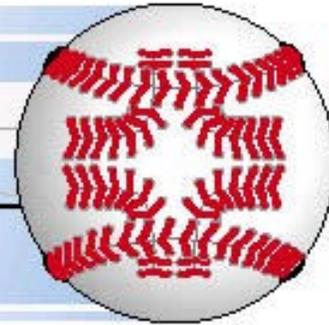


LINE DRIVE



*Fermilab Series*  
of Linear Collider  
Double-Headers



# Interaction Region Issues at a Linear Collider

Tom Markiewicz  
March 1, 2001



# Basic Issues

## Bunch Structure:

	TESLA-500	NLC-500H	CLIC-3TeV
$\tau_B$	337 ns	2.8ns/1.4ns	0.67 ns
$N_B$	2820	95/190	154
f	5 Hz	120 Hz	100 Hz

⇒ Crossing Angle, Detector Effects, Feedback Design, Extraction

## Beam-beam effects & Machine Backgrounds

N	$2.0 \times 10^{10}$	$0.75 \times 10^{10}$	$0.4 \times 10^{10}$
$\sigma_z$	300 $\mu\text{m}$	110 $\mu\text{m}$	30 $\mu\text{m}$

⇒ IP Backgrounds, Pinch, Disruption, Synchrotron Rad, Neutrons

## Small spot sizes:

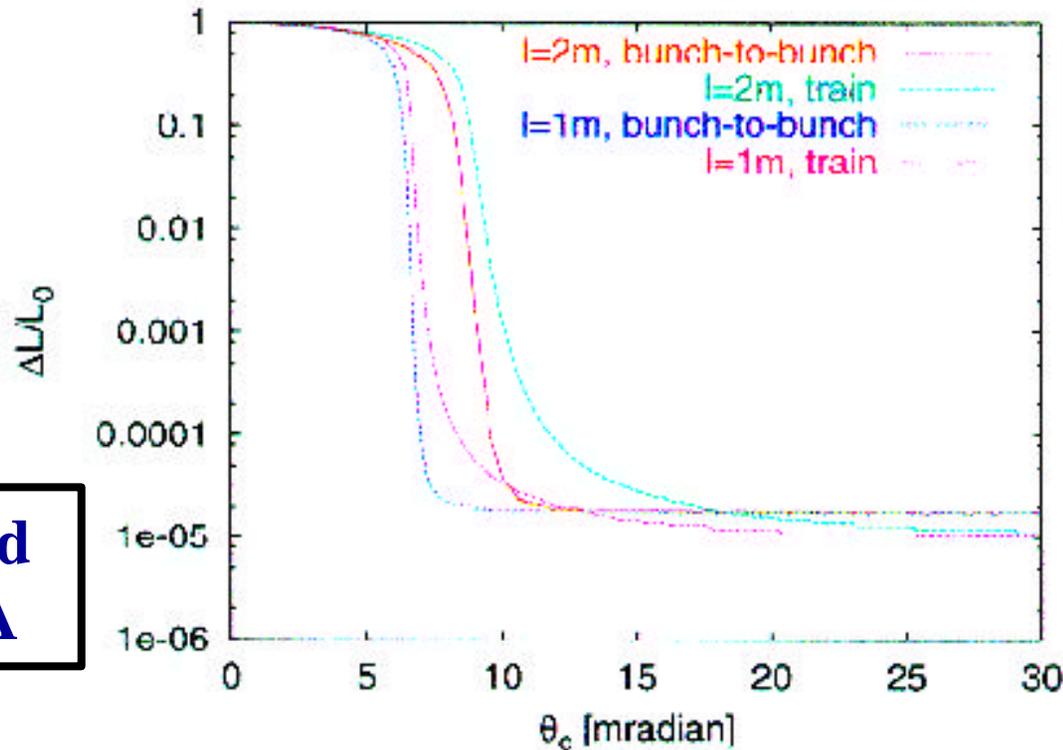
$\sigma_x$	550 nm	245 nm	43 nm
$\sigma_y$	5 nm	2.7 nm	1 nm

⇒ Control position & motion of final quads and/or the beam pm Markiewicz



# Minimum Crossing Angle

Avoid unwanted collisions before bunch gets to the IP



$q_c > \sim 4 \text{ mrad}$   
for NLC

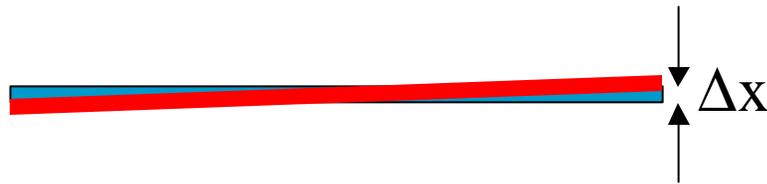
$q_c = 0 \text{ mrad}$   
for TESLA

Luminosity Loss vs. Crossing Angle for CLIC,  $\tau_B=0.67 \text{ ns}$



# Maximum Crossing Angle Crab Cavity

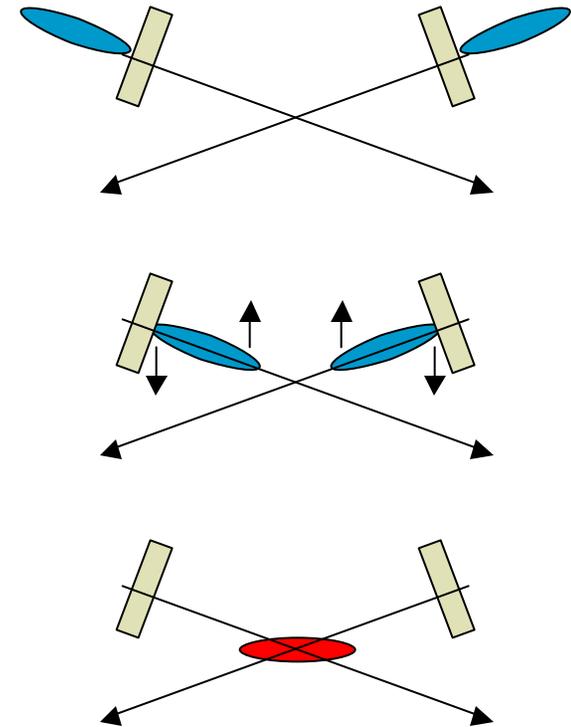
- Transverse RF cavities on each side of IP rotate the bunches so they collide head on
- Cavity power req. and relative voltage & phase stability limit maximum crossing angle



- 2%  $\Delta L/L$  when bunch overlap error  $\Delta x \sim 0.4 \sigma_x$

Since  $\Delta x = (\theta_C/2)\Delta z$ , at  $\theta_C=20\text{mrad}$  phase error  $\Delta z$  corresponds to  $\sim 10\mu\text{m}$

$\sim 0.2$  degree of X-Band phase



$$q_C < 40 \text{ mrad}$$



# Crossing Angle Considerations

## Interaction with Detector's Solenoid

---

### Beam Steering before IP:

- Transverse component of solenoid changes position and angle of beams at the IP
  - $1.7 \mu\text{m}$  ,  $34.4 \mu\text{rad}$  at 1 TeV,  $L^*=2\text{m}$ ,  $B_s=6 \text{ T}$ ,  $\theta_C=20\text{mrad}$
- Dispersion and SR cause spot size blow up
  - $3.1 \mu\text{m}$  added to vertical spot size
- **Handle with clever upstream beam steering gymnastics and by moving QD**
  - **So NOT a problem** (unless SR term  $\propto (L^*B_s\theta_C)^{5/2}$  grows too large)

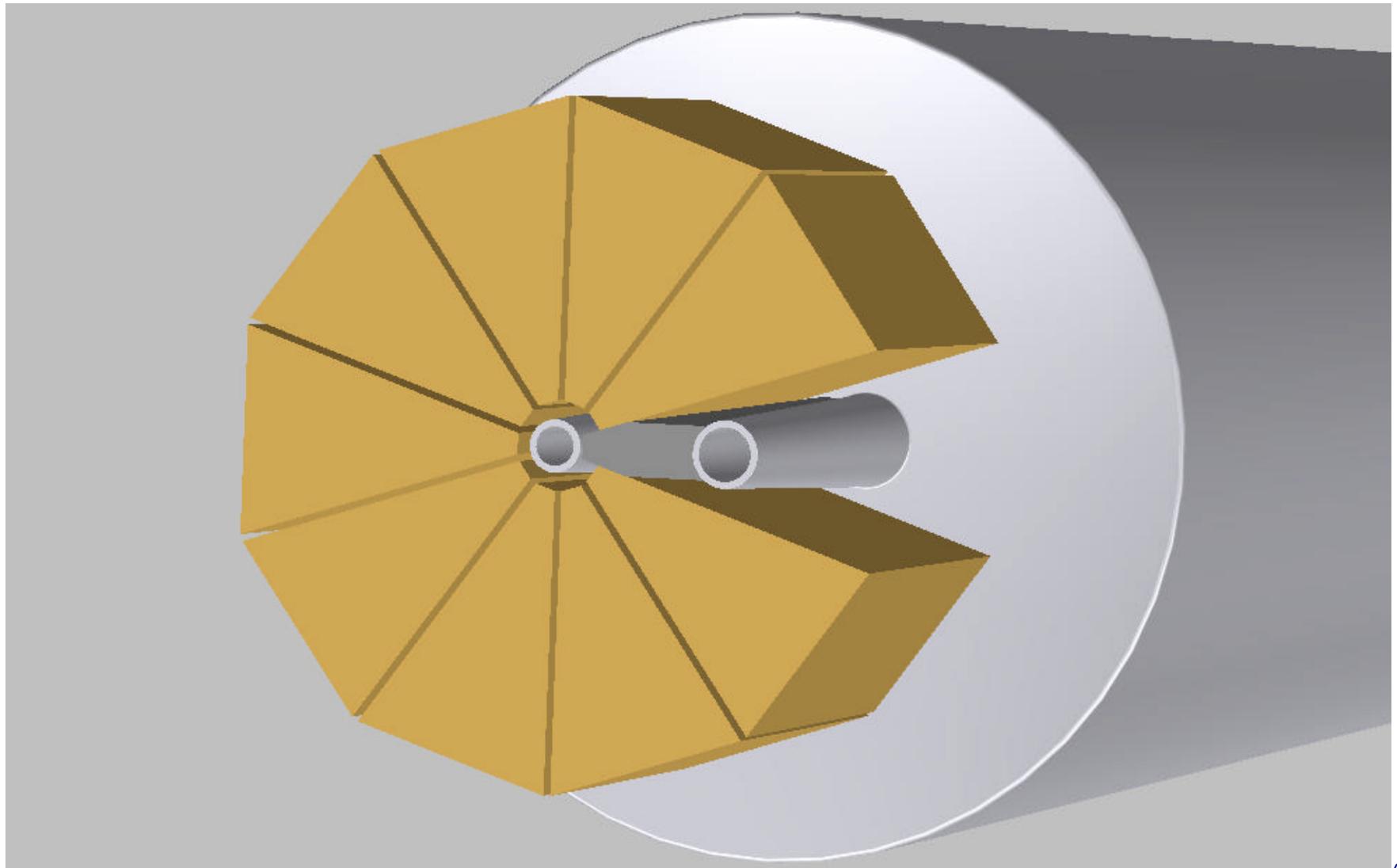
### Beam Steering after IP:

- Energy dependence of angle of extraction line
  - Steering: position ( $410 \mu\text{m}$ ) & angle ( $69 \mu\text{rad}$ ) different from  $B=0$  case at 1 TeV
    - **Only run with solenoid ON and Realign extraction line when necessary**



# Luminosity Monitor Detail

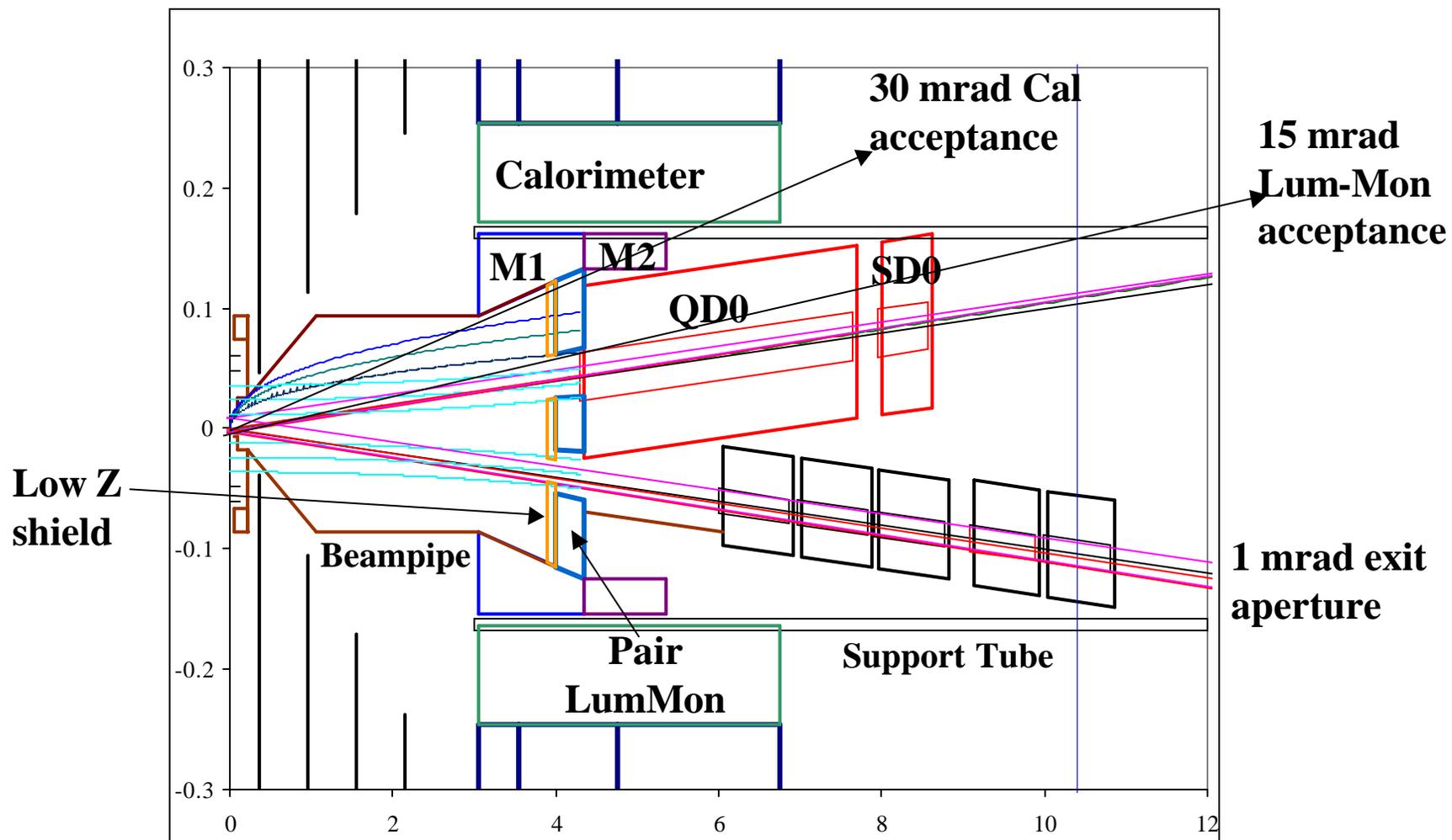
Non cylindrically symmetric geometry for inner detectors





