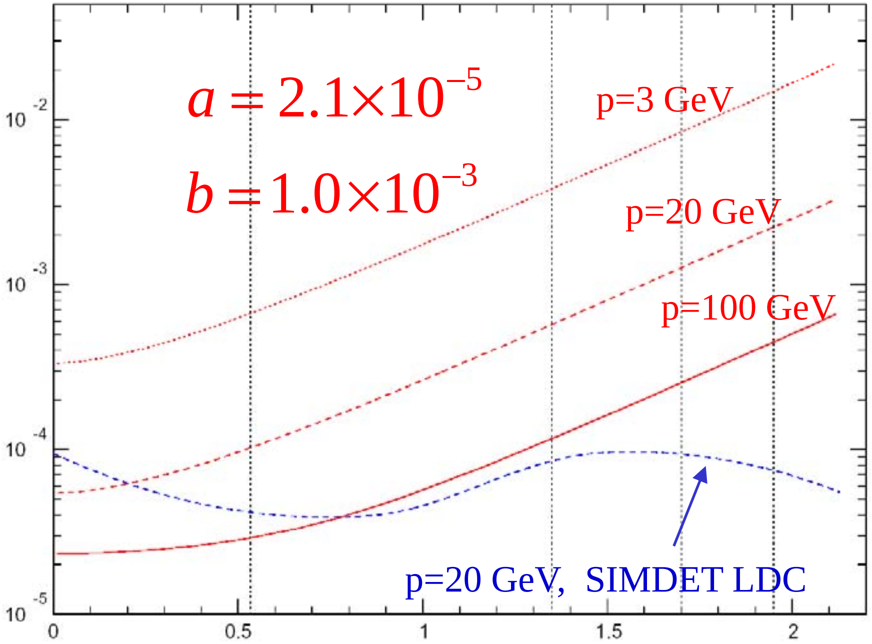
Instead of using a fixed detector model, one use simple parameterization of tracker momentum resolution to rapidly vary momentum resolution:

$$\frac{\delta p_t}{p_t^2} = a \oplus \frac{b}{p_t \sin\theta}$$

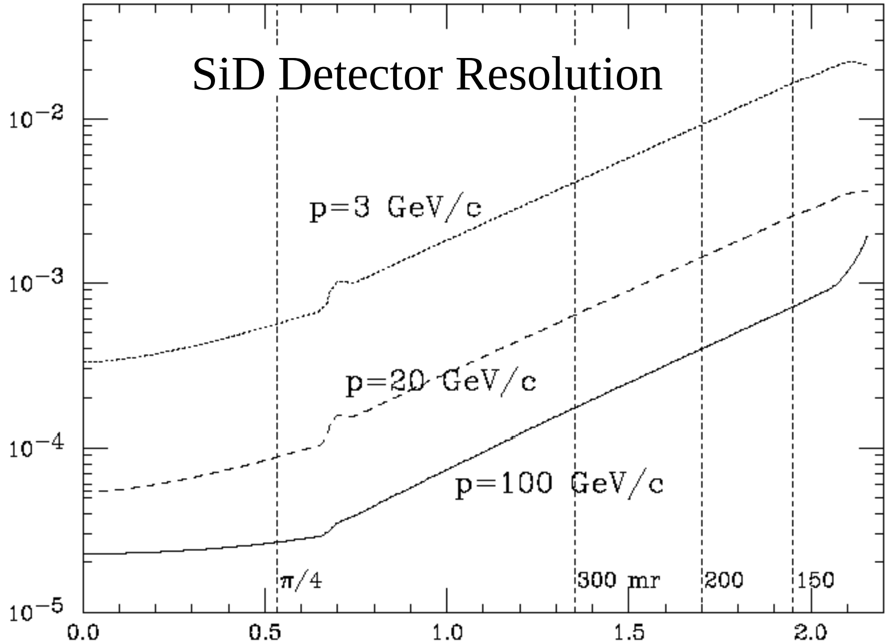
SIDAUG05: $a = 1.6\times10^{-5}$, $b = 1.4\times10^{-3}$

SDMAR01: $a = 2.1\times10^{-5}$, $b = 1.0\times10^{-3}$

$\frac{\delta p_t}{p_t^2}$



$-\log_{10}(1-\cos\theta)$



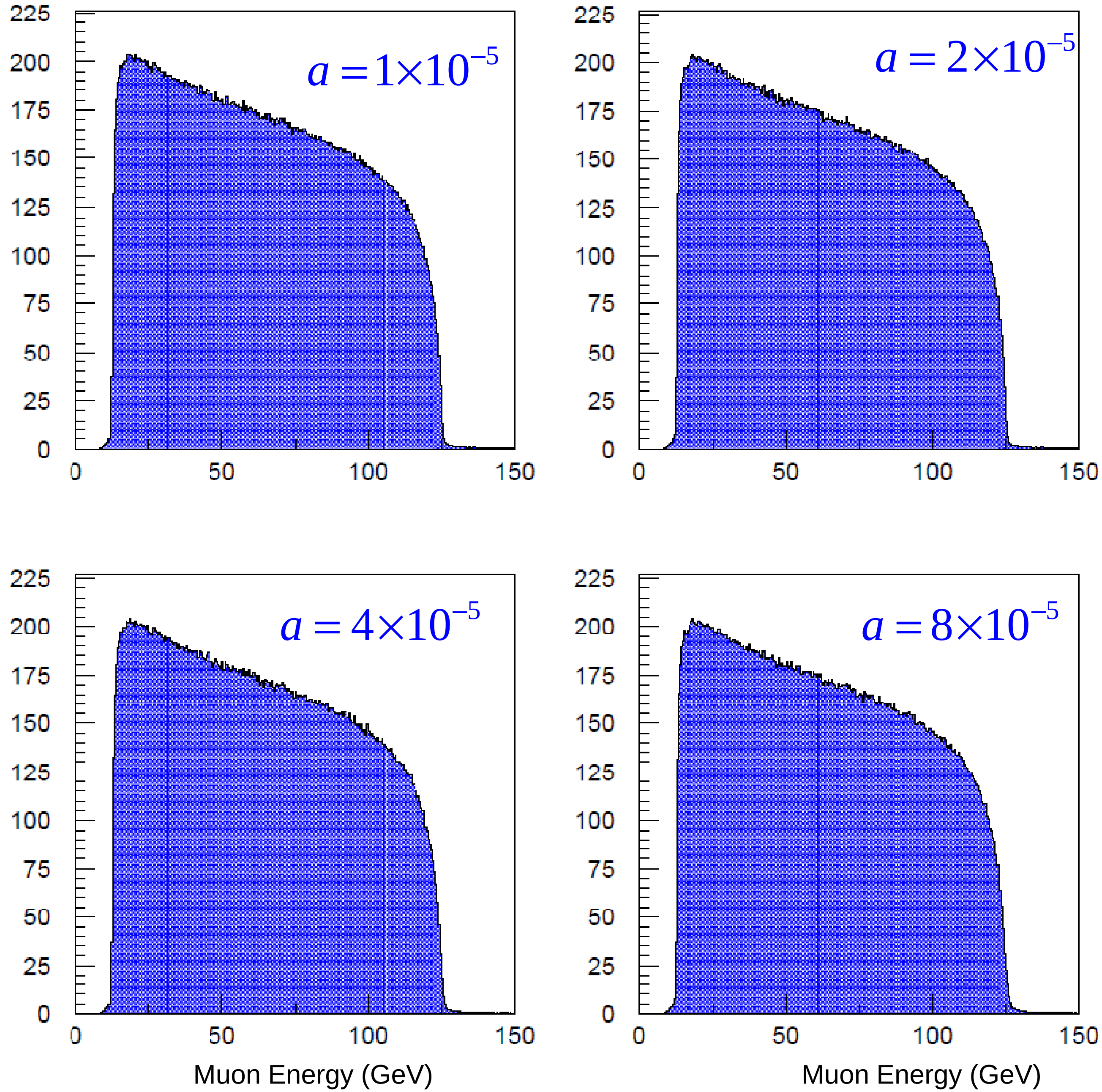
$-\log_{10}(1-\cos\theta)$

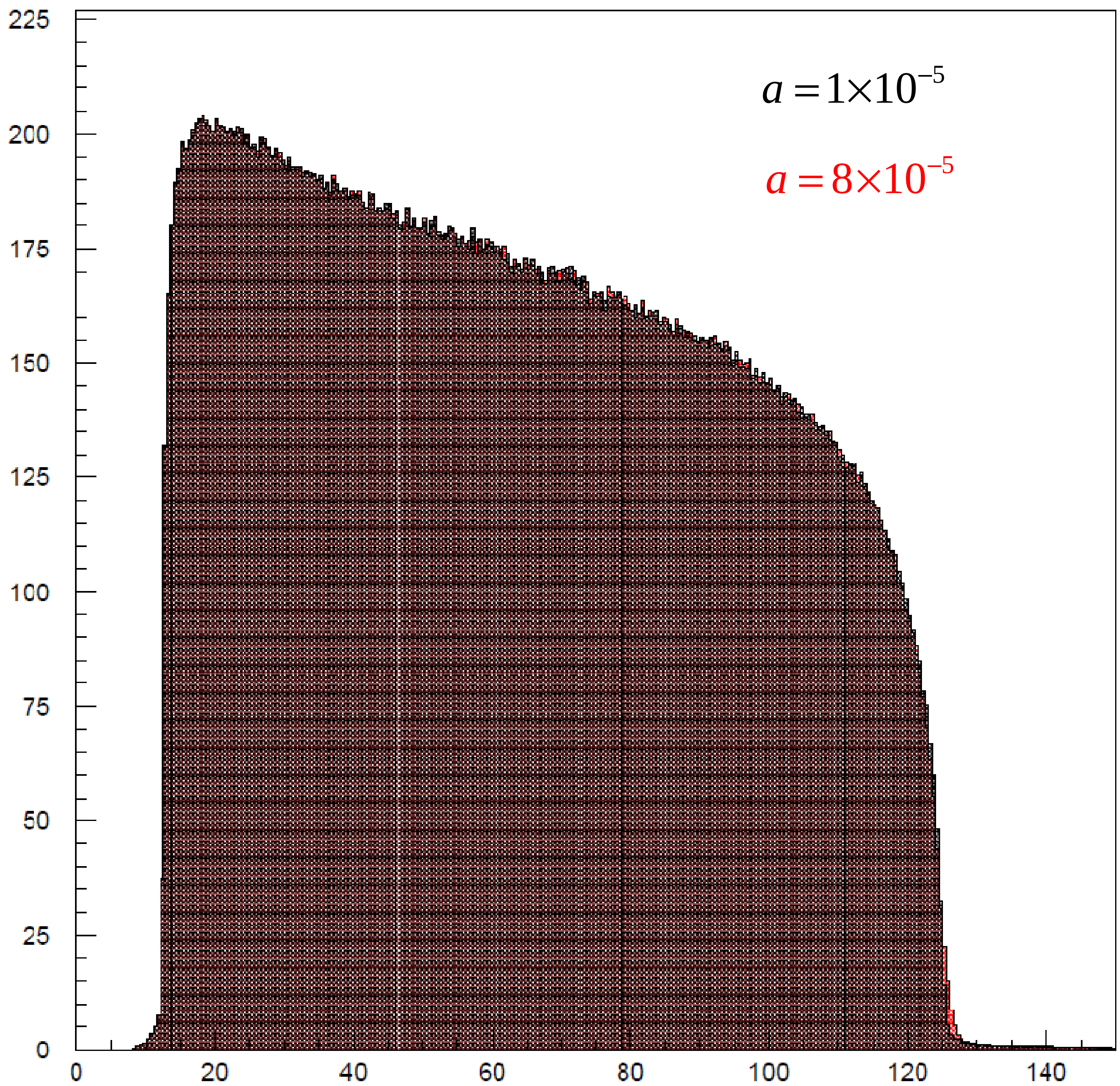
$$e^+e^- \to \tilde{\mu}^+\tilde{\mu}^- \to \mu^+\mu^-\tilde{\chi}_1^0\tilde{\chi}_1^0$$

$$\sqrt{s} = 500\ GeV$$

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

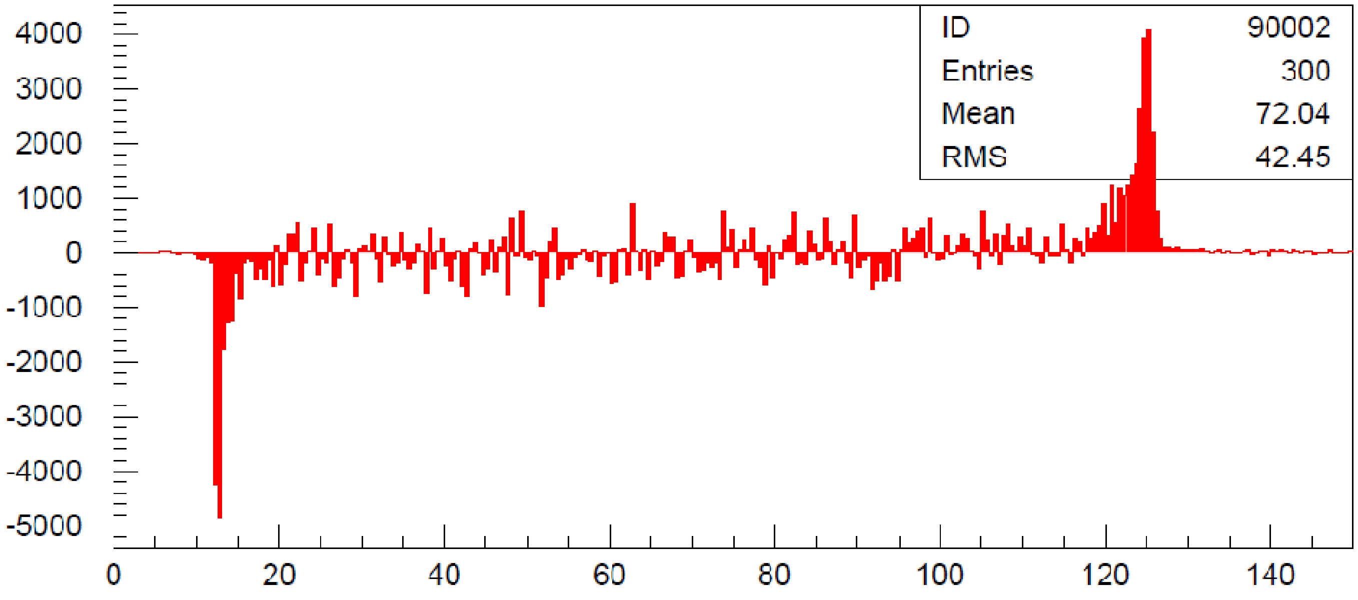
$$\frac{\delta p_t}{p_t^2} = a \oplus \frac{b}{p_t \sin\theta}$$



