Effects of beam energy spread and disruption angles on precision measurements of m_t and m_H

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

Effect I want to consider today is the beam energy spread.

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

Energy Spread Study

MatLIAR-generated files from Andrei Seryi

LIAR+DIMAD+Matlab used to generate files
Tools developed by NLC Accelerator physics group
Files were used for TRC studies

They were obtained with non-perfect machines:
LCs were initially misaligned and then brought back to ~nominal luminosity by one-to-one correction in the linac.

- generates distributions of incoming beams at IP
- 6 files each for NLC-500 and TESLA-500 machines
- Electron and positron beams are symmetric;
  ie. similar spotsizes, bunch lengths, charge

Guinea-Pig simulation

- ISR and Beamstrahlung turned off
- electron.ini and positron.ini files from MatLIAR simulation
- beam1.dat and beam2.dat files for outgoing beam distributions
- lumi.dat file for distribution of particles that make luminosity

Summary of Results for energy spread effect

Note: energies are given in units of ppm, ie. the deviation from the nominal energy, for example:

$$\langle E_1 \rangle (ppm) = \frac{\langle E_1 \rangle - 250}{250}$$

E_1, E_2 and E_{cm} all come from The Guinea-Pig file lumi.dat

~500ppm effect for NLC
~ 50ppm effect for TESLA

NLC file	L ($cm^{-2}s^{-1}$)	$<E_1>$ (ppm)	$<E_2>$ (ppm)	$<E_{cm}>$ (ppm)
1	2.0×10^{34}	+641	+454	+547
2	2.0×10^{34}	+543	+187	+365
3	1.8×10^{34}	+398	+626	+512
4	2.0×10^{34}	+301	+187	+244
5	1.7×10^{34}	+995	+298	+647
6	1.7×10^{34}	+537	+878	+707

TESLA file	L ($cm^{-2}s^{-1}$)	$<E_1>$ (ppm)	$<E_2>$ (ppm)	$<E_{cm}>$ (ppm)
1	3.3×10^{34}	+90	+100	+95
2	3.2×10^{34}	+38	+103	+71
3	3.3×10^{34}	-33	+49	+8
4	3.6×10^{34}	+12	+58	+35
5	3.2×10^{34}	+51	+92	+72
6	3.3×10^{34}	+3	+70	+36

See files ESPREAD_NLC.pdf and ESPREAD_TESLA.pdf for distributions of beam parameters and correlations for

- incoming beams
- outgoing beams, and
- luminosity particles

Dominant cause for $\langle E \rangle^{\text{lum-wt}} \neq \langle E \rangle$, appears to be due to a combined effect of

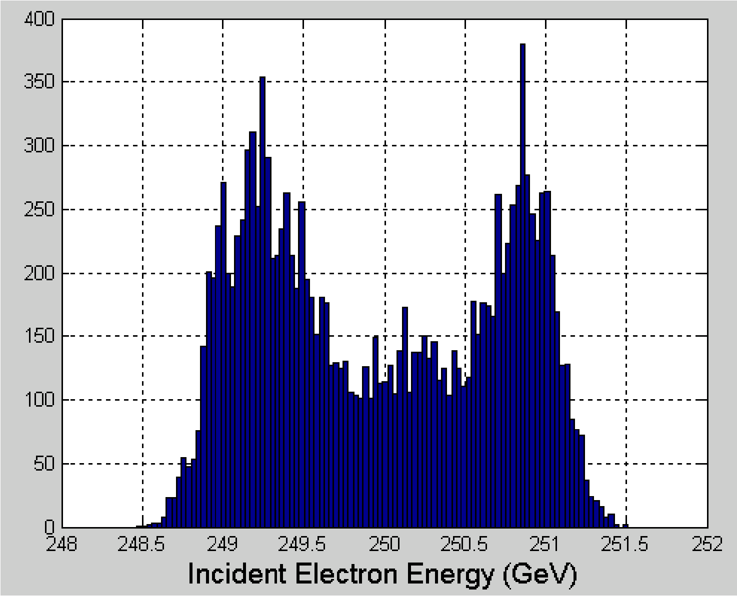
- Energy-z correlation of the incoming bunches
- pinch and disruption of the colliding beams in y

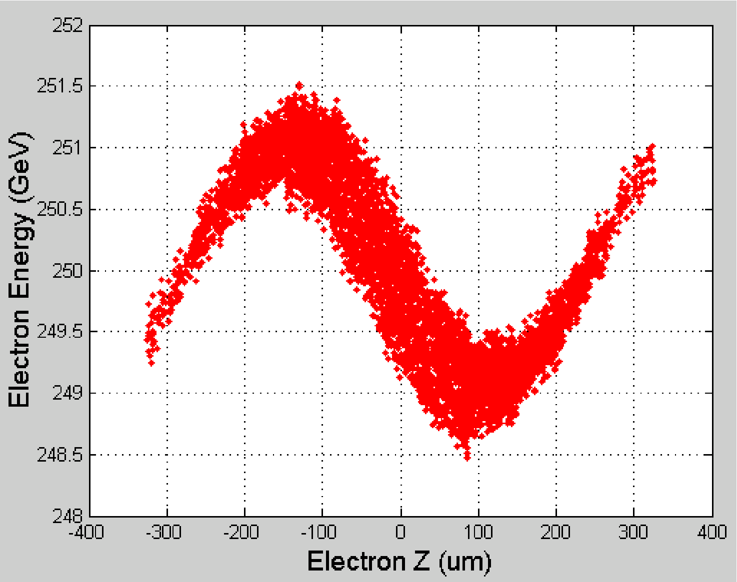
Can consider collision of opposing bunches to be approximated by:

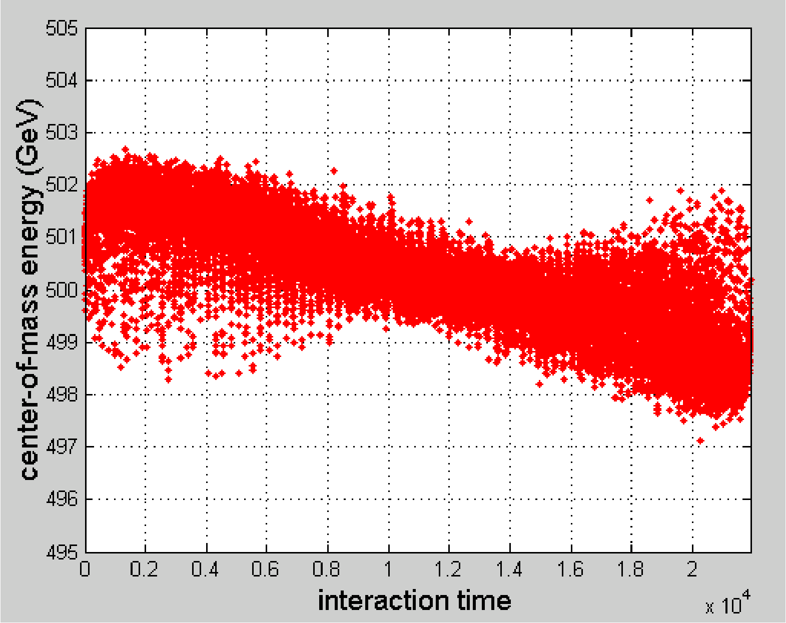
- head-head collisions (nominal luminosity; high E_{CM})
- head-tail collisions (~nominal luminosity due to pinch, disruption; nominal E_{CM})
- tail-tail collisions (lower luminosity due to disruption; low E_{CM})

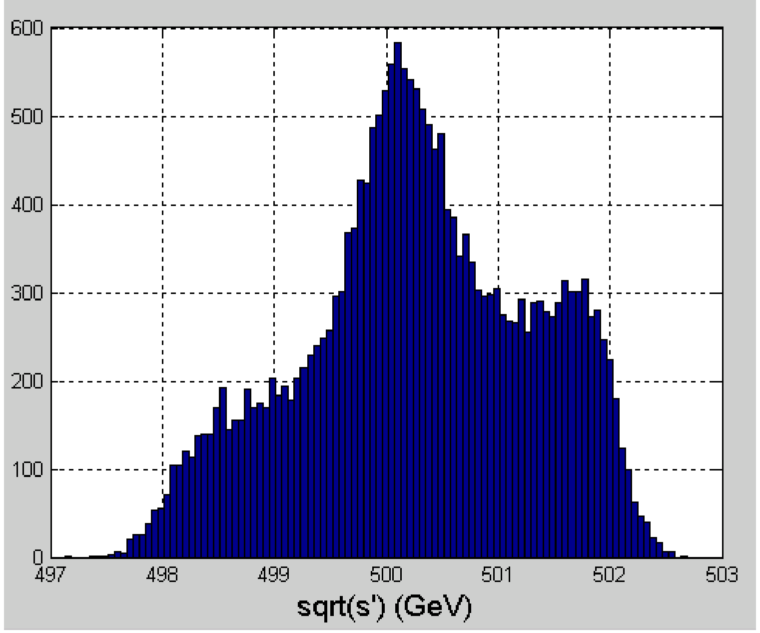
$$\left(50\,\mu rad \cdot 100 um = 5 nm\right)$$