# LCD-L2 (3T) with 4.3m L\* Optics

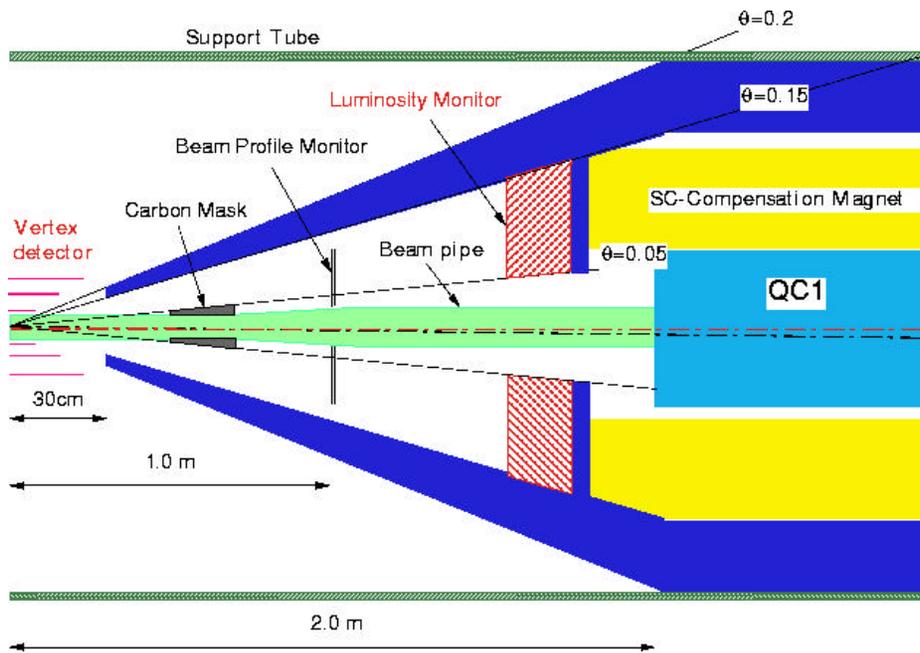
## Separate (Easier?) Extraction Line $q_c=20$ mrad



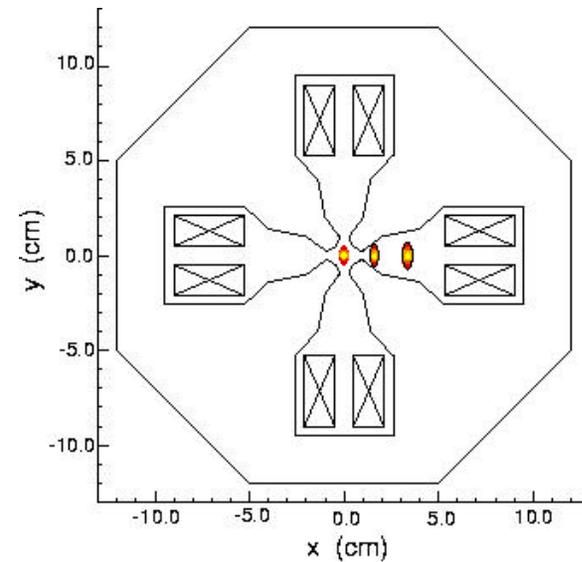
# JLC IR

## 8 mrad Design

Elevation View



- Iron magnet in a SC Compensating magnet
- 8 mrad crossing angle
- Extract beam through coil pocket
- Vibration suppression through support tube

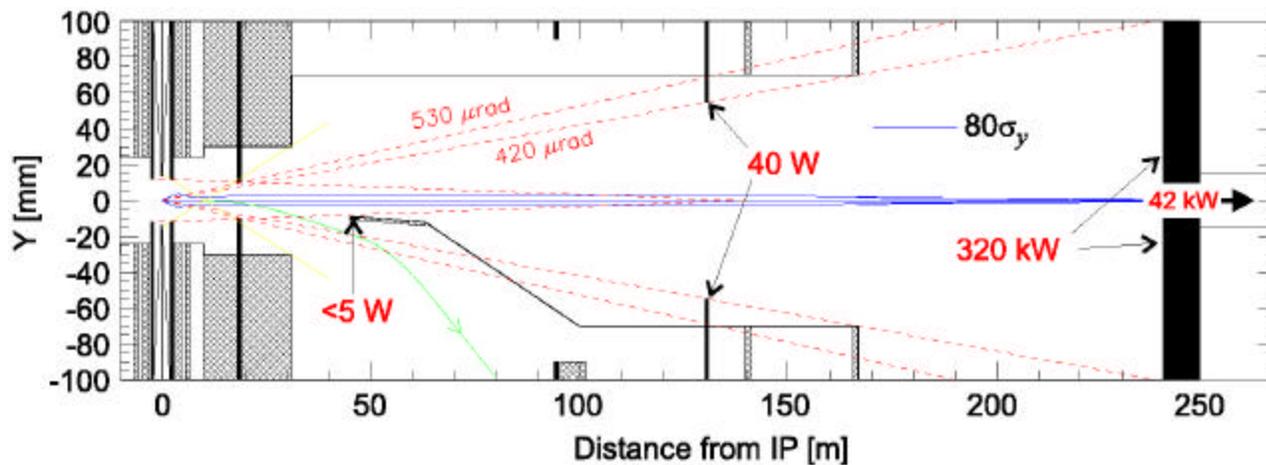
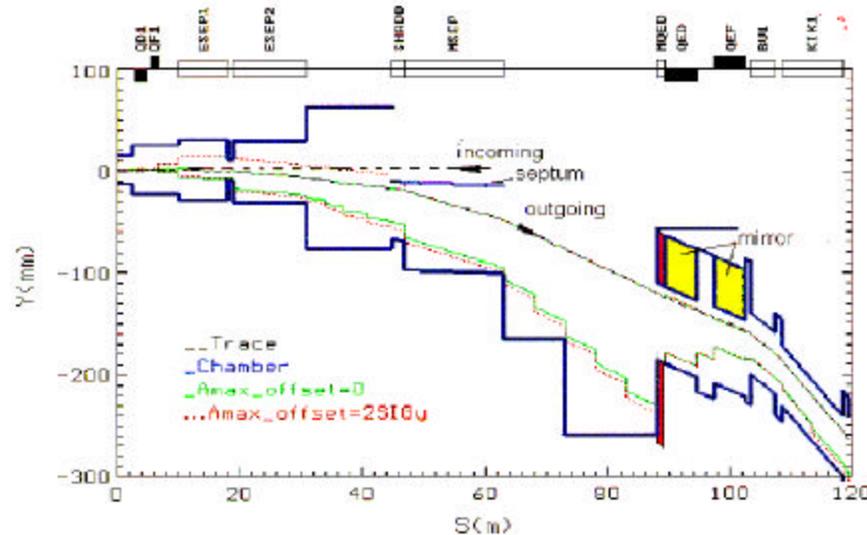




# TESLA Extraction at 0°

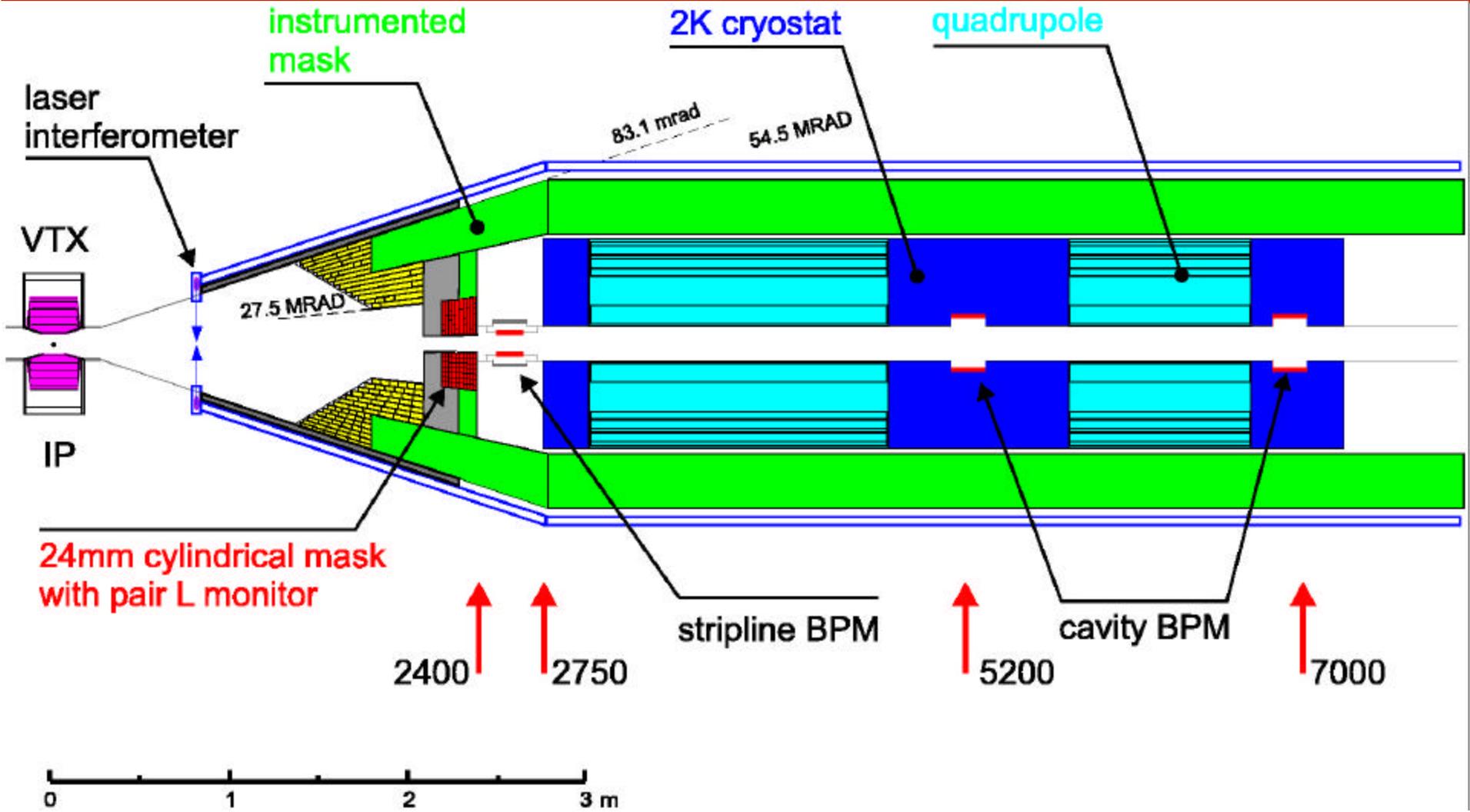
Vertical extraction with electrostatic separators, septum, and dipoles to dump at  $z=240\text{m}$

Beams separated by  $c\tau_B/2=50\text{m}$  (800 GeV)



Beamstrahlung photons to separate dump at  $z=240\text{m}$

# TESLA IR





# Magnet Technology Choices

---

## Permanent Magnets (NLC)

- Compact, stiff, few external connections, no fringe field to affect extracted beam
- Adjustment more difficult

## Superconducting (TESLA)

- Adjustable, big bore
- Massive and not stiff, would require windings to eliminate fringe field affecting extraction line

## Iron (JLC)

- Adjustable, familiar
- Massive, shielded from solenoid, extraction in coil pocket seems daring



## **Basic Issue#2: Backgrounds**

### **Well Studied by ALL GROUPS: Not a Problem**

---

#### **IP Backgrounds:**

##### **•Beam-Beam Interaction**

- Disrupted primary beam
  - Extraction Line Losses
- Beamstrahlung photons
- $e^+, e^-$  pairs from beams.  $\gamma\gamma$  interactions
- Hadrons from beams.  $\gamma\gamma$  interactions

##### **•Radiative Bhabhas**

#### **Machine Backgrounds:**

- Synchrotron Radiation
- Muons Production at collimators
- Direct Beam Loss
  - Beam-Gas
  - Collimator edge scattering
- Neutron back-shine from Dump

**“Good”, scale with luminosity**

- 1) Transport them away from IP**
- 2) Shield sensitive detectors**
- 3) Detector Timing**

**“Bad”, get nothing in exchange**

- 1) Don't make them**
- 2) Keep them from IP if you do**



# Beam-Beam Interaction

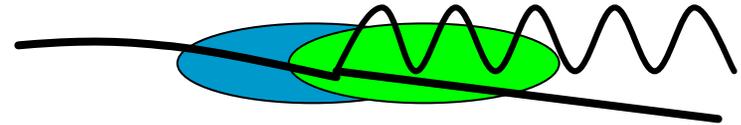
SR photons from individual particles in one bunch when in the electric field of the opposing bunch

**Beams attracted to each other reduce effective spot size and increase luminosity**

- $H_D \sim 1.4-2.1$

**Pinch makes beamstrahlung photons:**

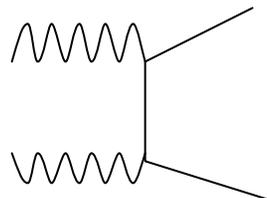
- 0.9-1.6  $\gamma/e^-$  with  $E \sim 3-9\% E_{beam}$
- Photons themselves go straight to dump
  - Not a background problem, but angular dist. (1 mrad) limits extraction line length



**Particles that lose a photon are off-energy**

- Physics problem: luminosity spectrum
- Extraction line problem:
  - NLC 1 TeV design has 77 kW of beam with  $E < 50\% E_{nom}$ , 4kW lost (0.25% loss)