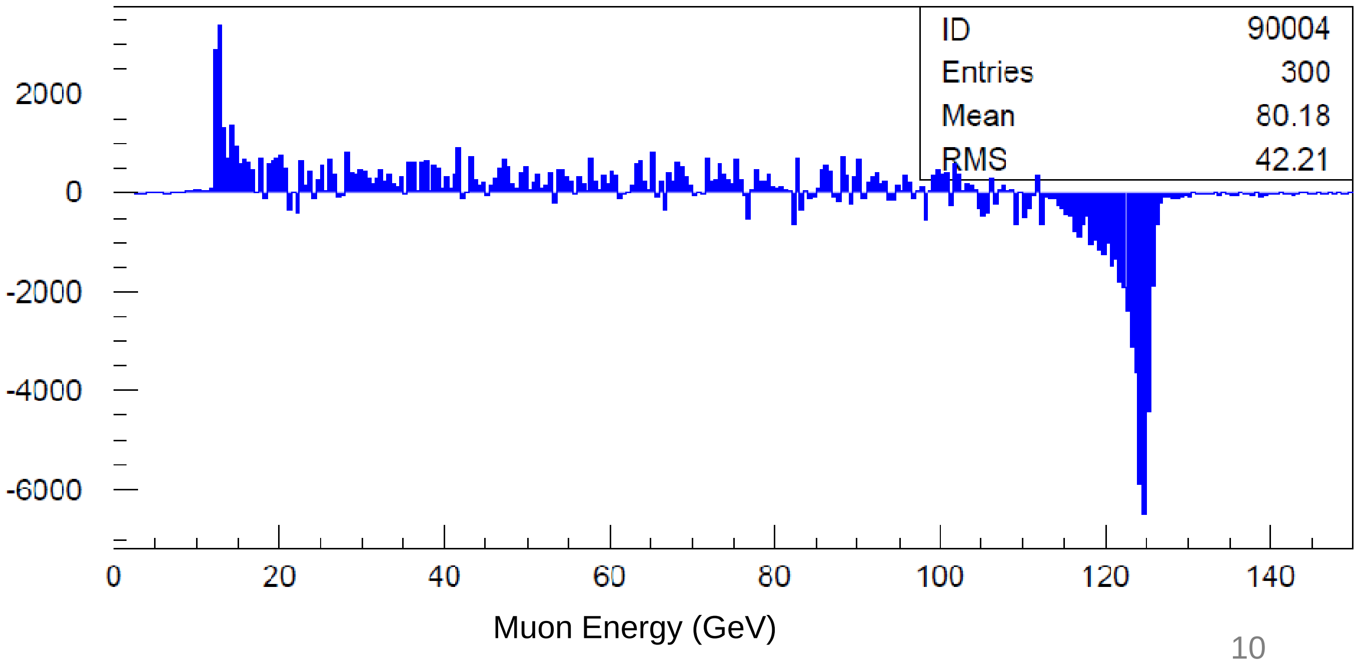


$a = 1\times10^{-5}$
$a = 8\times10^{-5}$
225
200
175
150
125
100
75
50
25
0
0
20
40
60
80
100
120
140

$$\left.\frac{dN_{bin}}{dM_{\tilde{\mu}}}\right|_{M_{\tilde{\mu}}=143\,GeV}$$



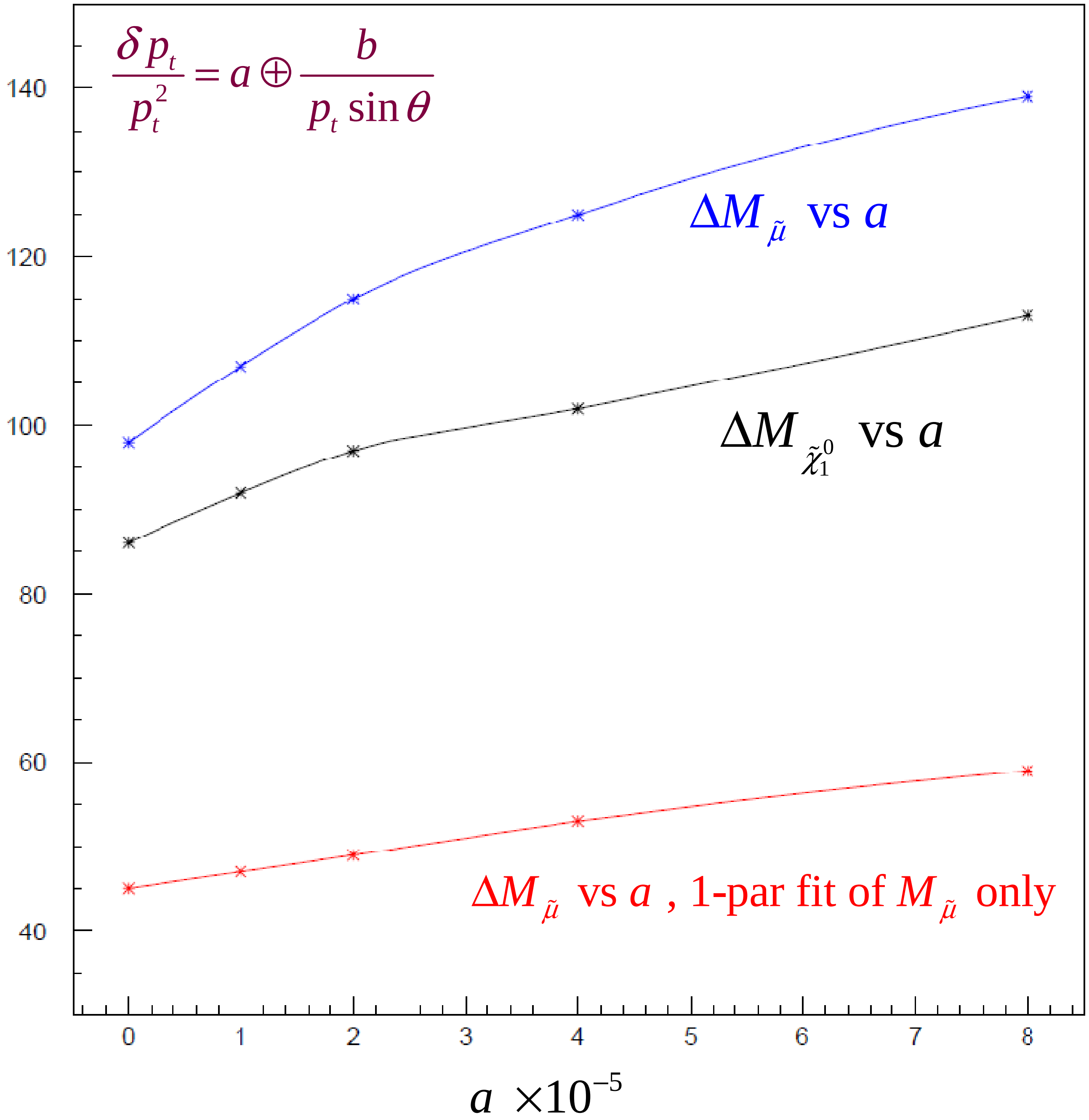
$$\left.\frac{dN_{bin}}{dM_{\tilde{\chi}_1^0}}\right|_{M_{\tilde{\chi}_1^0}=96\,GeV}$$

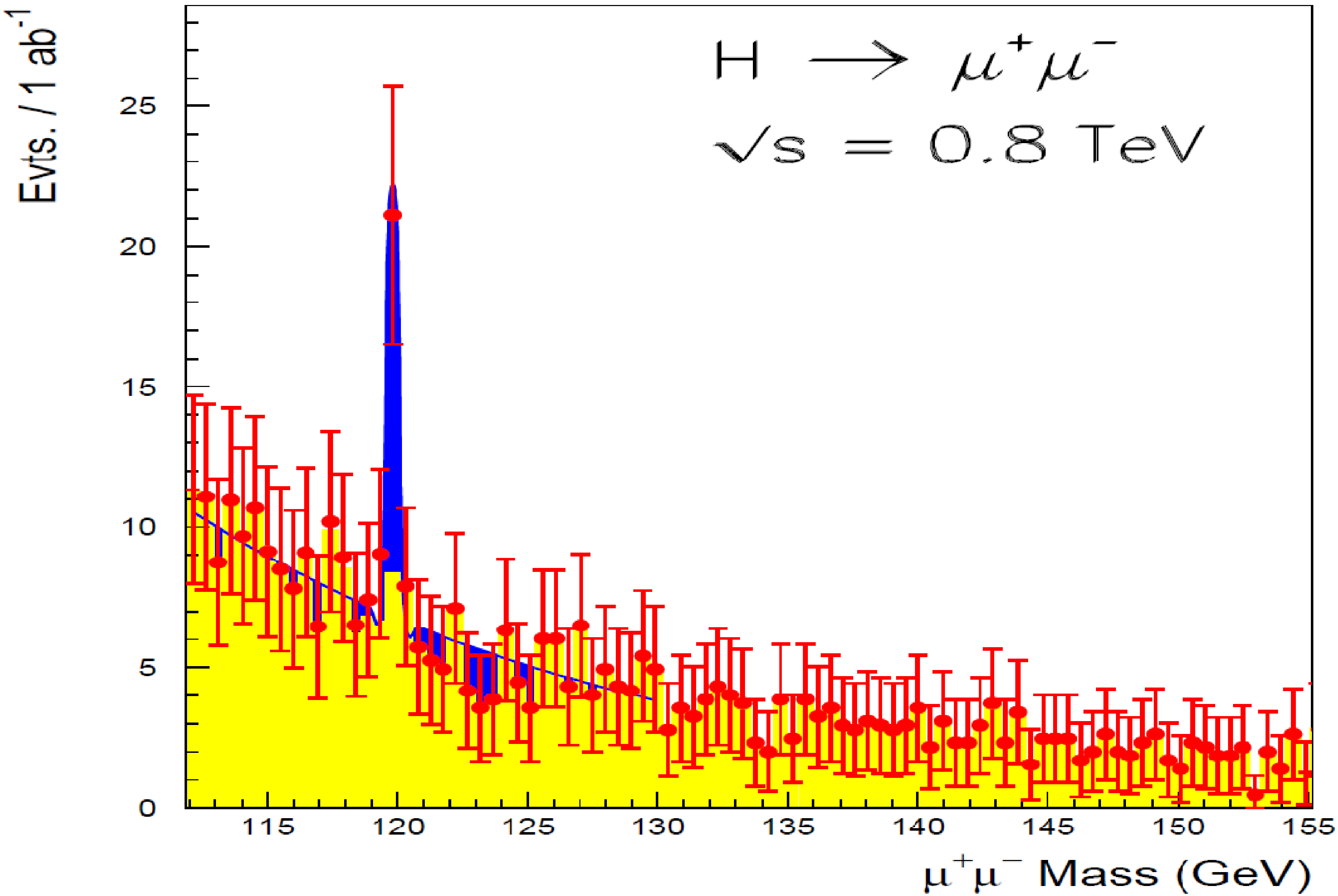


$$e^+e^- \to \tilde{\mu}^+\tilde{\mu}^-$$
$$\to \mu^+\mu^-\tilde{\chi}_1^0\tilde{\chi}_1^0$$

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

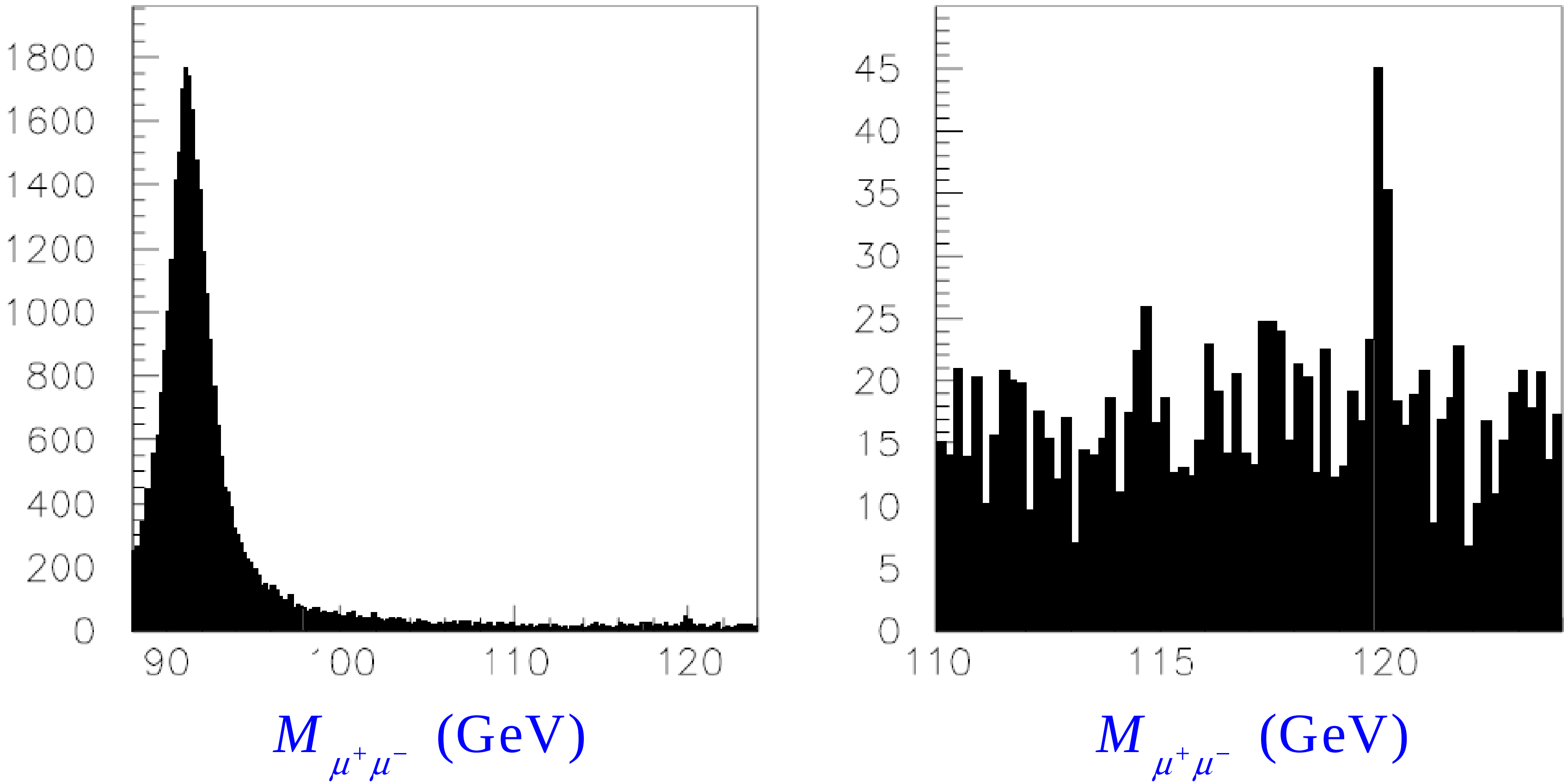
$\Delta M_{\tilde{\mu}}$, $\Delta M_{\tilde{\chi}_1^0}$ (MeV)





