Energy Spread and Energy Precision: Comparison of NLC and TESLA

Colloque international sur les collisionneurs linéaires
LCWS 21 Avril, 2004 Paris, France

Luminosity Spectrum

Bias in ECM Measurement

Effect of E spread on
Top, Higgs, SUSY Mass

T. Barklow and M. Woods (SLAC)

Beam Energy Scale Determination

Beam instrumentation goals

• Top mass:	200 ppm (35 MeV)
• Higgs mass:	200 ppm (25 MeV for 120 GeV Higgs)
• W mass:	50 ppm (4 MeV) ??
• 'Giga'-Z A_{LR}:	200 ppm (20 MeV) (comparable to ~0.25% polarimetry)
	50 ppm (5 MeV) (for sub-0.1% polarimetry with e+ pol) ??

$$\langle E \rangle^{\mathrm{lum-wt}} \neq \langle E \rangle$$

The beam energy spectrometers measure <E>,
but for physics we need to know $\langle E \rangle^{\text{lum-wt}}$.

The largest source of bias is beamstrahlung, but this will be removed using Bhabha acollinearity analysis.

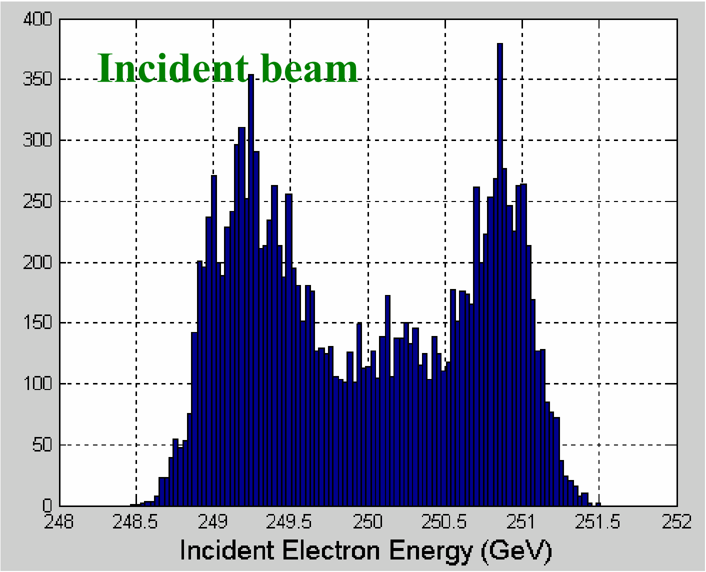
Another source is the beam energy spread before collision (This is what we shall mean by BEAM ENERGY SPREAD.)

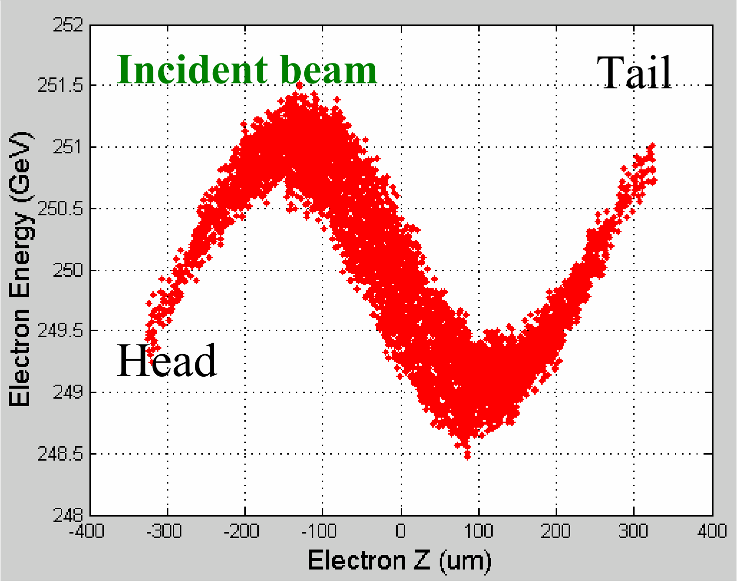
At NLC, σ(E) ~ 0.3% rms, and at TESLA it is ~ 0.1% rms.
(3000 ppm) (1000 ppm)

Guinea-Pig simulation for beam energy spread study

- ISR and Beamstrahlung turned off
- electron.ini and positron.ini files from MatLIAR simulation of beam transport from damping ring to IP
- beam1.dat and beam2.dat files for outgoing beam distributions (G-P input)
- lumi.dat file for distribution of particles that make luminosity

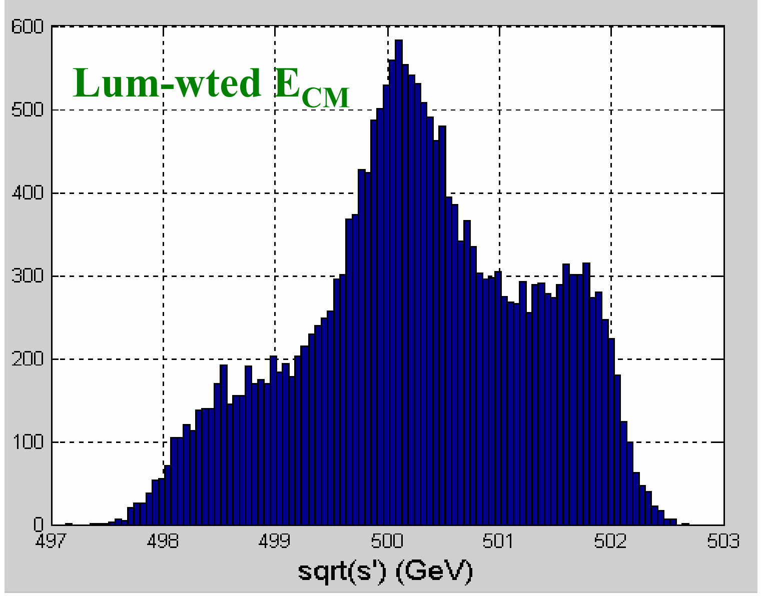
Example of Lum-wted Energy Bias related to Beam Energy Spread at NLC-500





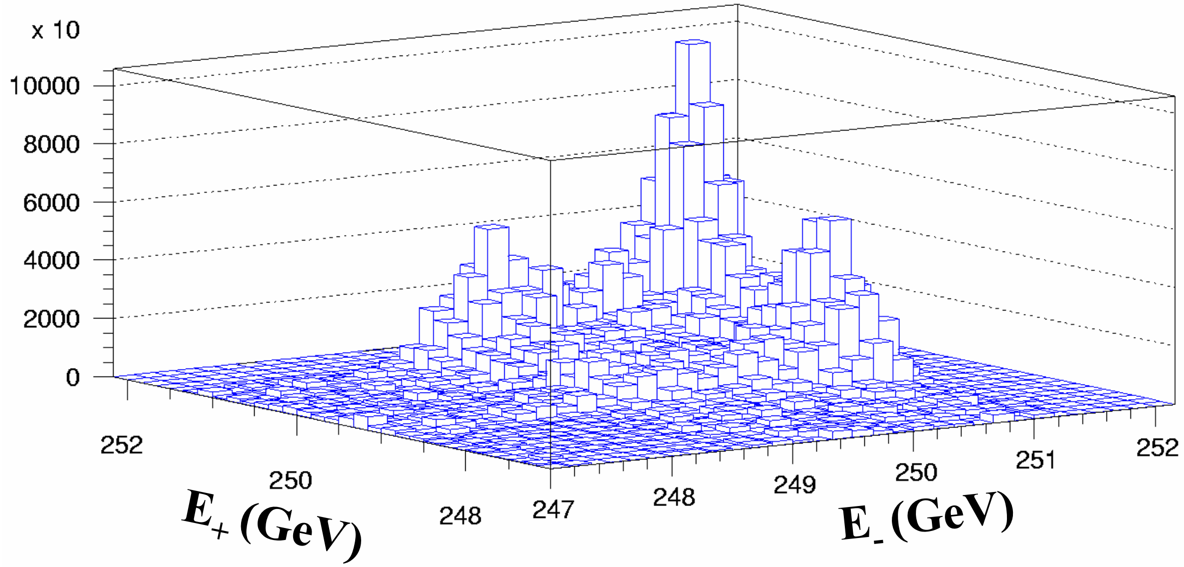
For energy bias study, turn off beamstrahlung and only consider beam energy spread.