**Photons interact with opposing e,g to produce e+,e- pairs and hadrons**



$$\begin{aligned} \gamma\gamma &\rightarrow e^+e^- \text{ (Breit-Wheeler)} & e\gamma &\rightarrow ee^+e^- \text{ (Bethe-Heitler)} \\ ee &\rightarrow eee^+e^- \text{ (Landau-Lifshitz)} & \gamma\gamma &\rightarrow \text{hadrons} \end{aligned}$$



# NLC/TESLA Beam-Beam Comparison

$$D_Y = \frac{2r_e N_e s_Z}{g s_Y (s_X + s_Y)}$$

$$Y = \frac{5gr_e^2 N_e}{6as_Z (s_X + s_Y)} = g \frac{B_{bunch}}{B_c}$$

	NLC500H	TESLA500
$D_y$	14	25
$Y$	0.11	0.06
$n_\gamma$	1.17	1.6
$\delta_b$	4.6%	3.2%
$H_D$	1.4	2.1
# pairs/bunch	88,000*	130,000
$\langle E \rangle_{\text{pair } e}$	10.5 GeV*	2.8 GeV

\* 1 TeV

$N_e, \sigma_x, \sigma_y, \sigma_z \Rightarrow$

More disruption for TESLA with larger luminosity enhancement (but more sensitivity to jitter) and more, but lower energy photons per bunch (but fewer bunches to integrate over)

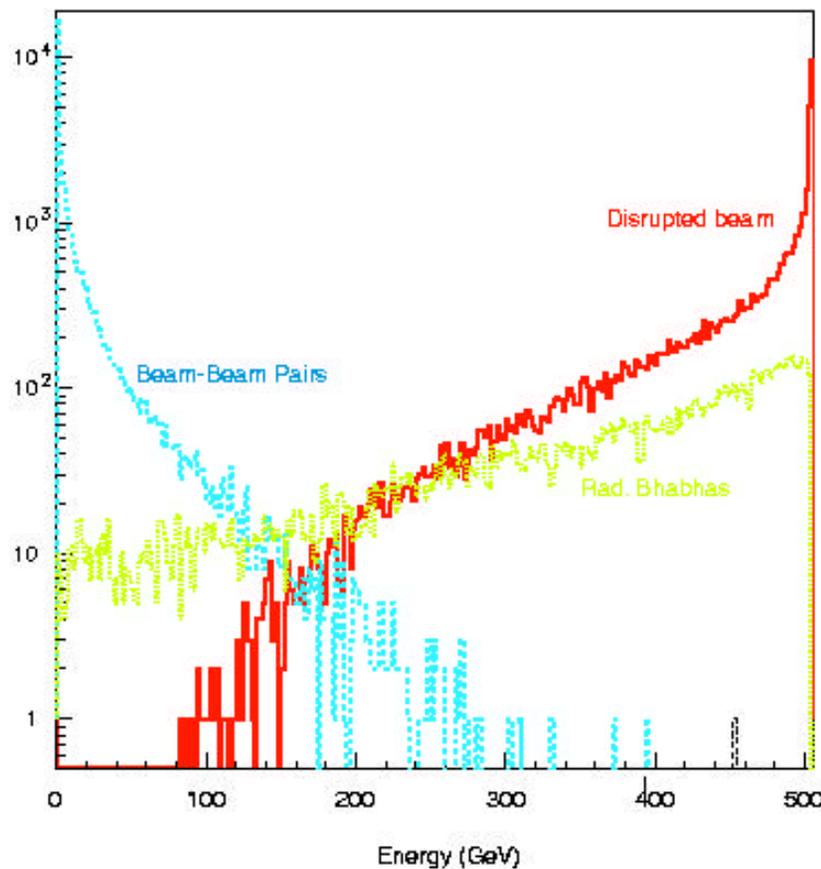
Real results come from beam-beam sim. (Guinea-Pig/CAIN) and GEANT3/FLUKA



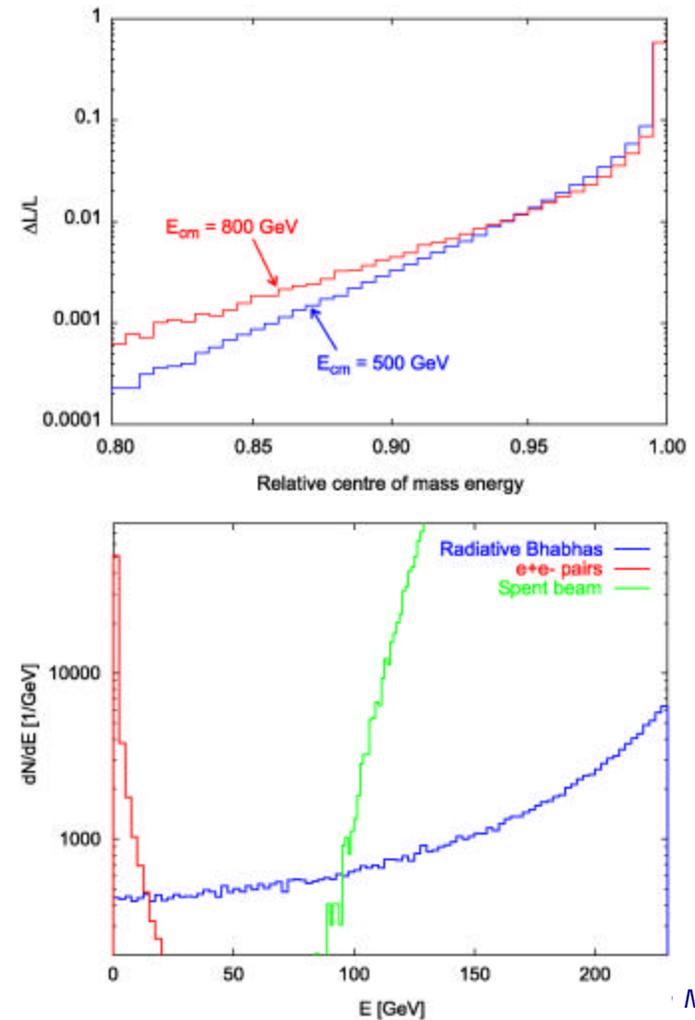
# Energy Distributions

## NLC-1 TeV

Energy Distribution



## Tesla 500 GeV





# Measuring the Luminosity Spectrum

Analyze the acolinearity distribution of Bhabha scattering in the forward tracking region

Klaus Mönig, DESY, LC-PHSM-2000-60-TESLA

$$\frac{\sqrt{s'}}{\sqrt{s}} = \sqrt{1 - 2 \frac{\sin(\mathbf{q}_1 + \mathbf{q}_2)}{\sin(\mathbf{q}_1 + \mathbf{q}_2) - \sin \mathbf{q}_1 - \sin \mathbf{q}_2}} \approx 1 - \frac{1}{2} \frac{\Delta \mathbf{q}}{\sin \mathbf{q}}$$

- Polar angle resolution  $\sim 10^{-4}$  to measure beam energy spread
- Beamstrahlung distribution parameterized

$$f(x) = a_0 \mathbf{d} (1-x) + a_1 x^{a_2} (1-x)^{a_3}$$

and  $a_i$  fit to 1% with  $3 \text{ fb}^{-1}$  data with  $\theta > 7^\circ$

$$\Delta \left\langle \frac{\sqrt{s'}}{\sqrt{s}} \right\rangle = 10^{-4} \quad \text{and} \quad \Delta(\text{BS})/\text{BS} = .5\%$$

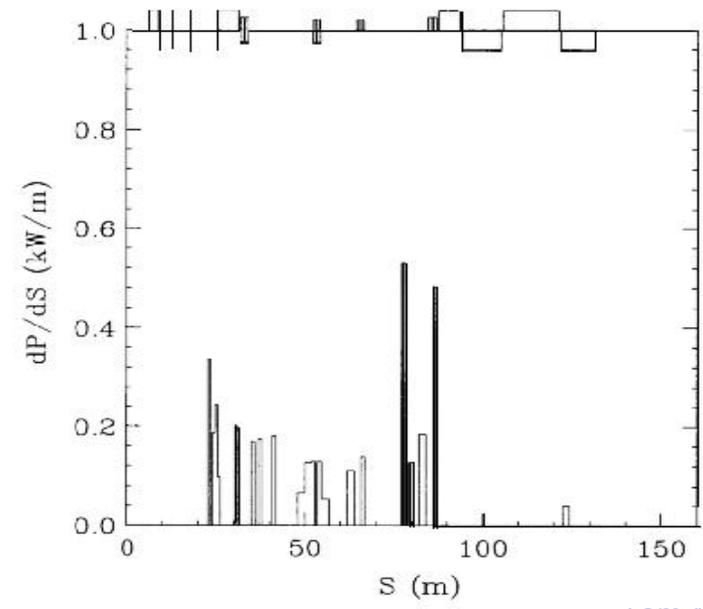
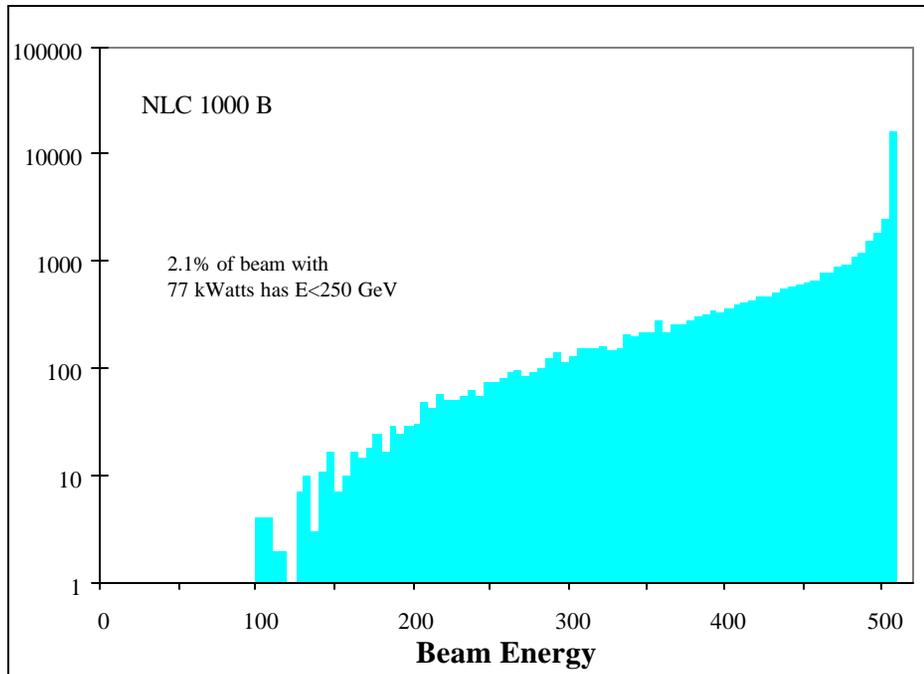
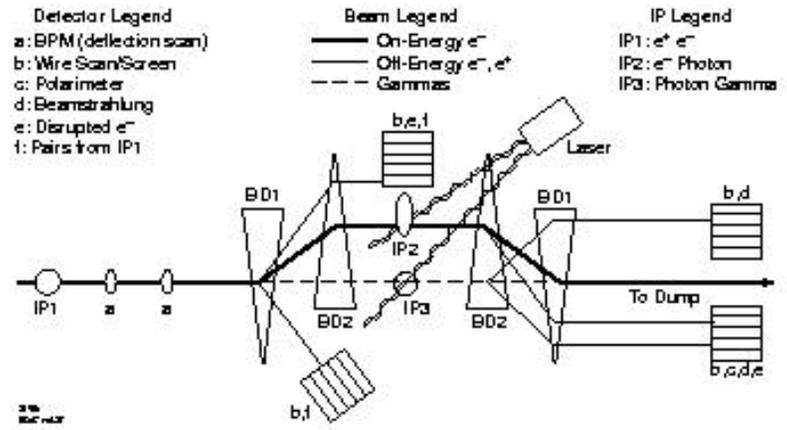


# NLC Extraction Line

150 m long with chicane and common  $\gamma$  and e- dump

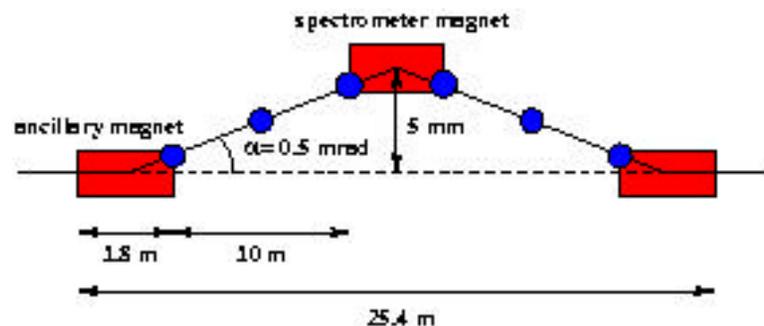
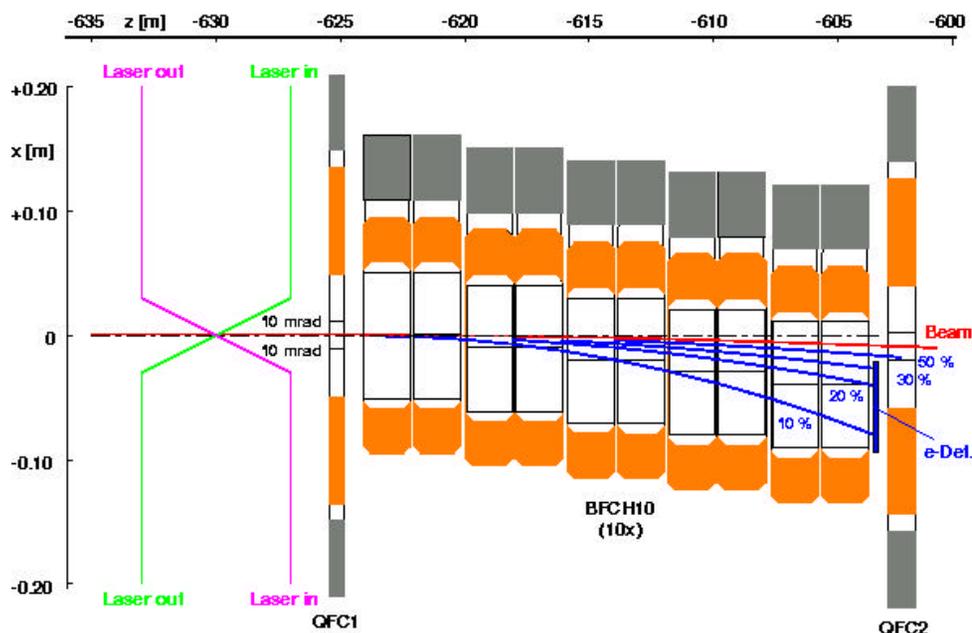
**Problem: Handling the large low E tail on the disrupted beam cleanly enough to allow extraction line diagnostics**