M. Battaglia et al.

$M_{\mu\mu}$ Distributions for NN>0.95 for signal and background summed



$a = 2\times10^{-5}$

$b = 1\times10^{-3}$

$$\frac{\delta p_t}{p_t^2} = a \oplus \frac{b}{p_t \sin\theta}$$

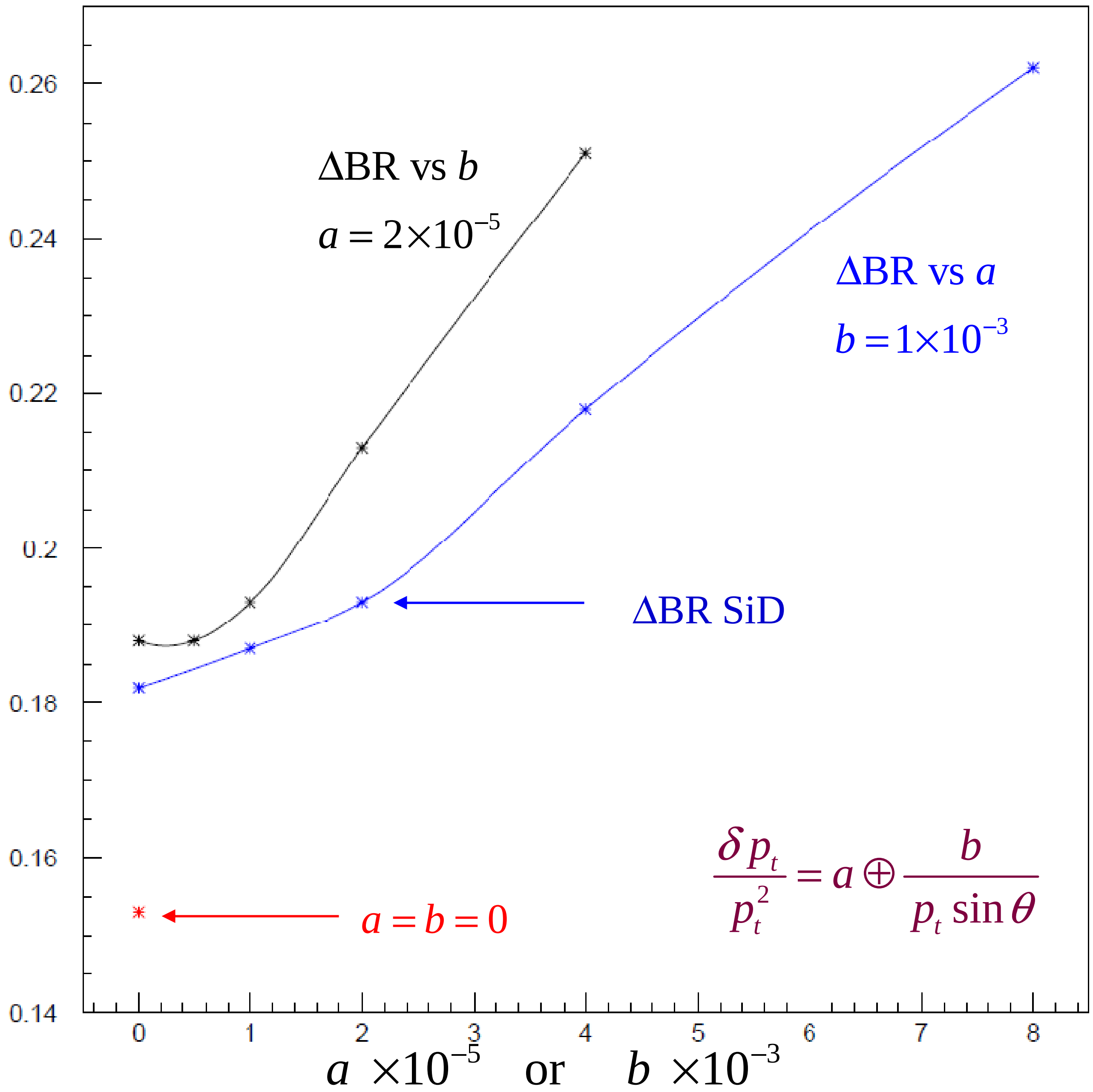
Resolution for **BR(H→ μμ)** vs a or b

$$e^+e^- \to \nu_e \bar{\nu}_e h \to \nu_e \bar{\nu}_e \mu^+ \mu^-$$

$$\sqrt{s} = 1\,TeV$$

$$L = 1000\ fb^{-1}$$

$$\Delta BR(h \to \mu^+ \mu^-)$$

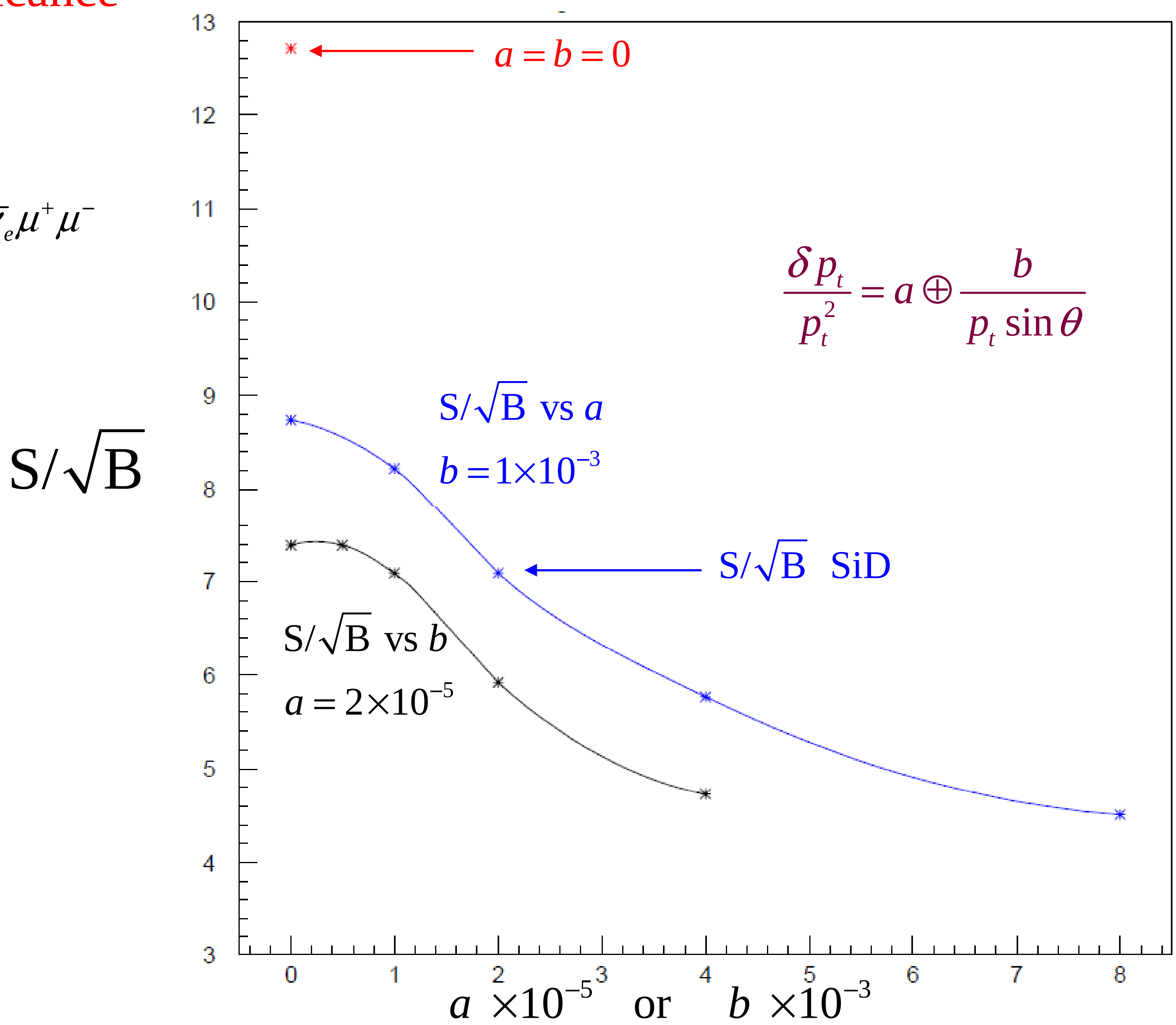


Signal Significance
for H→ μμ
vs a or b

$$e^+e^- \to \nu_e\bar{\nu}_e h \to \nu_e\bar{\nu}_e \mu^+\mu^-$$

$$\sqrt{s} = 1\,TeV$$

$$L = 1000\ fb^{-1}$$

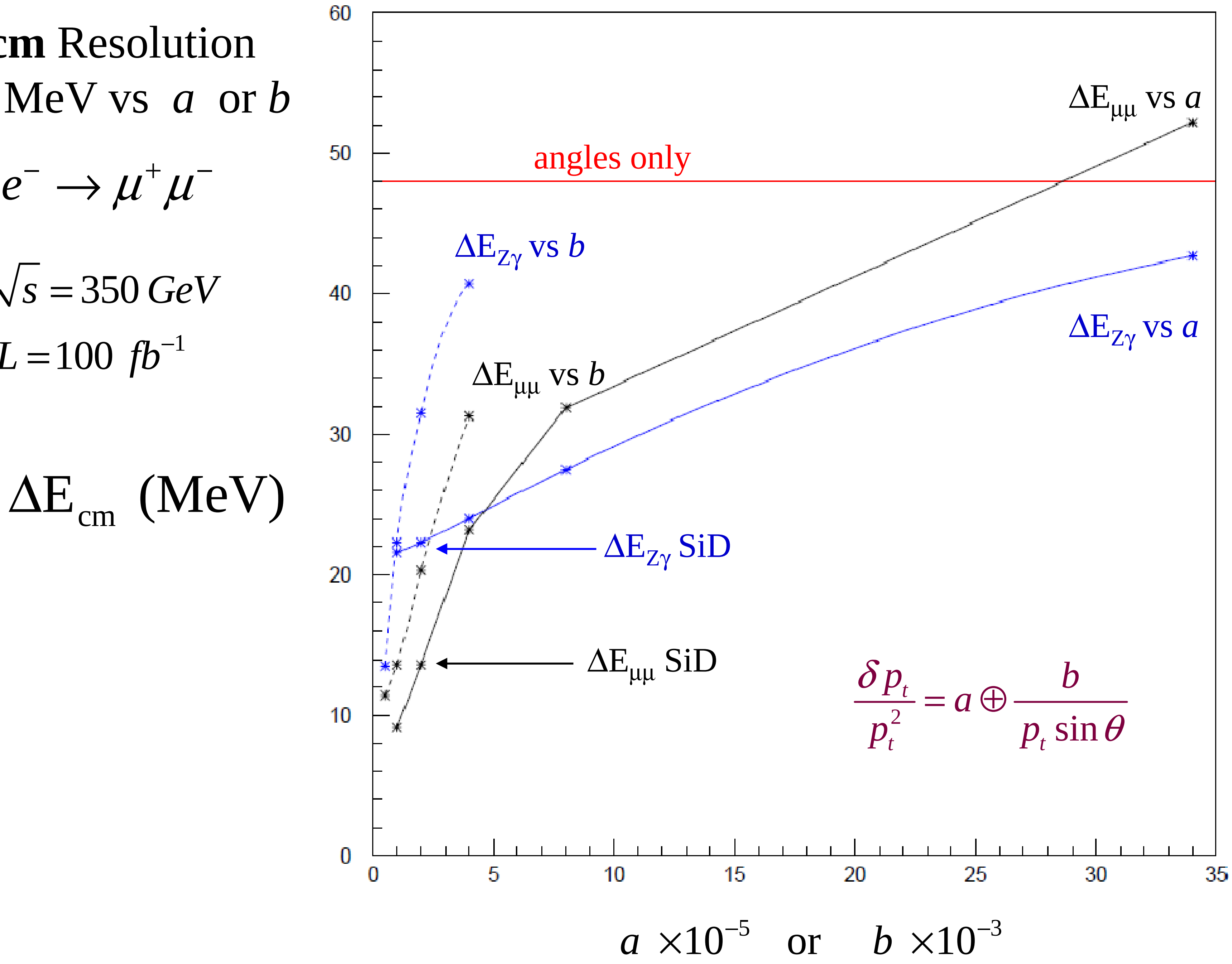


Ecm Resolution in MeV vs *a* or *b*

$$e^+e^- \rightarrow \mu^+\mu^-$$

$$\sqrt{s} = 350\,GeV$$

$$L = 100\ fb^{-1}$$



Calorimeter Performance Studies

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

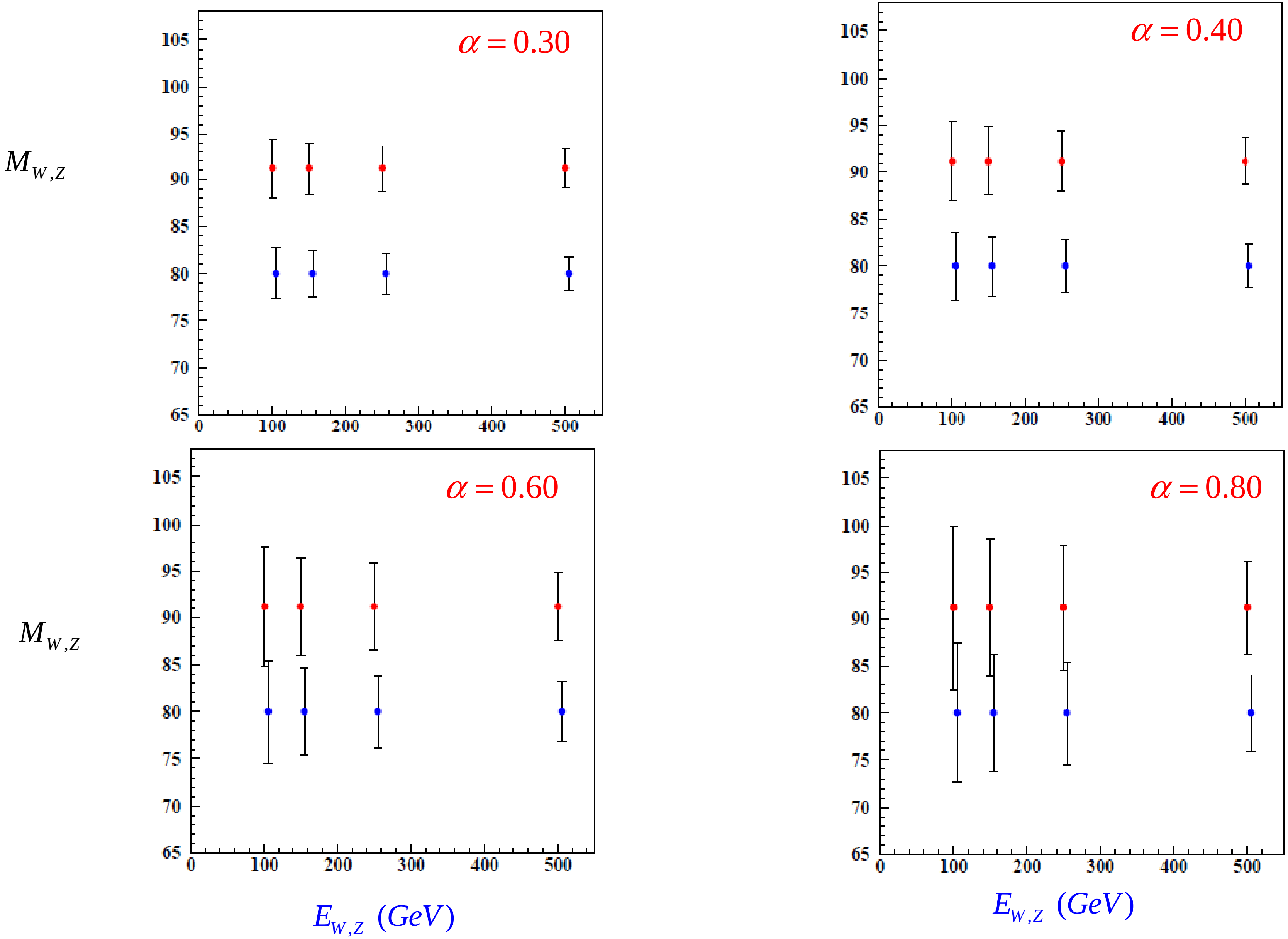
$$e^- \gamma \rightarrow \nu_e W^- \rightarrow \nu_e \bar{u} d$$

