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SUMMARY OF WORKING GROUP SEVEN PART II: LINAC PROTECTION AND COLLIMATION OF MEGAWATT MICRON SIZED 250-500 GeV ELECTRON BEAMS*,◇

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Order of Presentation

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◇Work on collimation systems was presented in Working Group 7 by B. Holzer, Deutches Elektronen Synchrotron, D-2000 Hamburg 52, Germany, and J. Irwin (SLAC).

ABSTRACT

The average beam powers and beam size anticipated for next generation linear colliders makes them awesome tools of destruction. Systems for machine protection will be crucial. A scheme for linac structure protection by sacrificial collimators is presented in Section 3.

No matter what precautionary measures are taken, the tails of the beam will be populated by hard coulomb collisions along the linac. To remove these halos before reaching the final focus sytem optics, where particle showers can blind the detector, it will be necessary to collimate these beams. Section 5 discusses the equations governing the parameters of a conventional collimation system. Wakefields determine gap sizes and lattice functions. Materials properties dictate mimimum beam sizes at collimators so they can withstand occasionally mis-steered beams. Spoiler scattering and edge scattering effects mandate that the final doublet phase be collimated twice, and depending on the results of further tracking studies, it may be necessary to collimate each phase two times. Section 6 describes a nonlinear collimation system that can collimate beams to smaller apertures than the conventional system. The tolerances for such systems resemble final focus tolerances. Section 7 addresses the problem of repopulation of the tails after the collimation system.

The main conclusions are that it appears possible to collimate the beams for these machines with conventional passively protected collimation systems. However the length of present designs, which collimate energy and both transverse planes and meet the requirements of complete tail scraping, exceed one kilometer per linac. A collimation system may also be desirable at the low energy end of the linac to minimize collimation of high energy particles.

1. Horrors

The beam powers being considered have enormous destructive capability. Several experiments (as well as accidents) at the SLC have demonstrated this, and confirmed methods for estimating and quantifying consequences. The entry-point temperature rise for beams from all of the present design parameters for a single pulse train or until turn-off, whichever is smaller, is shown in the Table on page 7.II.3 (these page numbers refer to numbers occurring on the accompanying transparancies—7.II. refers to Working Group 7, Part II.) A single mis-steered pulse train from any of these machines can destroy a substantial length of linac accelerating structure.

2. Properties of materials

We propose use of various materials in protection and collimation systems:

- Tungsten for sacrificial spoilers in the linac and clean-up collimators in the collimation system, because of short length per radiation length;
- Carbon (plated) for spoilers in the collimation system, because of their low entry-temperature and thermal ruggedness;
- Copper for the main absorbers in the collimation system, because of their good thermal conductivity.

The graph on page 7.II.2 shows temperature rise in carbon and titanitum as a function of radiation length for a 10^{11} particle pulse with a $\sigma_x \sigma_y$ product of 2000 square microns.

3. Linac protection

The most likely failure scenarios involve elements, like feedback correctors, that are designed to change on a pulse-to-pulse basis. The worst-case scenario addressed here consists of:

- The between-pulse short of two legs of a single quadrupole,
- No immediate response by the magnet monitoring system, and
- No detection of beam trajectory change from downstream BPMs.

We assume machine turn-off in one pulse based on a signal from machine protection ionization monitors.

The linac may be protected from this failure mode by "sacrificial spoilers" at each quadrupole. Proposed spoilers are made of tungsten; have an aperture about one quarter of the quadrupole tip radius; are 5 cm long, and have an entrance and exit taper (to reduce wakefields) of about 5 cm each. The effect of the wakefields on beam emittance has been calculated and is negligible. Condition determining length is that temperature rise of downstream copper from residual photon beam should be less than 200°C. The spoiler will burst in one pulse, with resulting release of tungsten vapor. The impact on conventional and superconducting structures needs to be assessed.

4. Collimation requirements

On page 7.II.6 there is a diagram of a typical final focus doublet showing 10 σ trajectories in both horizontal and vertical plane. This particular doublet design allows for a σ_x two times smaller than that for $\sigma'_x = \sigma'_y$. Flexibility in σ_x is desirable because of strong dependence of beam-beam dynamics on σ_x. Doublet apertures are somewhat larger than those required based on consideration of resistive-wall and geometric wakes. They are a little larger yet in this design. Collimation for this doublet is required at about 5 σ_x and 30 σ_y to avoid Synchrotron Radiation (SR) photons from impinging on quadrupole bore.

5. Conventional collimation system

The typical system consists of a thin, thermally-rugged spoiler, followed by a thick, conductive absorber. These are shown together with exemplary lattice functions in the figure on page 7.II.9. The beam must be large enough at the spoilers so that the spoilers are not destroyed.

Wakefields also control conventional collimation system design. The $1/g^3$ behavior for resistive-wall wake and the $1/g^2$ behavior of taper section for taper length are chosen to minimize total kick from geometric and resistive wakes. Collimation system is a jitter amplifier, where the component produced by the system is perpendicular to incoming jitter. The resultant controling equation is

$$2x^3 - 3ax^2 + 1 \leq 0$$

where definitions of terms are given on the bottom of page 7.II.8. Equations are more complex when there are several collimators of different length and material in each phase. For Next Linear Collider (NLC) parameters, in the horizontal plane, $n_{\min} = 3$ and in the vertical plane, $n_{\min} = 20$, for a 40% increase in jitter. The practical working point is about $n = 5$ in the horizontal and $n = 35$ in the vertical. Possibly, because of large final doublet aperture, a conventional system would be adequate for collimation.

Because of the large amount of scattering from the spoilers, three phases of collimation are certainly required, and perhaps four phases (Interaction Point (IP) phase, Final Doublet (FD) phase, IP phase, FD phase) will be necessary, so that the edge scattering from the last phase collimated is acceptably small. The goal is *zero* particles hitting the final doublet, assuming up to 1% of 10^{12} being collimated. About one tenth of the particles hitting within .1 μ from the edge of the final scrapers re-emerge at large angles in the beam. See pages 7.II.10 and 7.II.11.

Lattice functions for a three-phase system, followed by the big bend for muon protection, are shown on page 7.II.12.

6. Nonlinear collimation system

If a conventional system is not adequate, a nonlinear system can be used to scrape apertures that are smaller yet. The beam is first blown up by a sextupole, then collimated, then a second sextupole at $-I$ cancels out the effects of the first. Equations governing this system are shown on pages 7.II.13 and 7.II.14. Jitter at the sextupole causes jitter at the scraper, in addition to incoming beam jitter at scraper phase. The wakefield kick at the scraper can result in incomplete cancellation of the sextupoles.

Tolerances on sextupole stability (over time periods between lattice checks with diagnostic bumps) are quite small (.4 μ in one system investigated)—comparable, but still larger than, similar tolerance (.1 μ) in the final focus system.

Possible lattice functions are shown on page 7.II.15. Lattice functions for a nonlinear system combined with a conventional system are shown on page 7.II.16.

7. Tail repopulation

Hard coulomb scattering can result in a repopulation of the tails as the beam travels from the collimation system to the IP. There is a maximum angle for this scattering, determined by the nuclear species and radius, with the result that the R_{12} from the scattering point to the final doublet must be greater than 200 m for a particle scattered there to hit the doublet. A very large R_{12} occurs in the collimation system when the IP phase is scraped, so it follows that the FD phase must be scraped last.

Page 7.II.18 shows that the integral of the ratio of $(R_{12}/200)^2$ over the beam line for which this ratio is greater than one, must be less than 280 m for a gas pressure of 10^{-8} Torr which indicates that a gas pressure of one quarter 10^{-8} Torr will be required in the big bend.

8. Conclusions

It looks possible to protect the linac from the worst credible failure (and others as well).

It looks possible to collimate the beam with conventional collimation for all designs now being considered. However, the system requires considerable length, and lengths have yet to be optimized. Ideas for length reduction are welcome!

Much design work remains to be done, particularly to combine an EGS code with particle tracking, to follow all particles produced at scrapers and other accelerator parts, and to determine placement of absorbers along with cooling and radiation protection requirements.

