STATUS OF DYNAMIC FOCUSING FOR LINEAR COLLIDERS

&

1st THOUGHTS ON DYNAMIC FOCUSING FOR MUON COLLIDERS

J. IRWIN

HEMC WORKSHOP

9/27/99

SPECIAL THANKS TO

GORDON BOWDEN	STRONG OCTUPOLES / CRAB SYSTEM
HOBIE DE STAEBLER	OIDE / FINAL QUAD RADIATION
JOHN FOX	FEED FORWARD & BACK
DICK HELM	OCTUPOLE LATTICE
TED LAVINE	COST COMPARISONS
PANTALEO RAIMONDI	SLC EXPERIMENT
TOR RAUBENHEIMER	DAMPING RING DESIGN + ..
SAMI TANTAWI	CRAB CAVITY SYSTEM
PERRY WILSON	LINAC DESIGN (rf)

I T P, SANTA BARBARA WORK BEGIN

PLUS KATHY THOMPSON
DANIEL SCHULTE } "THICK" LENS SIMULATIONS —

↑ GUINEA PIG SIMULATIONS —

6)

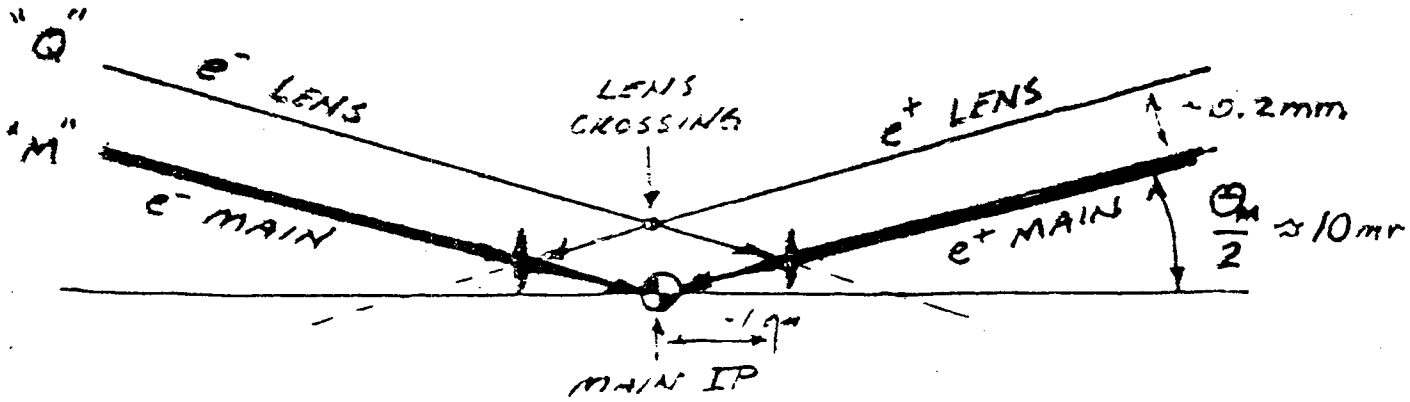
2(

DYNAMIC FOCUSING

DERIVED FROM "SUPERDISRUPTION"