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

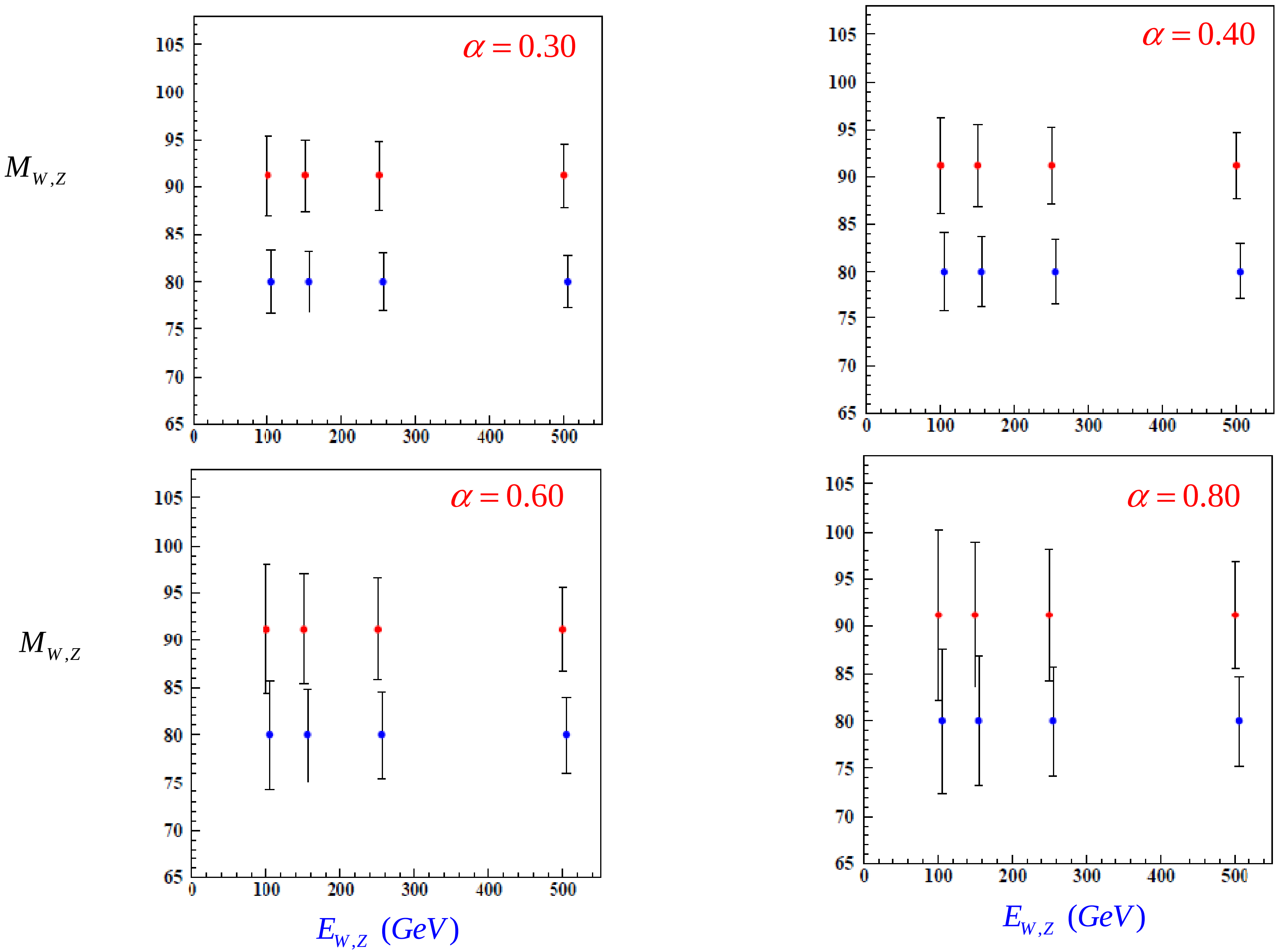
No resolution loss from jet-finding, neutrinos, or particles outside fid. vol.

Assume energy dependence $\frac{\Delta E_{jet}}{E_{jet}} = \frac{\alpha}{\sqrt{E_{jet}}} \oplus \beta$

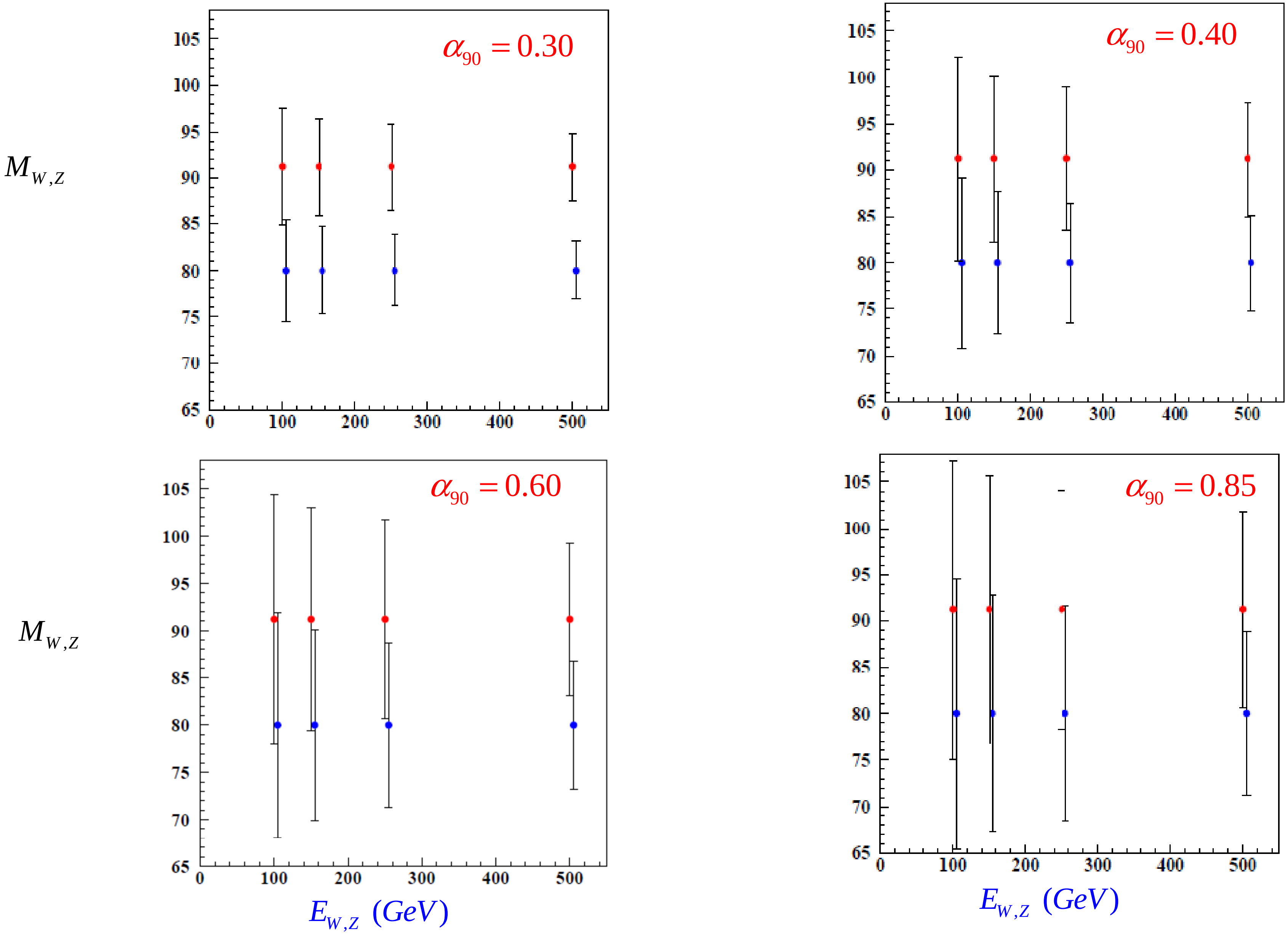
$$\frac{\Delta E_{jet}}{E_{jet}} = \frac{\alpha}{\sqrt{E_{jet}}}$$



$$\frac{\Delta E_{jet}}{E_{jet}} = \frac{\alpha}{\sqrt{E_{jet}}} \oplus 0.03$$



Use rms of central 90% core to define α_{90} : $\frac{(\Delta E_{jet})_{90}}{E_{jet}} = \frac{\alpha_{90}}{\sqrt{E_{jet}}}$



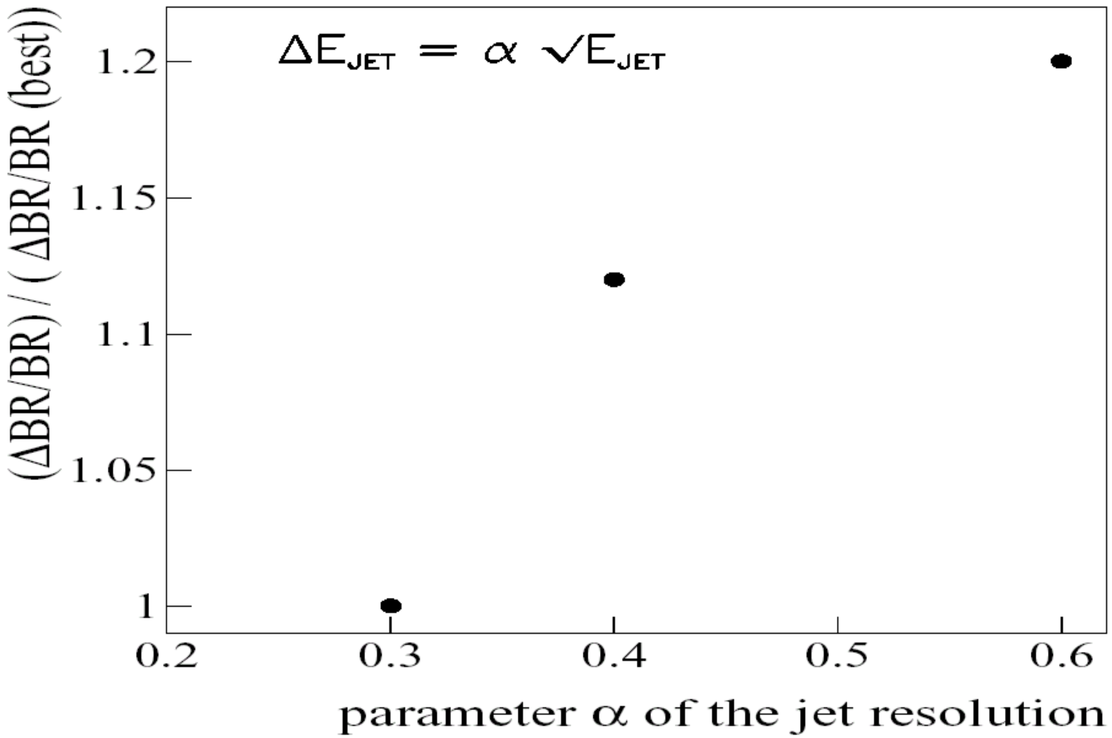
Error on $BR(H \to WW^*)$ from measurement of

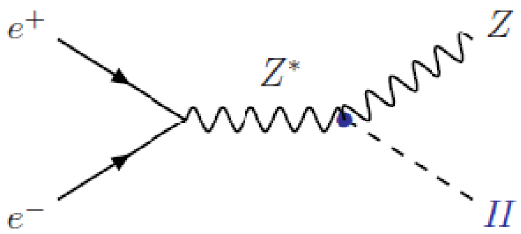
$e^+e^- \to ZH \to q\bar{q}WW^* \to q\bar{q}q\bar{q}l\nu$ at $\sqrt{s} = 360$ GeV, L=500 fb^{-1}