**Working plan: Ignore for now- not a problem @ 500 GeV; @ 1 TeV either measure Pol, E upstream, steal undisrupted pulses for diagnostics, calibrate other**





# TESLA Pre-IP Polarimeter and Energy Spectrometer



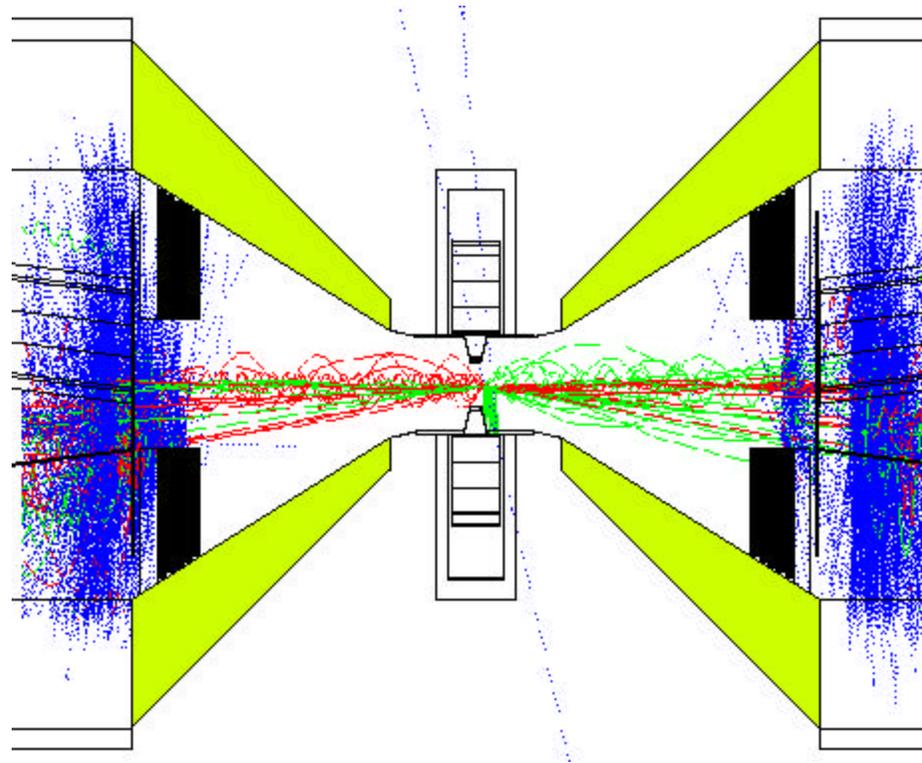
No TESLA plans for post IP diagnostics

NLC plans pre-IP diagnostics but no work yet begun



# $e^+, e^-$ pairs from beams. $\gamma\gamma$ interactions

At NLC-1000: 44K per bunch @  $\langle E \rangle = 10.5$  GeV (0.85 W)





# Controlling $e^+,e^-$ Pair Background

---

## Direct Hits

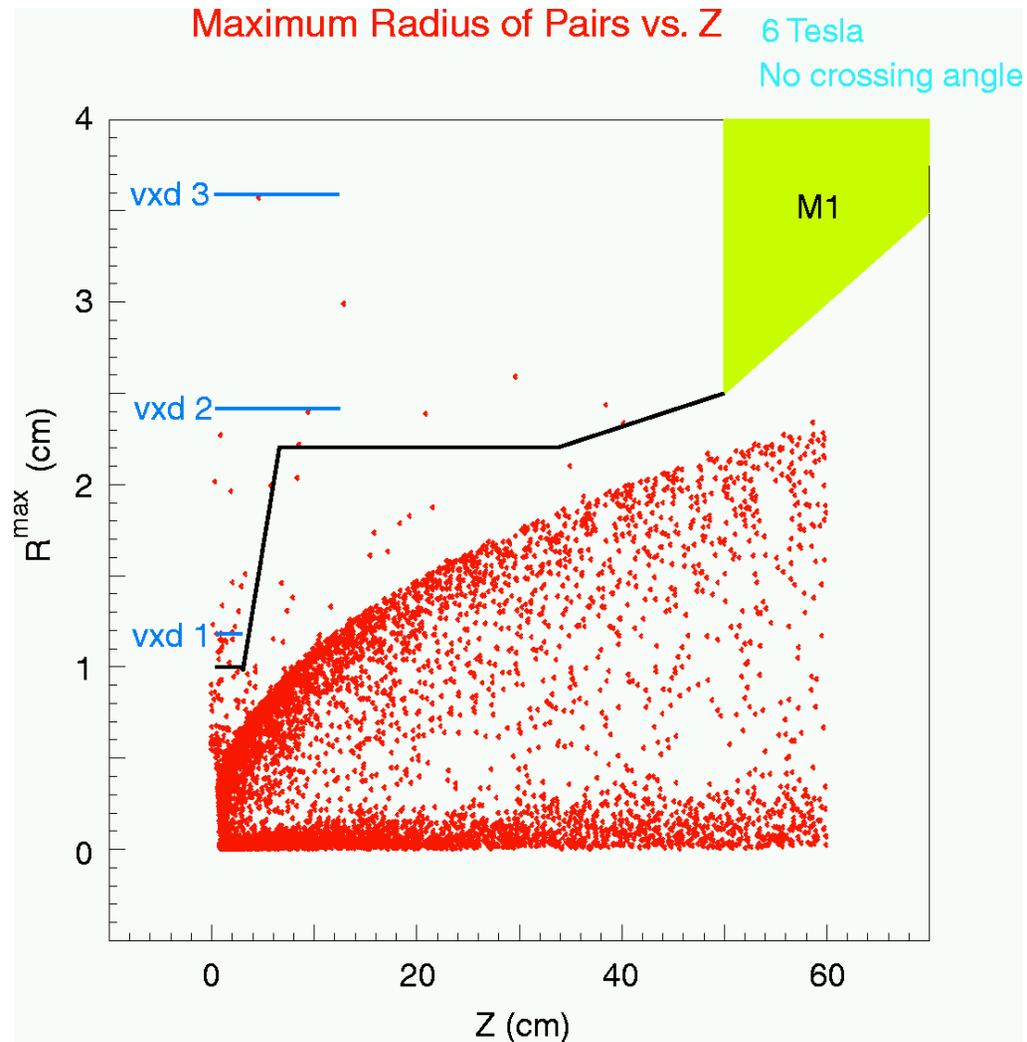
- Increase detector solenoid field to wrap up pairs (3 Tesla adequate, 4 T better)
- Increase minimum beam pipe radius at VXD and stay out of pair “dead cone”

## Secondaries ( $e^+,e^-$ , $g,n$ )

- Remove point of first contact as far from IP/VXD as possible
  - Increase  $L^*$  if possible
  - Largest exit aperture possible to accept off-energy particles
  - Keep extraneous instrumentation out of pair region
- Masks
  - Instrumented conical “dead cone” protruding at least ~60cm from face of luminosity monitor and 8-10cm thick to protect against backscattered photons
  - Low Z (Graphite, Be) 10-50cm wide disks covering area where pairs hit the low angle W/Si Pair Luminosity monitor