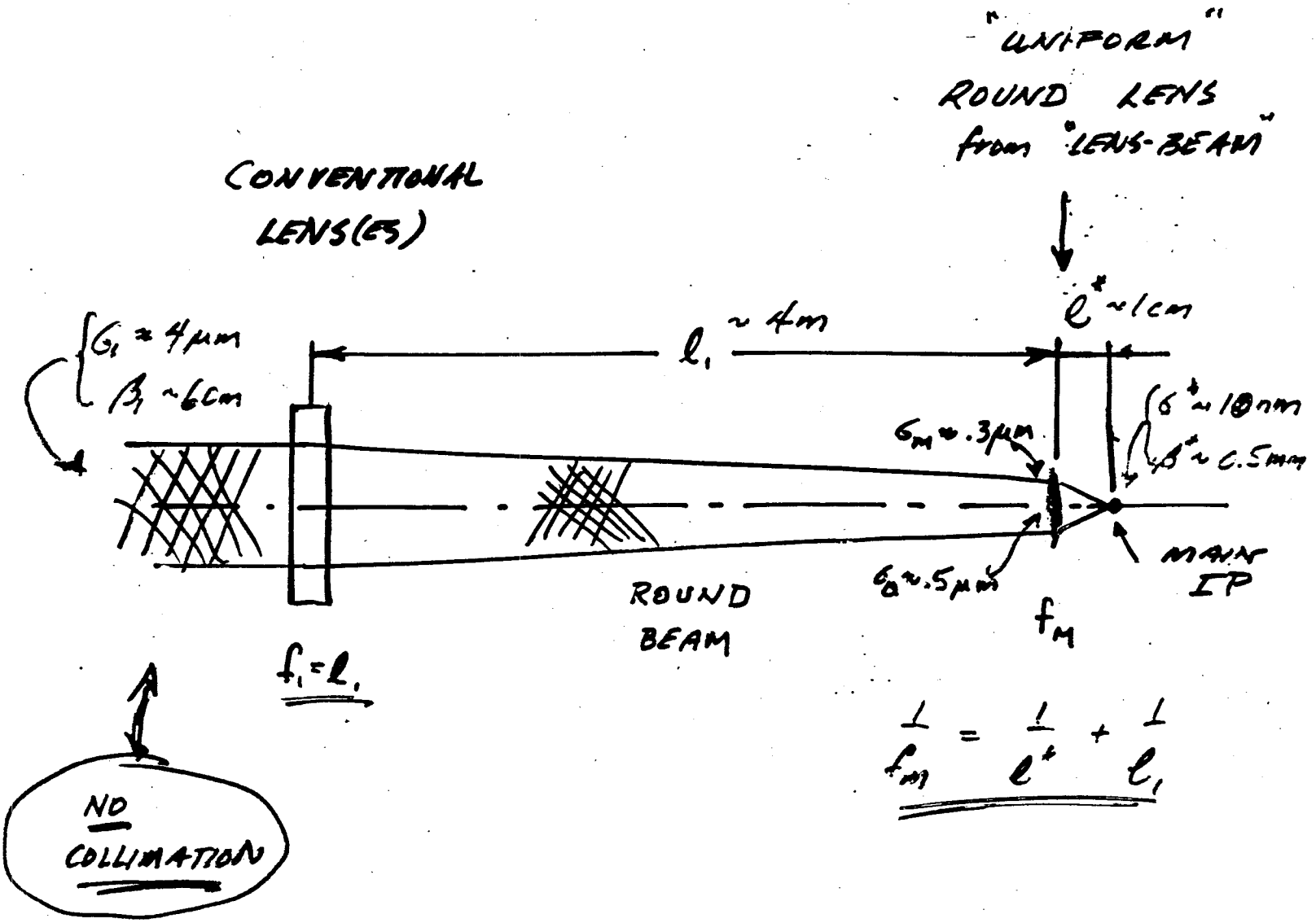
D. LEITH
R. PALMER
J. IRWIN

[VIEW FROM ABOVE]



DYNAMIC FOCUSING

"TELESCOPE"



$$\frac{1}{f_m} = \frac{1}{l^*} + \frac{1}{l_1}$$

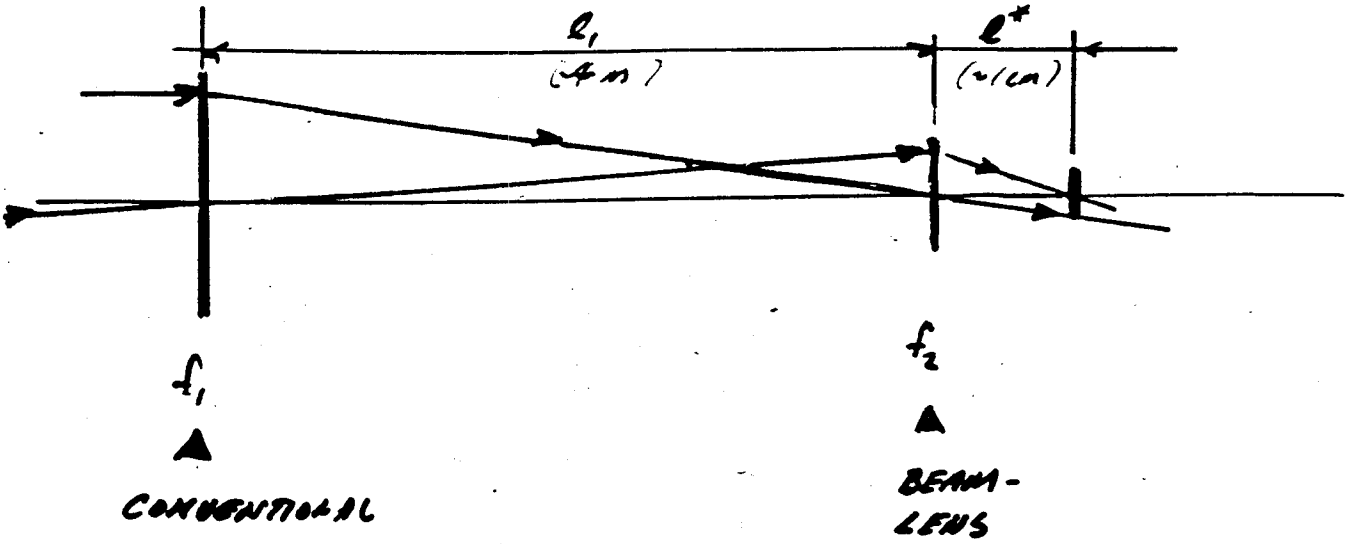
$$\frac{\sigma_M}{\sigma^*} = \frac{\sigma'^* l^*}{\sigma^*} = \frac{l^*}{\beta^*} \equiv \xi \quad \text{("final" (demagnification))}$$

$$\left(\frac{\sigma^*}{\sigma_1}\right)^2 = \left(\frac{l^*}{l_1}\right)^2 - \left(\frac{l^*}{l_1}\right)\left[2 - \frac{l^*}{l_1}\xi^2\right]\bar{\delta}^2 + \bar{\delta}^4$$

$> 2\%$ BAND-WIDTH

CHROMATICITY CAN BE ZERO –

(IT CAN EVEN BE NEGATIVE!)