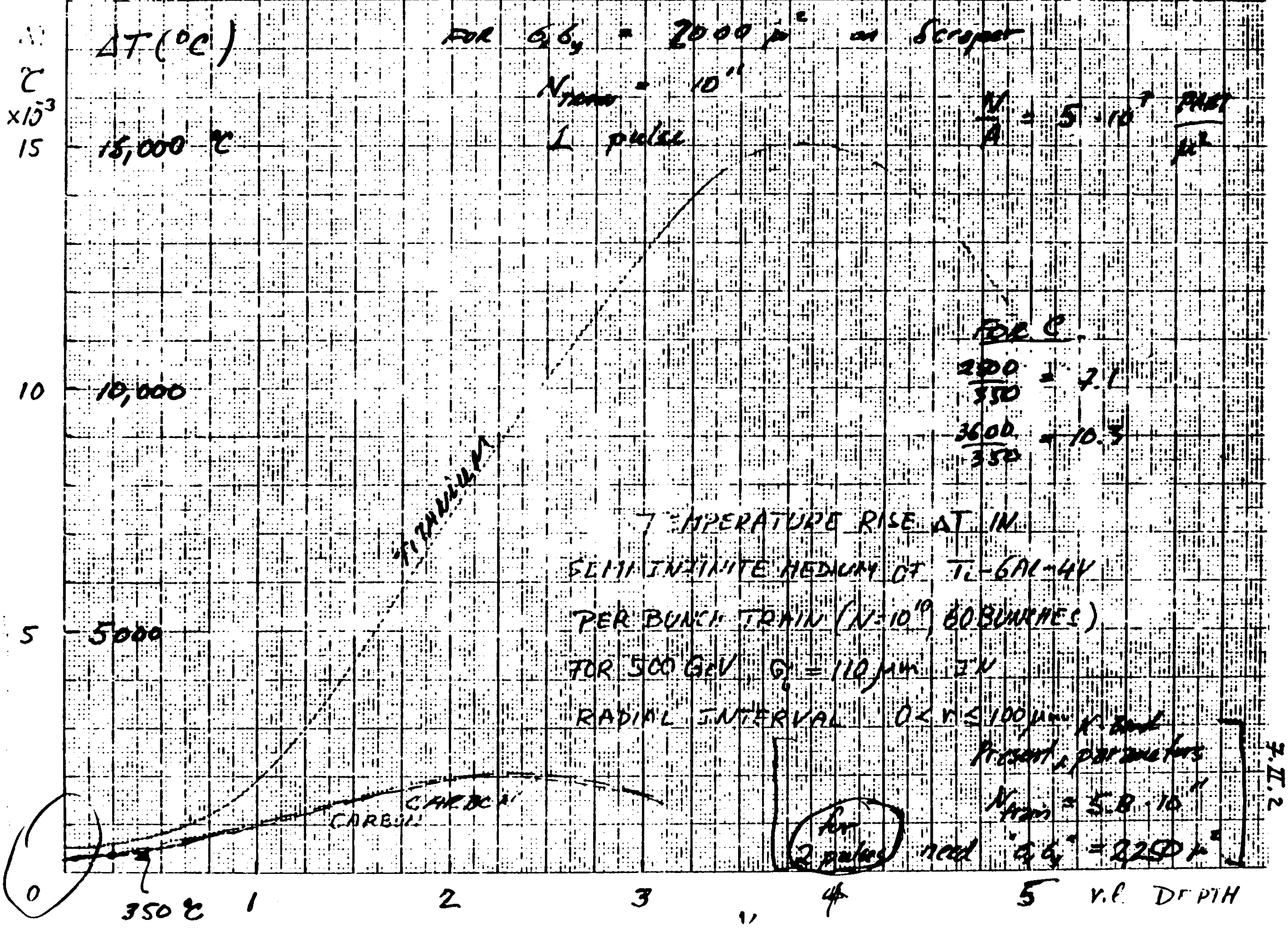
II. PROPERTIES OF MATERIALS

Temperature Limits (°C)

		Stress Limit	Melting Point	Vaporization Temp.	
THIN	CARBON (Graphite) (Pyrolytic)	≤ 2500	3600	4200	← but high ρ. (× 300)
	Titanium	≤ 1000	1800	3260	
THICK	Copper	≤ 180	1080	3000	but comes in as $\rho^{1/12} = \underline{1.6}$
		↑ FAILURE MODE for single train	↑ FAILURE for multiple TRAINS		

TEMP vs X_{RL}

D.R. Walz 6-17-92

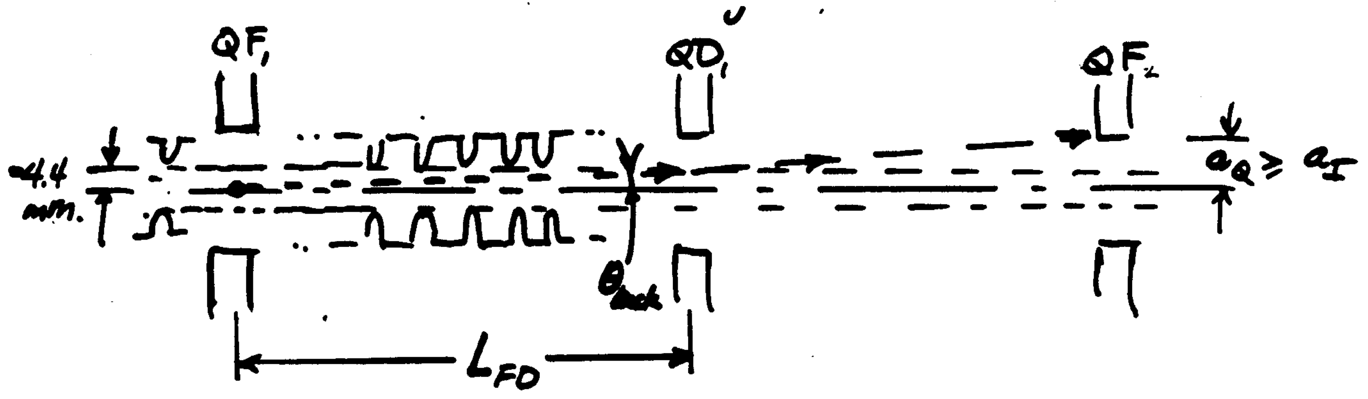


SURFACE ENTRY POINT TEMPERATURES.
END OF LINAC

	DLC	JLC	NLC	VLEPP	CLIC	TESLA
$(\times 10^{10})$ N (til turn-off)	(172)·2.1	(72)2.1	(90)·.65	(1)·.20	(4)·.5	(80)5.1
A (μ^2) End of Linac	30	8	10	18		600
$\frac{N}{A}$ $\left(\frac{10^{10}\,\#}{\mu^2}\right)$	12	19	6	1		.7
$\frac{N/A}{(N/A)_{\text{GRAPH}}}$	2400	3800	1200	200		140
$T_{Ti}\Big\vert_{\text{SURFACE}}$	$1.2\cdot10^{6}$	$1.9\cdot10^{6}$	$6\cdot10^{5}$	10^{5}		$7\cdot10^{4}$

CONCLUSION: SINGLE "TRAIN" OF MIS-STEERED BEAM CAN DESTROY SUBSTANTIAL LENGTH OF ALL THESE LINAC.