# Pair Stay-Clear from Guinea-Pig Generator and Geant



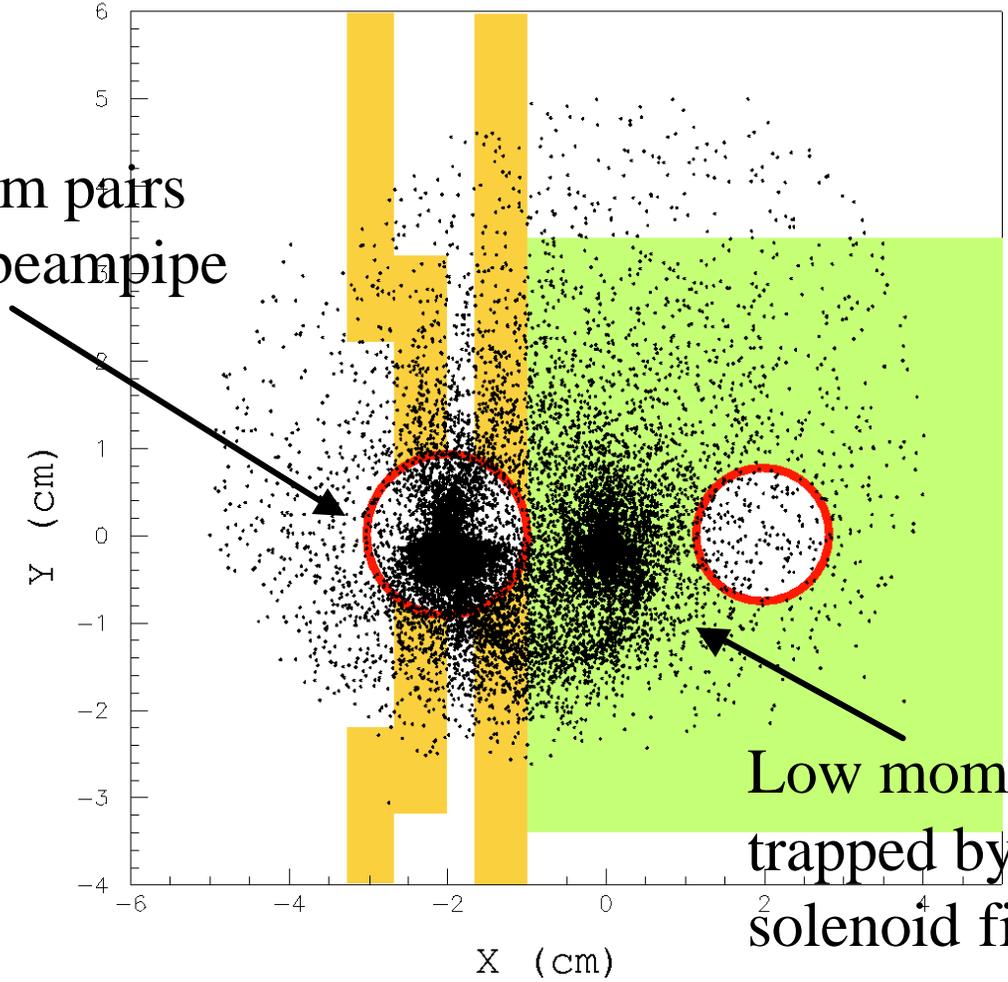


# e,g,n secondaries made when pairs hit high Z surface of LUM or Q1

Pair distribution at z=200 cm

6 Tesla

High momentum pairs mostly in exit beampipe

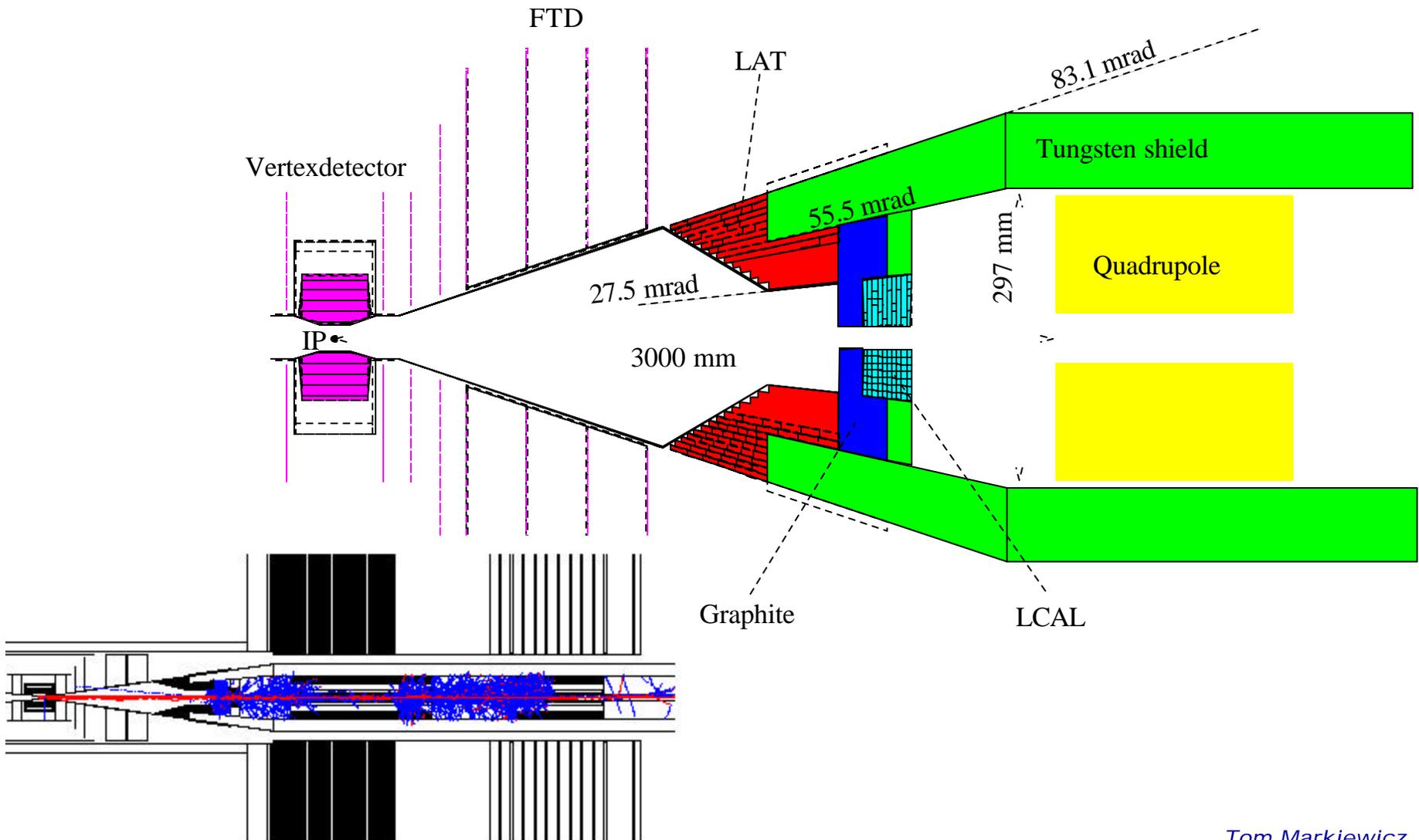


Low momentum pairs trapped by detector solenoid field



# TESLA IR

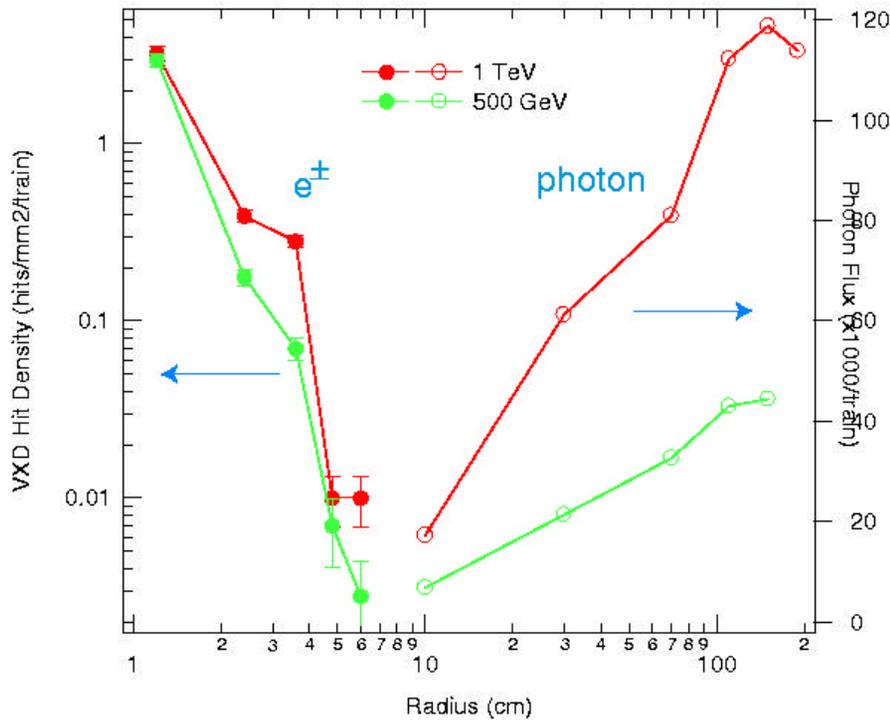
## NLC/JLC/CLIC Similar



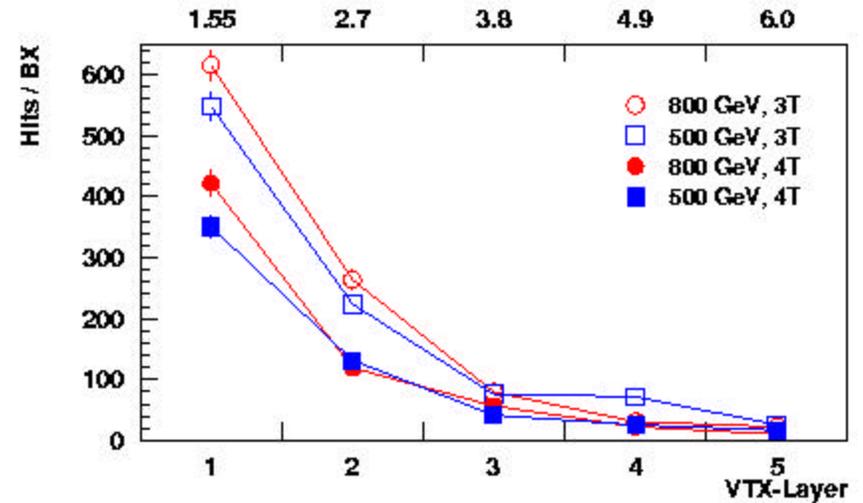


# VXD/TPC Backgrounds from Pairs

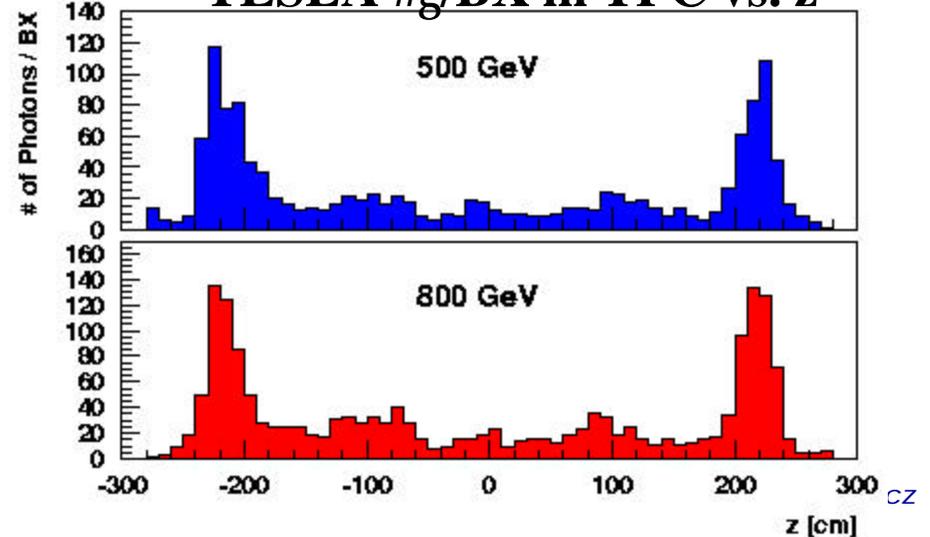
## LCD VXD Hit Density/Train & #g/Train in TPC vs. Radius



## TESLA VXD Hits/BX vs. Radius



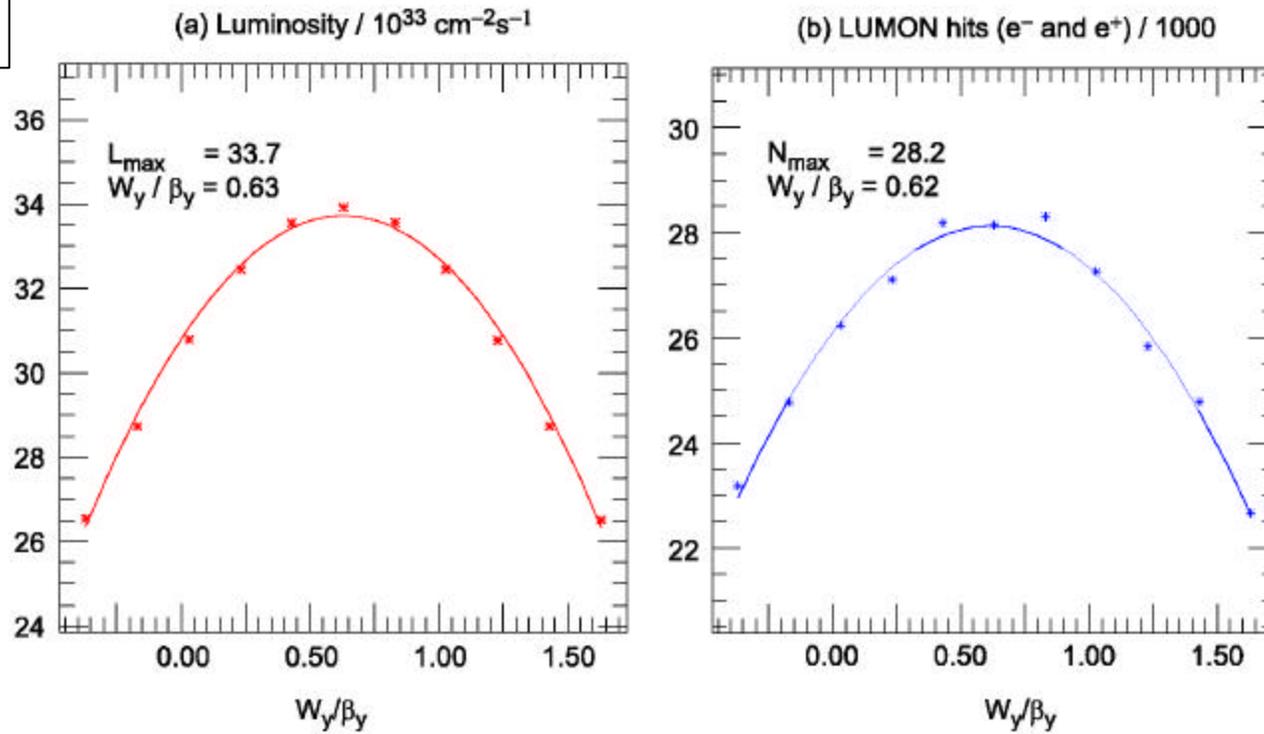
## TESLA #g/BX in TPC vs. z





# Pairs as a Fast Luminosity Monitor

TESLA



Also, Pair angular distribution carries information of beam transverse aspect ratio (Tauchi/KEK)



# $e^+e^-$ $\text{\textcircled{R}}$ $e^+e^- gg$ $\text{\textcircled{R}}$ $e^+e^-$ Hadrons

Studied by TESLA using Guinea Pig and HERWIG

Type	Events/BX	Multiplicity/ Event	Chg. Mult./ Event	Etot/BX
All	0.02	34.4	17.4	2.1 GeV

Leads to

VXD Hit densities  $\sim 10^{-5}$  hits/mm<sup>2</sup>

119 TPC tracks (in 160 BX), probably resolved via TPC time resolution

**NLC: No new work done since ~1991 (Help please!)**

Need to integrate 190 bunches

Event rate/BX probably scales like  $n_\gamma^2$  (50%)

One detector element with good time resolution will help



# Neutron Backgrounds

The closer to the IP a particle is lost, the worse

- e+/e- pairs and radiative Bhabhas hitting the Pair Lum-Mon, beam-pipe and magnets in the extraction line.
- Disrupted beam lost in the extraction line.
  - 0.25 % beam loss in recent redesign
- Disrupted beam and beamstrahlung photons in the dump

## Neutron hit density in VXD

	NLC-500 GeV	Tesla-500 GeV
Beam-Beam pairs	$3.2 \times 10^8$ hits/cm <sup>2</sup> /yr	O(10 <sup>9</sup> hits/cm <sup>2</sup> /yr)
Radiative Bhabhas	$3.1 \times 10^6$ hits/cm <sup>2</sup> /yr	$< 0.5 \times 10^8$ hits/cm <sup>2</sup> /yr
Beam loss in extraction line	$0.1 \times 10^8$ hits/cm <sup>2</sup> /year	
Backshine from dump	$2.5 \times 10^8$ hits/cm <sup>2</sup> /yr	negligible
<b>TOTAL</b>	<b><math>5.8 \times 10^8</math> hits/cm<sup>2</sup>/yr</b>	

Figure of merit is  $3 \times 10^9$  for CCD VXD



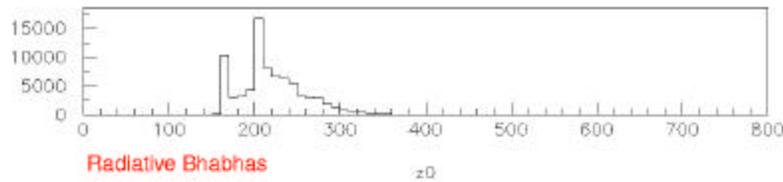
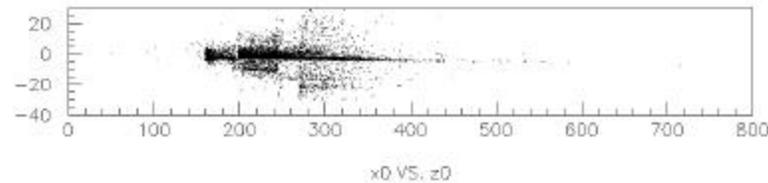
# Neutrons from Lost Pairs and Rad. Bhabhas

## Sources of VXD Neutrons

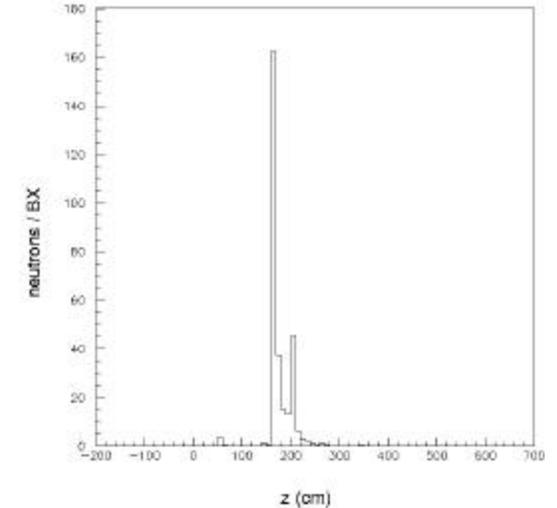
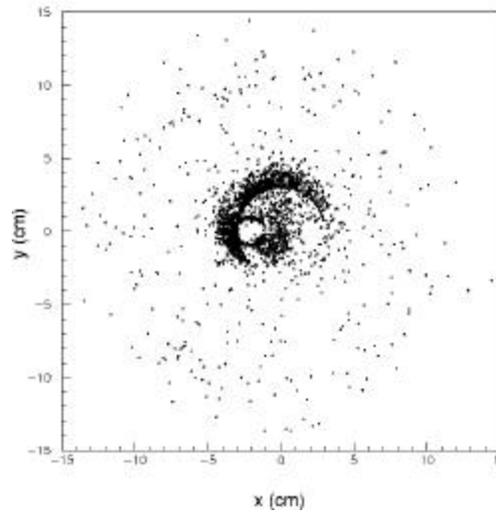
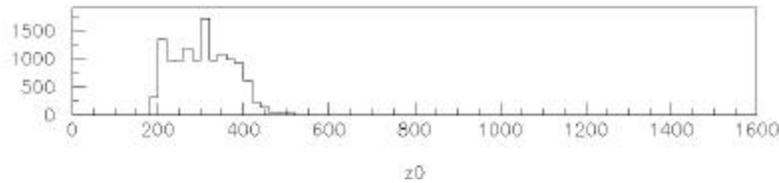
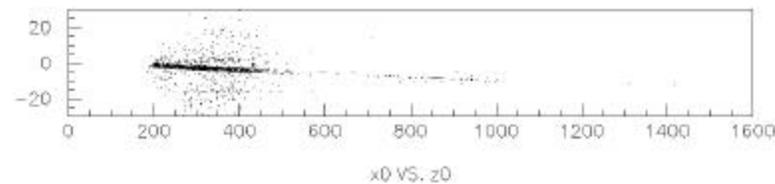
### Neutron Background