NLC-500 Results

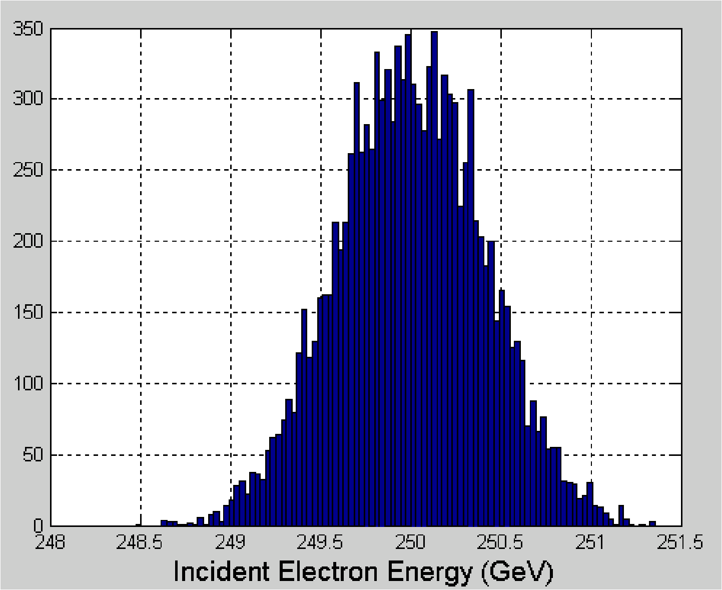


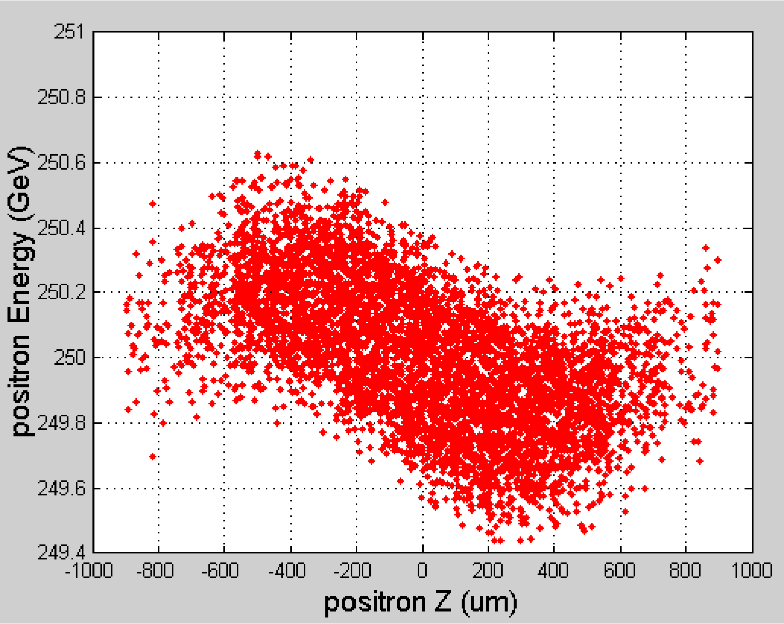


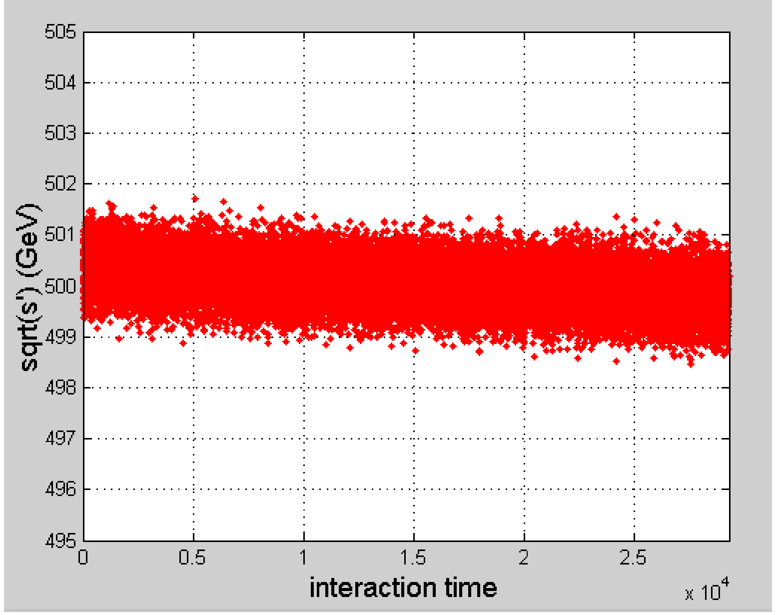


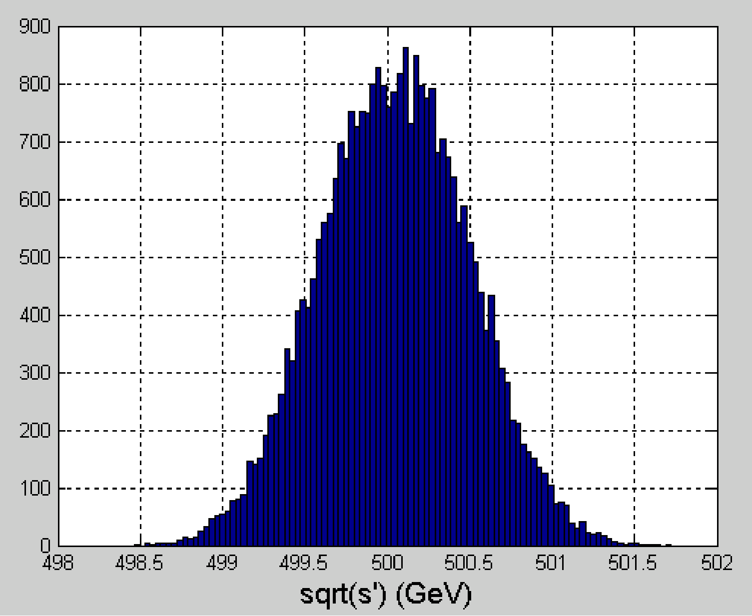


TESLA-500 Results









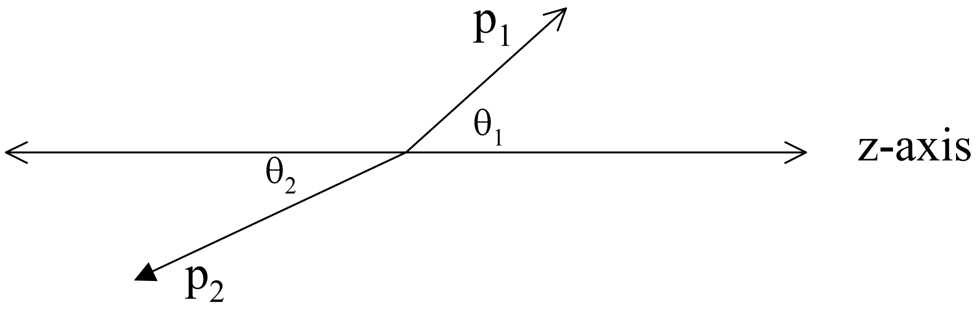
Energy spread study is ongoing

- how to constrain effect? (what measurements needed?)
- how to reduce effect? (Linac rf quads?)

Need to further study effects of:

- beam offsets
- residual dispersion
- waist offsets
- asymmetric beam distributions for electrons, positrons:
  ex. transverse spotsizes, bunch lengths
- add in beamstrahlung

Bhabha Acolinearity to measure Energy Spread and Beamstrahlung