III: LINAC PROTECTION



SUPPOSE QF_1 fails catastrophically -

BEAM GETS DIPOLE KICK AT QF_1

$$\theta_{kick} = \frac{B_D L_Q}{B\rho} = \frac{B_T L_Q}{a_Q B\rho} \cdot \left(\frac{B_D}{B_T}\right) \cdot a_Q$$

$$= (k_Q a_Q) \cdot \left(\frac{B_D}{B_T}\right)$$

Beam Position AT QD

$$r = \theta_{kick} \cdot L_{FD} = (k_Q L_{FD}) \cdot \left(\frac{B_D}{B_T}\right) \cdot a_Q$$

$$= \sqrt{2}\ \frac{B_D}{B_T} \cdot a_Q.$$

$$\boxed{\text{if } \frac{B_D}{B_T} < \frac{1}{\sqrt{2}} \quad r < a_Q \ !}$$

Beam POSITION AT QF_2

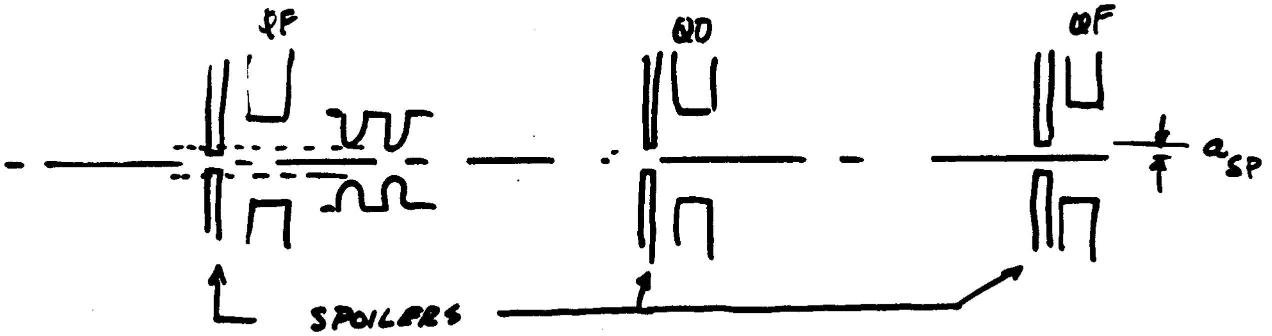
(assume kick in x plane (defocussing)

$$x_{QF_2} = \underbrace{(2+\sqrt{2})}\, x_{QD_1} = \underline{4.8\ \frac{B_D}{B_T} \cdot a_Q}$$

FOR ≈90° FODO LATTICE

$$\boxed{\text{if } \frac{B_D}{B_T} \geq \frac{1}{5} \quad x_{QF_2} > a_Q}$$

III. LINAC PROTECTION (cont'd)



"SACRIFICIAL" PROTECTION

NEED

1) $(2+\sqrt{2})\, a_{SP} \leq a_I \Rightarrow \underline{a_{SP} \leq 1.3\text{ mm}}$

must taper ~ 40mrad

2) $\underbrace{\left(\frac{15}{E(\text{MeV})}\sqrt{t}\right)}_{\theta_{RMS}} \cdot L_{FD} \geq \underbrace{2\text{ mm}}$

valid for small t only

Cu protection @ $6\cdot10^{11}$ part. (1 bunch train!)

$L_{FD} = \sqrt{\frac{\gamma}{\gamma_0}}\, L_0$ w. $L_0 = 2.2$ m. $\gamma_0 mc^2 = 16$ GeV

$E(\text{MeV}) = \frac{\gamma}{\gamma_0}\cdot 1.6\cdot 10^4$

$\underline{t \geq .24\left(\frac{\gamma}{\gamma_0}\right)\text{ RL.}}$

AT 500 GeV

$\underline{t \geq 7.2}$ RADIATION LENGTHS (but $\sqrt{t}$ not valid)

Perhaps $t \sim 5$ r.l. needs to be determined

7.II.6

IV. COLLIMATION REQUIREMENTS
FINAL DOUBLET

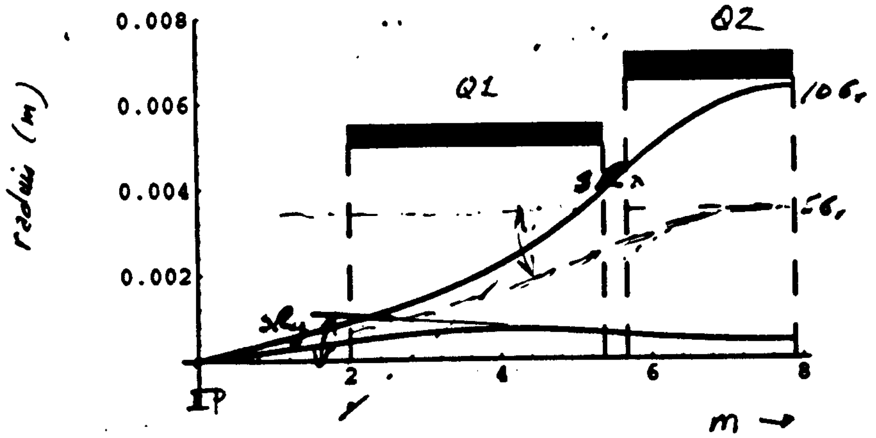
$E = 500$ GeV $L^* = 2m$

$$\boxed{\frac{\beta_x}{\beta_y} = 25}$$

x2 Luminosity Inc!

```
                   -12              -14
egev=500  epsx=5. 10      epsy=5. 10
betaystar=0.0001 betaxstar=0.0025  betaRatio=25

lfree=2.  dfree=0.3 anal=False
btip=1.4  aperture=0.005  aperatio=1.3 nsig=10

Lchromy=3.33652  Lchromx=32.2961
 psiy=33365.2 psix=12918.5

sigayMax=0.0000705421  betayMax=99523.8  nsigyStayClear=

  70.8796
sigaxMax=0.000632935  betaxMax=80121.3  nsigxStayClear=

  10.2696

TenSigx[endOfQ1]/aper[Q1] =0.785447
TenSigx[endOfQ2]/aper[Q2] =0.973746

R12yEntryOverLchromy=0.580394
delyRWOveryStar=0.0911243
```

chromaticities getting large



CHOOSE: $5\sigma_x$ & $15\sigma_y$

AS PREFERRED COLL. σ's.

~ SR mask between Q1 & Q2. (!)

7.II.7

DESIGN EQUATIONS for CONVENTIONAL COLLIMATOR

1) It scrapes, eg:

$$\boxed{n\,\sigma_x = g}$$ (at scraper)

2) BEAM AREA $> A_{min}(t_{RL}, N_{train})$ (at spoiler)

For C , $t_{RL} = 0.25$ 2 pulses, melt Failure
no safety fac.

$2\,(.65 \cdot 10^{10}) \cdot 90$

$= 11.7 \cdot 10^{11}$ $\Leftrightarrow$ $A_{min} = 2{,}200\,\mu^2$

For $\frac{\text{500 GeV}}{\text{BEAM}}$ Emittances & $A_{min} = 2000\,\mu^2$

$$\boxed{\sqrt{\beta_x \beta_y} = 4000 \text{ m}}$$ (2000 m @ 250 GeV/c)

3) • Res. Wall Wake + Geom WAKE INCREASE
BEAM SIZE By $\leq$ 2%.

• SCRAPER IS TAPERED TO MINIMIZE
THIS SUM

$$\rightarrow \theta_{TAP} = 0.6 \left(\frac{\lambda_\delta \sigma_z}{g^2}\right)^{1/4}$$ (λ_δ is skin depth)

CONVENTIONAL COLLIMATOR EQUATIONS (cont'd)

NOTE: WE ARE USING WAKEFIELD EQUATIONS.

④

$C_2 = 2.2$
$$\theta_{RW}^4 = C_2 \cdot \frac{N r_e}{\gamma \sigma_z} \cdot \sqrt{\frac{\lambda_p}{\sigma_z}} \cdot \frac{\Delta y \; \sigma_z \cdot L_{SCR}}{g^3}$$

We usually assume "t 6" beam jitter!