$$\left\langle E_{CM}^{Bias} \right\rangle = \frac{\left\langle \sqrt{s'} \right\rangle - 500\,\text{GeV}}{500\,\text{GeV}} \approx 500\text{ppm}$$

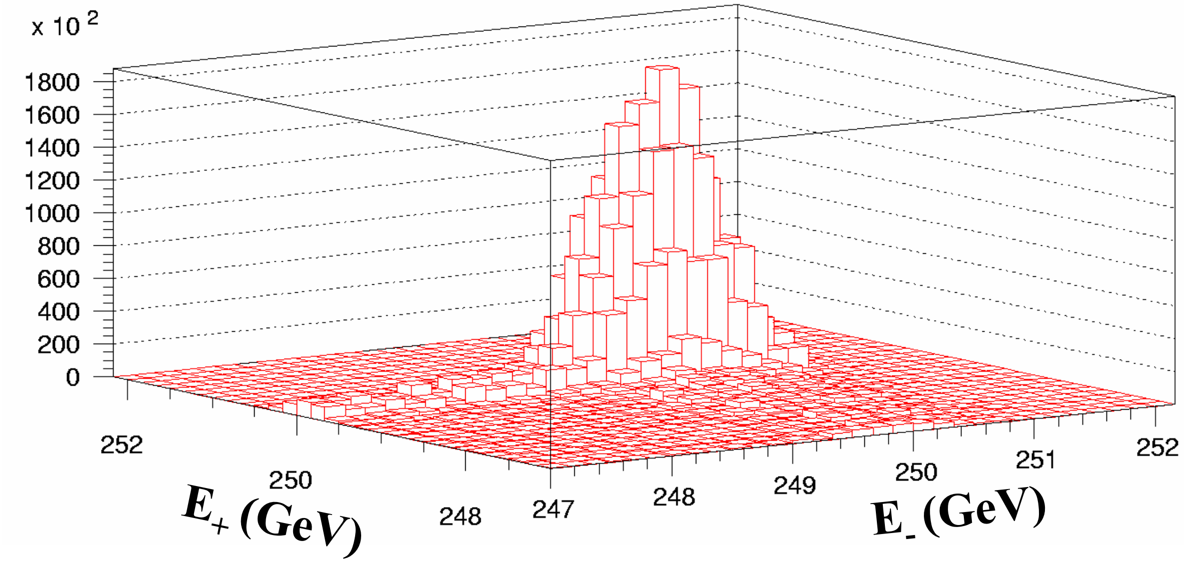


Bhabha acolinearity analysis alone won't help resolve this bias.

$\frac{d^2L}{dE_-dE_+}$ distributions



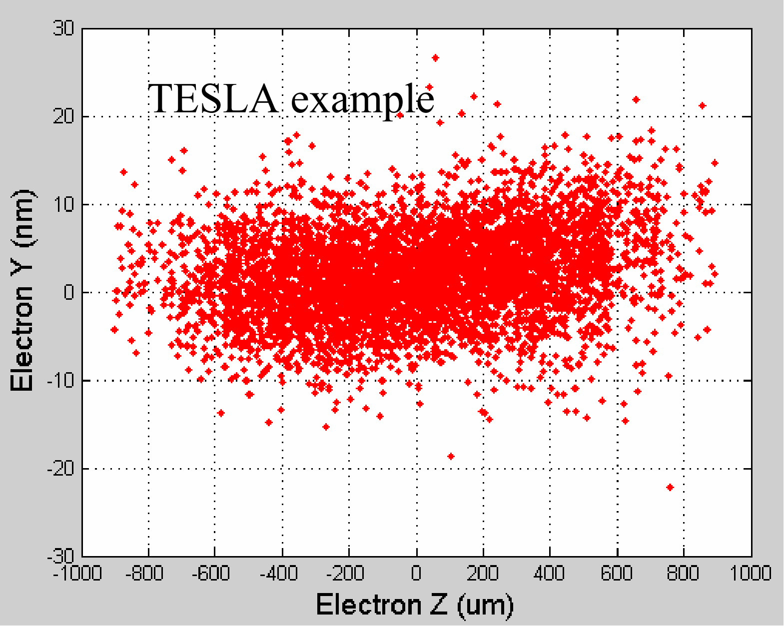
NLC

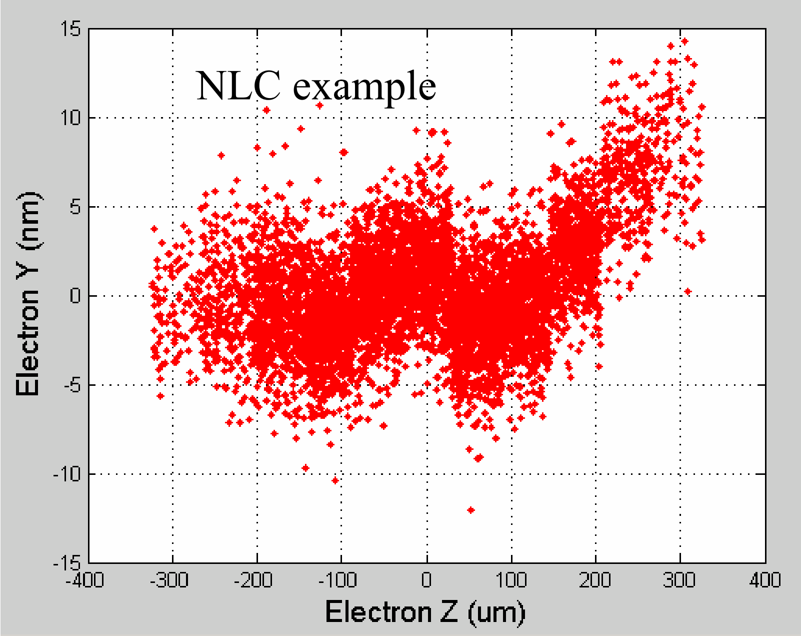


TESLA

Wakefields, Disruption and Kink instability

Linac wakefields generate “banana” beam distortions (larger for NLC than for TESLA)





Disruption parameter is ratio of bunch length to focal length: $D_y \equiv \frac{\sigma_z}{f_y} = \frac{2r_e N\sigma_z}{\gamma\sigma_x(\sigma_x+\sigma_y)}$

Disruption Parameter	**NLC-500**	**TESLA-500**
D_x	0.16	0.23
D_y	13.1	25.3

(larger for TESLA than for NLC)

Kink instability and E_{CM} Bias

(larger for NLC) (larger for TESLA) (comparable at NLC, TESLA)

Wakefields + **Disruption** → **Kink instability**

(larger for NLC) (comparable at NLC, TESLA) (larger for NLC)