WRITE DOWN TRANSFER MATRIX ELEMENTS

$$\langle x_{1p}^2 \rangle = R_{11}^2 \langle x_1^2 \rangle + R_{12}^2 \langle x_1'^2 \rangle$$

$$R_{12} = (\ell_1 + \ell^*)\delta^- \qquad R_{11} = -\left(\frac{\ell^*}{\ell_1}\right) + \left(\frac{\ell_1 + \ell^*}{\ell_1}\right)\delta^{-2}$$

$$\approx \ell_1 \delta^- \qquad \approx -\frac{\ell^*}{\ell_1} + \delta^{-2}$$

$$\left(\frac{\sigma^*}{\sigma_1}\right)^2 = \left(-\frac{\ell^*}{\ell_1} + \delta^{-2}\right)^2 + \left(\frac{\ell_1}{\beta_1}\right)^2 \delta^{-2}$$

$$= \left(\frac{\ell^*}{\ell_1}\right)^2 + \left(\left(\frac{\ell_1}{\beta_1}\right)^2 - 2\frac{\ell^*}{\ell_1}\right)\delta^{-2} + \delta^{-4}$$

UNANTICIPATED SIDE BENEFITS

+ FOCUS x & y → ROUND MAIN BEAM
  → LOW BUNCH CHARGE ($\times \frac{1}{16}$)
  → LOWER single bunch WAKES
  → SMALLER a/λ &/or HIGHER FREQ.
  → HIGHER GRADIENTS

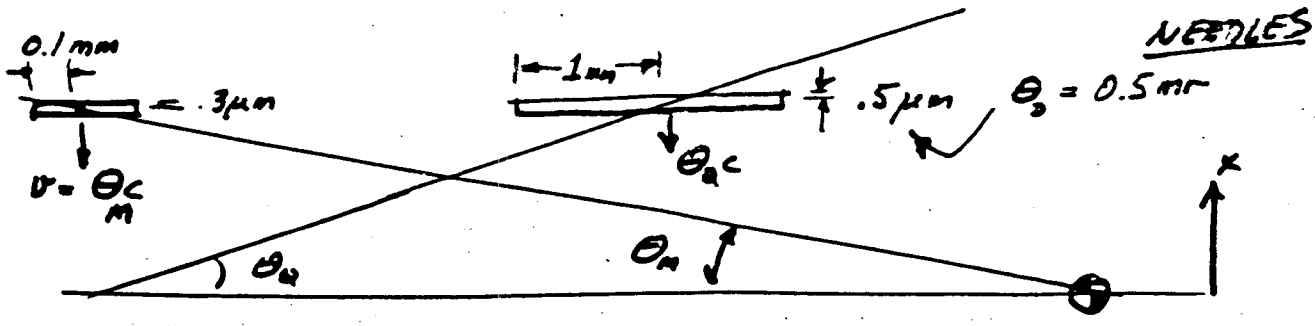
+ HUGE BANDWIDTH
  → EASY ENERGY COMPENSATION
  → ≥1% BW SPREAD w/o MAKE-UP.

+ NO COLLIMATION REQUIRED

+ PRE-CURSOR TRAIN ALIGNMENT
  → NO OPTICAL ANCHOR, etc

+ NO QUADS INSIDE DETECTOR
  → SMALLER DEAD ANGLE
  → GREATLY REDUCED BACKGROUNDS

LENS-BEAM ENTRY ANGLE



During collision $c\Delta t = \sigma_{zQ}$

$$\Delta x = \theta c \Delta t = \theta \sigma_{zQ} \approx 10^{-2} \cdot 10^{-3}$$

$10\mu m$

LENS – MAIN
NEED THEM TO MOVE TOGETHER

$$(\Delta x)_{rel} = (\theta_M - \theta_Q)\,\sigma_{zQ} \ll 0.5\mu m$$

$$\Rightarrow \underline{(\theta_M - \theta_Q) \ll 0.5 \text{ mr}}\ !$$

$\leq \frac{1}{5}$ $\rightarrow \leq 100\mu r$

RIGHT – LEFT
AT IP NEED

$$(\theta_M^R - \theta_M^L)\,\sigma_{zM} \ll \sigma^*$$

$$\underline{\theta_M^R - \theta_M^L \ll \frac{\sigma^*}{\sigma_z}}$$

$\frac{14\,nm}{100\,\mu m} = 0.14$ mr

$\leq \frac{1}{5}$

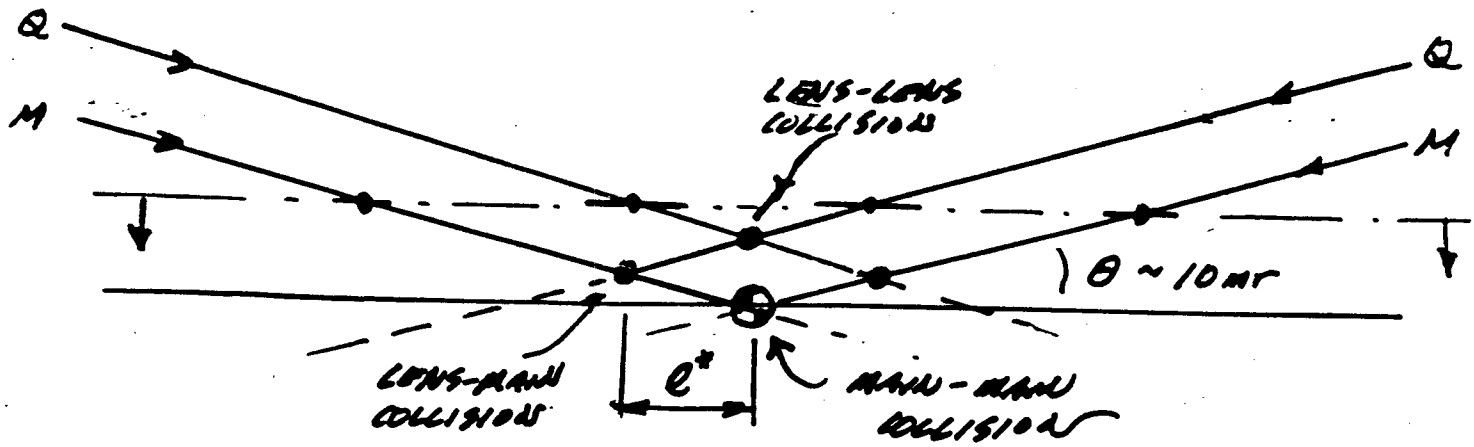
$\frac{1}{5}(.14) = .03$ mr

$\rightarrow \leq 30\,\mu r.$

14)