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

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

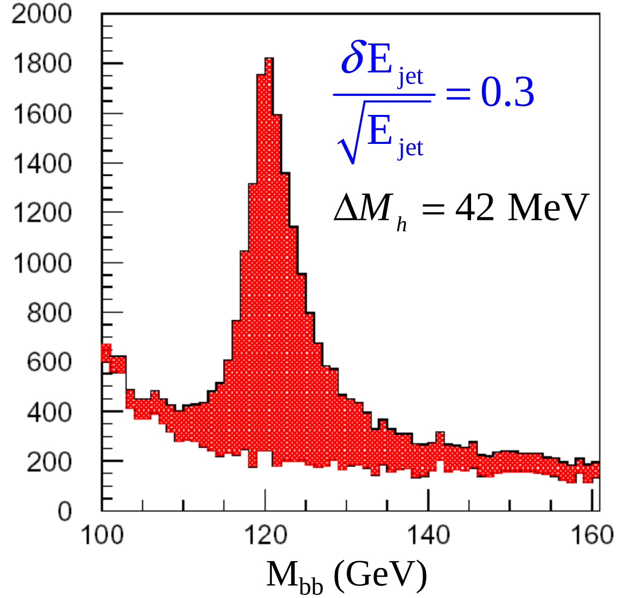
equiv to $1.4\times$ Lumi

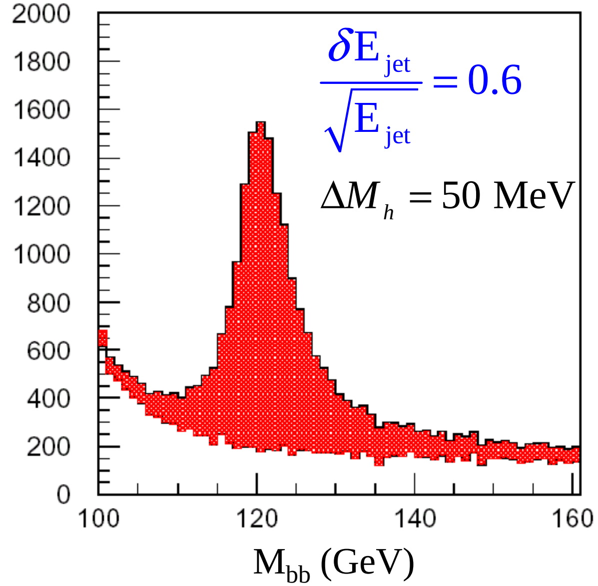


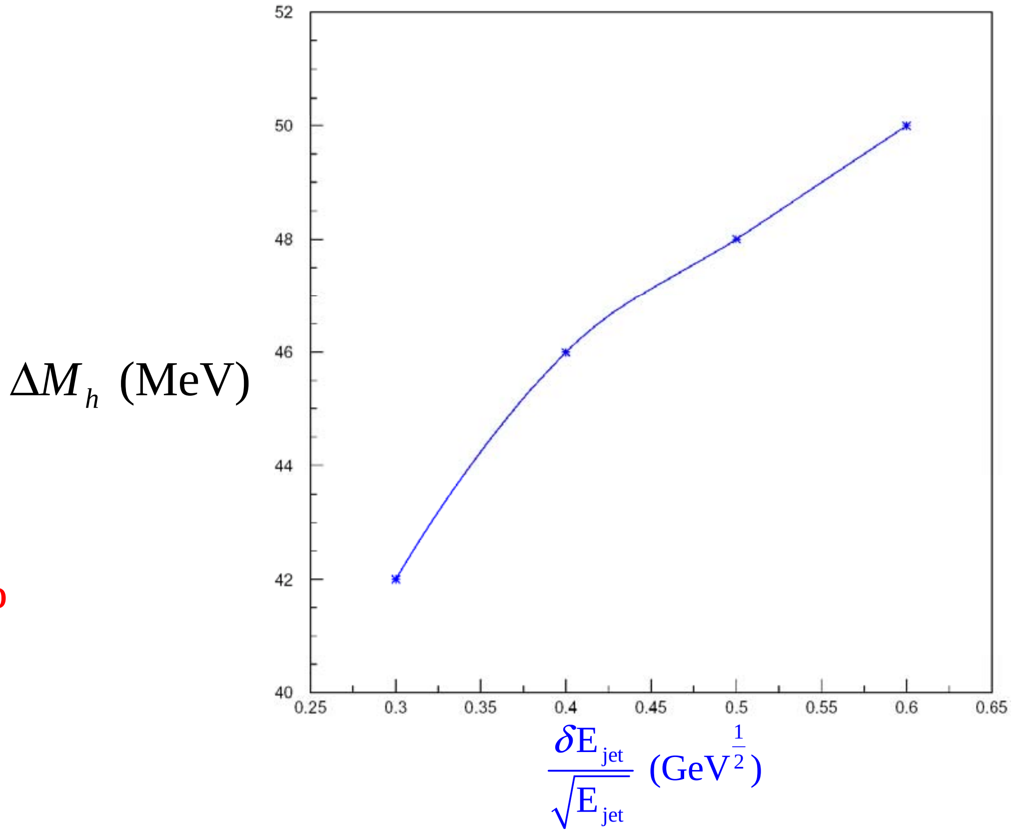


$$e^+e^- \to ZH$$
$$\to qqb\bar{b}$$

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







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

equiv to $1.4\times$ Lumi

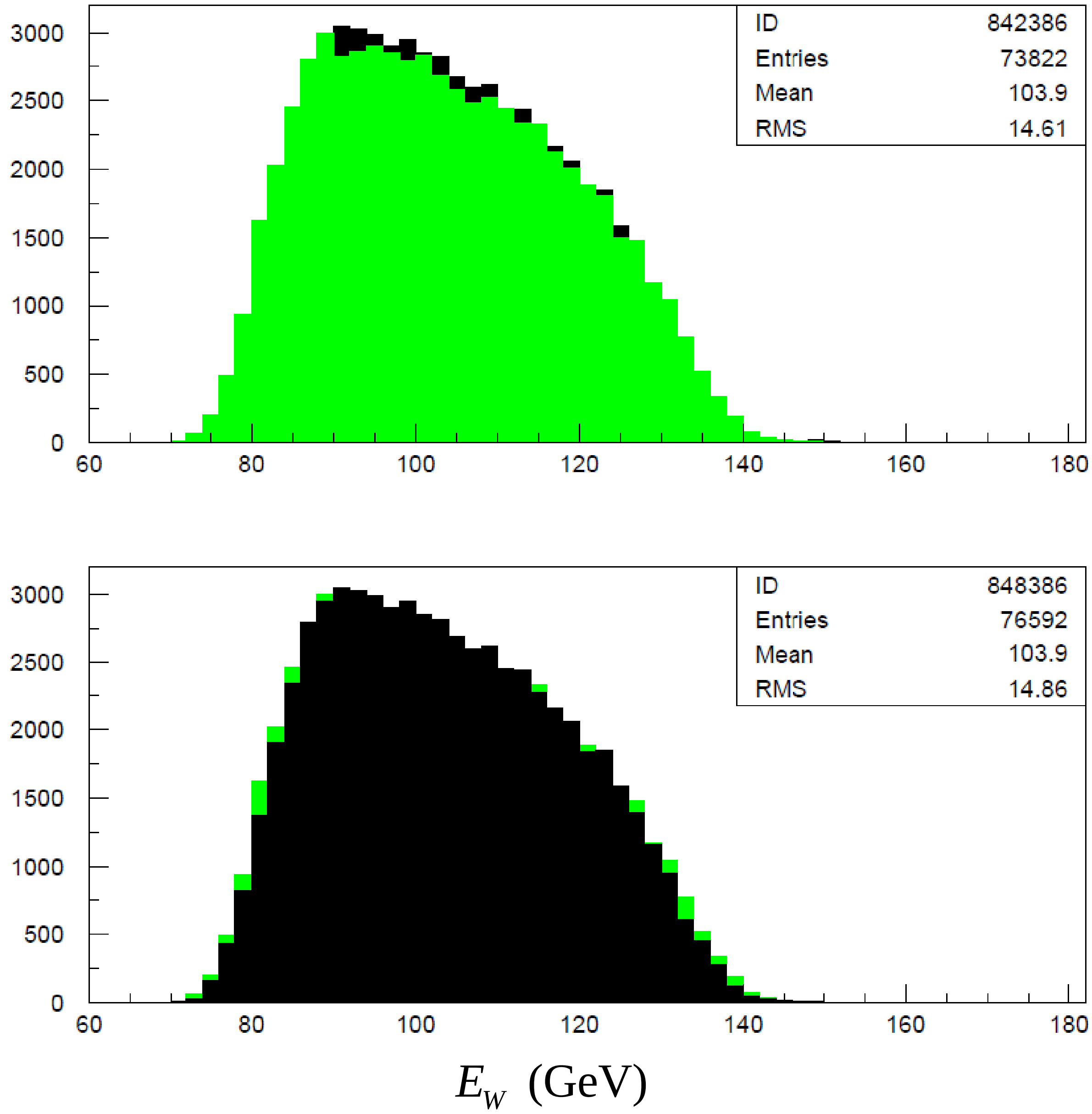
$$e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 W^+W^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 qqqq$$

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

$\sqrt{s} = 500$ GeV

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

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



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.

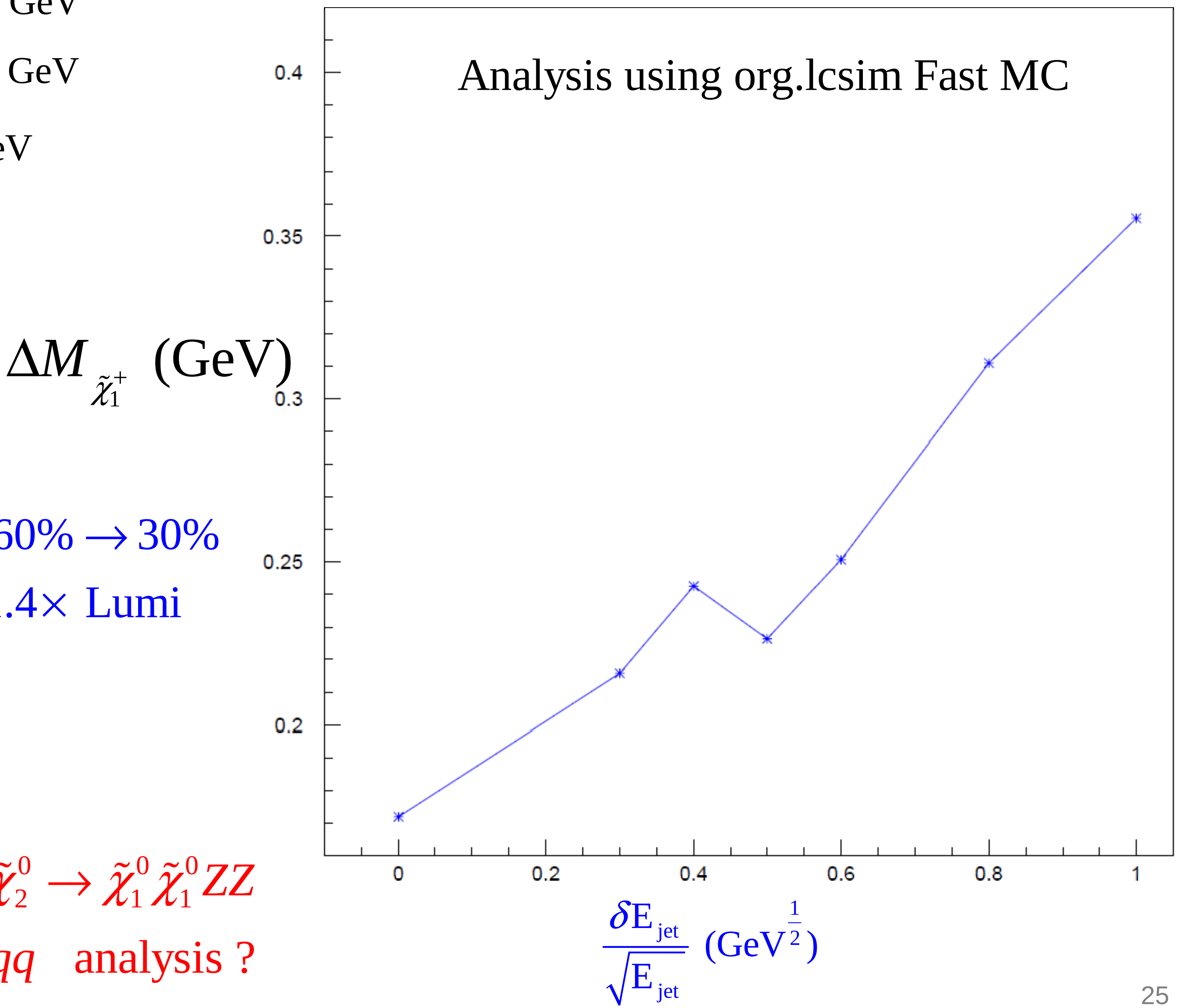
$$e^+e^- \rightarrow \tilde{\chi}_1^+\tilde{\chi}_1^- \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0 W^+W^- \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0 qqqq$$

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

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

$\sqrt{s} = 500$ GeV

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

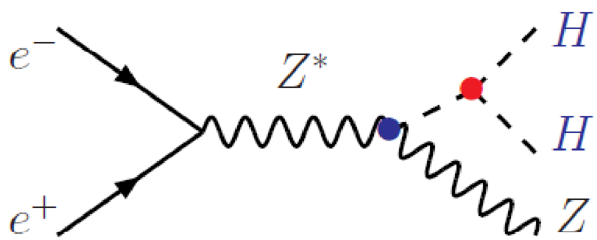


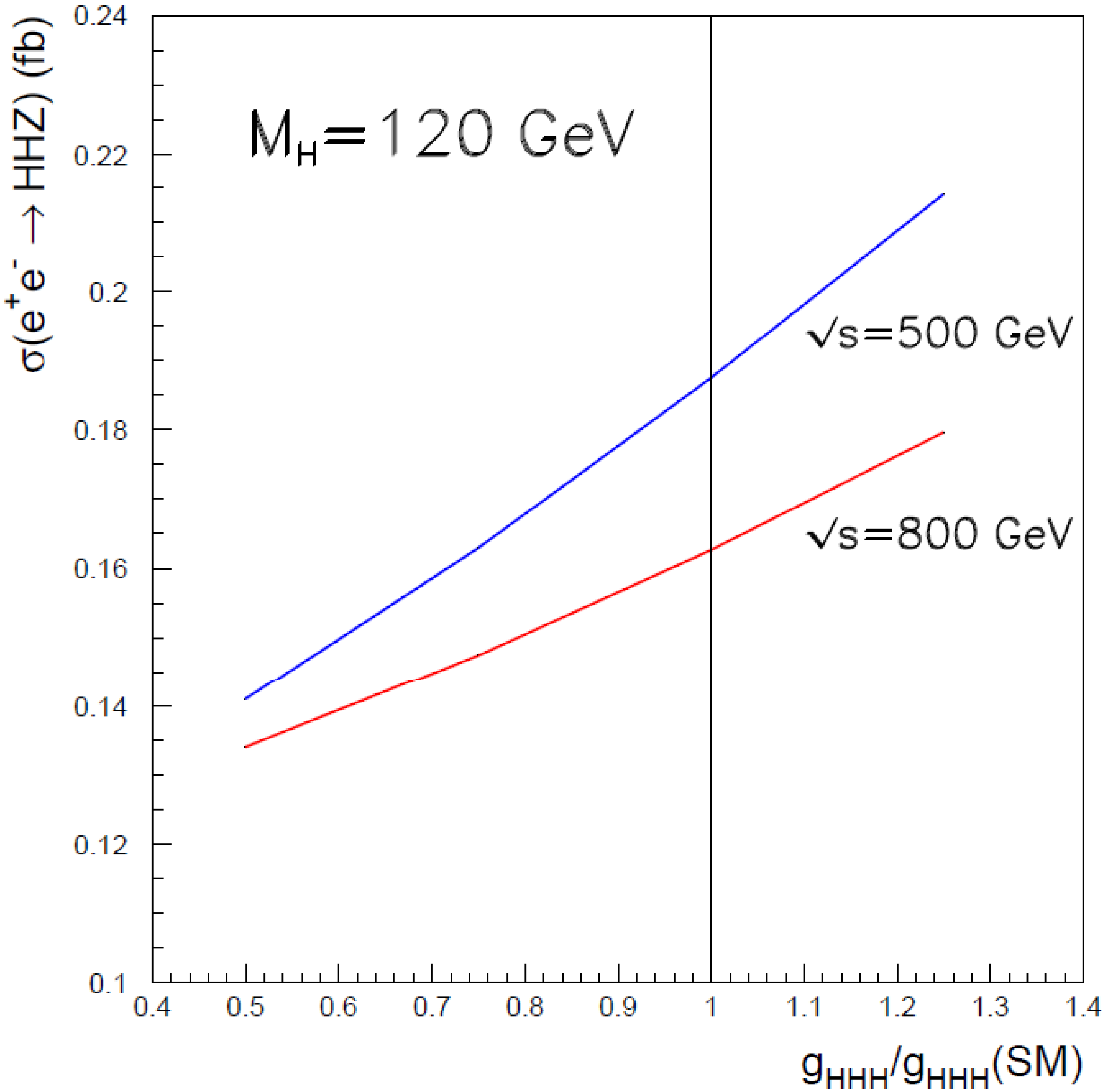
$\Delta E/\sqrt{E} = 60\% \rightarrow 30\%$