E-Spread + E-z correlation + Kink instability → **E_{CM} Bias**

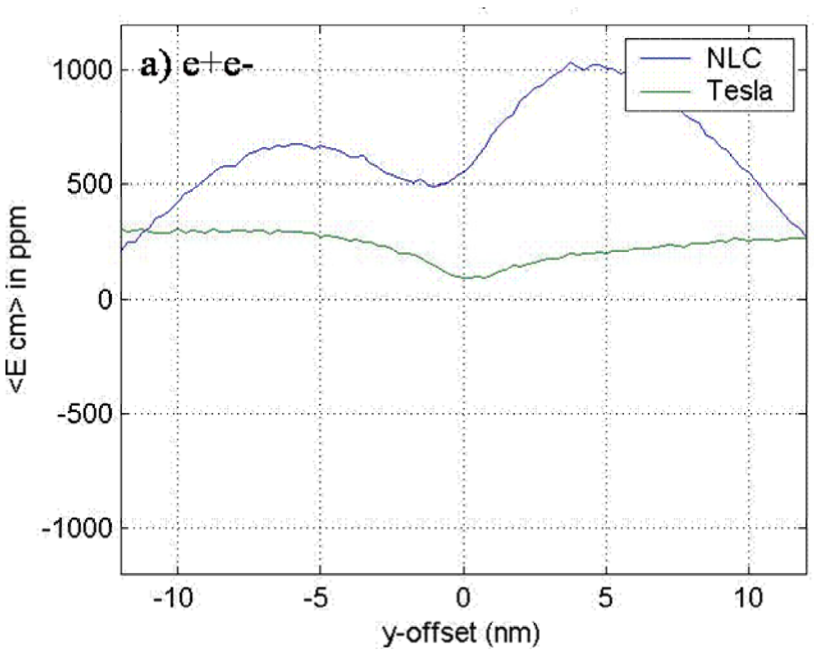
$$E_{CM}^{Bias} = \frac{\langle E_1 \rangle + \langle E_2 \rangle - \langle E_{CM}^{lum-wt} \rangle}{\langle E_1 \rangle + \langle E_2 \rangle},$$

E_1 and E_2 are beam energies measured by the energy spectrometers

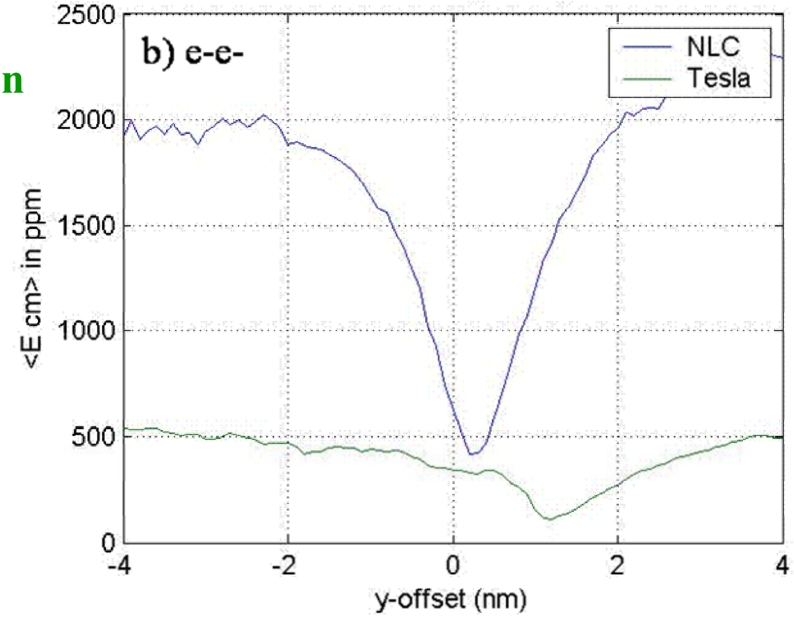
Summary of $E_{CM}{}^{bias}$

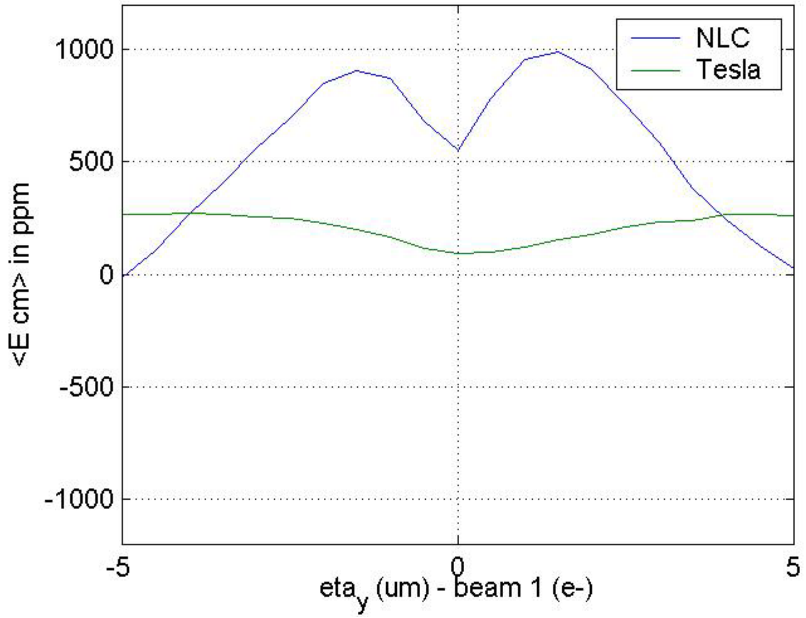
LC Machine Design	Collider Mode	$<E_{CM}{}^{bias}>$ ($\Delta y = 0$)	$\sigma(E_{CM}{}^{bias})$ ($\Delta y = 0$)	Max($E_{CM}{}^{bias}$) vary Δy, η_y
NLC-500	e^+e^-	+520 ppm	170 ppm	+1000 ppm
TESLA-500	e^+e^-	+50 ppm	30 ppm	+250 ppm

E_{CM} Bias vs Δy, η_y

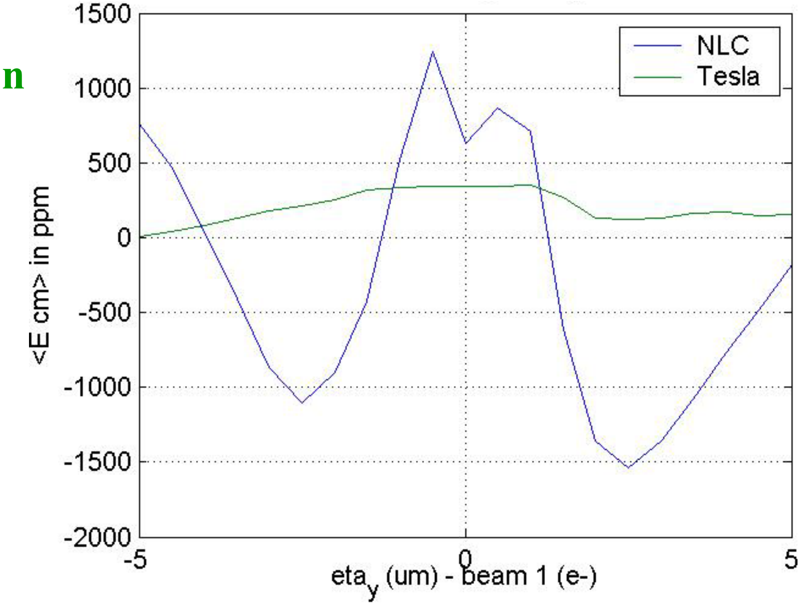


Y-offset scan





Y-dispersion scan



ILCSC LC Parameters document

Baseline Machine Parameters (in order of priority)

1. Energy reach: 500 GeV center-of-mass energy.
2. Luminosity: integrate 500 fb^{-1} in 4 years
3. Energy variability: 200-500 GeV
4. Energy *stability* and *precision*: sub-0.1%
5. >80% electron polarization
6. 2 IRs
7. 90 GeV operation for calibration at the Z

What does this mean?