BEAM LINES

VIEW FROM ABOVE



CRAB CAVITY DOES 2 JOBS

1) TWISTS BUNCH TO CORRECT ANGLE – "VOLTAGE"

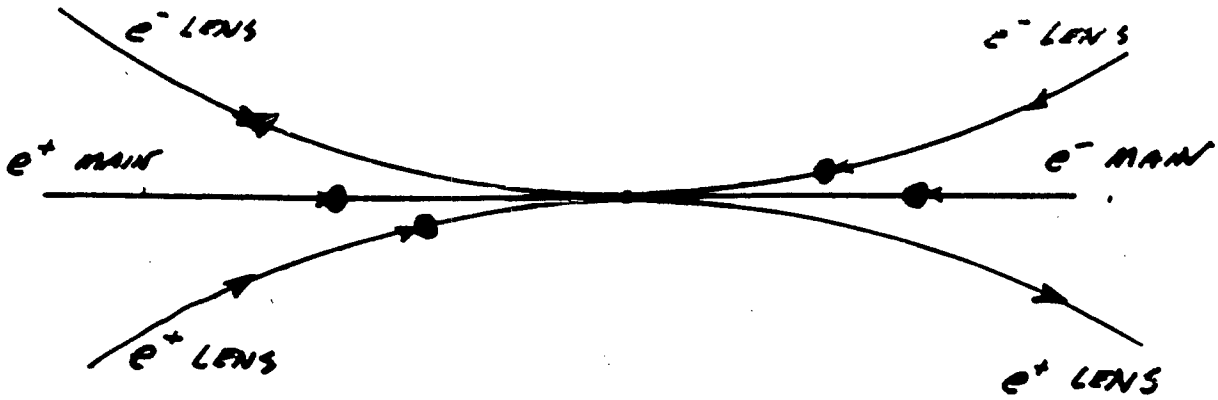
2) GETS BUNCHES ON SAME LINE – "PHASE R-L DIFFS"

- NEED 4 CRAB CAVITIES
- PHASE DIFF TOLERANCE WORSE BY ~14 → 10^{-2}° X-band

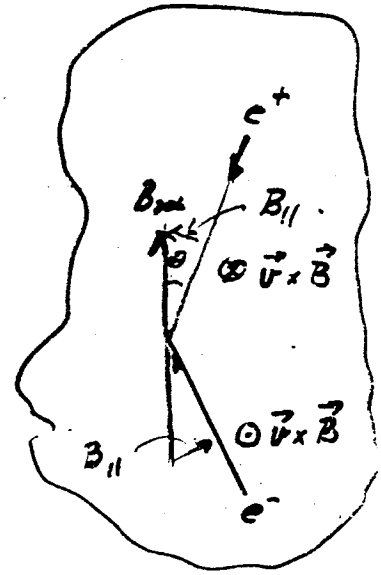
[IF THIS IS POSSIBLE
SYSTEM BECOMES "STRAIGHT"!]

20)

VIEW FROM SIDE



$$\left|\begin{matrix}\text{LENS BEAM}\\ \text{ENERGY}\end{matrix}\right\rangle \leq 1/50 \left\langle\begin{matrix}\text{MAIN BEAM}\\ \text{ENERGY}\end{matrix}\right|$$



FOR LENS.

