Work supported by Department of Energy contract DE-AC03-76SF00515. certain problems for intercepting detectors and implies sig-
nificantly higher operating costs. For $10 \phi / \mathrm{kWh}$, this repre-
sents a potential refund of as much as $\$ 45 \mathrm{~K} /$ day if energy bunch train in each pulse. This increased beam power poses



 control of the larger horizontal disruption angles. propagating beams. This enables us to reverse polarities
between the ingoing and outgoing quadrupoles for better

 DTS पł!M uosṭeduo ${ }^{\circ}$ II SLC was a prototype for the NLC we begin by reviewing
the SLC and FFTB experience relative to the NLC design. available distance for beam studies of 150 m . Because the leptons should share a common dump. This implies an
available distance for beam studies of 150 m . Because the the cost of beam dumps we decided that the photons and Due to the high power in the outgoing photon beam and leptons. Based on a 'worst' case prediction for these beams have a significant number of pairs and more photons than acteristics of the outgoing disrupted beams. These beams
 important to provide any monitoring and feedback that can tive dumps with minimal detector backgrounds, it is also Our overall goal is to optimize the luminosity. While an
 an assumed 10 MW in each 500 GeV beam. experiments as well as energy recovery and local reuse of
 and stabilization. Prototype optical and diagnostic layouts
are described that provide such functions. We also consider order correlations on a bunch-to-bunch basis for feedback
 the Interaction Point and transporting beams from the IP optimizing luminosity, characterizing beam properties at
the Interaction Point and transporting beams from the IP A prototype extraction line for the Next Linear Collider is
discussed that has several important functions that include ฉ.e.iłsq

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 angle that is more than double our worst case.The available length of the dump line was set by the
and the assumed size of the dump: being used to simulate the dump line with TRANSPORT
(for design) and TURTLE (for tracking) [4]. calculations were compared to analytic calculations before teristics of the outgoing beam as well as to produce ray sets
for all particle types for analysis and tracking. The ABEL used in ABEL91[3] to predict the composition and charac dicted beam parameters resulting from DIMAD were then quadrupoles. One assumption here was that the energy
loss, especially in the quads, can be neglected. The pretance growth from synchrotron radiation in the dipoles and predicting the spot characteristics at the IP due to emitcedure was to take the upstream final focus design 2 ] for know the characteristics of the outgoing beam. The pro-

III. Basic Design Procedures and Constraints e.g. $\Sigma_{y}=1 \mu \mathrm{~m}$ and $\mathrm{N}=3.5 \cdot 10^{10}$ produces a peak deflection the beginning of the line to measure position, angle and disruption angle is dominated by energy, we can measure
the energy loss distribution and use precise RF BPMs in

 The lower invariant emittances and the factor of ten in
energy result in significantly greater disruption effects in

## IV. Optics

Once the disrupted electrons have cleared the detector, taken to be $\pm 5 \mathrm{~m}$ along the IP, using essentially a quadrupole doublet, we observe where the disrupted beam crosses the photon beam using third order TURTLE. Because this was nearly 20 m from the IP and it took 10 m to get the full energy beam moving parallel toward the dump, we find the first available space for diagnostics between 11 and 16 meters. RF BPMs [5] are assumed to begin at 5 m where the outgoing beams are still small and C-Band cavities could have apertures comparable to the quads $(\approx \lambda / 4)$.

The first dipole of a horizontal chicane, used to separate the outgoing photon and electron beams, begins at 16 m . It allows separate experiments, before recombining both beams into a common dump. Figure 1 shows the Twiss functions when the four bends are sized to separate the two beams by $12 \sigma$. Their maximum separation is

$$
\Delta x=2 \rho_{B}\left(1-\cos \theta_{B}\right)+L_{1} \tan \theta_{B}
$$

where $\theta_{B}$ is the bend angle for the full energy of any one rectangular dipole of length $L_{B}=\rho_{B} \sin \theta_{B}$ and $L_{1}$ is the separation between bends BD1 and BD2. Notice that this is just the dispersion $\eta_{x}$ in the center of the chicane. This separation requires a minimum distance of

$$
L_{\min }=2 \rho_{B} \sin \theta_{B}+L_{1}
$$

The change in the bunch separation, due to the chicane, after this point in the central region is

$$
R_{56}=\frac{\delta l_{z}}{\delta p / p}=2 \rho_{B}\left(\tan \theta_{B}-\theta_{B}\right)+L_{1} \tan ^{2} \theta_{B}
$$

This is proportional to the RF phase shift[6]. Thus we have a common beam pipe and sufficient dispersion to measure the energy and spread of the undisrupted beam.

For example, if we want to use the first bend for analyzing low energy particles from the IP or from a laser interaction before this bend, then the first order resolving power for some downstream location $L$ is

$$
R_{1}(\rho, \theta, L)=\frac{\rho(1-\cos \theta)+L \cdot \tan \theta}{\left[x_{i} \cos \theta+x_{i}^{\prime}(\rho \sin \theta+L / \cos \theta)\right]}
$$

In the middle of the chicane $R$ depends on the optics we impose. $R_{12} \rightarrow 0$ for point-to-point so $R=\Delta x /\left(10 \sigma_{x}^{*}=8000\right.$ for a magnification of 10 i.e. this region of the chicane can resolve a single beam, undisrupted energy spread of $\delta \mathrm{p} / \mathrm{p}=0.0125 \%$ while the region directly in front of BD2 gives $R \approx 800$ or $0.13 \%$ capability.