∴ if scraper has slow taper to beampipe $r >> g$.

$$\theta_{RW} = C_2 \frac{N r_e}{\gamma \sigma_z} \sqrt{\frac{\lambda_p}{\sigma_z}} \cdot \frac{\Delta y \; \sigma_z}{g^2} \left(\frac{L_{SCR}}{g} + \frac{1}{\theta_{TAP}} \right)$$

$C_1 = 1.5$
$$\theta_{GEOM} = C_1 \frac{N r_e}{\gamma \sigma_z} \cdot \frac{\Delta y}{g} \cdot \left(\frac{6}{\pi} \theta_{TAPER} \right)$$

Using Eqn 1 & Eqn 3c we get:

$$2x^3 - 3ax^2 + 1 \leq 0 \qquad x \equiv \left(\frac{g}{g_{min}} \right)^{1/2}$$

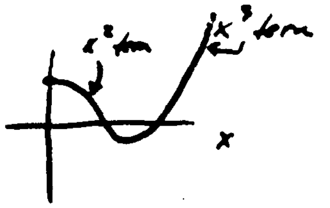
w/

$$a = \left(\frac{n}{n_{MIN}} \right)^2$$

35/350 (250)

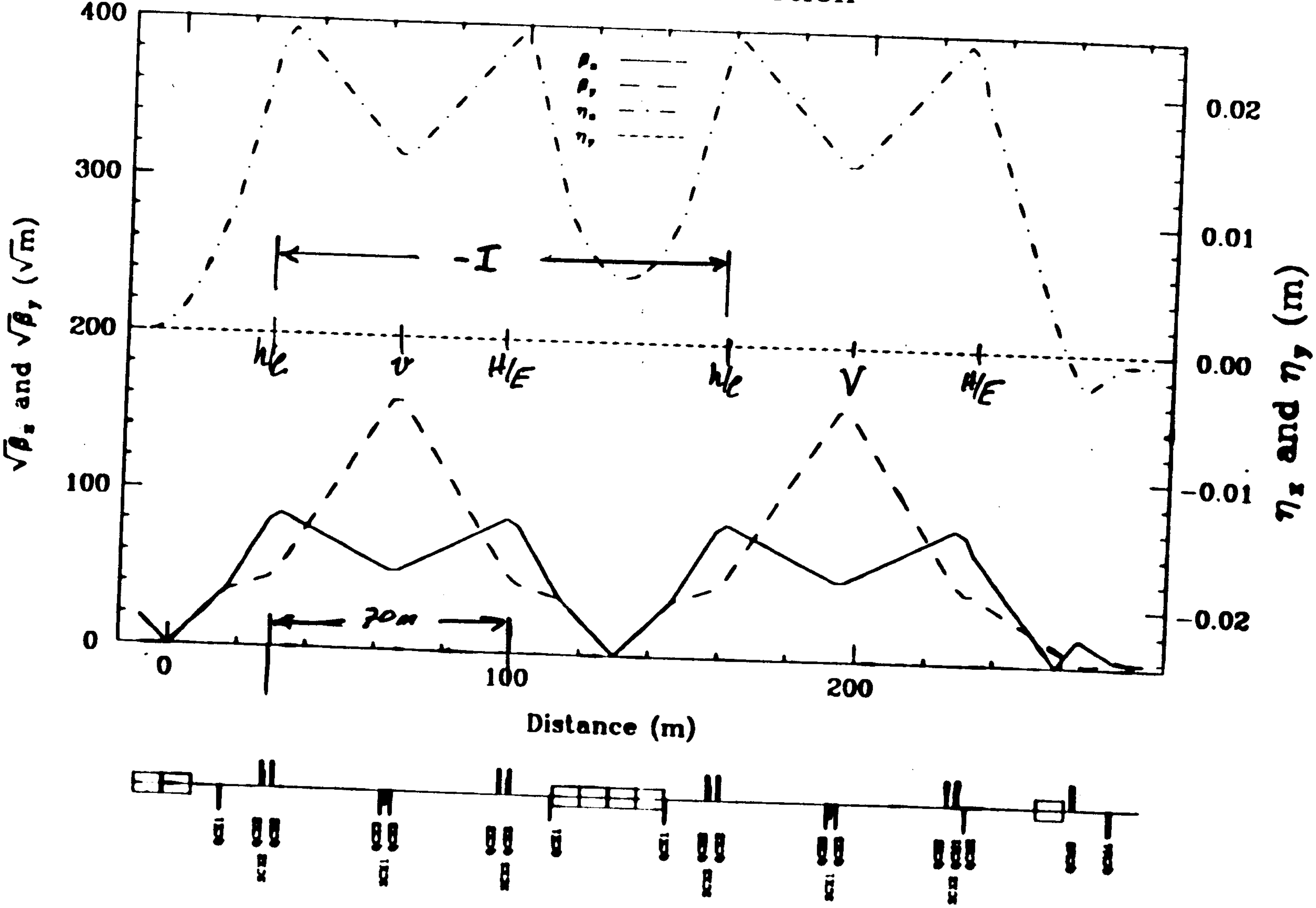
5/50 (500)
$$n_{min}^2 = 76 \cdot t \, \frac{N r_e}{\gamma \sigma_z} \cdot \frac{g_{min}}{\varepsilon}$$
ε_N

700μ
$$g_{min} = .84 \; L_{SCR}^{2/3} \, (\lambda_p \sigma_z)^{1/6}$$
← g at $n = n_{min}$.



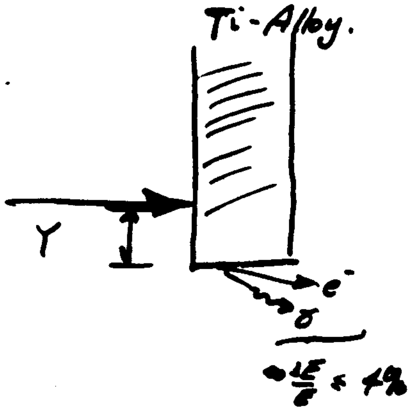
h/c . v . H/E — h/c . V . H/E

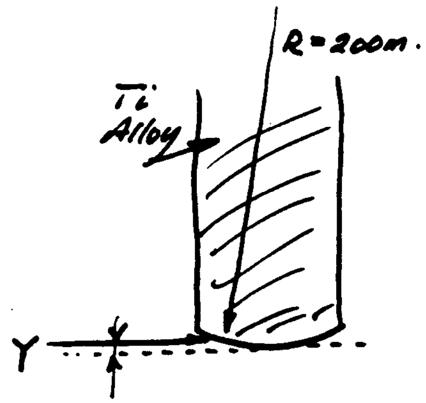
500 GeV Conventional Collimation section



7. II. 10

IIii/ EDGE SCATTERING RESULTS (EGS R. NELSON.