$$\frac{BL}{B\rho} = \frac{B_{sol} \cdot \theta \cdot L}{B\rho}$$

Take $L = 4\,m$

$B_{sol} = 4\,T$

$\theta = 20\,mr.$

$B\rho = 33$ @ 10 GeV

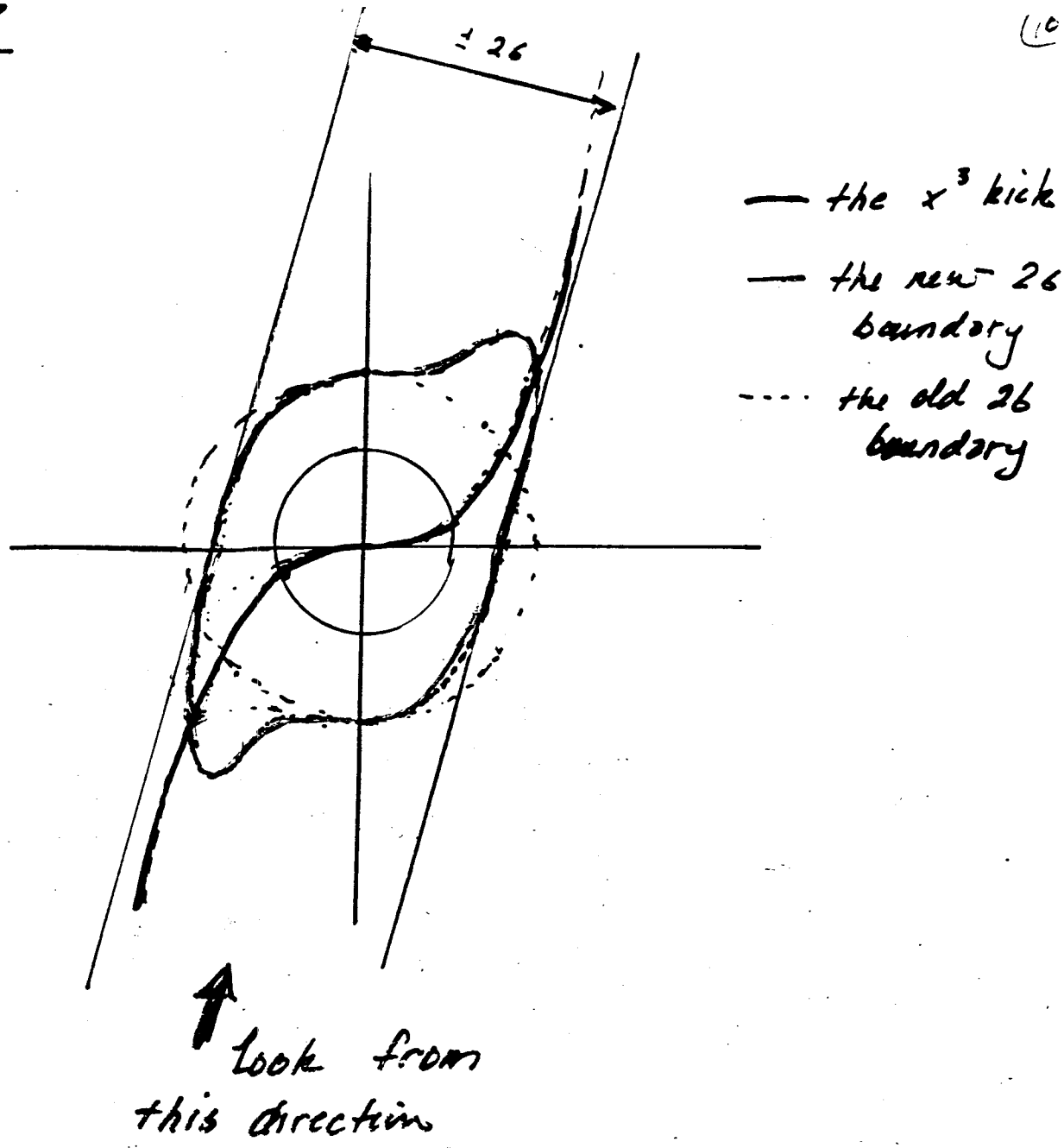
$$\frac{BL}{B\rho} = 10\,mr = \Theta$$

$$\Delta y = \frac{1}{2}\,\Theta \cdot L = 20\,mm.$$

VERY NICE SEPARATION OF BEAMS!

LENS IS OVER (OR UNDER) MAIN.

uniform?



PHASE SPACE DIAGRAM on

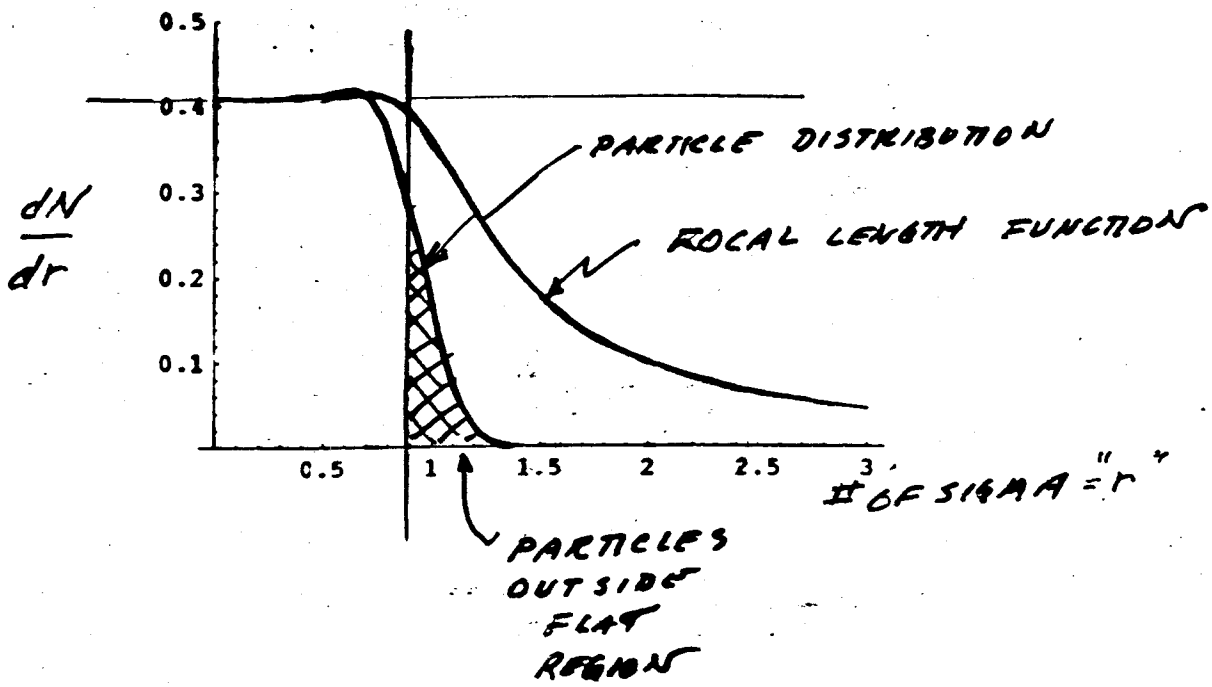
"UNIFORM from GAUSSIAN"

w/ OCTUPOLES.