#### Neutron Sources

e+e- pairs



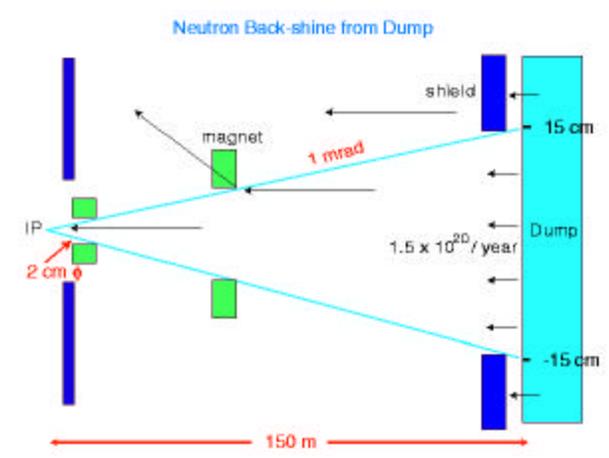
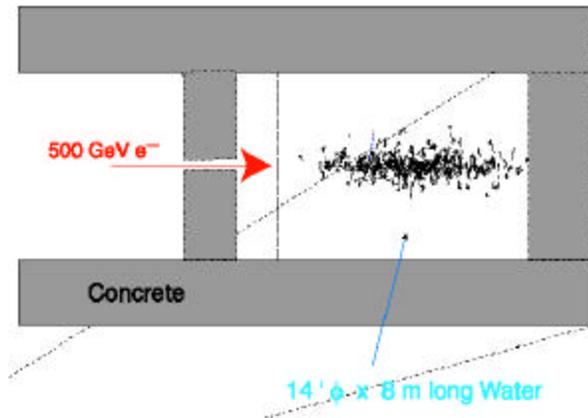
Radiative Bhabhas



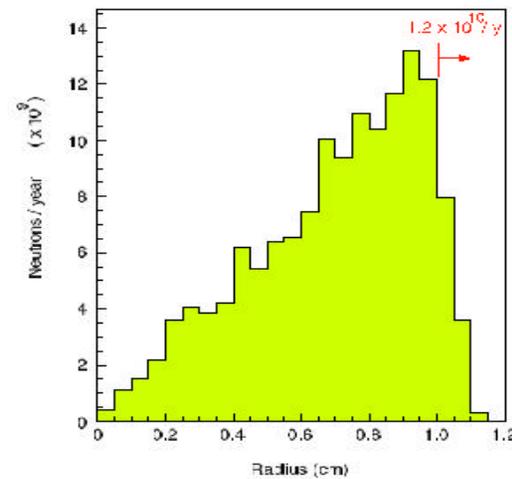
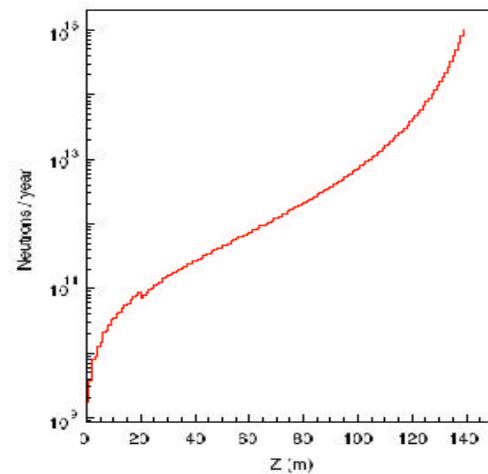
Neutrons which reach the IP are produced close to the IP, mainly in the luminosity monitor



# Neutrons from the Beam Dump



Neutron Back-shine from Dump





# Synchrotron Radiation

## At SLD/SLC SR WAS a PROBLEM

- SR from triplet WOULD have directly hit beam-pipe and VXD
- Conical masks were installed to shadow the beam pipe inner radius and geometry set so that photons needed a minimum of TWO bounces to hit a detector
- Quantitative measurements of background rates could be fit by a “flat halo” model where it was assumed that between 0.1% and 1% (in the early days) of the beam filled the phase space allowed by the collimator setting.

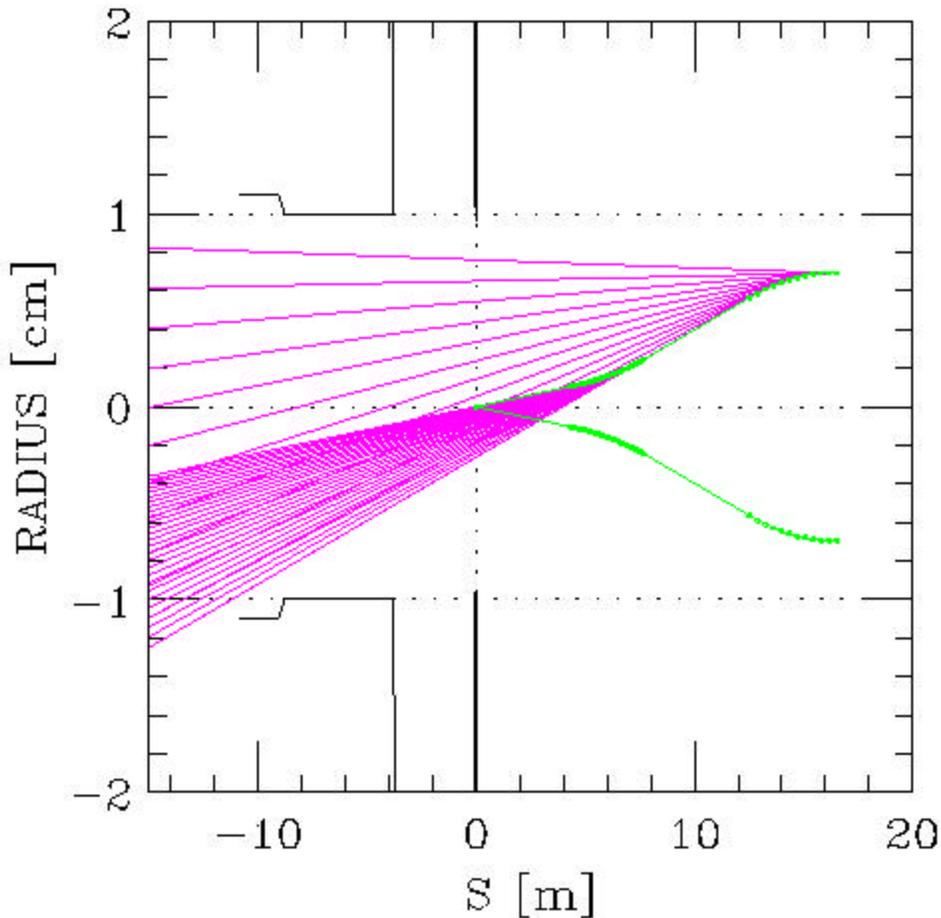
## At NLC/TESLA

- Allow NO direct SR hits ANYWHERE near IP
- SR due to BEAM HALO in the final doublet, not the core of the beam
  - Collimate halo before the linac AND after the linac
  - Halo estimates are  $\sim 10^{-6}$  of beam; designing system to handle  $10^{-3}$
  - Optical solutions to handle halo under development

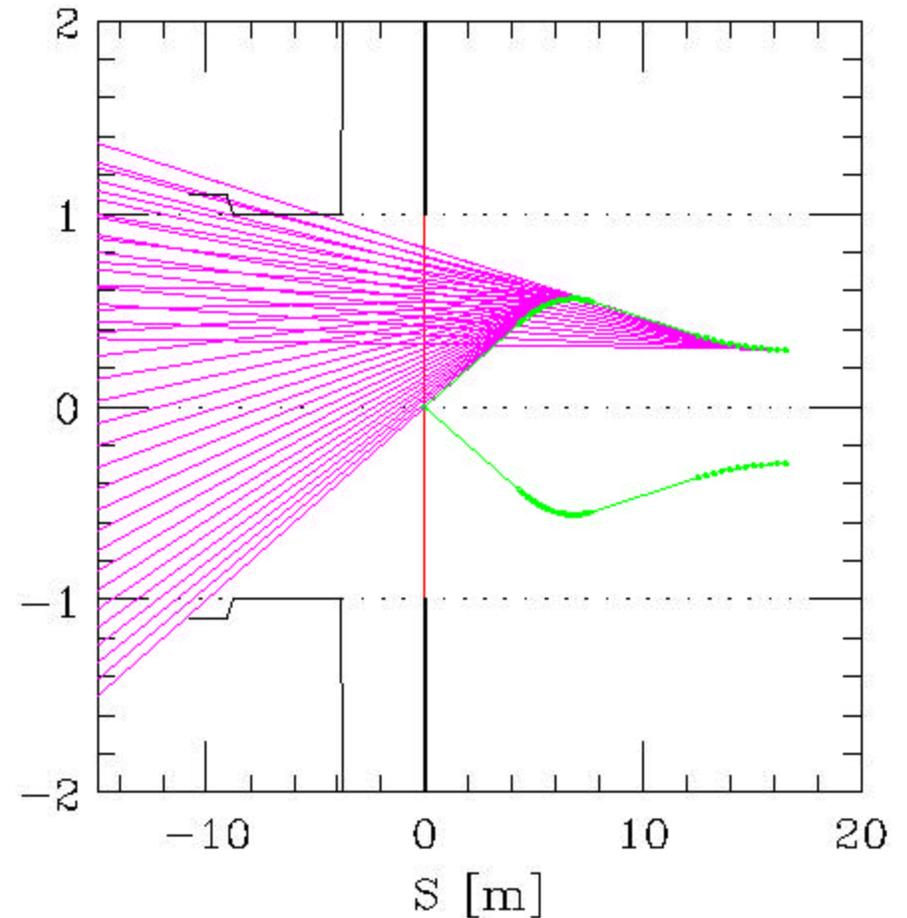


# HALO Synchrotron Radiation Fans with Nominal 240 mrad x 1000 mrad Collimation

X vs S for  $8.57 \sigma * 28.00 \mu\text{rad}$



Y vs S for  $25.00 \sigma * 40.00 \mu\text{rad}$

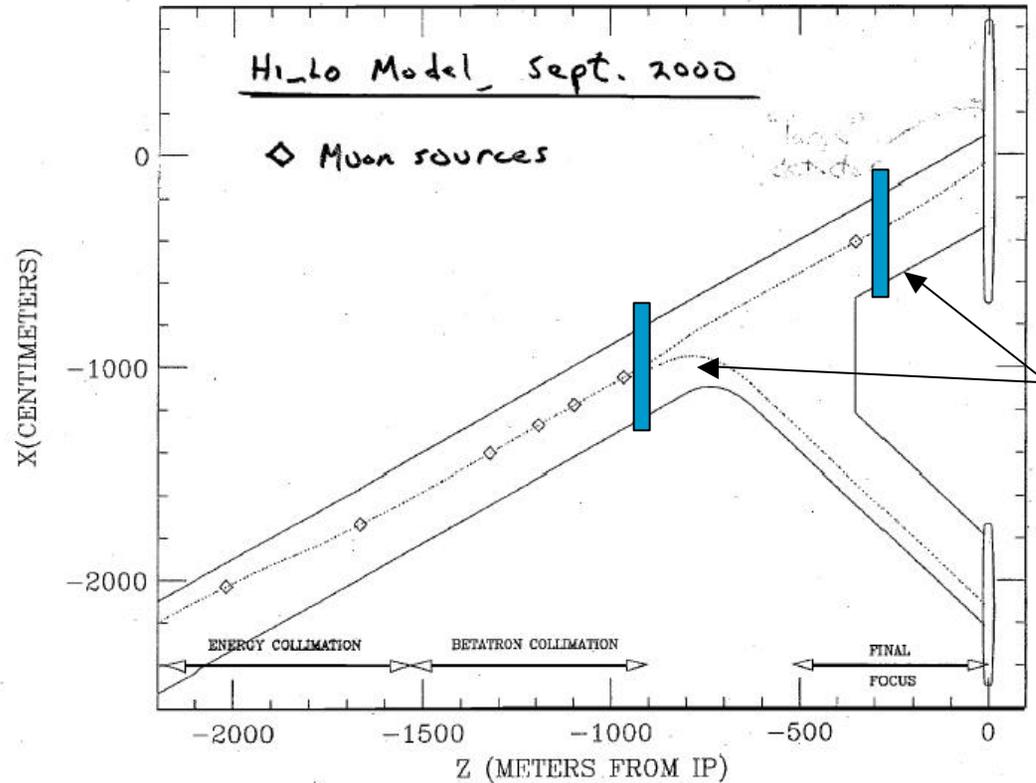


(Similar plots for TESLA)