Use conservation of transverse momentum, and assume that only 1 beam radiates:

$$p_1 \sin\theta_1 = p_2 \sin\theta_2$$

$$\text{Let } r = \frac{\min(p_1, p_2)}{\max(p_1, p_2)} = \frac{\min(\sin\theta_1, \sin\theta_2)}{\max(\sin\theta_1, \sin\theta_2)}$$

$$\text{Assume } \max(p_1, p_2) = p_{beam}$$

$$\sqrt{s'_{angles}} = p_{beam}(1 + r)$$

→ Use energy spectrometers to measure $\boldsymbol{p_{beam}}$, and forward detectors to measure θ_1 and θ_2.

Sources of Bhabha Acolinearity

Incoming Beam

- $\langle E_1 \rangle \neq \langle E_2 \rangle$
- energy spread
- beam divergence

Collision Process

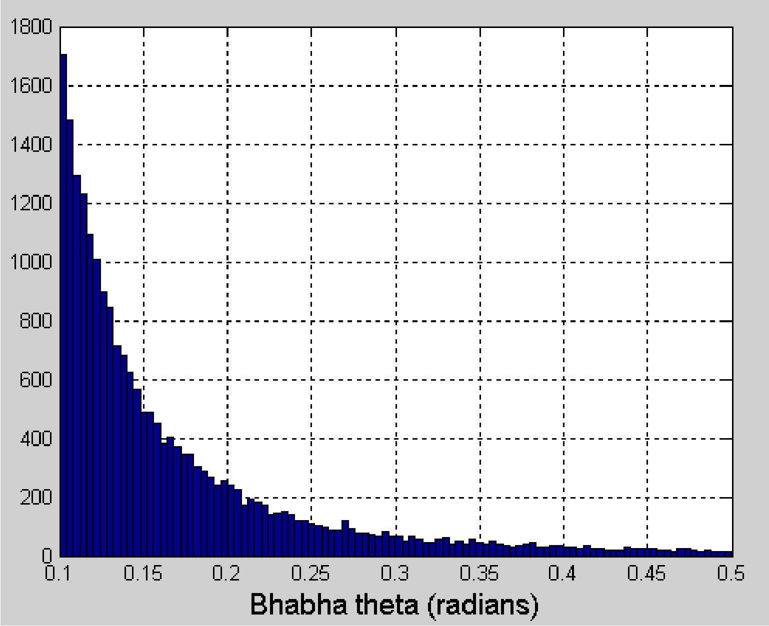
- ISR
- beamstrahlung
- disruption angles