- CAN BE DONE IN x & y SIMULTANEOUSLY -

A FLAT 1-D DISTRIBUTION USING AN OCTUPOLE

Lens_7_98.nb

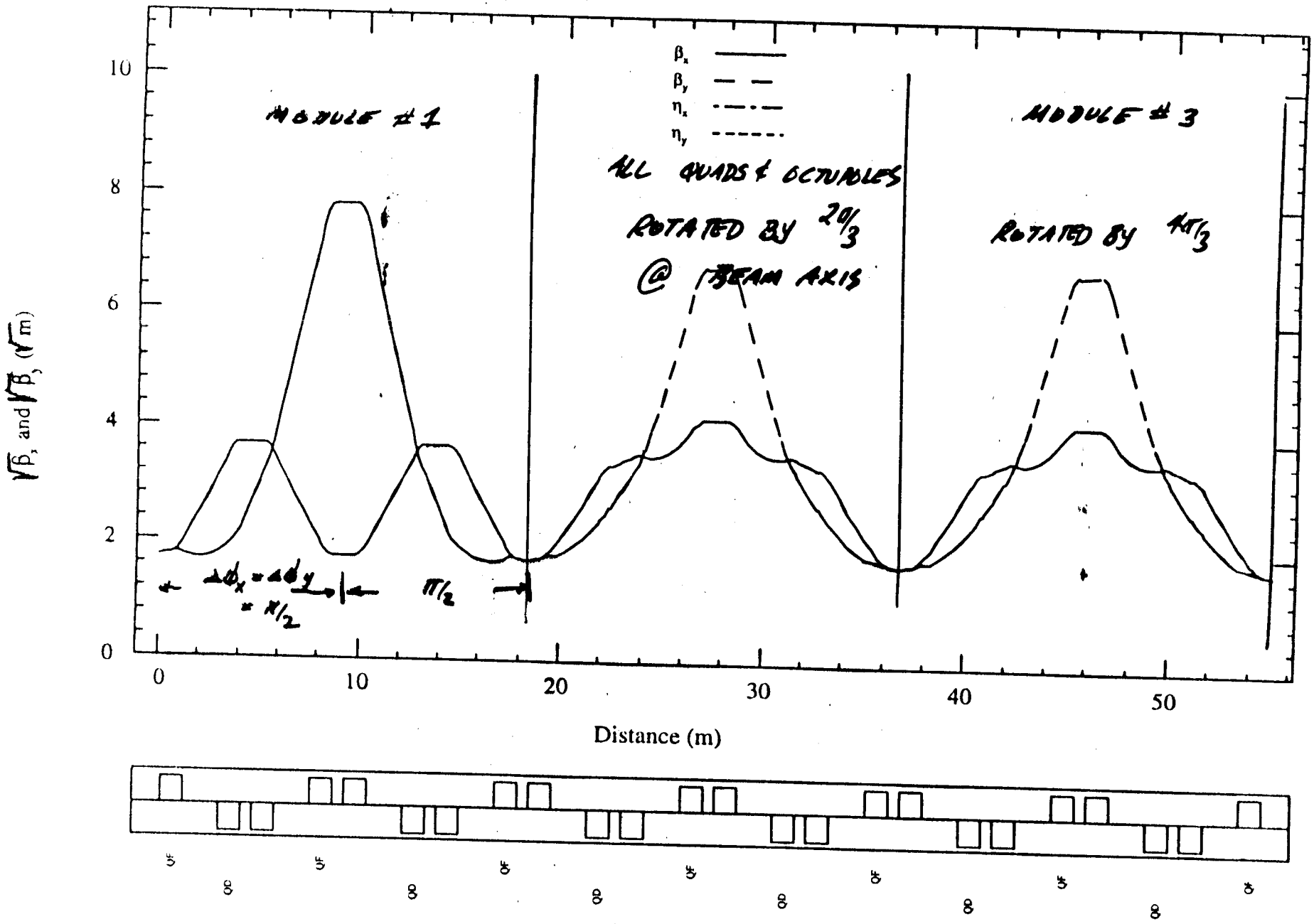


UNIFCHAN.

R. HERM

"80% of charge in disk"