ILCSC LC Parameters document

Requirement on beam energy *precision* should be taken to mean "the systematic rms uncertainty in $\left\langle E_{CM}^{lum-wt} \right\rangle$ be below the tenth of percent level"

Bhabha acolinearity analysis studies and the expected capabilities for the beam energy spectrometers indicate that this parameter requirement should be met for both the *warm* and *cold* baseline LC designs

Requirement on beam energy *stability* should be taken to mean "corrected beam energy (rms) jitter be below the tenth of percent level"

Beam energy spectrometer studies indicate that this parameter requirement should be met for both the *warm* and *cold* baseline LC designs.

Some Analyses require better than 0.1% energy precision

For these analyses, energy spread and E_{CM}^{bias} effects are significant and could limit the precision.

Improved analysis techniques for determining the luminosity-weighted E_{CM}

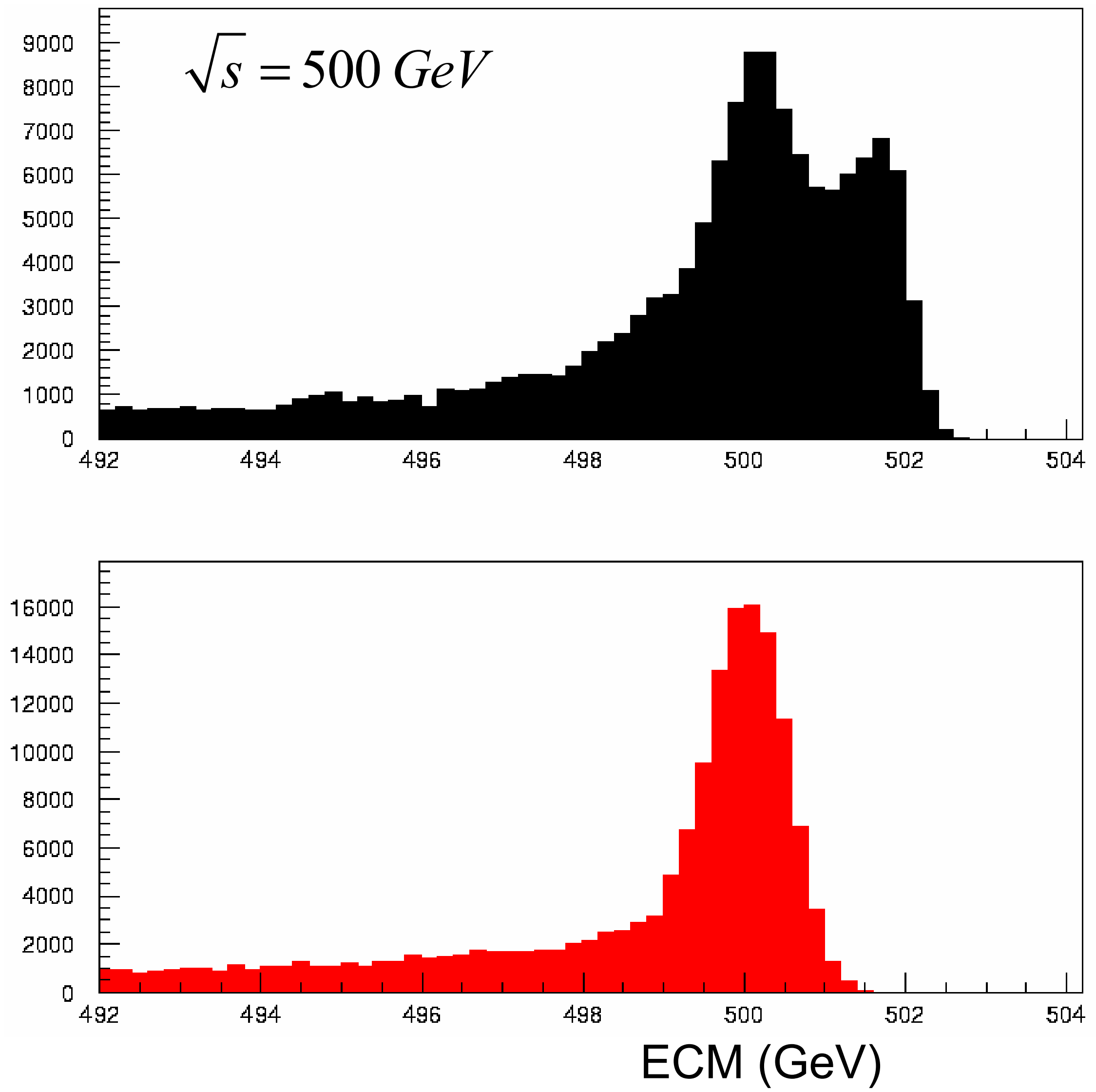
1. Continue to use energy spectrometers and Bhabha acollinearity, but correct for energy bias by modelling the beam-beam interaction.
2. Possibilities for additional input:
    - i) γZ, ZZ and WW events; use existing Z and W mass measurements
    - ii) utilize Bhabha energies in addition to Bhabha acolinearity
    - iii) μ-pair events; use momentum measurements for the muons

The improved analysis techniques should work well to achieve 200 ppm precision on $E_{CM}^{lum\text{-}wt}$ for both NLC-500 and TESLA-500.

Achieving 50 ppm precision on $E_{CM}^{lum\text{-}wt}$ will be difficult for both NLC-500 and TESLA-500. Detailed studies are required.