16 ~ 100 μ

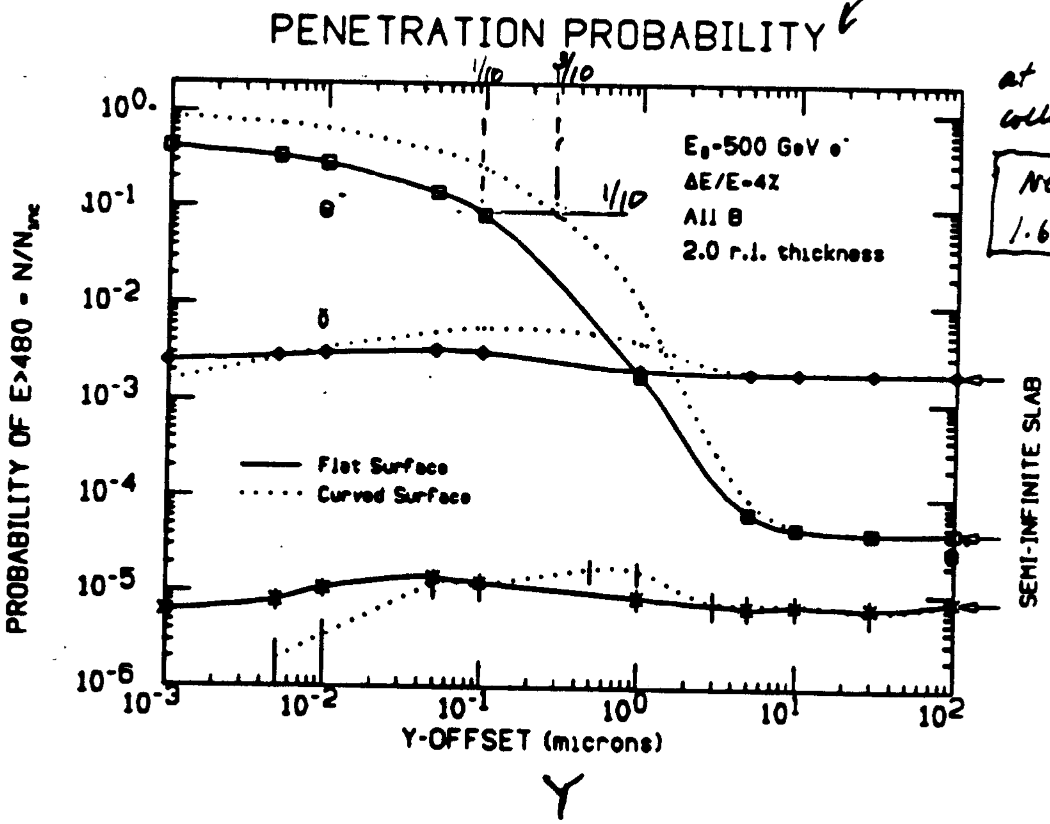
$\frac{.1}{100} = 10^{-3}$

↓

10^{-4}

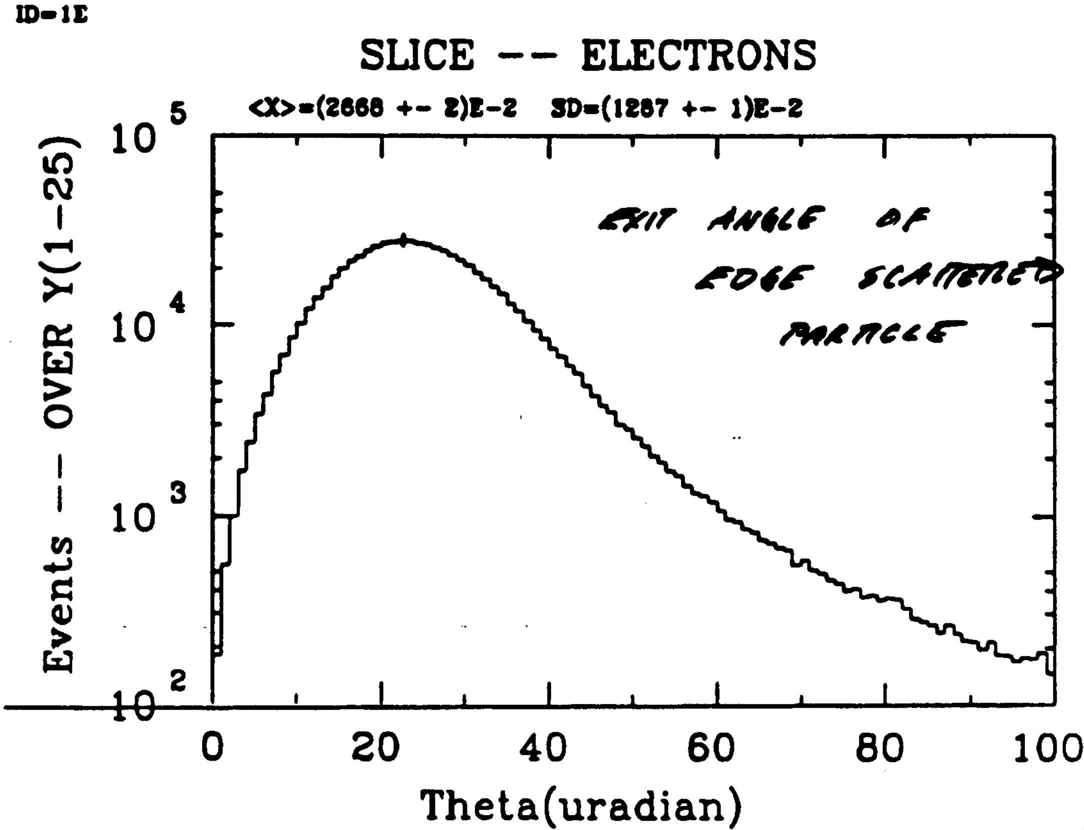
at one collimator!

$\boxed{\text{Need } 1.6 \times 10^{-10}}$



IIii/ EDGE SCATTERING

500 GeV INCIDENT PARTICLE @ 0.1 μ



$10^3\sigma$

$\sigma_x' \sim 35$ nrad

$\sigma_{y'} \sim 3.5$ nrad

$10^4\sigma$

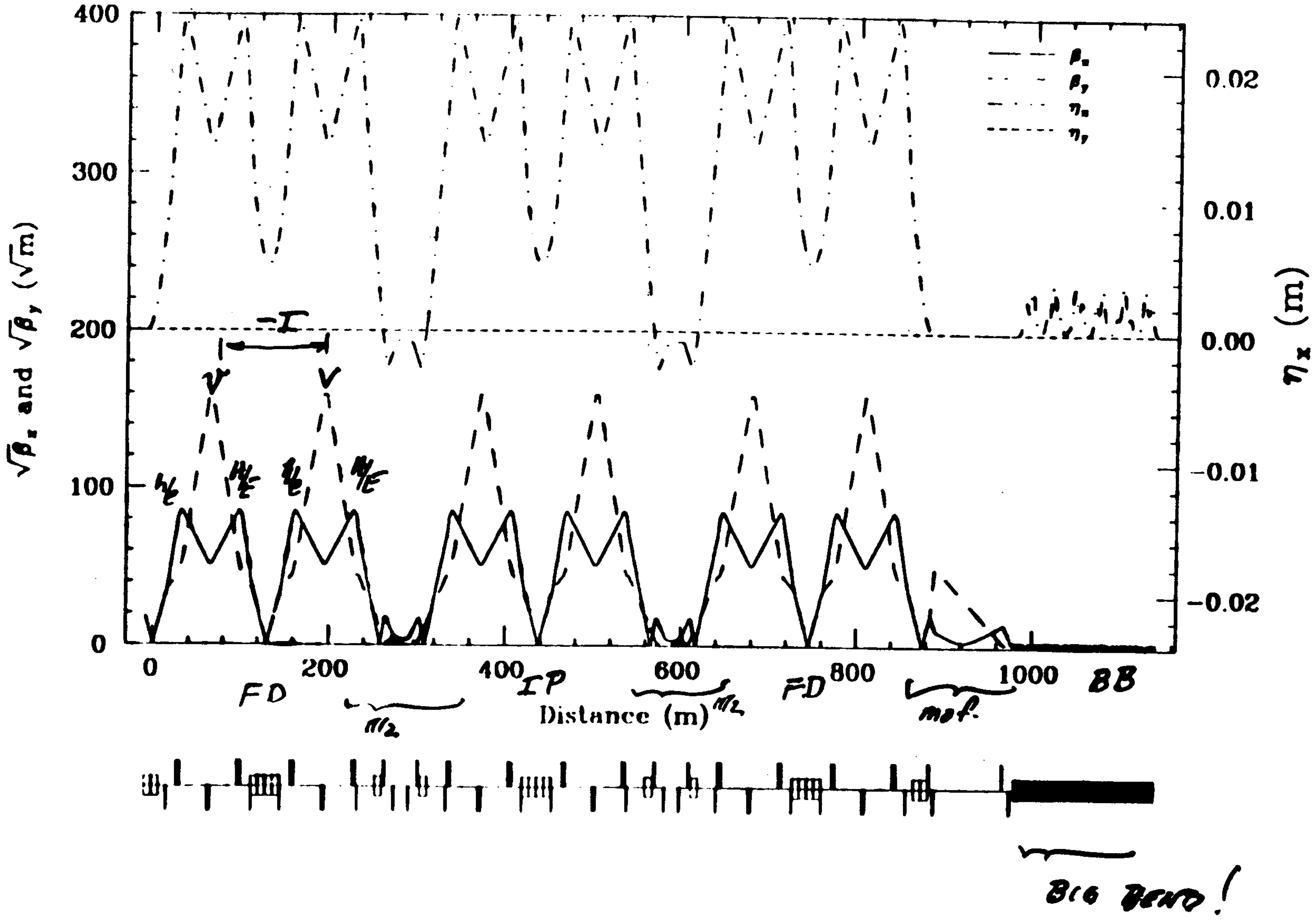
IF USE $\theta_{rms} = \dfrac{15\sqrt{E}}{E_{(MEV)}} \approx 25\ \mu r$

GET $t \approx 0.7$ (RL)

3# (35)

CONVENTIONAL SYSTEM

500 GeV Conventional Collimator & Big Bend 920406

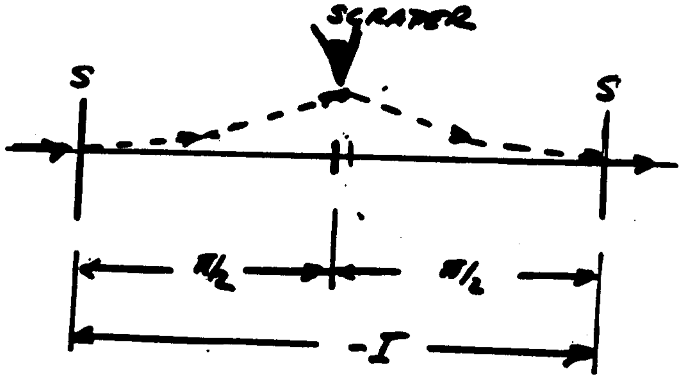


7.II.'92

7.II.13

VI: NON LINEAR COLLIMATION

THE IDEA:



S = SEXTUPOLE - for x kick $\Delta x' = \frac{1}{2} k_s x^2$ $\sigma_x \gg \sigma_y$

SS = Skew Sextupole - for y kick $\Delta y' = \frac{1}{2} k_{ss} y^2$ $\sigma_y \gg \sigma_x$

SCRAPING EQUATIONS:

① $\boxed{\frac{1}{2} k_s \; n^2 \varepsilon_y / \beta_y \; R_{12}^y = g}$

For a beam of "width" σ_x missteered at S by $n\sigma_x$

$$y_{RMS}^{SCRAPER} = \frac{2g}{n}$$

② ⇒ BEAM Area ($\sigma_x \sigma_y$ product) → $\boxed{\sigma_x \cdot \frac{2g}{n} = \sigma_x^* \sigma_y^*}$

Hoping we can get large $\frac{2g}{n}$!

EASIER AT LOWER ENERGY ×10

note! ③ SEXT. TOLERANCE

$$\Delta y_s = \frac{1}{5 k_s / \beta_y} = \frac{n^2 \varepsilon_y R_{12}^y}{10 \; g} = \frac{n \varepsilon_y R_{12}^y}{5 \, "\sigma_y"}$$

for $R_{12} = 100$, $n = 15$

$g = 300 \mu$

$(\Delta y)_s = 0.4 \mu$! @ 500 GeV/beam

7.II.14

NON-LINEAR DESIGN EQUATIONS

③ **WAKES:** JITTER AT SCRAPER CAN COME FROM $\boxed{2 \text{ SOURCES}}$

1) NORMAL BEAM JITTER AT THIS PHASE

$$t\,\sigma_x\big|_{sc} = t\,R_{12}\,\sigma_{x'}\big|_s = t\sqrt{\frac{\varepsilon}{\beta}}\cdot R_{12}$$

2) BEAM JITTER AT SEXTUPOLE

$$\frac{1}{2}k\,(x^2)_{RMS}\,R_{12} = \frac{1}{2}k\,(x_\beta+\Delta x)^2_{RMS}\cdot R_{12}$$

$$= \left[\frac{1}{2}k\,\sigma^2 + \underline{\frac{1}{2}k\,(\Delta x)^2}\right]\cdot R_{12}$$

$$② \quad = \frac{1}{2}k\,t^2\sigma^2\cdot R_{12}$$

DEFINE

$$r \equiv \frac{①}{②}$$

ASSUME $r \ll 1$, only $k_s\beta_s$ as product enters

Can solve for min $g \equiv g_{min}$

$$g_{min} = 30\;t^2\;\frac{N r_e}{\gamma\sigma_z}\cdot\frac{\sqrt{\lambda\sigma_z}}{\varepsilon}\;L_{sex}\cdot\frac{1}{n^4}$$

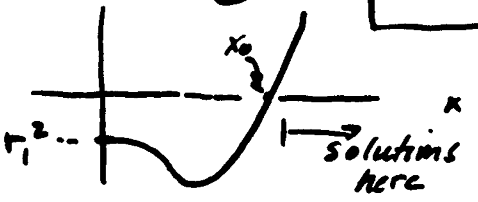
ε_N 30μ

IF "r" NOT SMALL:

④ $\boxed{x^5 - x^3 - r_1^2 \geq 0}$

$x = \frac{g}{g_1}$

$r_1 = r(g_{min})$

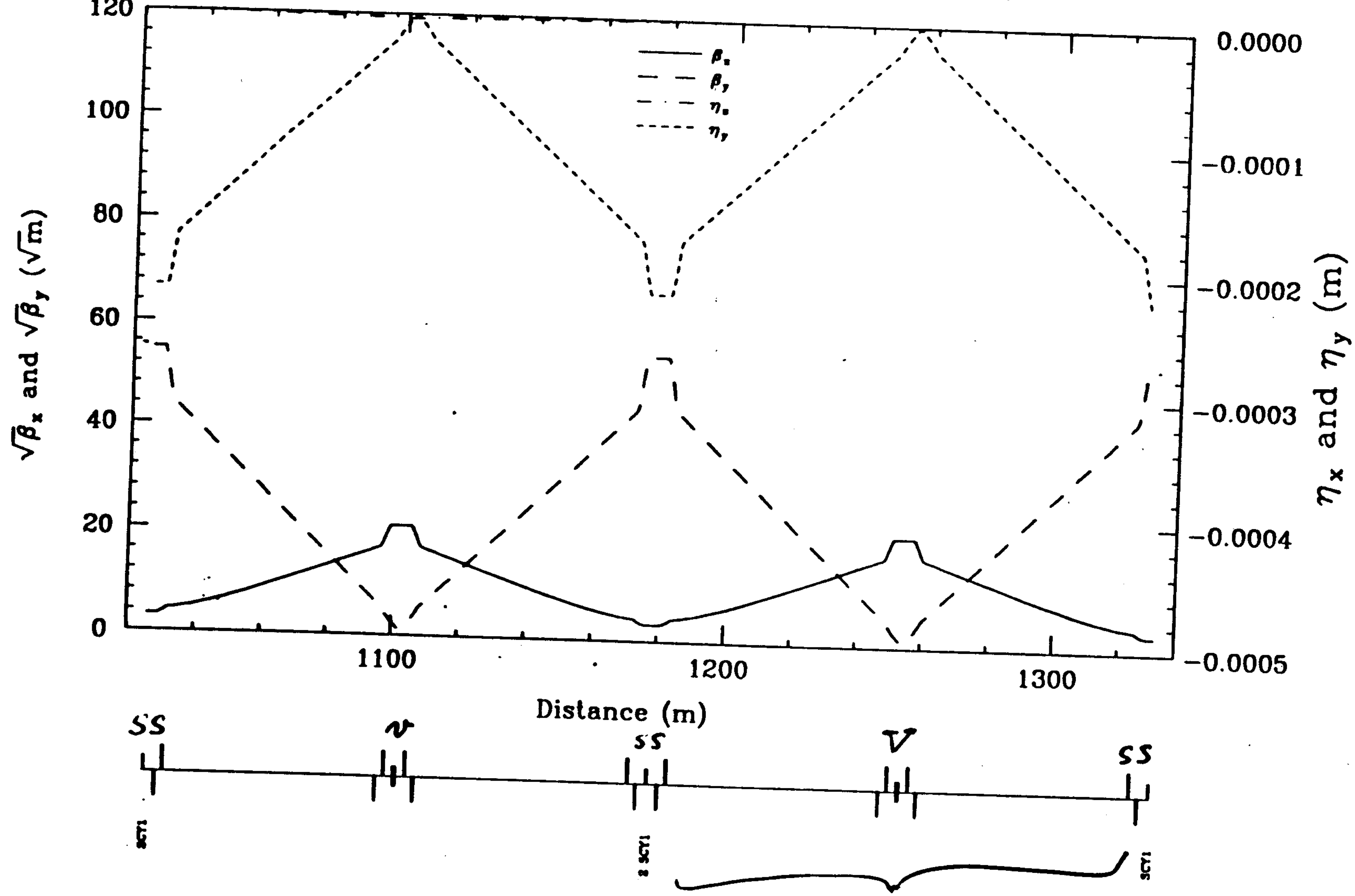


$6_x \cdot \frac{2g}{n} = 2000\mu^2$

per Beam Ĵ

$\beta_{x\,SEX} = 480\,m$ $g = 300\mu$ $\delta y_{SEPT} = .2\mu$.

TLCCOL10 500 GeV Collimator: Nonlinear Insertion



REPEAT FOR TAIL CLEAN-UP

NOT OPTIMIZED!

TOTAL ≃ 300 m.