equiv to $1.4\times$ Lumi

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

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





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}

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

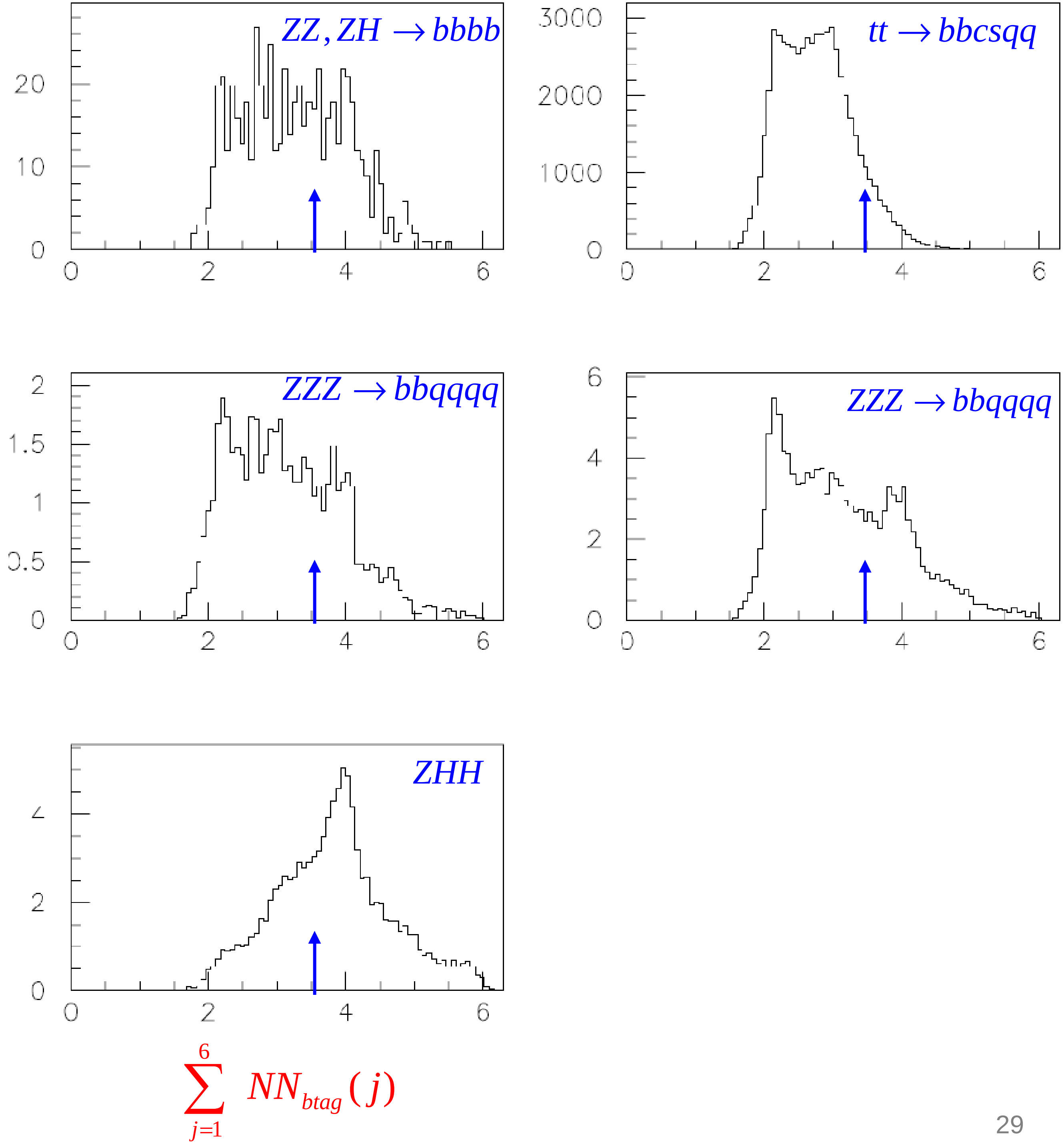
$$\chi^2_{ZHH\_ZHHmass} = \chi^2_{ZHH\_HHmass} + \frac{(M_{12} - M_Z)^2}{\sigma^2_{M_Z}}$$

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

$M_{ij} =$ 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.)