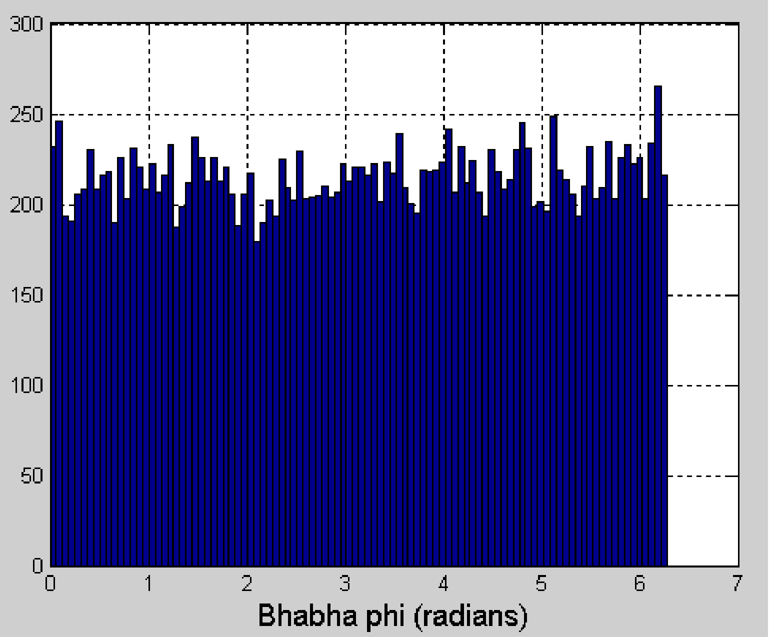
Detector Effects

- angular resolution
- alignment errors
- backgrounds

Bhabha Simulation and Acolinearity Study

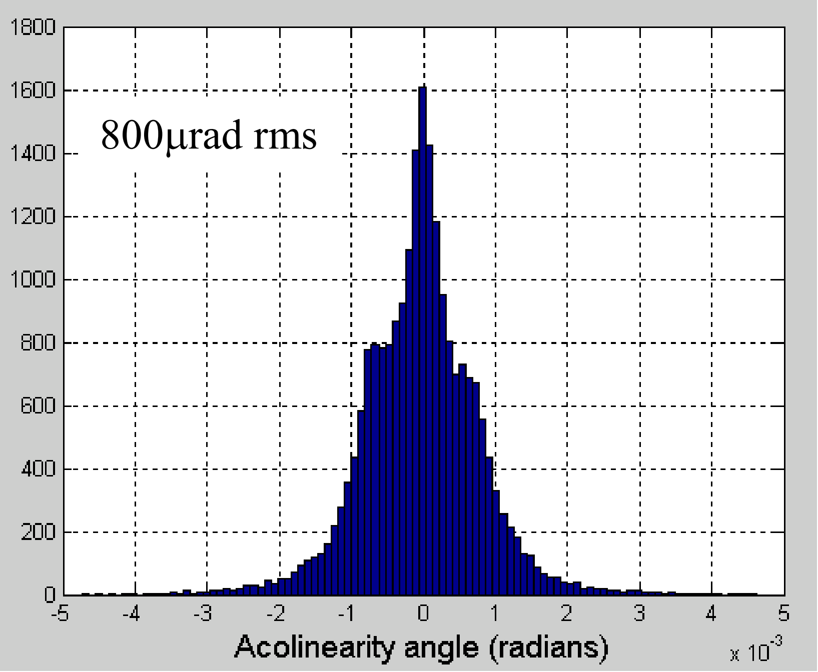
- Generate Bhabhas with θ_1 in range 100-500 mrad and $1/\theta^3$ distribution
- Use GuineaPig to generate collision electron, positron energies (p_1,p_2)
- Balance transverse momenta to generate θ_2,Φ_2 angles
- (put in effects of disruption angles)
- (put in effects of detector resolution)
- Reconstruct $\sqrt{s'_{angles}}$ assuming only 1 particle radiates