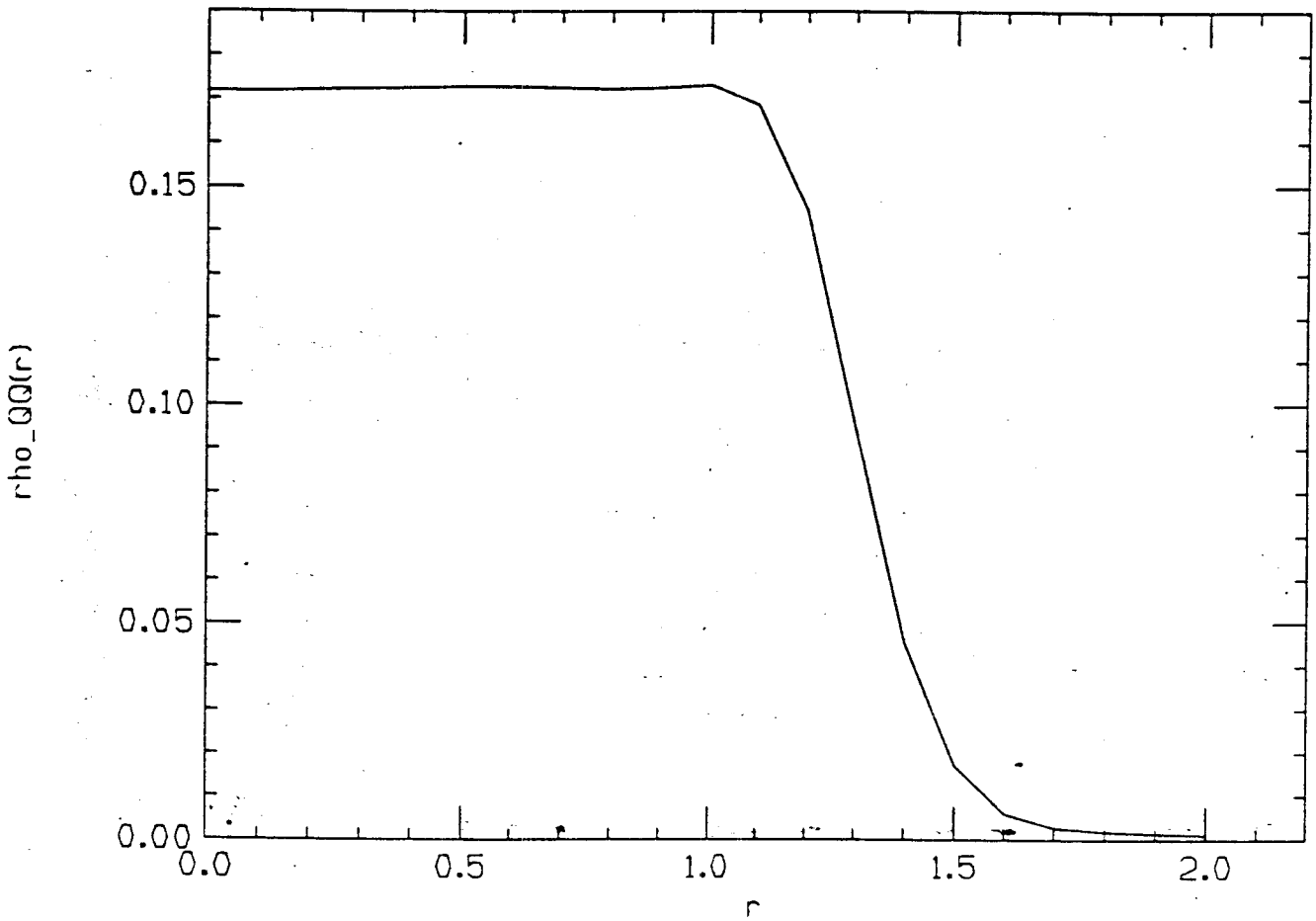
SQUARE1: Lattice for 'squared' beam (?)



IT IS POSSIBLE TO DO EVEN BETTER THAN 80%!

A ROUND UNIFORM DISK USING 2 SETS OF 3 OCTUPOLES

Using 2 sets of octupoles it is possible to get an extremely flat distribution



$P_{11} = -0.5$ $\qquad$ $\theta_{00} = \pi + 0.6$

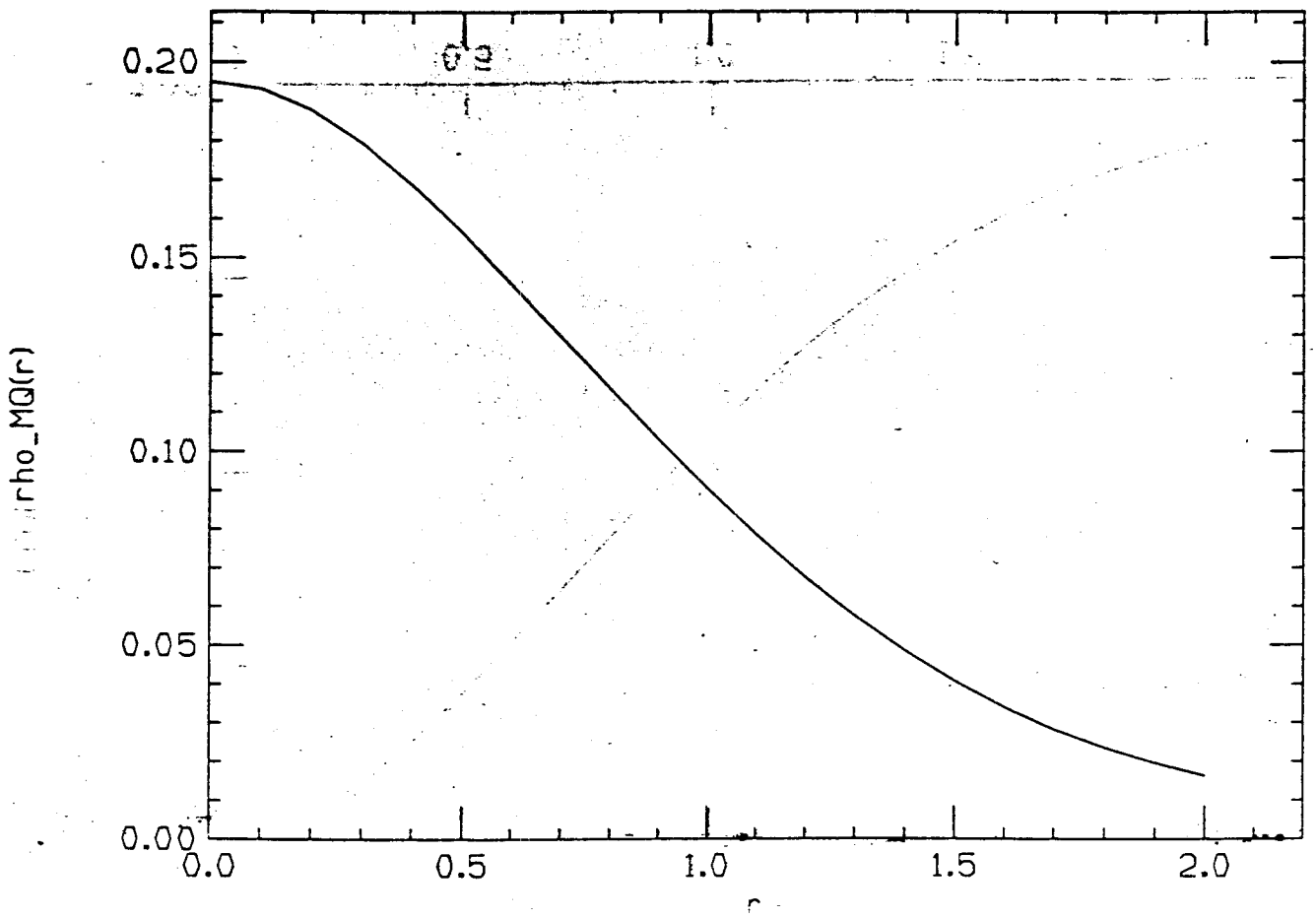
$P_{21} = 0.1$ $\qquad$ $\theta_{Q2} = \pi - 0.4$