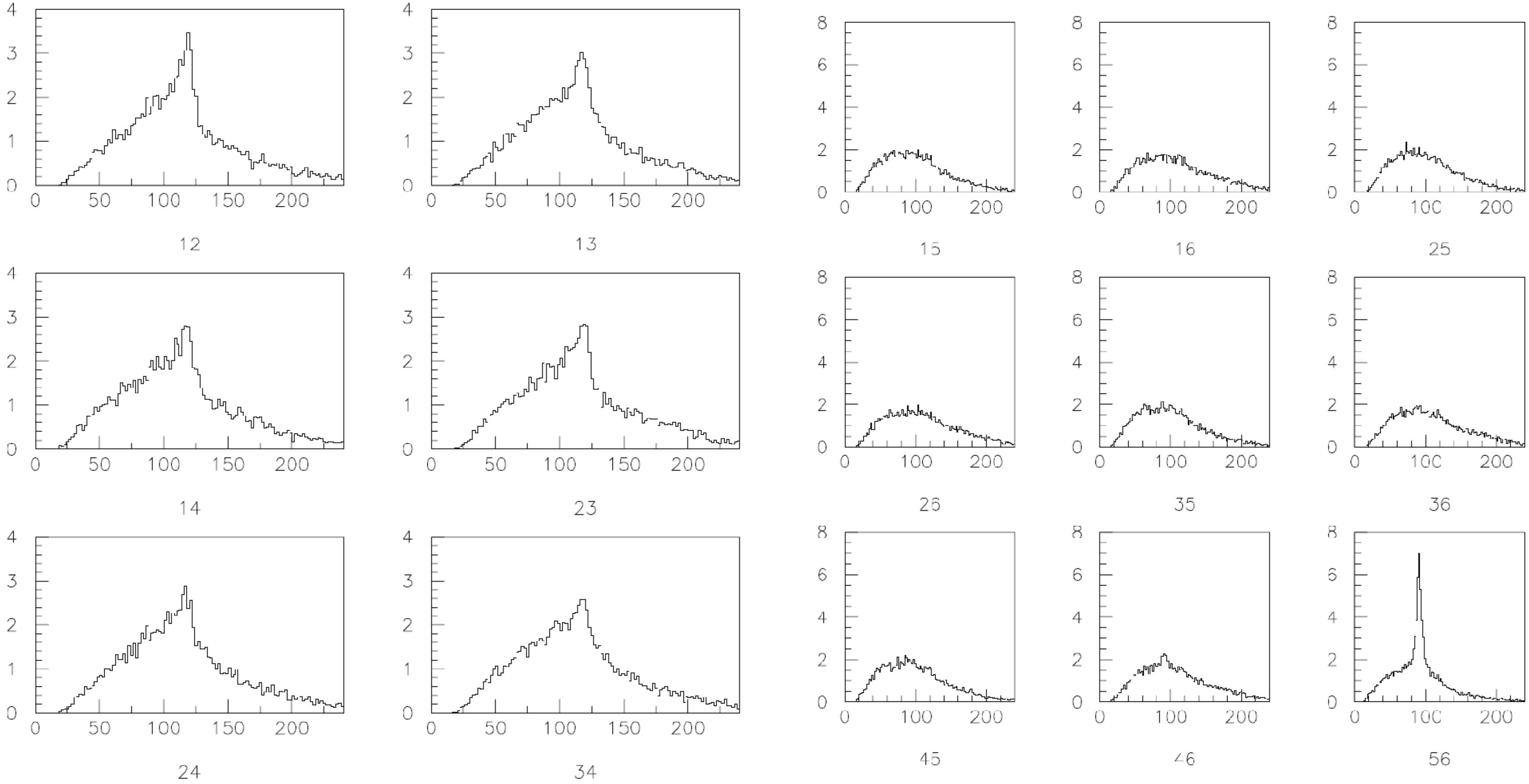
Require

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

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

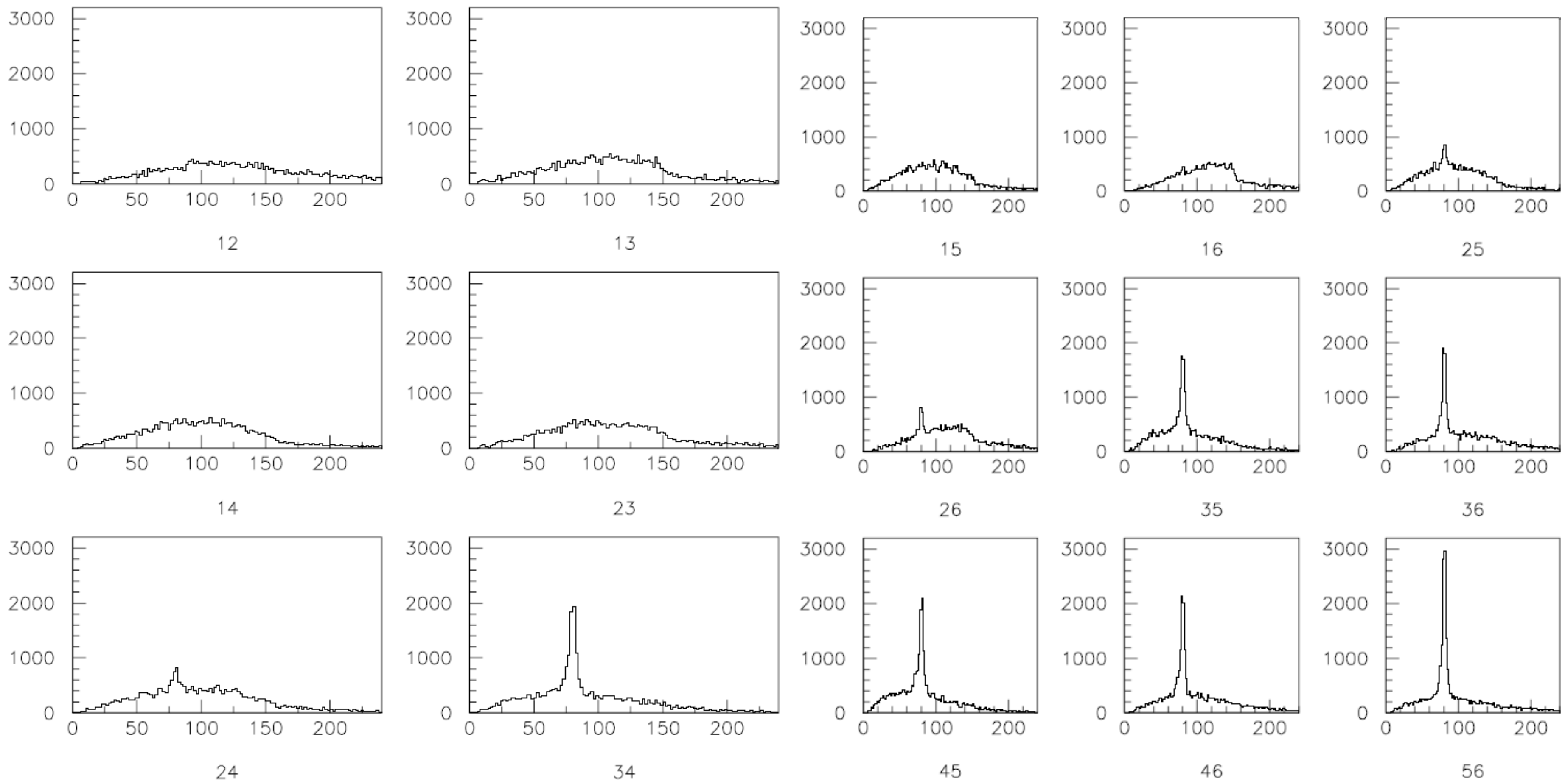


$M_{jk}\,(GeV)$

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

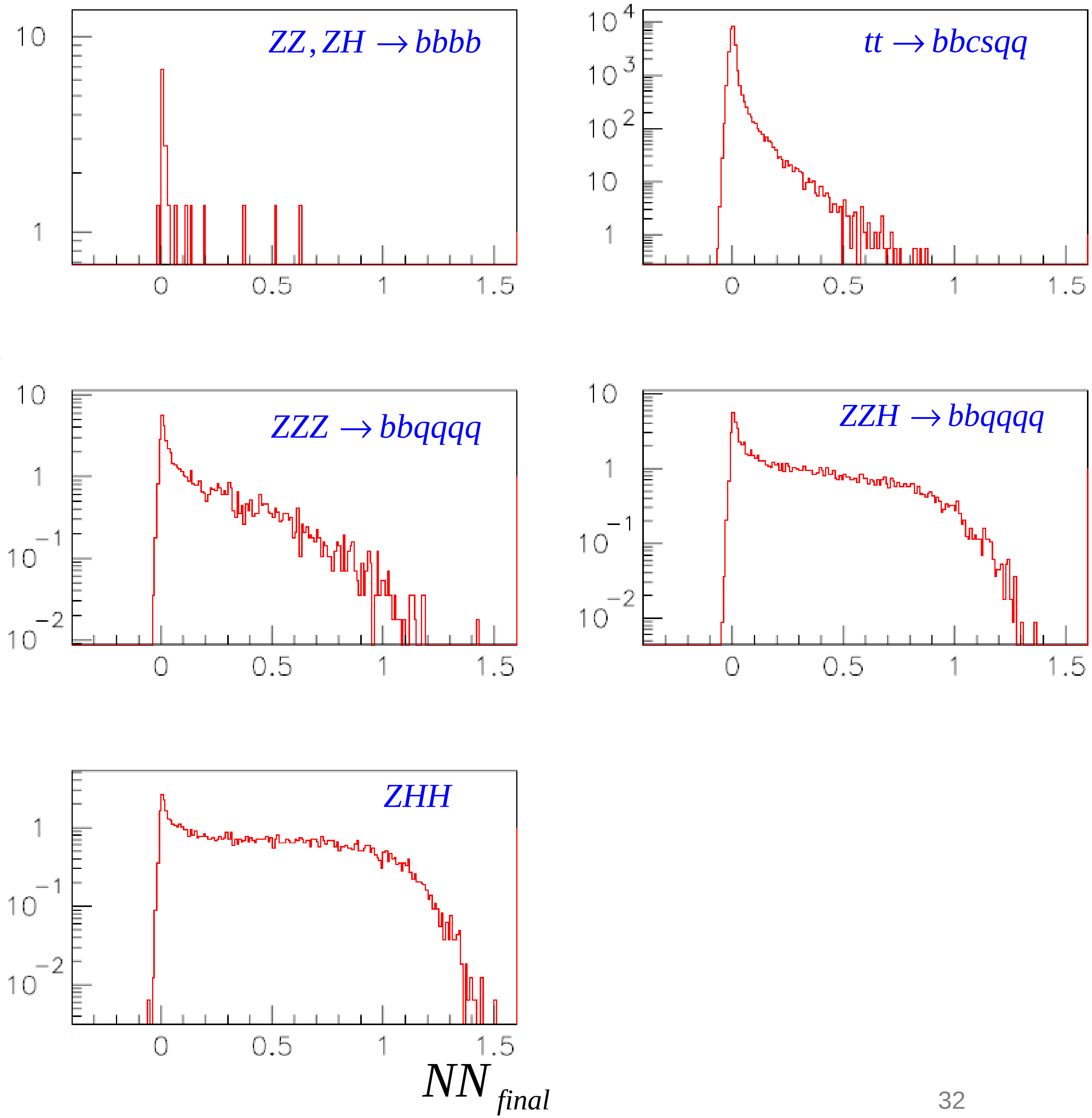
$t\bar{t}$



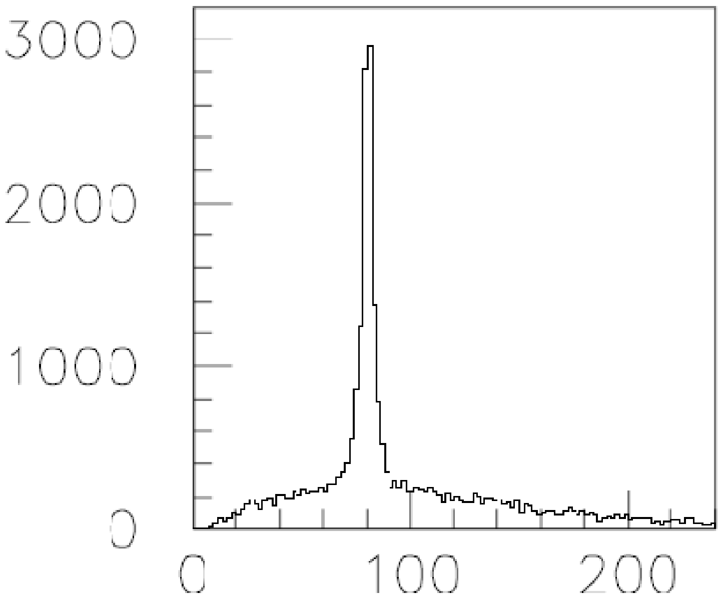
$M_{jk}\ (GeV)$

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 χ^2_{HH}, χ^2_{ZZZ} only 6 comb. for χ^2_{tt}, χ^2_{ZZH})

QCD rad turned off



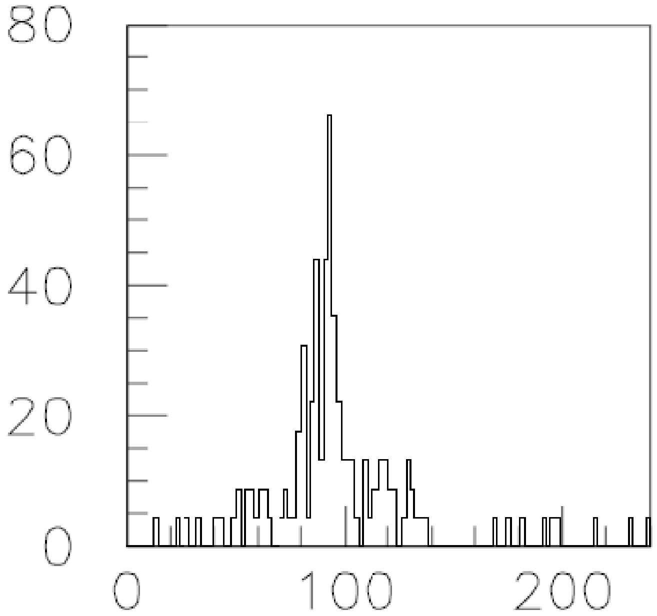
all $t\bar{t}$ with $\sum_{j=1}^{6} NN_{btag}(j) > 3.5$



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)