Notice that there were several factors that constrained the bends e.g. electron spin rotation as well as the energy resolution necessary to resolve low-energy electrons near the Compton edge (required for monitoring beam polarization). Further, dipoles drive many higher order aberrations that act to blow the beam up that require higher multipoles to correct. These were not needed to get the beams into the dump with the $12 \sigma$ constraint through the line.


Fig.1: Prototype Optical Layout for the NLC Dump Line.

## V. Instrumentation

The guiding principle in the instrument layout Fig. 2 was to minimize the material in the high power beams. Thus, there is a significant use of lasers to control the production of additional particles. Nevertheless, since beamstrahlung is unavoidable, there are possibilities[7] to use either Compton or beamstrahlung photons that could prove quite useful for monitoring the position, size and correlations of the bunches at the IP on a bunch-to-bunch basis. Clearly, beamstrahlung is quite sensitive to any changes in these parameters at the IP. In fact, the photon distribution is a better measure of the bunch profile at the IP than the outgoing, disrupted electrons. We also assume wire scanners and screens similar to SLC[8].

An important tool for optimizing luminosity at the SLC is the beam-beam deflection scan[9]. This gives the deflection of each beam as a function of the relative offset. Typically, this procedure requires many points and makes a number of assumptions about the beam's characteristics. Multi-bunch trains complicate this. Depending on the beam's aspect ratios, one can estimate many effects as though an additional quad was added e.g. energy loss can be calculated. In lowest order this is proportional to the beam sizes but is very small for SLC so that it is masked by the incident beam's energy spread. Taking the simple expression for the deflection of one particle at the periphery of the other beam:

$$
\theta_{D} \approx p_{\perp} / p=\frac{2 N r_{e}}{\gamma \sigma_{\perp}} \rightarrow \frac{2 N r_{e}}{\gamma\left(\sigma_{x}+\sigma_{y}\right)}=\frac{D_{x, y} \sigma_{x, y}}{\sigma_{z}}
$$

we find a maximum outgoing angle of $\theta_{x, \text { max }}=\theta_{D}=256$ $\mu \mathrm{rad}$. The disruption parameters are $D_{x, y}=0.104,10.2$ while $\sigma_{x, y}^{*}=245,2.5 \mathrm{~nm}$. $D_{y}$ is so large that there is over focusing or a thick lens effect whereas the focusing over the length of the beam in $x$ is weaker but cumulative i.e. more like a simple thin lens. This is most easily dealt with by reversing the polarity of the first outgoing quad.

The final angle of relevance here is the spin precession angle $\theta_{s}$. This can be expressed in terms of the spin tune:


## Fig 2: NLC Electron Extraction \& Diagnostic Line

$$
\nu_{s}=\frac{E[G e V]}{0.44065} \cdot \frac{\Theta}{2 \pi}
$$

where $\Theta$ is some deflection angle in radians. For the bends used here this is typically $2-4$ times the maximum disruption angle $\theta_{D}=256 \mu \mathrm{rad}$. The effective polarization after such a bend is $P_{\text {eff }}=P_{\text {inc }} \cos \left(2 \pi \nu_{s}\right)=0.42-0.84$ although this is just a rotation in the bend plane.

We need to make a good measurement of the polarization that doesn't interfere with the primary disrupted beam on its way to the dump or other measurements. While this can be done at other locations, it is done here in the middle of the chicane shown in Fig. 2 because this is where the dispersion is largest and the net rotation from the bends is zero. In our worst case scenario $20 \%$ of the beam goes undisrupted i.e. should have its original polarization. Compton scattering can then be used to monitor the polarization at this point by measuring the asymmetry in the scattered electrons as a function of laser polarization[10].

For best results, one needs to measure the electrons near the Compton edge with good resolution. In lowest order:

$$
\epsilon_{c}^{e d g e}=\frac{\epsilon_{i n}}{1+x}=\frac{\epsilon_{i n}}{1+0.0153 \epsilon_{i n}(G e V) \omega_{L}(e V)} \approx 26 \mathrm{GeV}
$$

Because these electrons fall on the far tail of the disrupted beam spectrum, the only requirement is the ability to resolve their energy to one-half GeV i.e. a resolving power of only $R=\mathrm{P} / \Delta \mathrm{P} \geq 50$. Because $R=8000$ for the full energy beam, there is clearly no problem i.e. the laser spot can be any required size up to $\eta \delta \approx 4 \mathrm{~mm}$. This is also a good place to measure the electron beam profile and disruption characteristics to monitor bunch overlap, synchronization and luminosity.

## VI. The Beam Dump

The dump has to dispose of essentially all of the power. Water is the primary absorber in a cylindrical vessel housing a vortex-like flow of water with vortex velocity $\approx 1-1.5$
$\mathrm{m} / \mathrm{s}$ normal to the beam momentum. The vessel is 1.5 m diameter and has a $5.5-6.5 \mathrm{~m}$ long water section, followed by $\approx 1 \mathrm{~m}$ of water-cooled solids to attenuate a $500-750 \mathrm{GeV}$ EM cascade shower. The beam enters through a thin window $\approx 1 \mathrm{~mm}$ thick and 20 cm diameter. Production of $\approx 3$ $l \mathrm{H}_{2} / 10$ MW beam power from radiolysis[11] can be mitigated with a catalytic $\mathrm{H}_{2} / \mathrm{O}_{2}$ recombiner that has a closed loop system that contains all radioisotopes.

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