Study Effect of Energy Spread on Top, Higgs, and SUSY Mass Meas

Lumi Weight Ecm Distribution



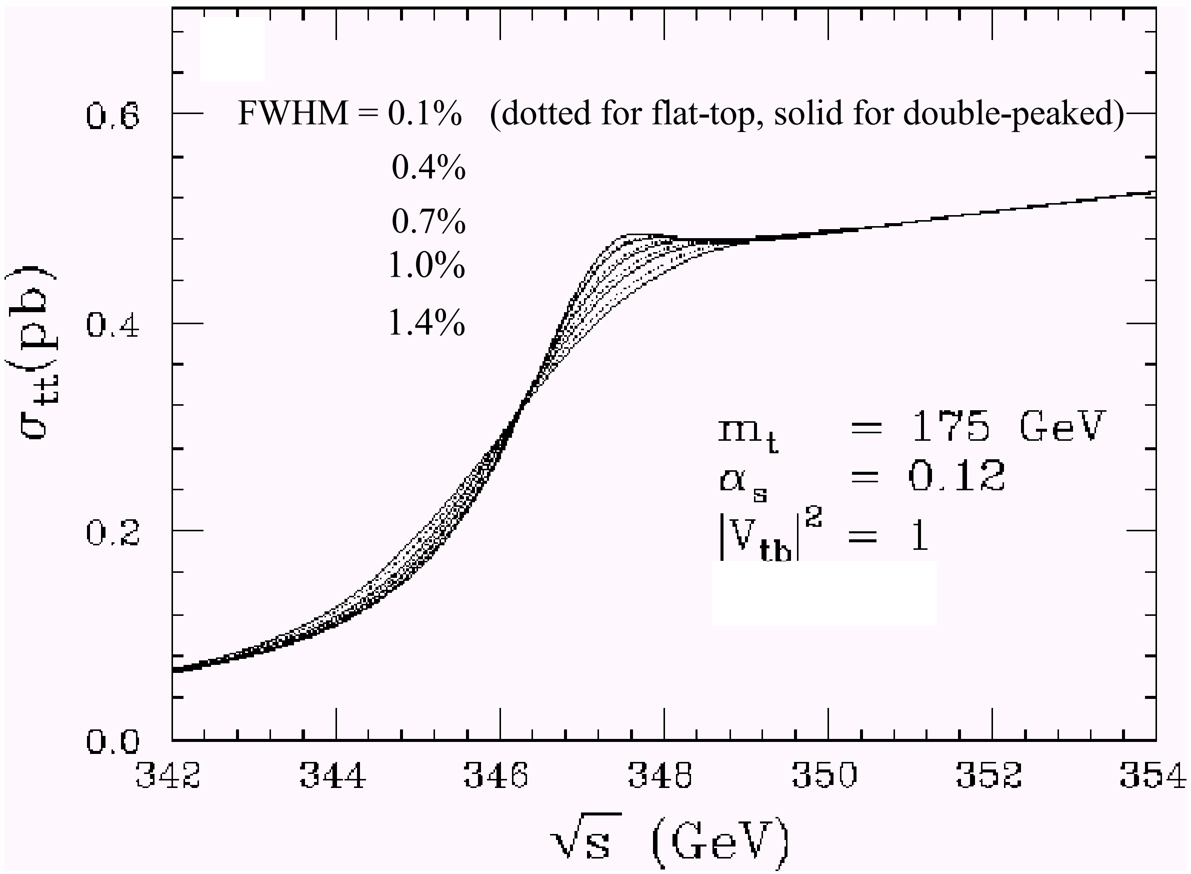
NLC

FWHM ≈ 0.6% (peak region)

TESLA

FWHM ≈ 0.2% (peak region)

Top Pair-Prod. Cross Section @ Threshold



from ACFA report
hep-ph/0109166

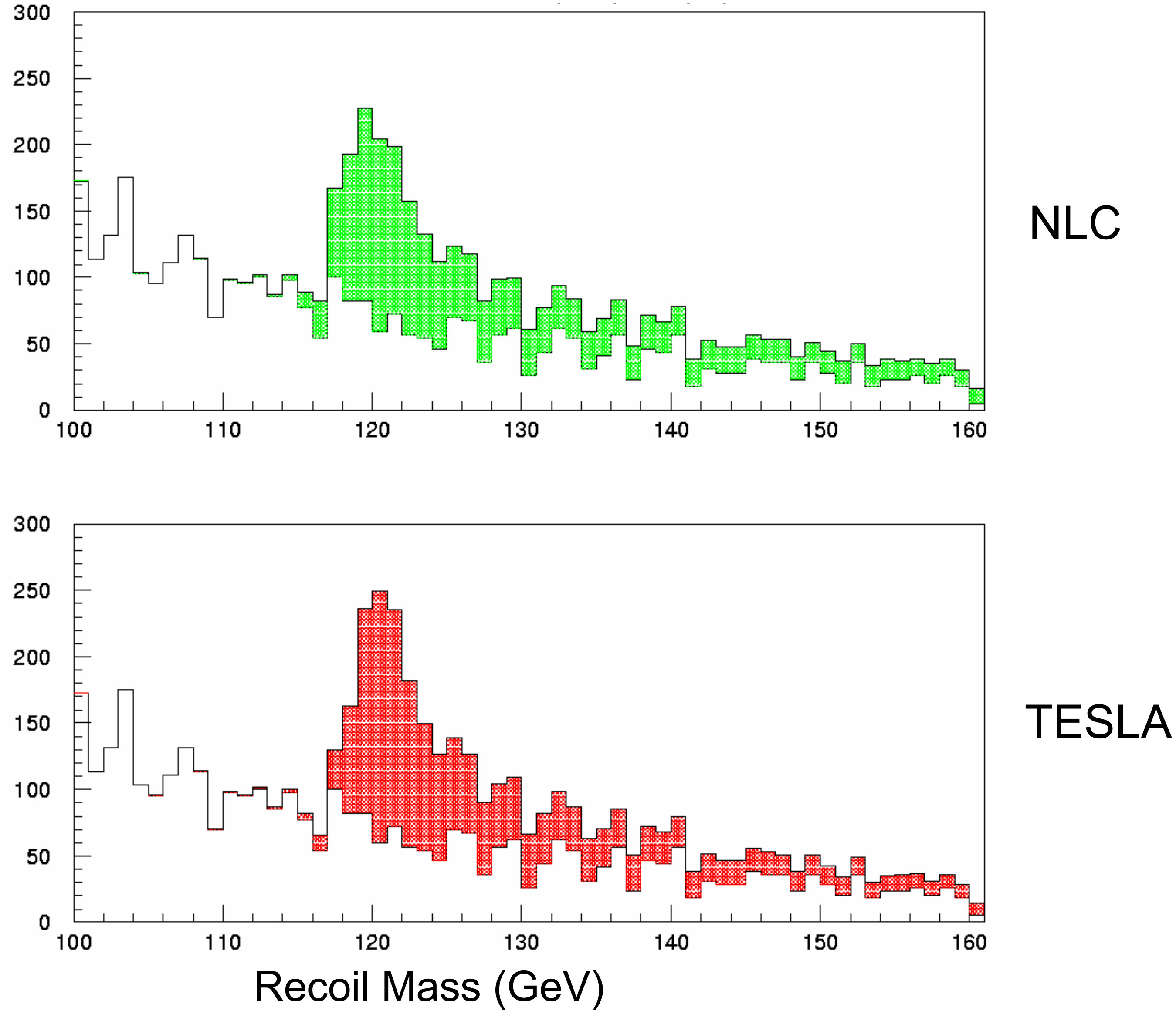
- need knowledge of E-spread FWHM to level of ~0.1%
- top mass error still under study, but statistical improvement should be small when E-spread is reduced from 0.6% FWHM to 0.2% FWHM