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

$e^+e^- \to ZHH$

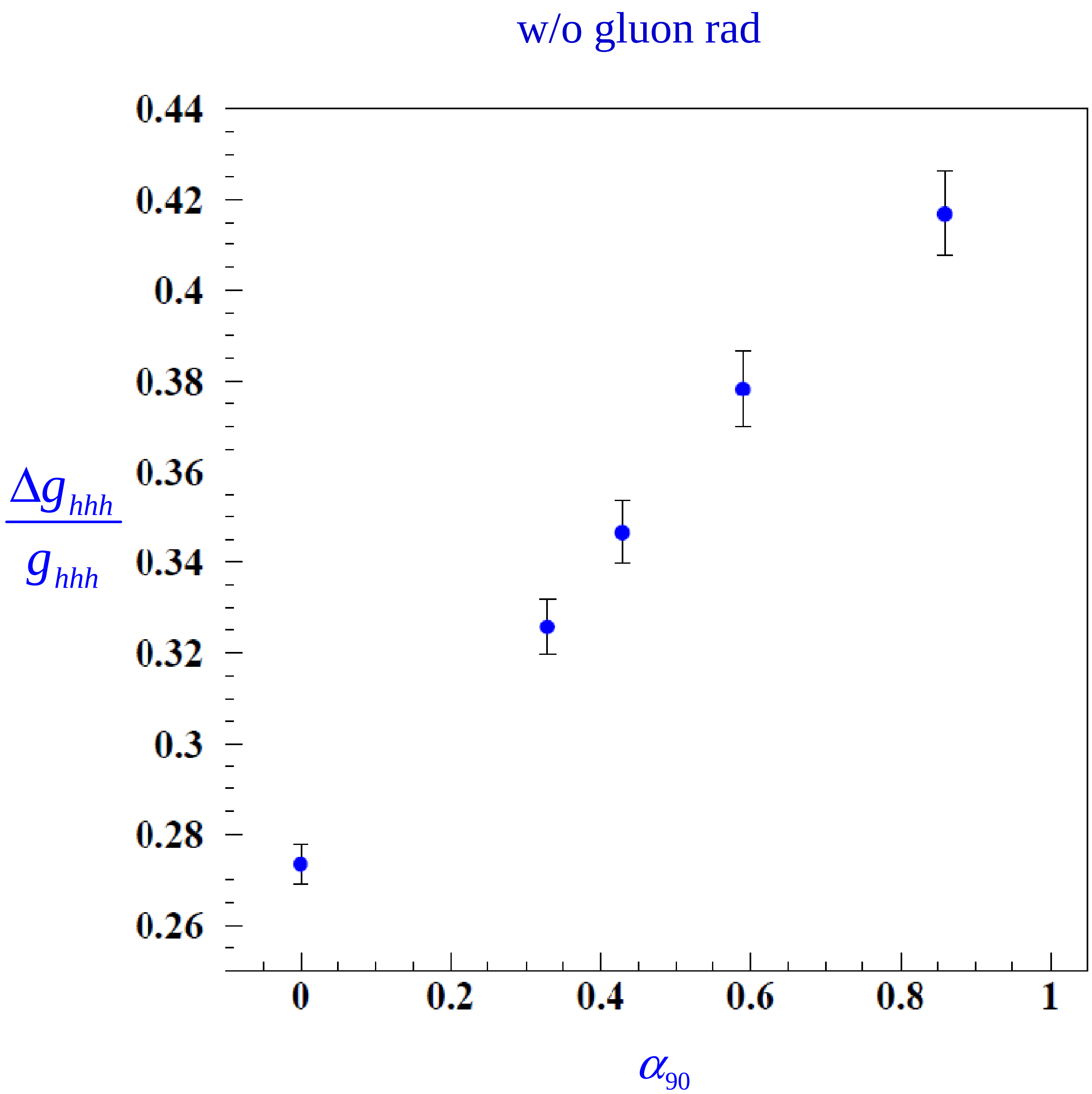
$\to qqb\bar{b}b\bar{b}$

$\sqrt{s} = 500\ GeV$

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

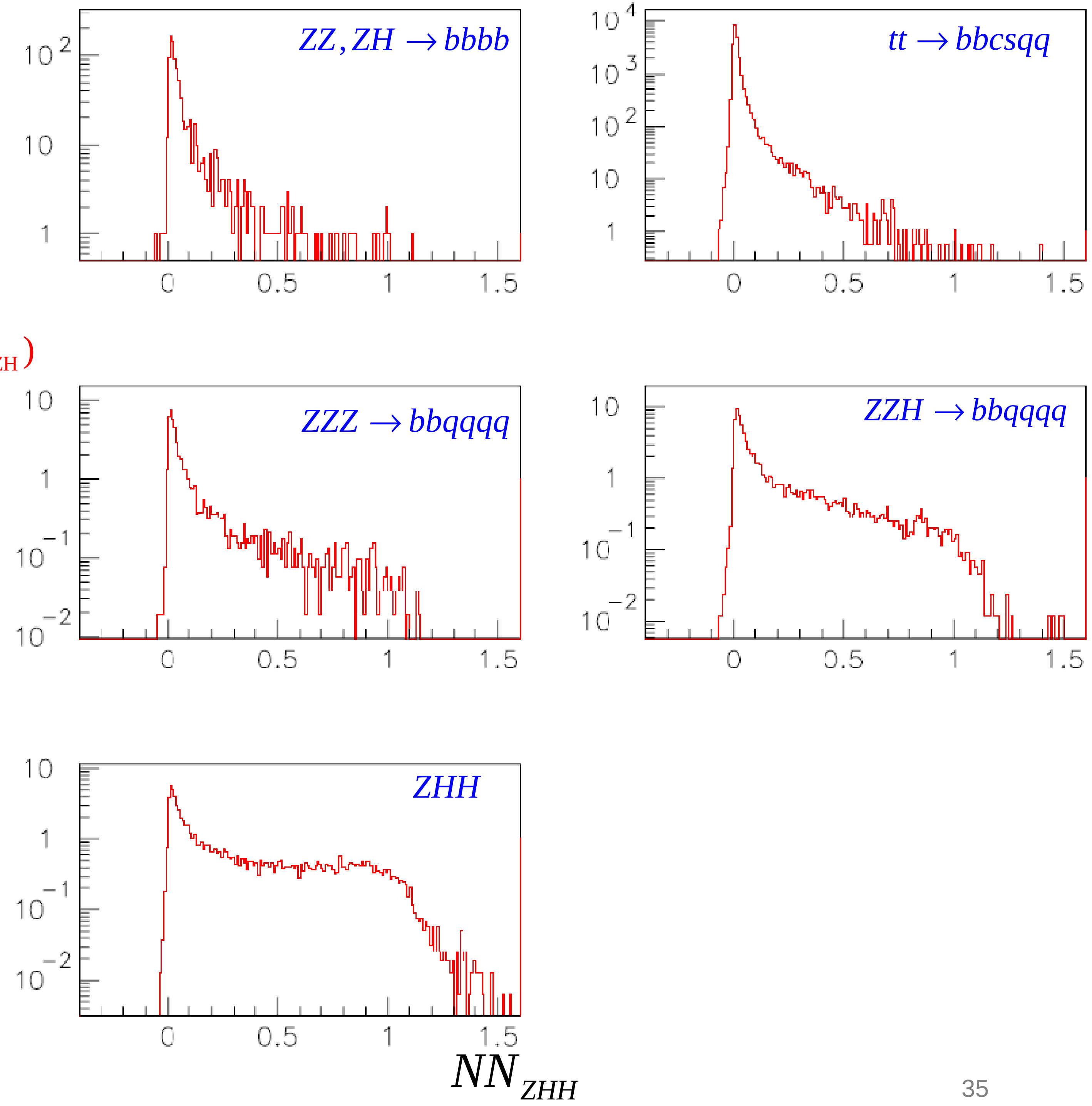
$\Delta E/\sqrt{E} = 60\% \to 30\%$

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



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

$e^+e^- \to ZHH$

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

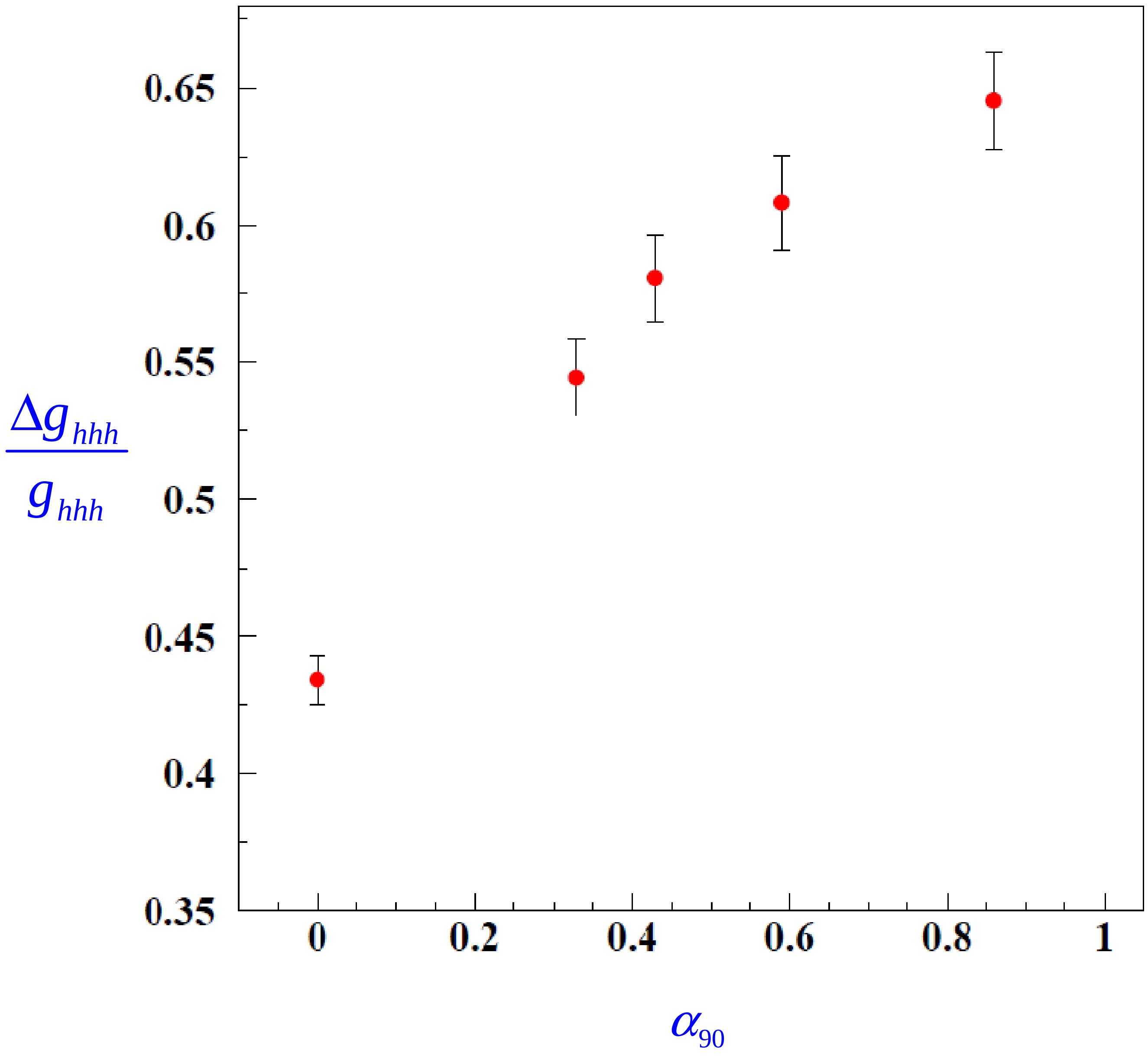
$\sqrt{s} = 500\ GeV$

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

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

equiv to $1.35\times$ Lumi

with gluon rad



Final state QCD problem may be solved with a more sophisticated jet algorithm and better b/c tagging. Note that we currently force recon particles into 6 jets, which may not be best approach in presence of hard gluon radiation. Better b/c tagging, including flavor tagging, can reduce combinatorics and provide b/c weighted jet energy corrections.

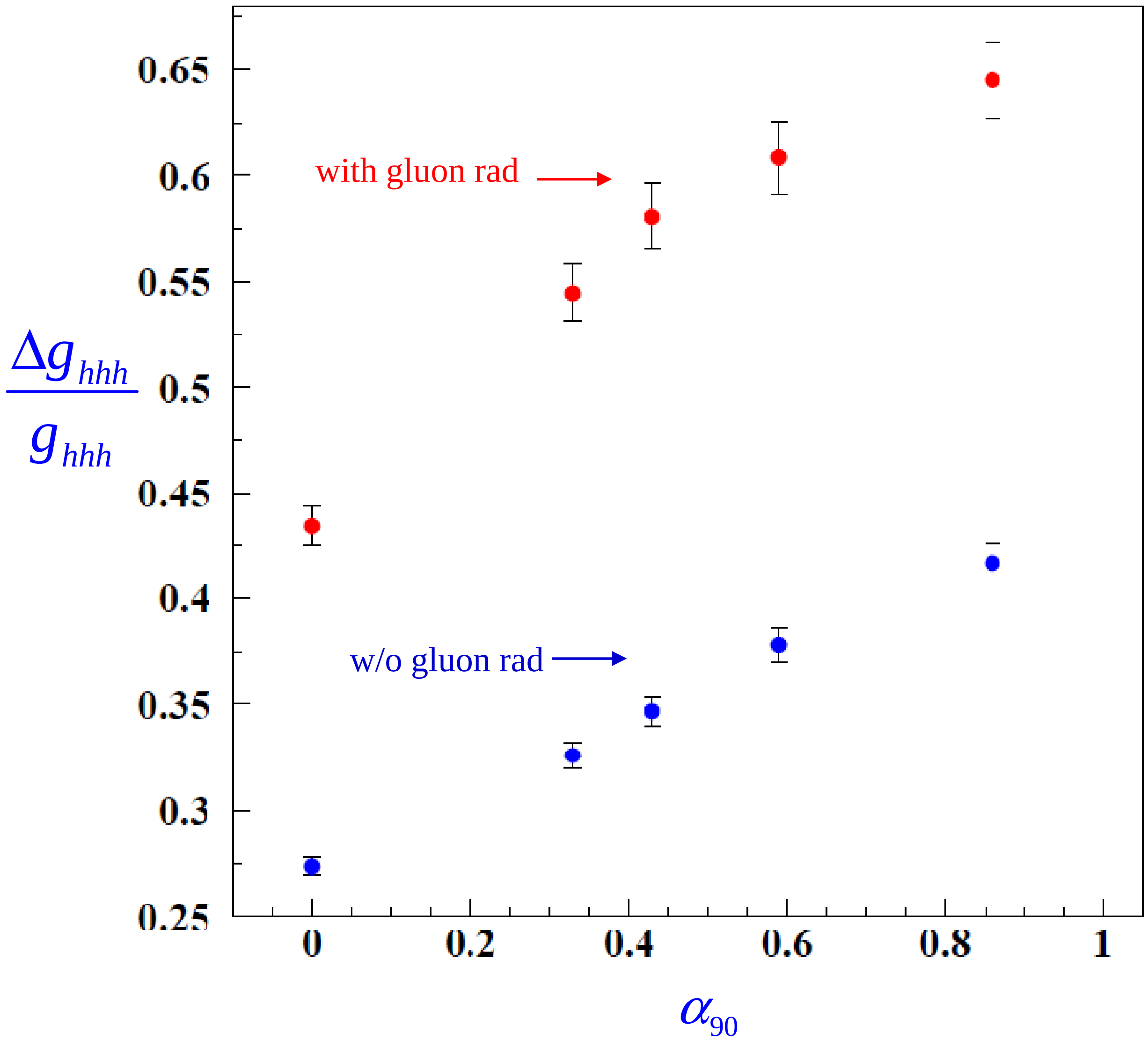
$BR(H \to b\bar{b})=0.678$

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

$$\sqrt{s} = 500\ GeV$$
$$L = 2000\ fb^{-1}$$

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

equiv to 1.4× Lumi



Benchmarking Goals

1) To go beyond $e^+e^- \to ZH \to \mu^+\mu^- X$ with full MC simulation and reconstruction we need to output PFA results in Reconstructed Particle LCIO format. Haiwen Zhao is working on this.

2) Once we have a PFA algorithm intefaced to Reconstructed Particle LCIO we will do simple analyses with full MC simulation and reconstruction that require jet reconstruction such as the Higgs mass measurement in the 4 jet channel $e^+e^- \to ZH \to qqbb$

3) Begin detector optimization studies

4) Compare full and fast MC and improve fast MC

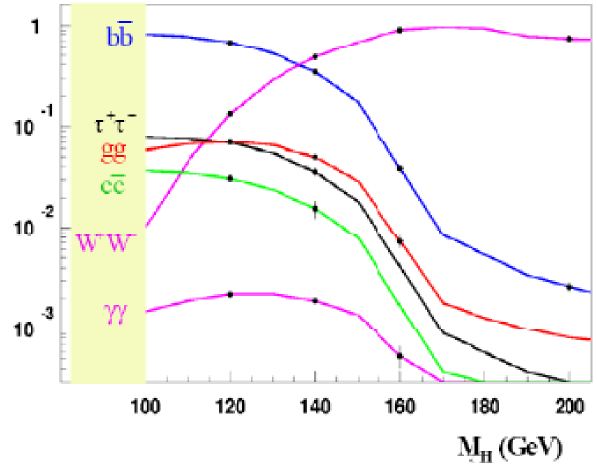
5) Continue fast MC physics studies

from Aurelio's Oct 2006 talk

Suggested Reduced Benchmark List

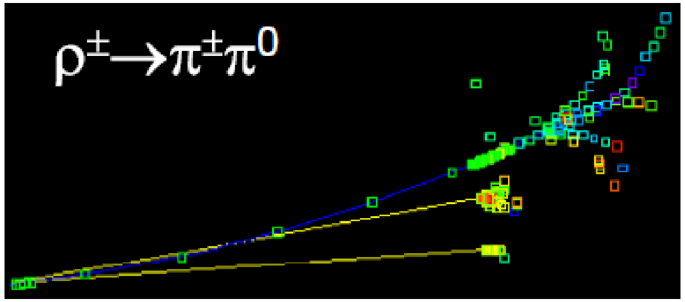
EWSB sector:

One of the highlights of the ILC physics program is the precise and model-independent measurement of Higgs properties, in particular couplings.



1) Studies involving $e^+e^- \to Zh$ at $\sqrt{s}$ = 350 GeV

- Measurement of B(h→bb,cc): targets vertexing and flavor ID capabilities. Who: orphaned
- Measurement of B(h→WW) with W/Z→jj: targets jet energy resolution to identify/separate Z and W bosons. Who: orphaned
- $h \to \tau^+\tau^-$:
  - Measurement of B($h \to \tau^+\tau^-$): targets vertexing. Who: orphaned
  - Exploit τ polarization in $h \to \tau^+\tau^-$ for determination of CP properties of Higgs boson: targets EM calorimeter granularity. Who: orphaned



from Aurelio's Oct 2006 talk

Suggested Reduced Benchmark List

EWSB sector (cont'd):

dominant

2) Studies involving $e^+e^- \to Zh, \nu\nu h$ at $\sqrt{s}$ = 1 TeV

- Measurement of $B(h \to \mu^+\mu^-)$: *done (with Fast MC)*
  targets μID and tracker momentum resolution in forward region. Who: ~~orphaned~~

- Measurement of $B(h \to \gamma\gamma)$:
  targets intrinsic EM calorimeter energy resolution and material in tracker.
  Instrumental background from multijets with jet(s) faking a photon potentially large
  $\Rightarrow$ may provide another motivation for fine EM calorimeter granularity to reject $\pi^0 \to \gamma\gamma$.
  Who: J. Yoh (Fermilab)

- Measurement of B(h→bb,cc):
  targets tracking, vertexing and flavor ID capabilities for forward jets, including the impact of material budget in the forward region. Who: orphaned

from Aurelio's Oct 2006 talk

Suggested Reduced Benchmark List

Precision measurements:

8) Measurement of the couplings of a multi-TeV Z' boson in $e^+e^- \rightarrow \tau^+\tau^-$ at $\sqrt{s}$ = 1 TeV exploiting tau polarization: targets EM calorimeter granularity. Who: orphaned

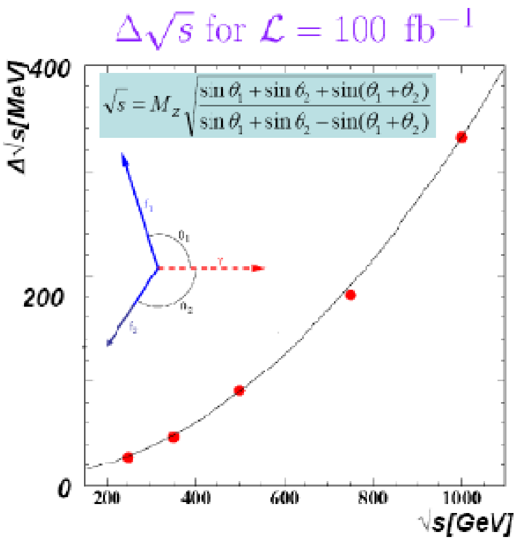
9) Measurement of forward-backward and left-right asymmetries in $e^+e^- \rightarrow$ bb,cc at $\sqrt{s}$ = 91, 350, 500 GeV and 1 TeV: targets tracking and vertexing via vertex charge performance. Who: orphaned

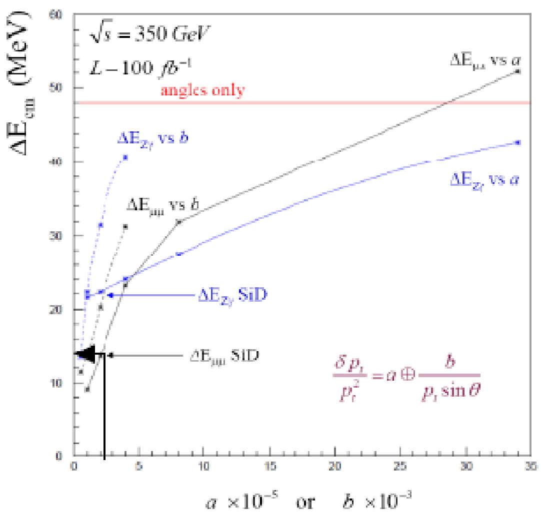
10) Determination of LEP using physics measurements:

- Luminosity spectrum via acollinearity in Bhabha: targets forward tracker. Who: orphaned
- Center-of-mass energy via $e^+e^- \rightarrow \mu^+\mu^-(\gamma)$: targets forward tracker. Who: R. Frey (U. Oregon)?

Angles only

H.J. Schreiber
K. Moning





Both angles and E_μ

- Polarization via $e^+e^- \rightarrow W^+W^-$: targets forward tracker. Who: orphaned

from Aurelio's Oct 2006 talk

Suggested Reduced Benchmark List

Additional studies:

11) Determine required particle ID performance (efficiency/purity, resolution vs. E, θ,..) for different species: e, μ, τ, $\pi^{\pm}$, π^0, K_S^0, γ.
$\Rightarrow$ in addition to having dedicated single particle studies, we would like, whenever possible, to have required ID performance assessed within each individual analysis.

12) Study how to improve b jet energy resolution, in particular for semileptonic decays.
Who: orphaned

$$e^+e^- \rightarrow qqHH, \quad \frac{\delta E_{jet}}{\sqrt{E_{jet}}} = 0.3$$

non-Gaussian Parameterization