# Muon Backgrounds

## WITHOUT Big Bend and with New Short FF



Magnetized steel spoilers

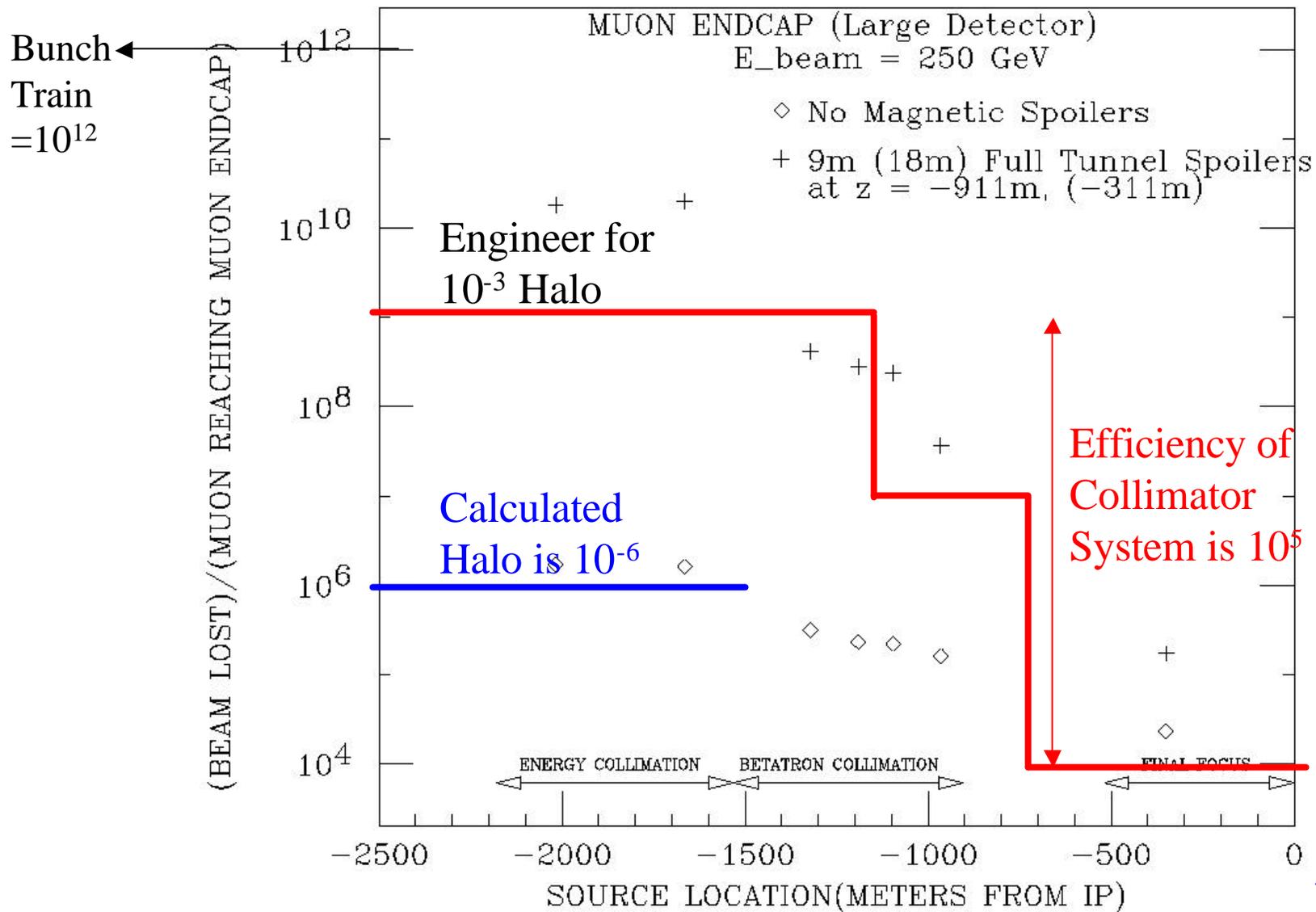
If Halo =  $10^{-6}$ , no need to do anything

If Halo =  $10^{-3}$  and experiment **requires**  $<1$  muon per  $10^{12}$  e- add magnetized tunnel filling shielding

Reality probably in between

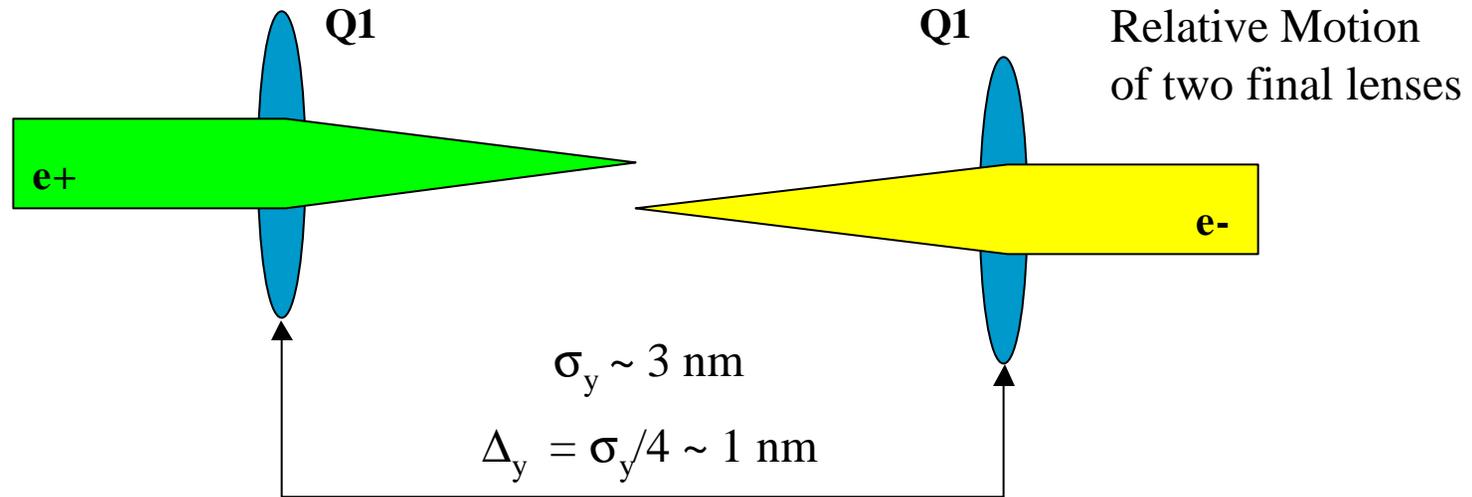


# 250 GeV/beam Muon Endcap Background



## Basic Issue #3

### Colliding Small Beam Spots at the IP



**Control position & motion of final quads and/or position of the beam to achieve/maintain collisions**

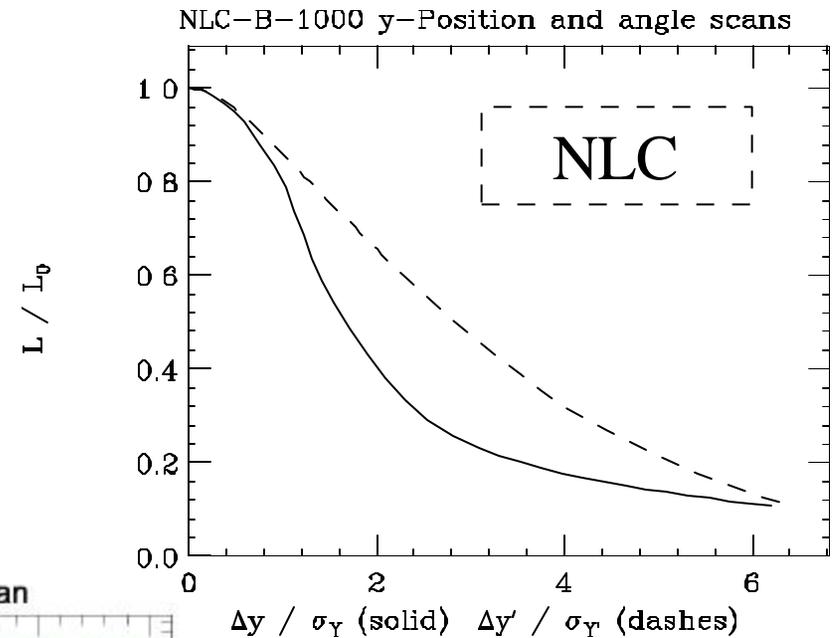
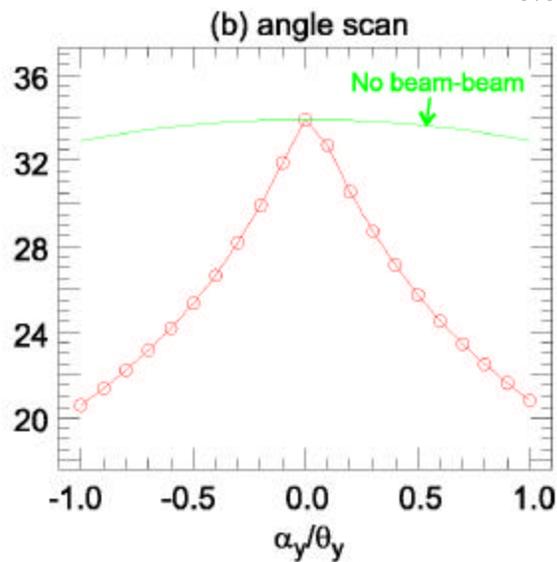
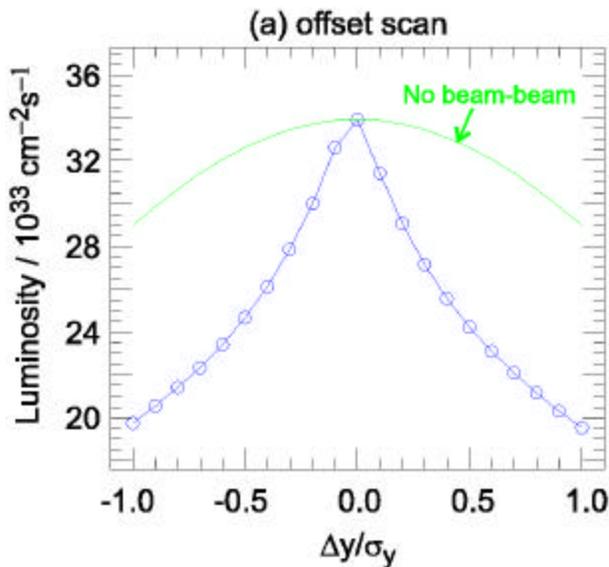
- **Get a seismically quiet site**
- **Don't screw it up: Pumps, compressors, fluids**
- **Good magnet and detector engineering: Light, stiff Q1 in a rigid detector**
- **Tie to "bedrock": get lenses outside detector as soon as possible**



# Luminosity Loss vs. Position & Angle Jitter

## TESLA

Larger  $D_y$  leads to  
sensitivity  $\sim 0.1\sigma \sim 0.5\text{nm}$





## Luminosity Stabilization

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Performance of ALL LCs based on feedback systems such as that developed at SLC

“SLOW” feedback based on machine rep rate  $f$  and can handle motion of frequencies up to  $\sim f/20$  to  $f/60$

- 0.1-1 Hz at TESLA where  $f = 5$  hz
- 2-5 Hz at NLC where  $f = 120$  Hz

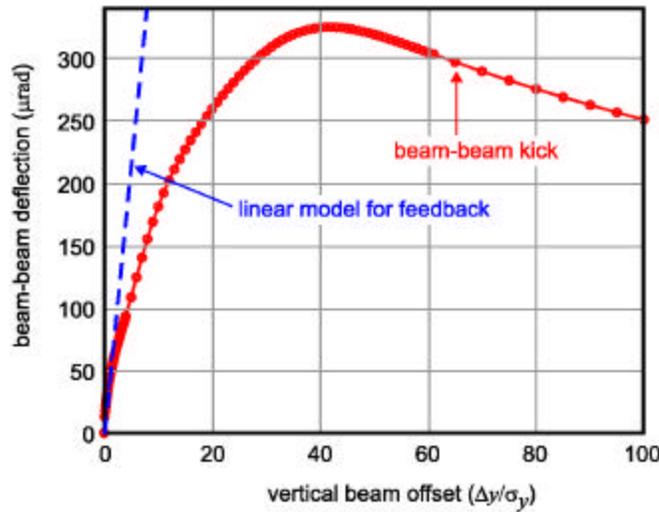
TESLA’s long (2820) train of widely (337ns) spaced bunches allows the extension of the technique to frequencies up to  $\sim 100$  kHz and should handle all correlated noise sources with minimal luminosity loss and little impact to the detector

NLC relies on a variety of techniques to stabilize the collisions against jitter above the 2-5 Hz range

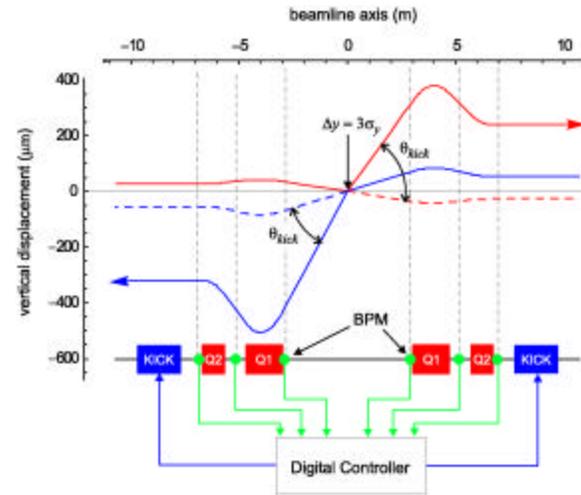


In 90 bunches and  $DL < 10\%$ , bunches are controlled to  $0.1\sigma_y$

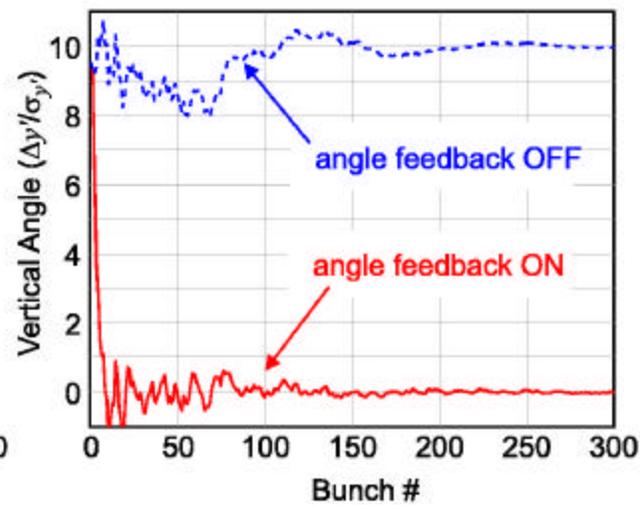
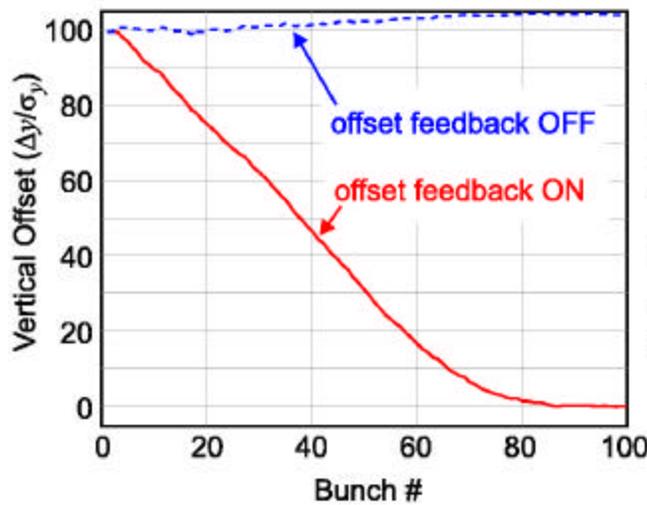
# Intra-train Feedback at TESLA