Simdet Detector Simulation of e+e- → Zh

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

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

with background

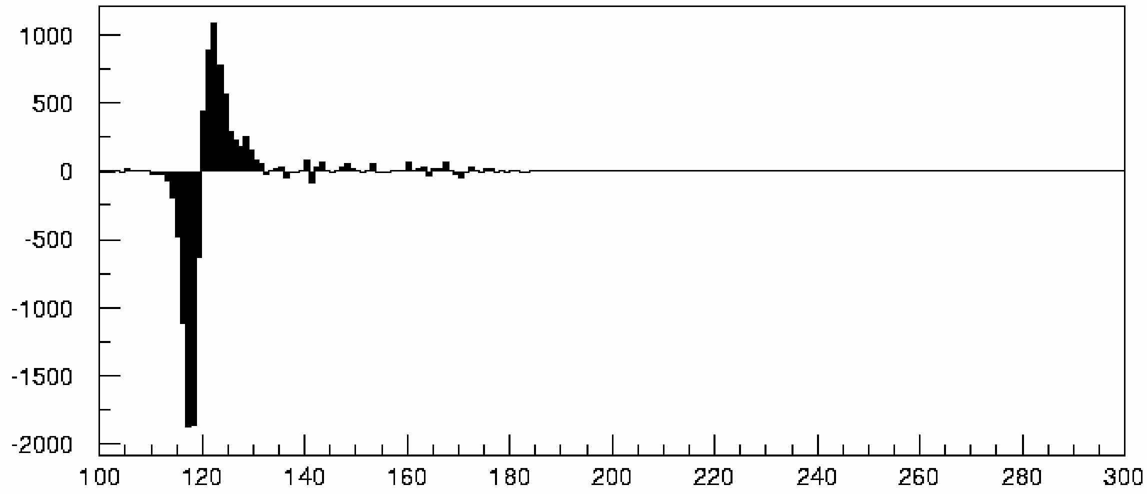


Energy Spread Comparison

Estimate Statistical Error on Higgs Mass Assuming Perfect MC Simulation

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

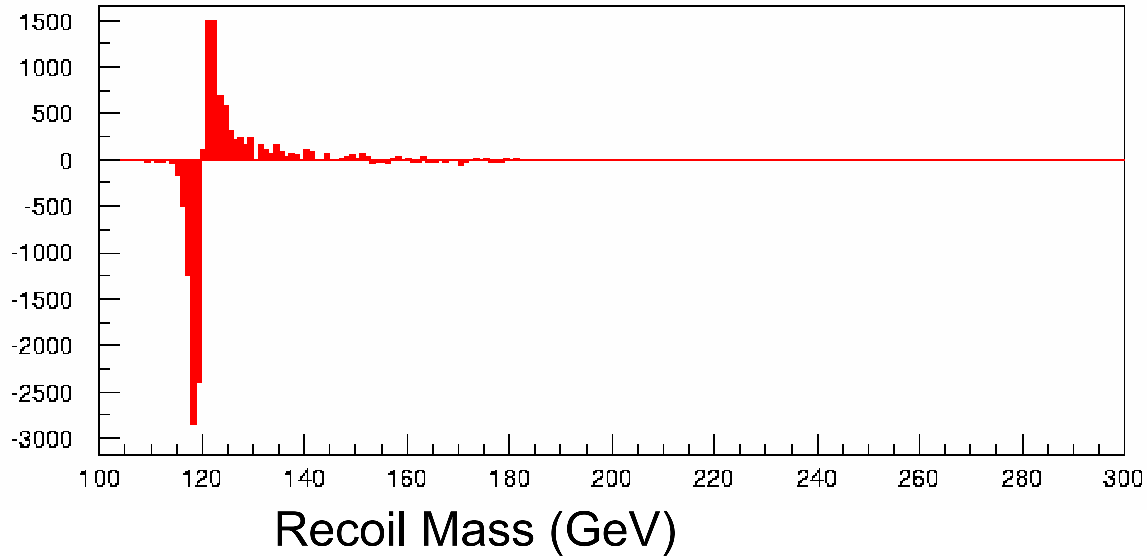
$$\left.\frac{dN_{bin}}{dM_h}\right|_{Mh=120}$$



NLC

$\Delta M_h = 143\, MeV$

$$\left.\frac{dN_{bin}}{dM_h}\right|_{Mh=120}$$

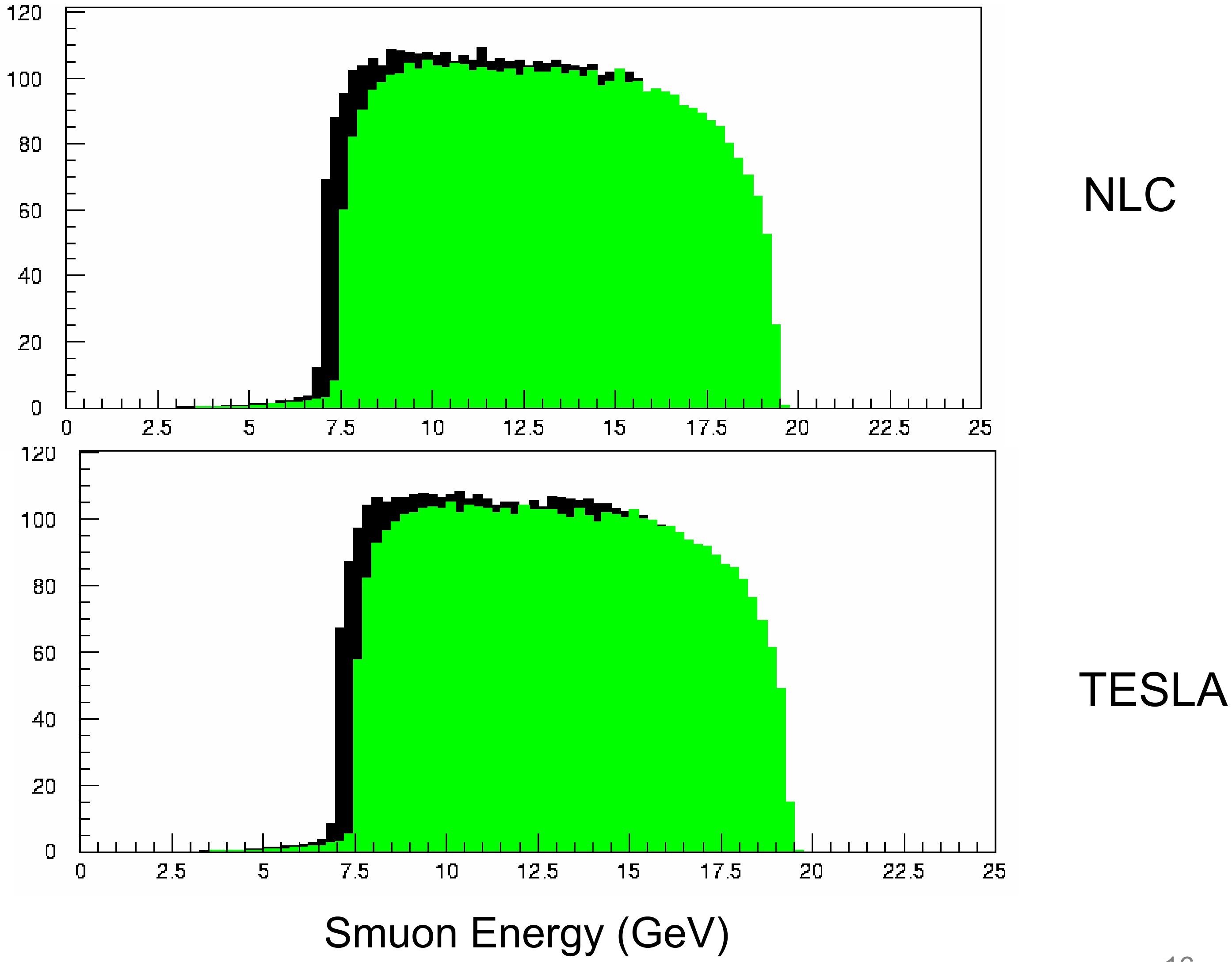


TESLA

$\Delta M_h = 117\, MeV$

Simdet Detector Simulation of $e^+e^- \rightarrow \tilde{\mu}_R^+\tilde{\mu}_R^-$ $\sqrt{s} = 500\ GeV\ L = 500\ fb^{-1}$