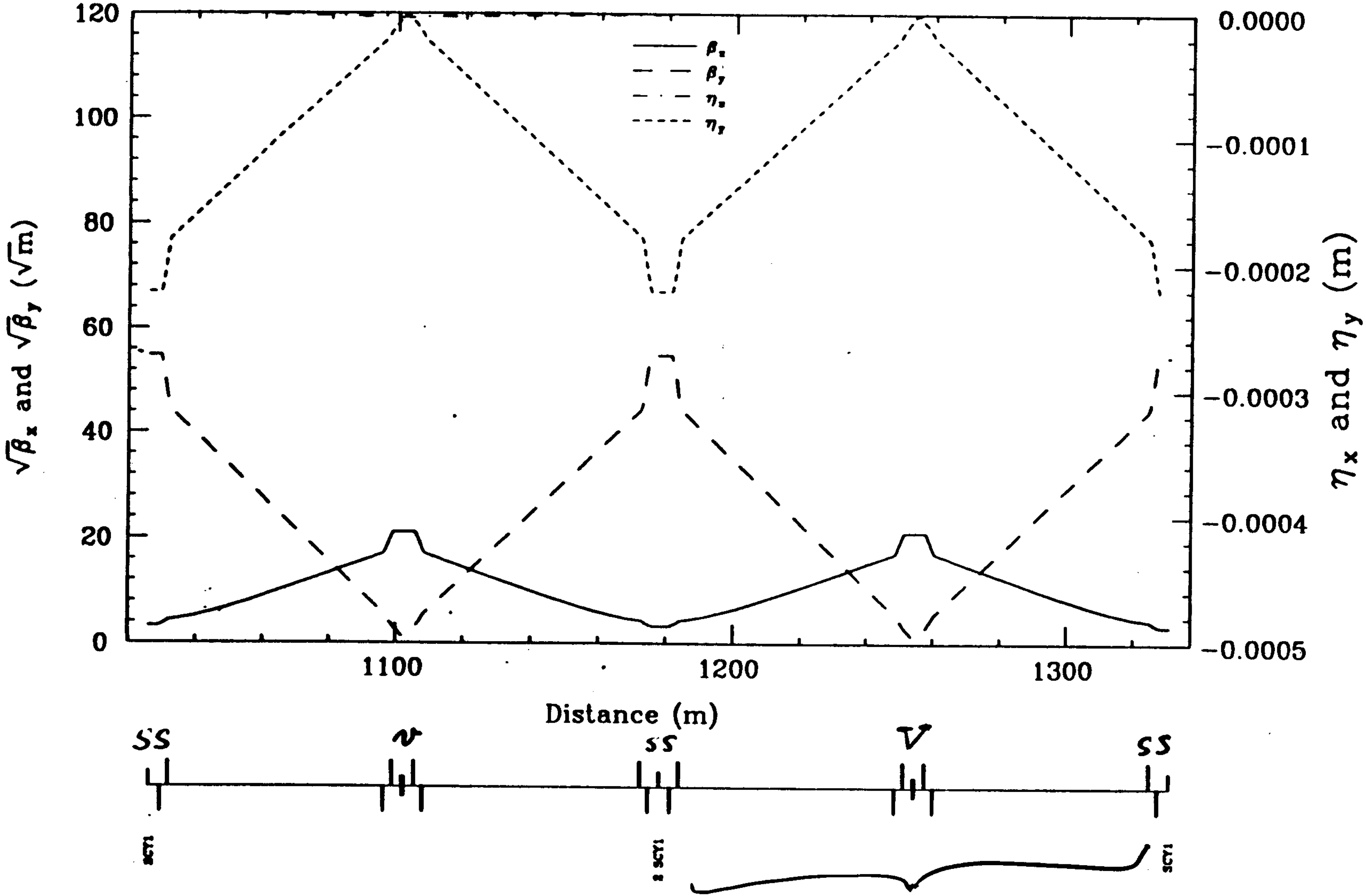
7.II.15

$6_x \cdot \frac{\Delta y}{n} = 2000\mu^2$

$\beta_{x\,SEX} = 460m$ $g = 300\mu$ $\Delta y_{SEPT} = .2\mu.$

per Beam ↓

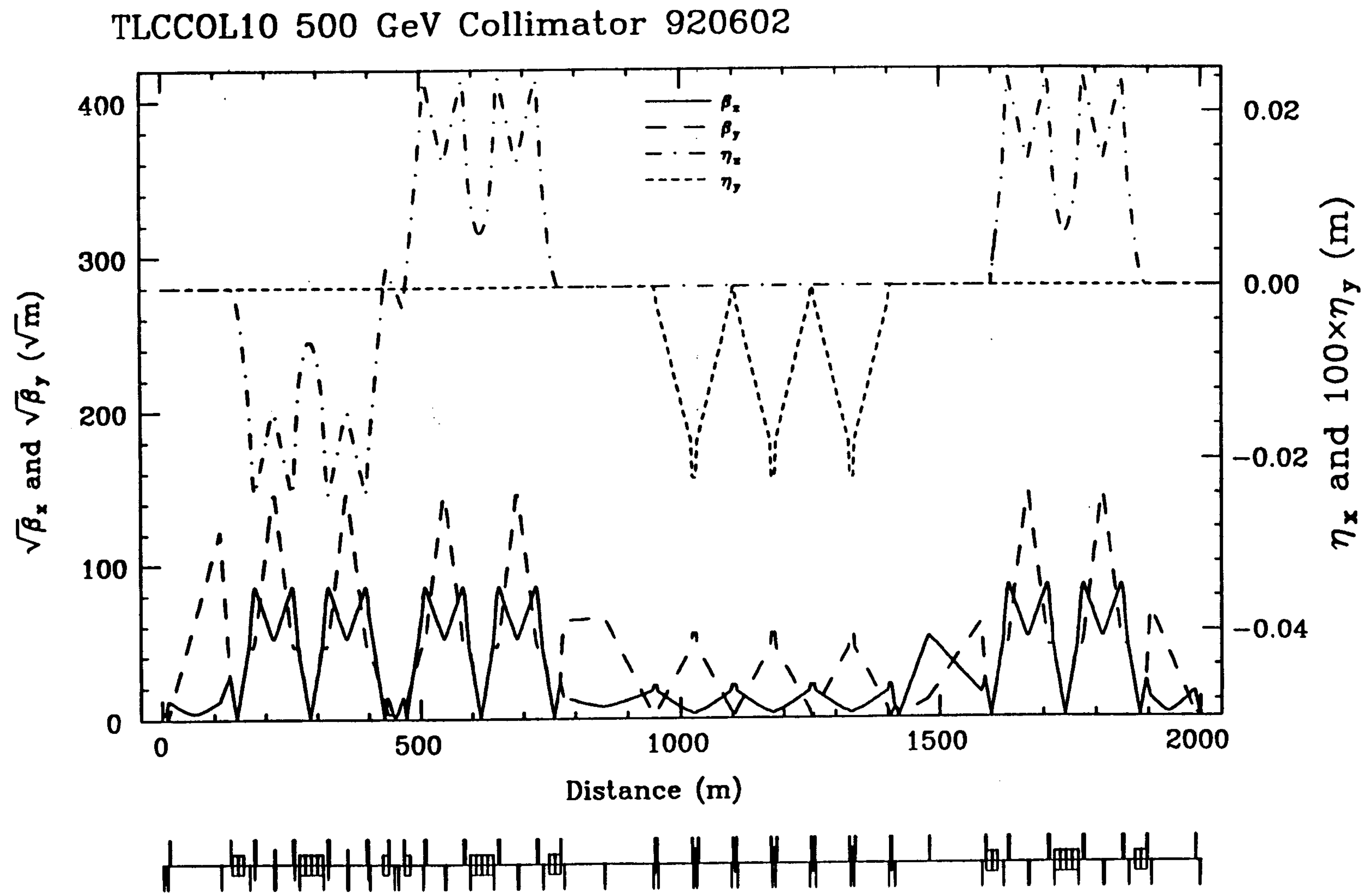
TLCCOL10 500 GeV Collimator: Nonlinear Insertion



REPEAT FOR TAIL CLEAN-UP

NOT OPTIMIZED!

TOTAL ≈ 300 m.