(a) Separation Response

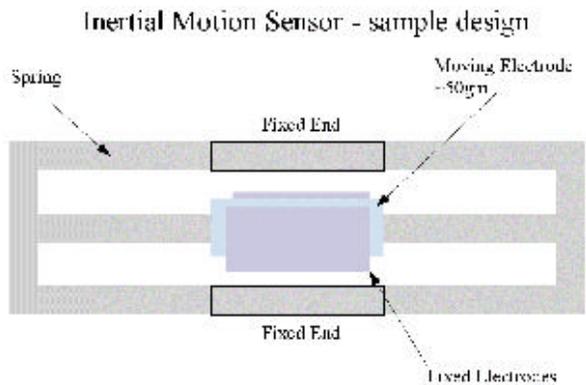


(b) Angle Response

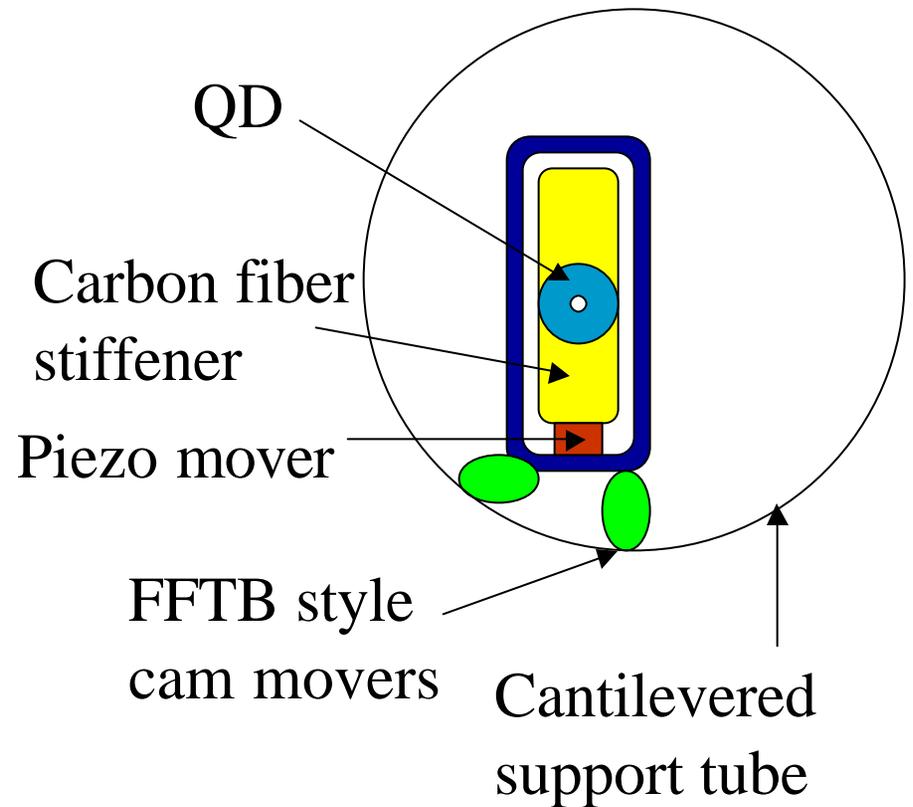
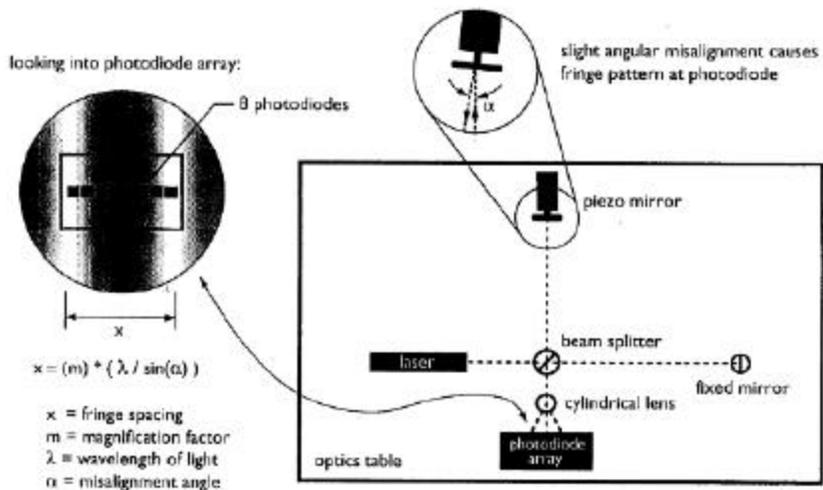


# Sensor Driven Active Vibration Suppression at NLC

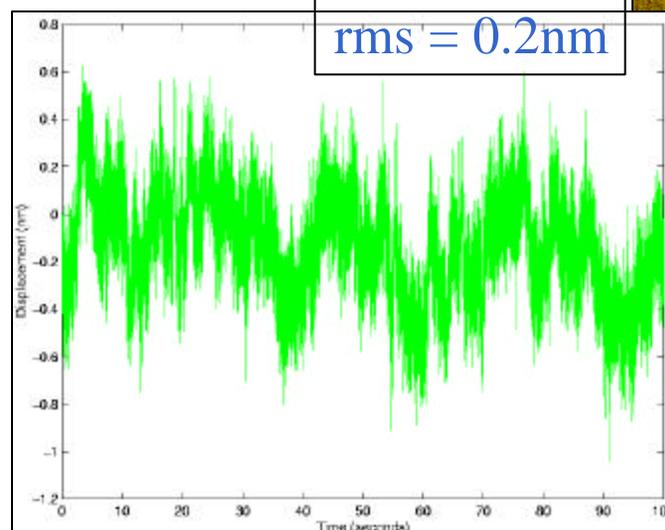
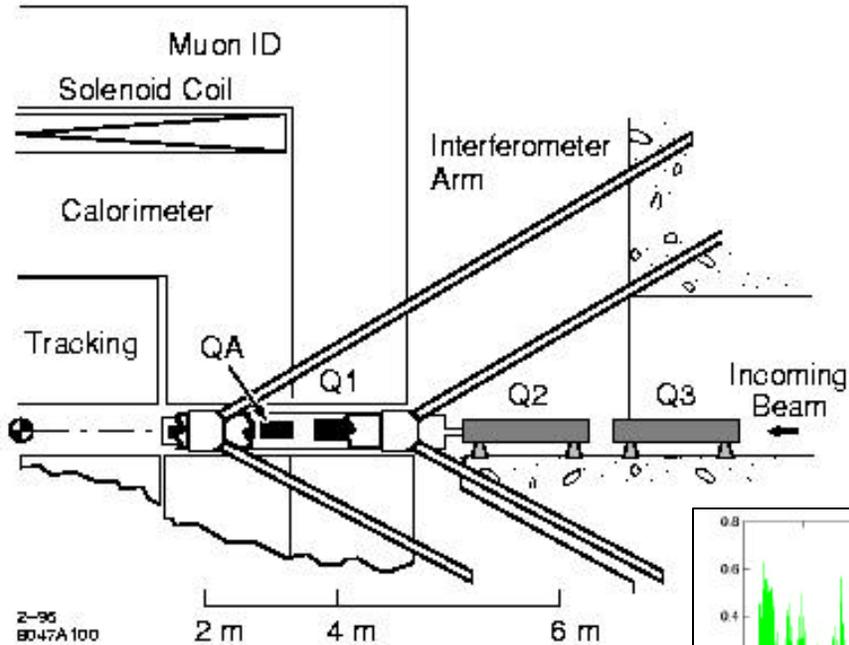
## Inertial Capacitive Sensors



## Interferometric Sensors: Optical anchor



# Optical Anchor R&D

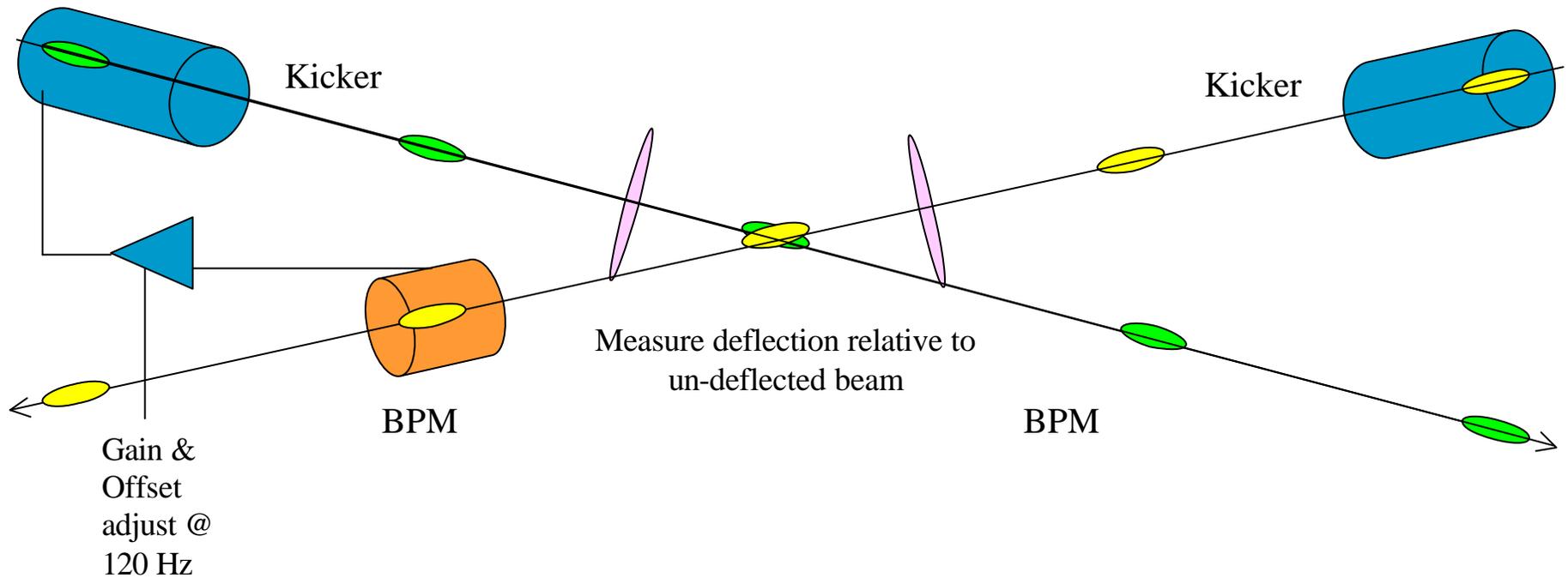


Measured Displacement over 100 seconds

# Very Fast IP Feedback

## Extend Intra-bunch feedback to 270ns long trains at NLC

- Simulation, Optimization, Layout
- Development of BPM sensors and low current correctors
- ASSET-like beam tests





# Intra-Train Feedback Simulations

D. Schulte LCC-026

## Assumptions

Initial offset =  $12 \sigma_y$

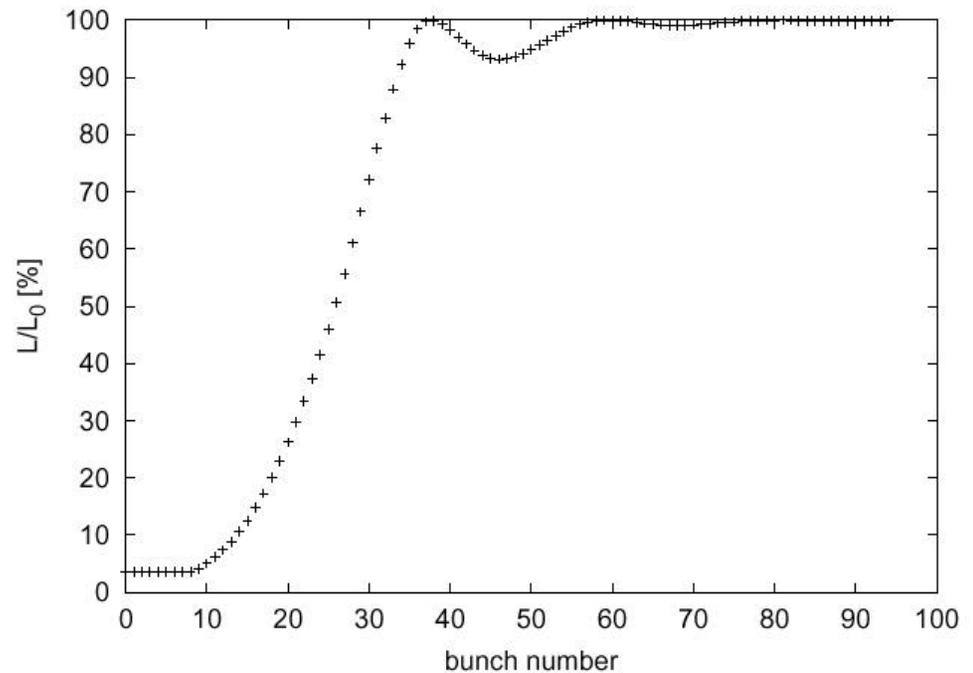
Latency = 20 ns

## Theoretical Performance

### Relative Luminosity

Feedback OFF = 4%

Feedback ON = 73%



## TESLA IR Summary

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- Design exploits large bunch spacing to allow axially symmetric geometry at expense of a possibly more complicated injection/extraction scheme.
- The fact that the detector typically integrates fewer bunch crossings permits larger bunch charges, given similar bunch transverse dimensions, to produce more pinch (and luminosity enhancement) at expense of more backgrounds per bunch and sensitivity to position and angle jitter, neither of which seem to be problems.
- The long trains allow for an extension of the SLC-like beam-beam feedback system to maintain collisions at  $0.1\sigma$  level without significant luminosity loss and minimal impact on the detector.



## NLC/JLC IR Summary

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- Bunch spacing requires a 4-40 mrad crossing angle which does not have any apparent problem, permits space for a separate extraction line, is applicable to the  $\gamma\gamma$  situation, and can accommodate still smaller bunch spacing if higher frequency machines (CLIC) are the path to the future.
- While the detector typically integrates a full 95/190 bunch train of backgrounds, these appear to be at a low enough level to not impact physics. Inclusion of a device with good timing resolution would further reduce the integrated backgrounds.
- The (reduced) sensitivity to jitter at the IP is handled by a combination of mechanical design, optical, inertial, and fast intra-train feedback.

## Conclusion

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Linear Collider IR design issues are common to all proposed machines.

The proposed designs look more similar than different

All projects have been actively collaborating to resolve issues through meetings (BDIR-2000, Daresbury U.K.; GM-2000, SLAC)

constant communication, & personnel exchange

**IR Design is well advanced and not a reason to delay consideration of a linear collider**

**Let's choose a machine technology**

**And get on with it!**