$M_{\tilde{\mu}_R} = 223.6\text{GeV}$ vs $M_{\tilde{\mu}_R} = 224.4\text{GeV}$

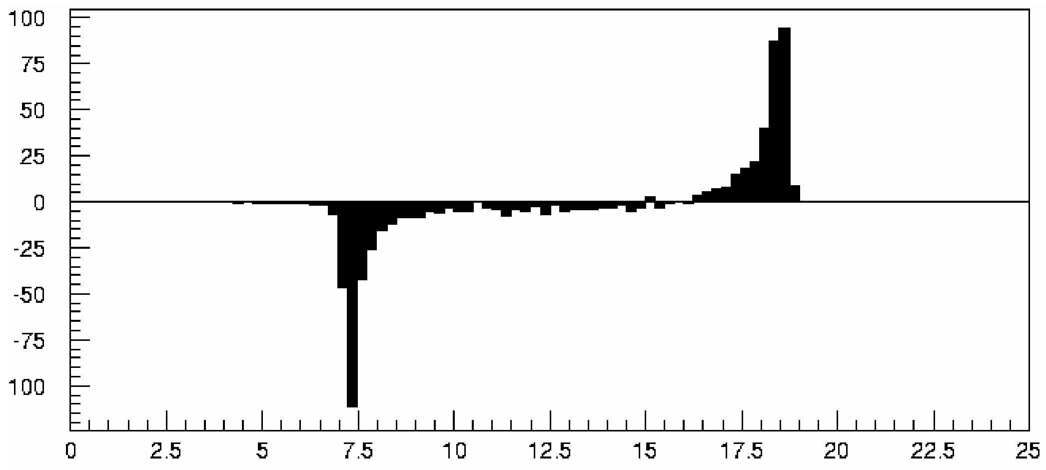


Energy Spread Comparison

Estimate Statistical Error on Smuon Mass Assuming Perfect MC Simulation

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

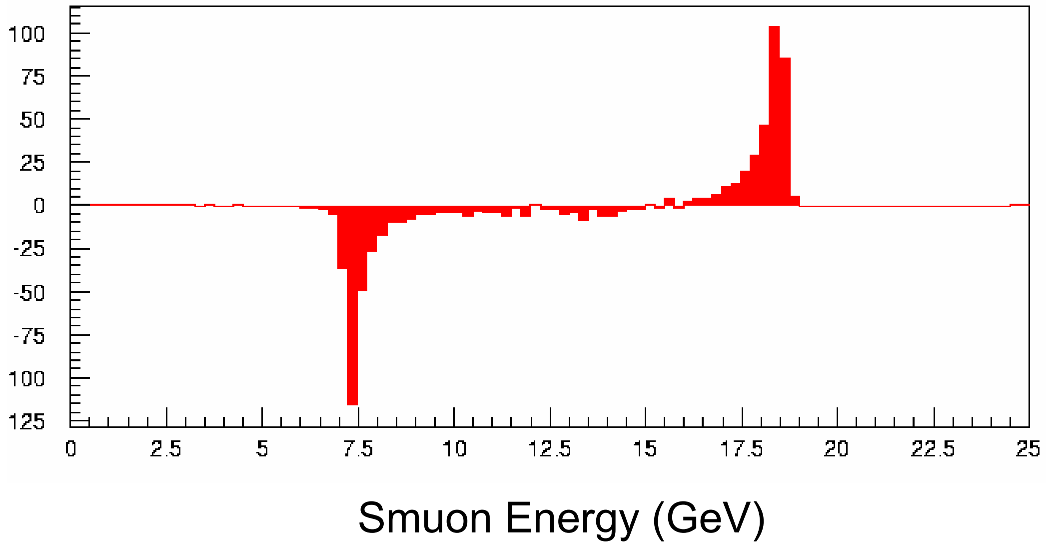
$$\left.\frac{dN_{bin}}{dE_{\tilde{\mu}}}\right|_{M\tilde{\mu}=224\ GeV}$$



NLC

$$\Delta M_{\tilde{\mu}} = 35\ MeV$$

$$\left.\frac{dN_{bin}}{dE_{\tilde{\mu}}}\right|_{M\tilde{\mu}=224\ GeV}$$

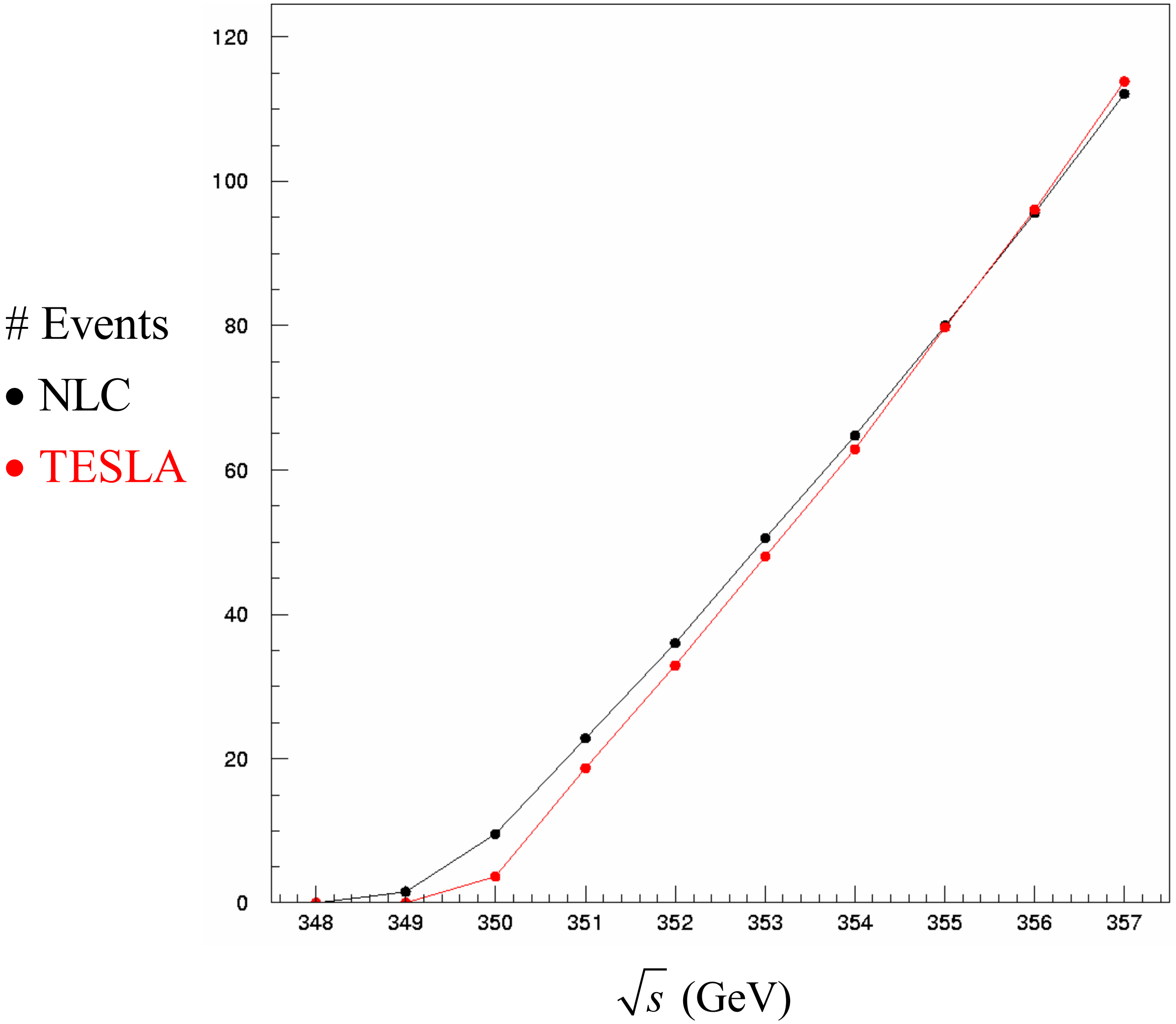


TESLA

$$\Delta M_{\tilde{\mu}} = 34\ MeV$$

$e^+e^- \rightarrow \tilde{\chi}_1^+\tilde{\chi}_1^-$ Threshold Scan   20 fb^{-1} per point

SPS1a $\tilde{\chi}_1^+$: $\text{BR}(\tilde{\chi}_1^+ \rightarrow \tilde{\tau}^+\nu_\tau) \approx 100\%$ $\Gamma_{\tilde{\chi}_1^+} = 8$ MeV