TLCCOL10 500 GeV Collimator 920602
β_x
β_y
η_x
η_y
$\sqrt{\beta_x}$ and $\sqrt{\beta_y}$ ($\sqrt{m}$)
η_x and $100\times\eta_y$ (m)
0
100
200
300
400
0.02
0.00
−0.02
−0.04
0
500
1000
1500
2000
Distance (m)

7.II.16

7.II.17

IV TAIL REPOPULATION

FROM LARGE ANGLE COULOMB SCATTERING

Assume major composition of gas is N_2 & O_2

Take $Z = 8$, $R_{Nuc} \approx 2.5 \cdot 10^{-15}$ m

$\rho_{Nuc} = 2 \cdot P_{GAS}$ (TORR) $3 \cdot 10^{22}$

MAXIMUM SCATTERING ANGLE

$$\theta_{max} = \frac{2 Z r_e}{\gamma R_N} \approx 20 \ \mu r.$$

MINIMUM R_{12} [S → FD]

$$R_{12}^{min} \cdot \theta_{max} = a_{FD} \approx 4 \text{ mm}$$

$$\Rightarrow \quad R_{12}^{min} \approx 200 \text{ m}.$$

Such an R_{12} is unlikely in Final Focus.

It could occur (barely) in Big Bend

Will Certainly Occur in Collimation of IP phase ($R_{12}' = \sqrt{\beta_{coll}' \cdot \beta_{FD}'} \approx 12{,}000!$) ⇐ Collimate FD phase last!

7.II.18

IV. TAIL REPOPULATION (cont'd)

FRACTION SCATTERED $= \dfrac{\Delta N}{N} = \rho_{Nuc} \cdot \Delta s \cdot \sigma$

$\sigma \approx \frac{1}{2}\pi b^2$: $\theta(b)\cdot R_{12}(s) = a^y$

$\Rightarrow b = \dfrac{2Z r_e}{\gamma a_y} \cdot R_{12}^y$

$$\frac{\Delta N}{N} = \underbrace{\frac{\pi}{2}\rho_{Nuc}\left(\frac{2Z r_e}{\gamma a_y}\right)^2}\int_{R_{12}>200} R_{12}^2(s)\, ds$$

$$= \frac{\pi}{2}\rho_{Nuc}\, r_{Nuc}^2 \cdot \int\left(\frac{R_{12}(s)}{200}\right)^2 ds$$

$$= 6\cdot 10^{-15} \cdot \int_{R_{12}>100}\left(\frac{R_{12}}{200}\right)^2 ds. \quad \leftarrow \rho_{GAS} = 10^{-8}\ \text{Tor}$$

For NLC

NEED $\dfrac{\Delta N}{N} \le \dfrac{1}{6}\cdot 10^{-11}$

or $\displaystyle\int\left(\frac{R_{12}}{200}\right)^2 ds \le 280$ m.

$\Rightarrow \rho \le \frac{1}{4}\cdot 10^{-8}$ T

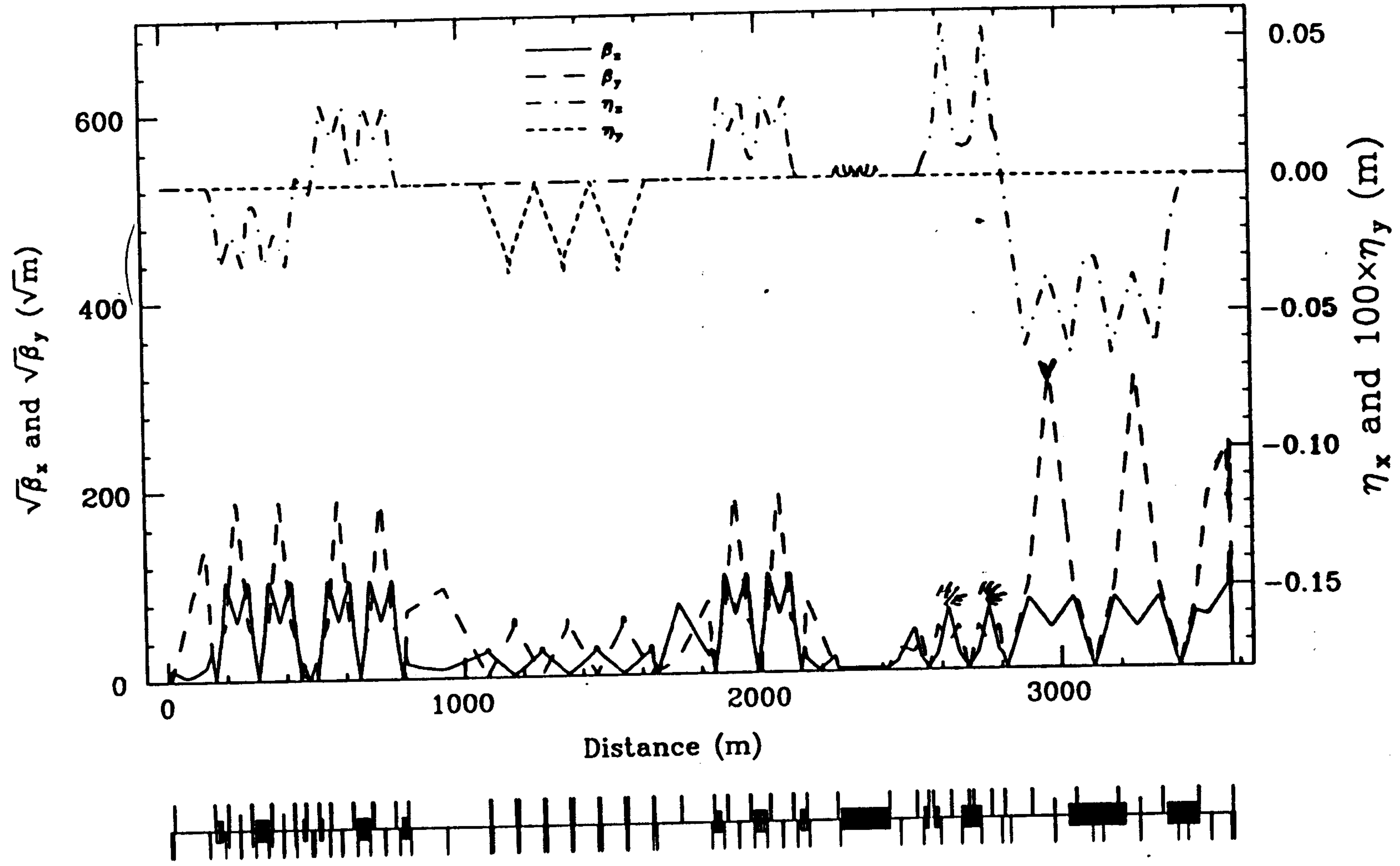
in BIG BEN

eg if $R_{12} > 400$ for 70 m. we're in trouble

(Lower Gas Pres Can Help)

per Beam Z

500 GeV Collimator, Big Bend and Final Focus 920714



VIII. Conclusions

1. It All Looks (barely) Possible with Conventional Collimation for 10^{12} Particles/Pulse
2. Requires Considerable Length (1 to1.5 km/linac)
3. Nonlinear System Can Collimate Smaller Apertures if Necessary
4. Need Better Estimate of Worst Probable Number of Particles to be Collimated
5. Much Work Remains to be Done

   i) Follow all particles, primaries and secondaries, through optical system

   ii) Simulate scattering and production from spoilers, absorbers, and beampipe.

   iii) Determine cooling requirements and radiation levels.

7.II.21

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1. **Collaborators:** *Dick Helm, Lia Merminga*

2. **Materials Information:** *Dieter Walz*

3. **Scattering Data:** *Ralph Nelson*

3. **Previous System Design Strategies:**
   - i) Spoilers followed by Absorbers
   - ii) Curved Collimator Surface von Holty *Unknown*

4. **Previous System Experience:**
   - i) Clean Up Edge Scattering Effects
   - ii) Correct Chromaticity Locally
   - iii) Collimate All Phases *P. Krejick , D. Burke*

5. **Non-Linear Collimation Idea:** *R. Ruth*
   with Elements at -I *K. Brown, K. Oide*

6. **Importance of Resistive Wall Wakes:** *K. Yokoya*

7. **Geometric Wake for Tapered Scrapers:**
   K. Yokoya, K. Bane, B. Warnock

8. **Helpful Discussions:** *Many Others*