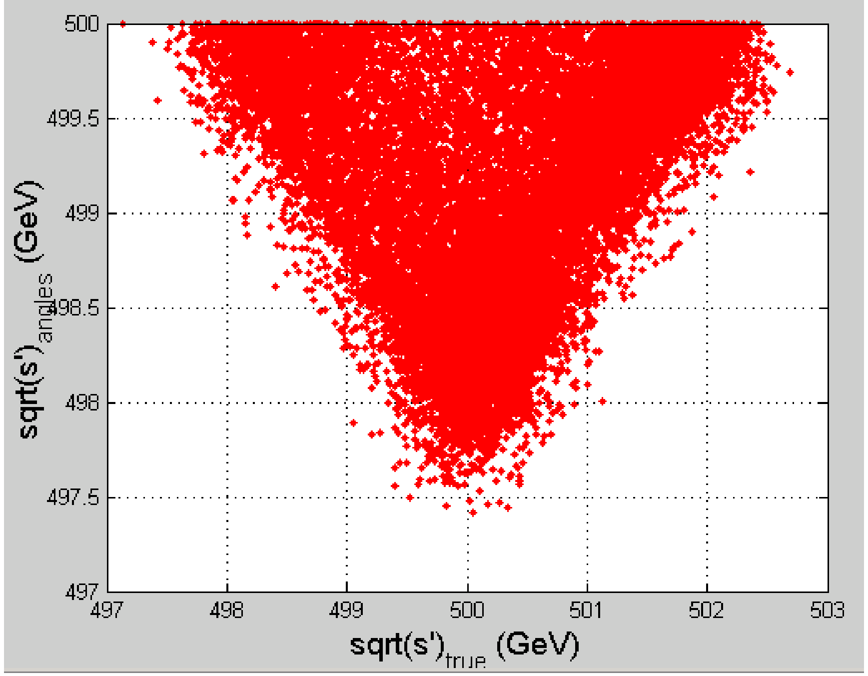




Bhabha Acolinearity Study
for energy spread effects only

NLC-500 study,





Acolinearity angle, θ_A: $\theta_A = \theta_2 - \theta_1$

Acolinearity analysis provides a measure of the energy spread,
but does **not** provide information on difference between $E_{cm}^{\text{lum-wt}}$ and $\langle E_{cm} \rangle$

Bhabha Acolinearity Study with beamstrahlung and energy spread effects

Optimistic assessments in the literature:

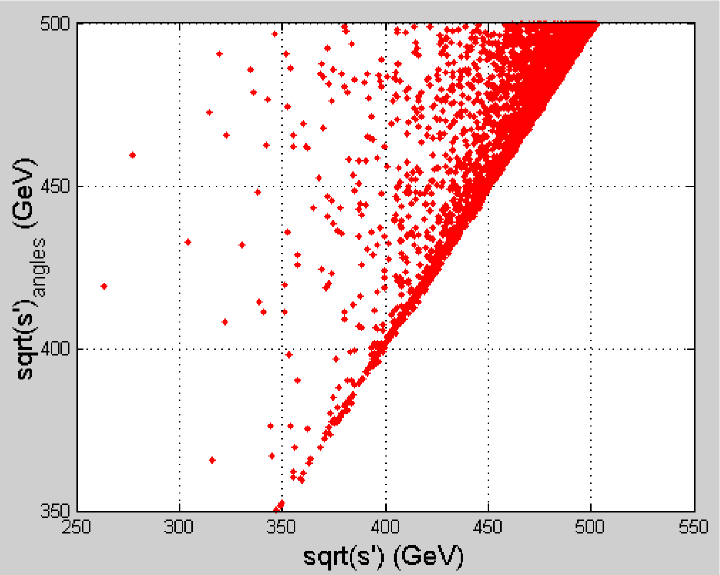
> "With an integrated luminosity of 3 fb-1 at sqrt(s)=500GeV the mean energy loss due to Beamstrahlung can be measured with a statistical precision of 50ppm and the beamspread to 5ppm. Systematic errors also seem to be controllable at this level."
> K. Moenig, LC-PHSM-2000-60-TESLA, Dec. 2000.

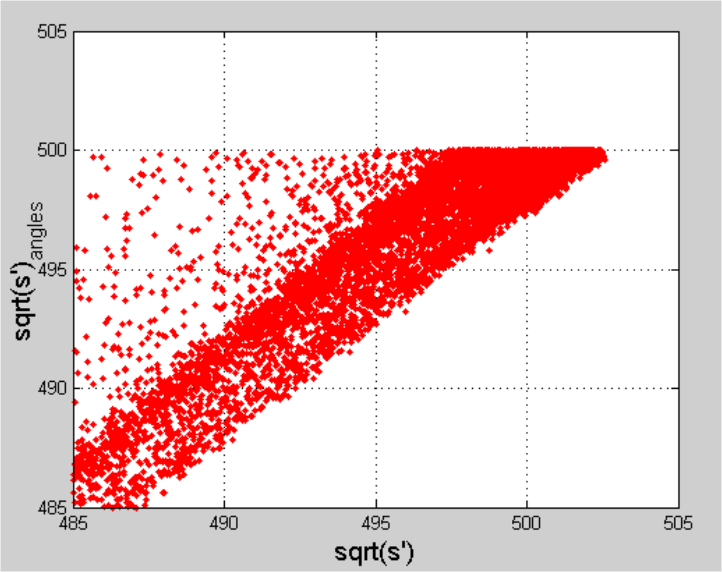
> "The analysis of the acolinearity distribution of the scattered e+ and e- particles allows to reconstruct the effective centre-of-mass energy sqrt(s) with a relative accuracy of the order of 100ppm or better depending on the assumed beam parameters."
> M. Battaglia, 'Luminosity Determination at CLIC', SNOWMASS-2001-E3015, Jun 2001.