Energy Spread Comparison

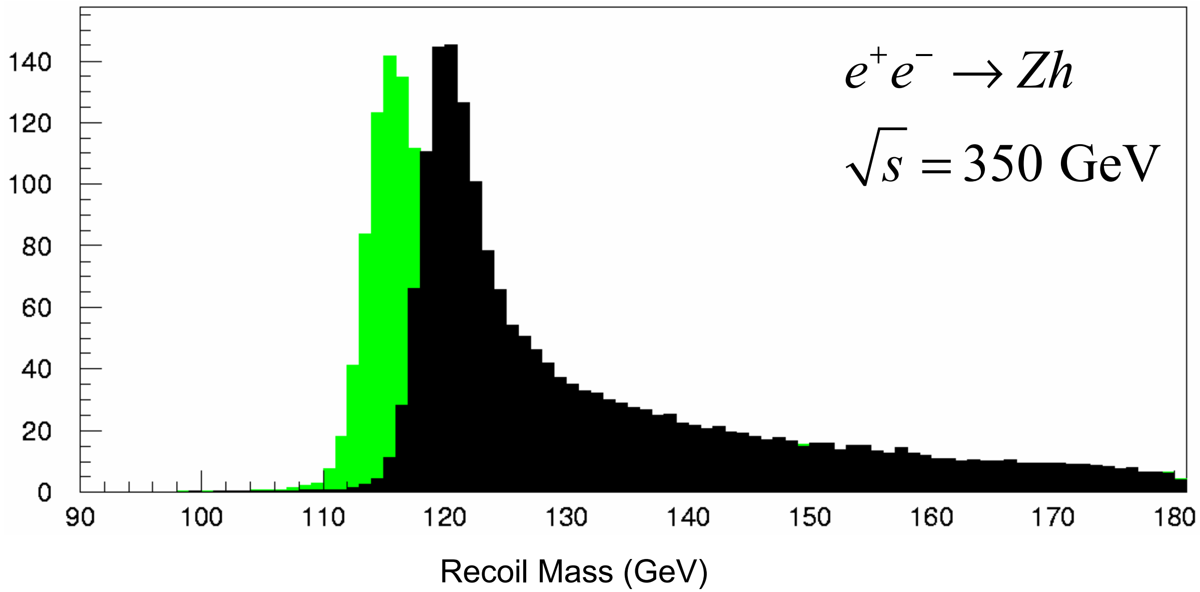
NLC $\Delta M_{\tilde{\chi}^+} = 42$ MeV

TESLA $\Delta M_{\tilde{\chi}^+} = 38$ MeV

Energy Scale Error

▬ $\frac{\Delta E_b}{E_b} = 0$

🟩 $\frac{\Delta E_b}{E_b} = 0.008$

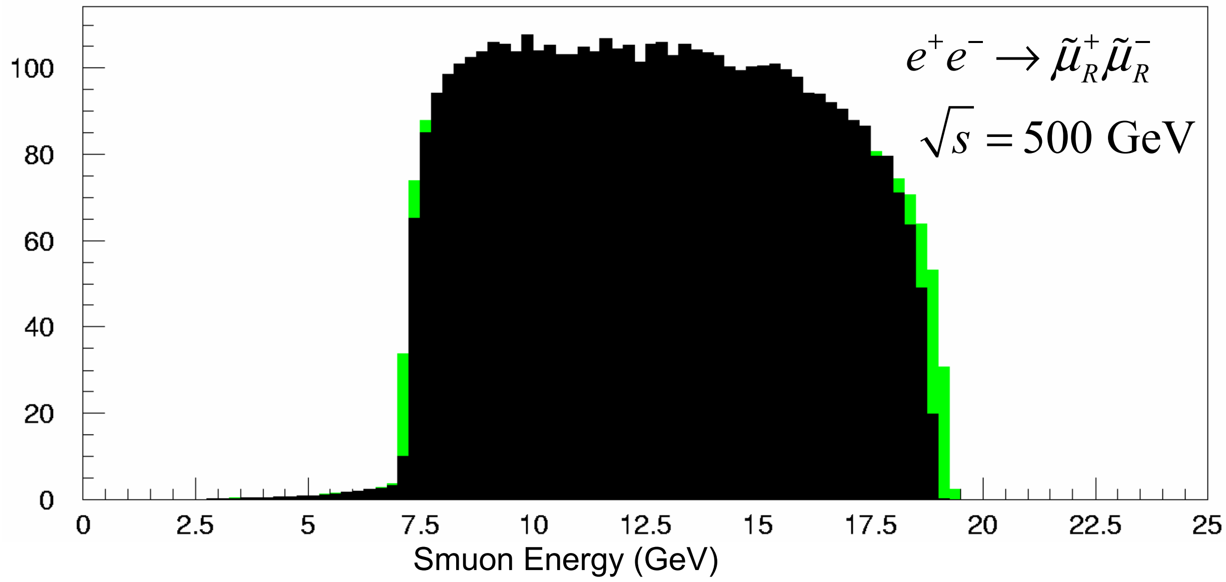


$$\Delta M_h \approx \frac{2E_b}{M_h}\Delta E_b = 2.9\,\Delta E_b \;\Rightarrow$$

$$\frac{\Delta E_b}{E_b} = \frac{M_h^2}{2E_b^2}\frac{\Delta M_h}{M_h} = 0.235\frac{\Delta M_h}{M_h}$$

$$\Rightarrow \frac{\Delta E_b}{E_b} = 100 \text{ ppm}$$

for $\Delta M_h = 50$ MeV



$$\Delta M_{\tilde{\mu}} \approx 0.05\Delta E_b \;\Rightarrow$$

$$\frac{\Delta E_b}{E_b} = 20\frac{M_{\tilde{\mu}}}{E_b}\frac{\Delta M_{\tilde{\mu}}}{M_{\tilde{\mu}}} = 9.0\frac{\Delta M_{\tilde{\mu}}}{M_{\tilde{\mu}}}$$

$$\Rightarrow \frac{\Delta E_b}{E_b} = 700 \text{ ppm}$$

for $\Delta M_{\tilde{\mu}} = 17$ MeV

Summary

E_{CM} Bias

- Beamstahlung is the largest source of bias in $E_{CM}^{lum\text{-}wt}$ determination, but will be removed using Bhabha acollinearity analysis
- *Kink instability* can reduce luminosity and causes $E_{CM}^{lum\text{-}wt}$ bias as high as 1000 ppm if accompanied by finite energy spread and beam E-Z correlation
- Improving the Bhabha acolinearity / energy spectrometer analysis to utilize additional info from γZ, ZZ and WW events should allow a robust determination of the luminosity-weighted E_{CM} with 200 ppm precision
- Achieving 50 ppm precision for $E_{CM}^{lum\text{-}wt}$ will be difficult for NLC and TESLA

ILCSC "LC Parameters" specification on energy stability, precision

- The NLC-500 and TESLA-500 machine designs both meet this specification

Impact of energy spread on mass measurements.

- The degradation in statistical error for m(SUSY) is negligible for the endpoint technique when the energy spread is increased from 0.1% to 0.3%. The degradation is of *O*(10%) for small width fermion threshold scans (42 MeV vs 38 Mev).
- There is a 20% degradation in the statistical error for m(Higgs) when the energy spread is increased from 0.1% to 0.3%, assuming the recoil mass technique (143 Mev vs 117 Mev). Other Higgs mass measurement techniques, such as a kinematic fit of *llbb* and *qqbb*, will have a smaller degradation.