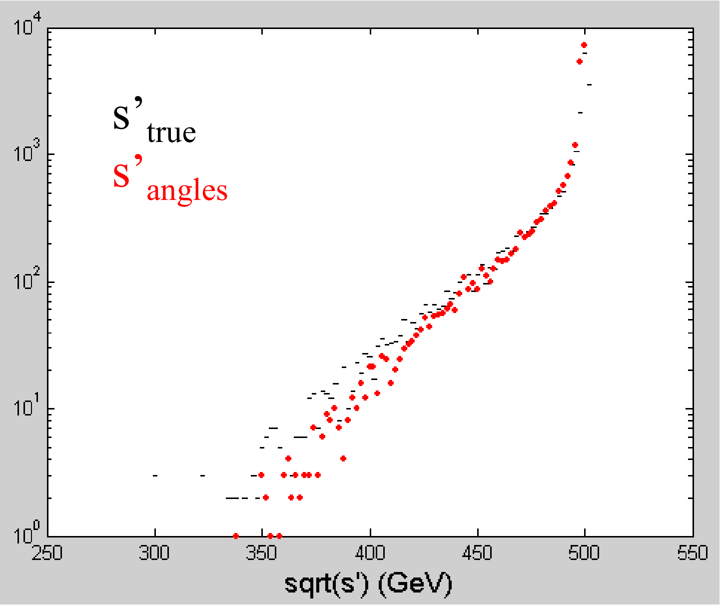
> "While at first glance the effect of ISR, beamstrahlung, and the linac energy spread seem daunting on the possibility of extracting top quark parameters in a scan of the ttbar threshold at a high energy e+e- linear collider, this detailed study shows that such extraction is not limited by the dL/dE spectrum. The dL/dE spectrum can be measured to an accuracy limited by the statistics of Bhabha scattering in various techniques using various features of the proposed detectors."
> D. Cinabro, hep-ex/0005015 May 2000.

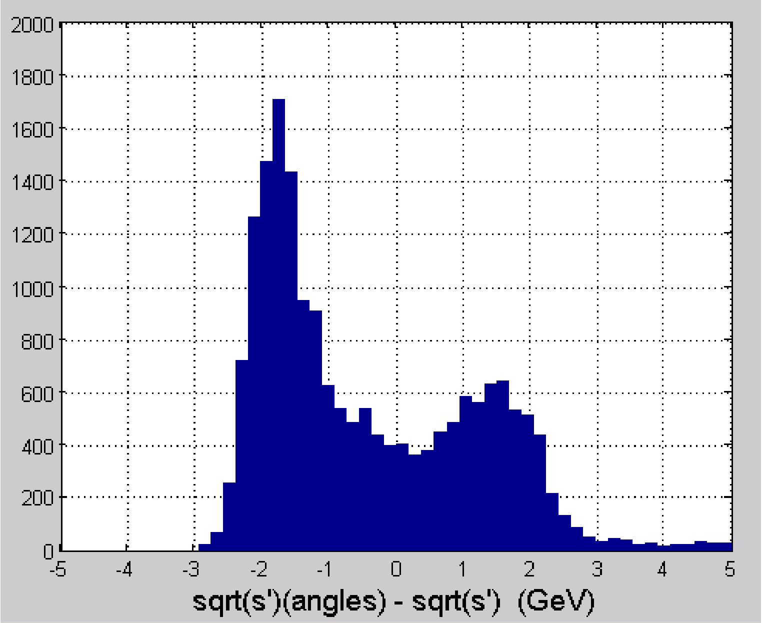
The authors did note that additional systematic studies were needed to address correlations, backgrounds and other effects.

NLC-500 study Bhabha acolinearity study with beamstrahlung and espread









2 measures of the luminosity spectrum are $\sigma(E), \sqrt{s'}$

Energy Spread:

$$\sigma(\mathrm{E})=0.3\%\mathrm{rms} \longrightarrow \sigma(\theta_{\mathrm{A}})=800\mu\mathrm{rad}$$

$$\Downarrow$$

$$\delta(\sigma(E)) = 100\,ppm \longrightarrow \delta(\sigma(\theta_A)) \approx 30\,\mu rad$$

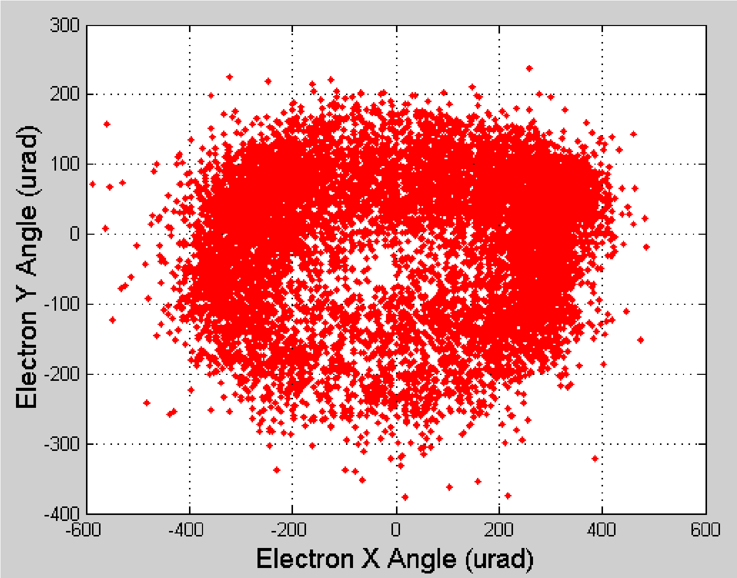
Beamstrahlung:

$$\frac{\sqrt{s}-\sqrt{s'}}{\sqrt{s}} \approx 2.5\% \qquad \sigma(\theta_{\mathrm{A}})=20\mathrm{mrad}$$

$$\frac{\sqrt{s'_{angles}}-\sqrt{s'}}{\sqrt{s'}} \approx 0.5\%$$

$$\delta\left(\sqrt{s'}\right) = 100\,ppm \longrightarrow \delta(\sigma(\theta_A)) \approx 100\,\mu rad$$

Disruption Angles at NLC-500



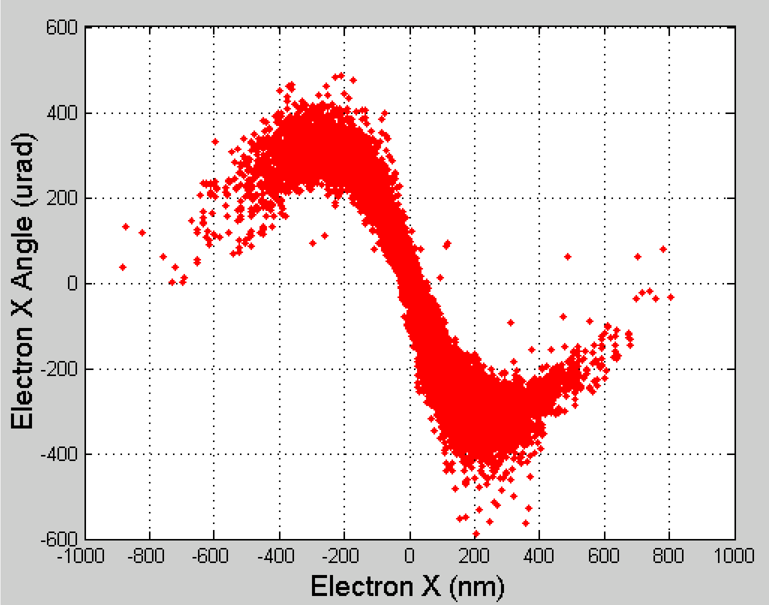
Outgoing beam angles from G-P beam1.dat

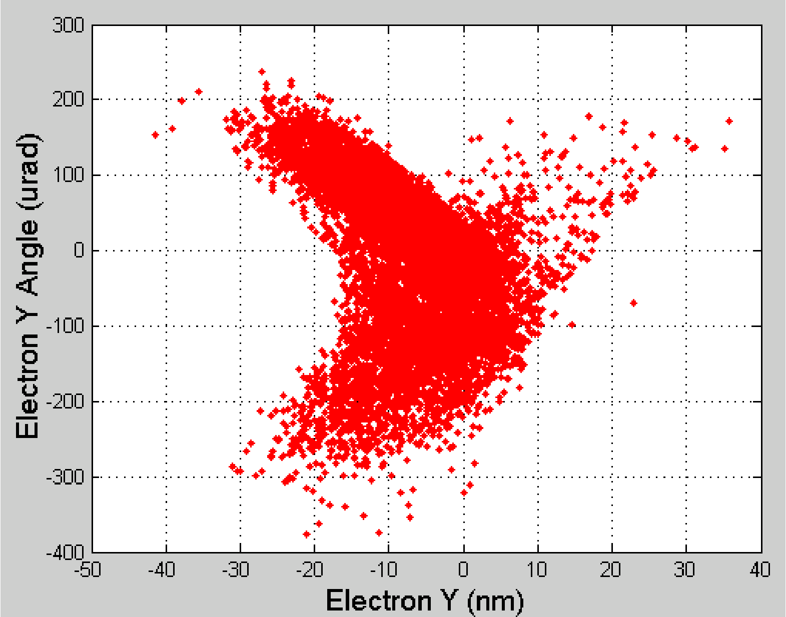
$$\sigma(\theta_x) \approx 240\,\mu rad$$

$$\sigma(\theta_y) \approx 100\,\mu rad$$

↳ Significant impact on acolinearity analysis

(also on estimating detector requirements)





Bhabha acolinearity study is ongoing

- need to implement Moenig's fitting procedure
  - use Circe parametrization of beamstrahlung to generate MC $\sqrt{s'_{angles}}$ distributions, varying the Circe parameters
  - use MatLiar/GuineaPig simulation to generate 'data' $\sqrt{s'_{angles}}$
  - extract Circe parameters from fit of 'data' to Circe-generated distributions
  - compare fit values with true values for $\langle s' \rangle, \sigma(E)$

Need to quantify effects and further study:

- disruption angles
- beam offsets
- residual dispersion
- waist offsets
- asymmetric beam distributions for electrons, positrons:
  ex. transverse spotsizes, bunch lengths