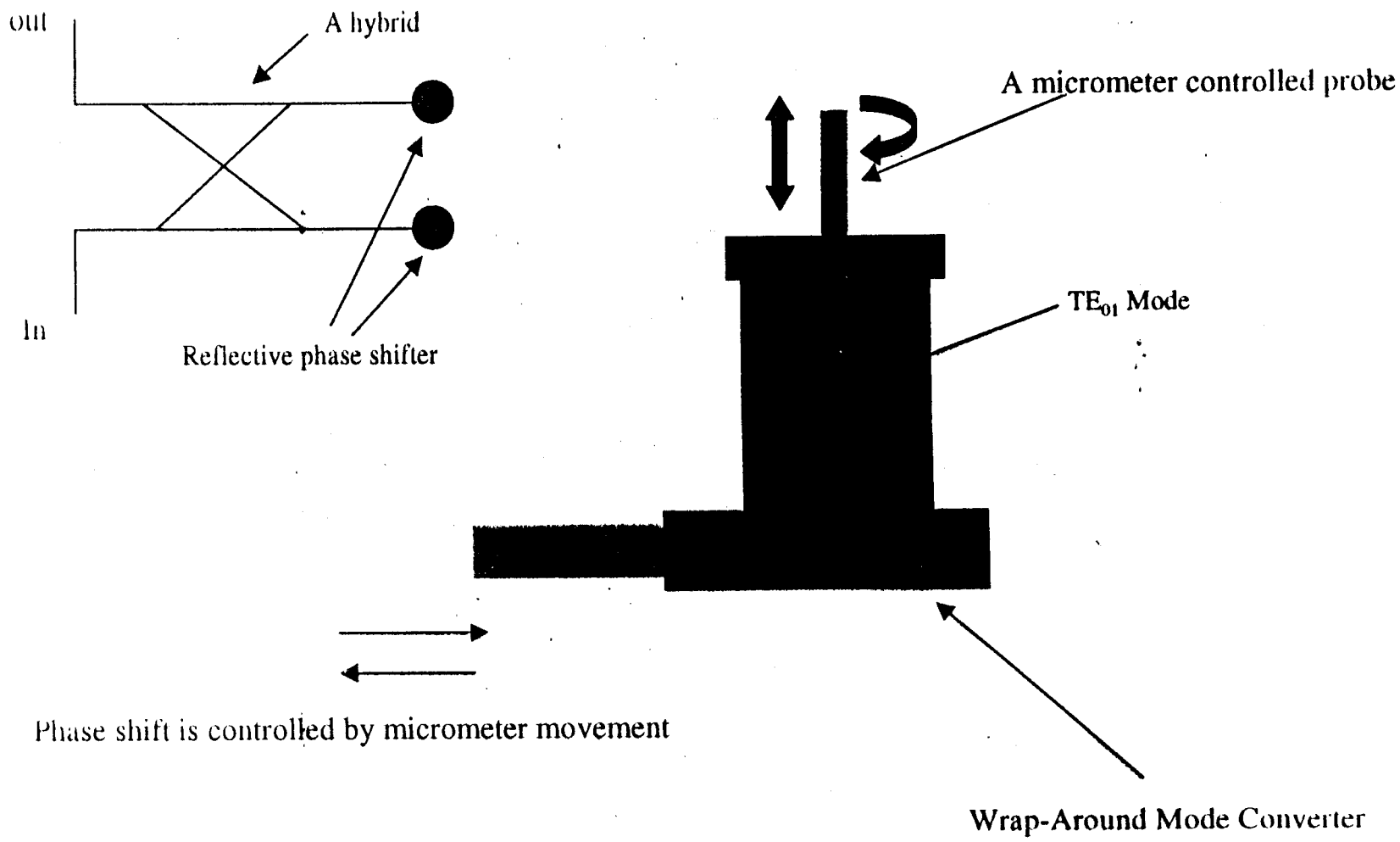
$$\frac{N_Q}{N_{QD}} \approx 1.2 \; !$$

NEED UNIFORMITY AT QQ AND MQ!

PRESENT MQ DISTRIBUTION
FOR LENS PROFILE

CURRENTLY IN PROCESS!

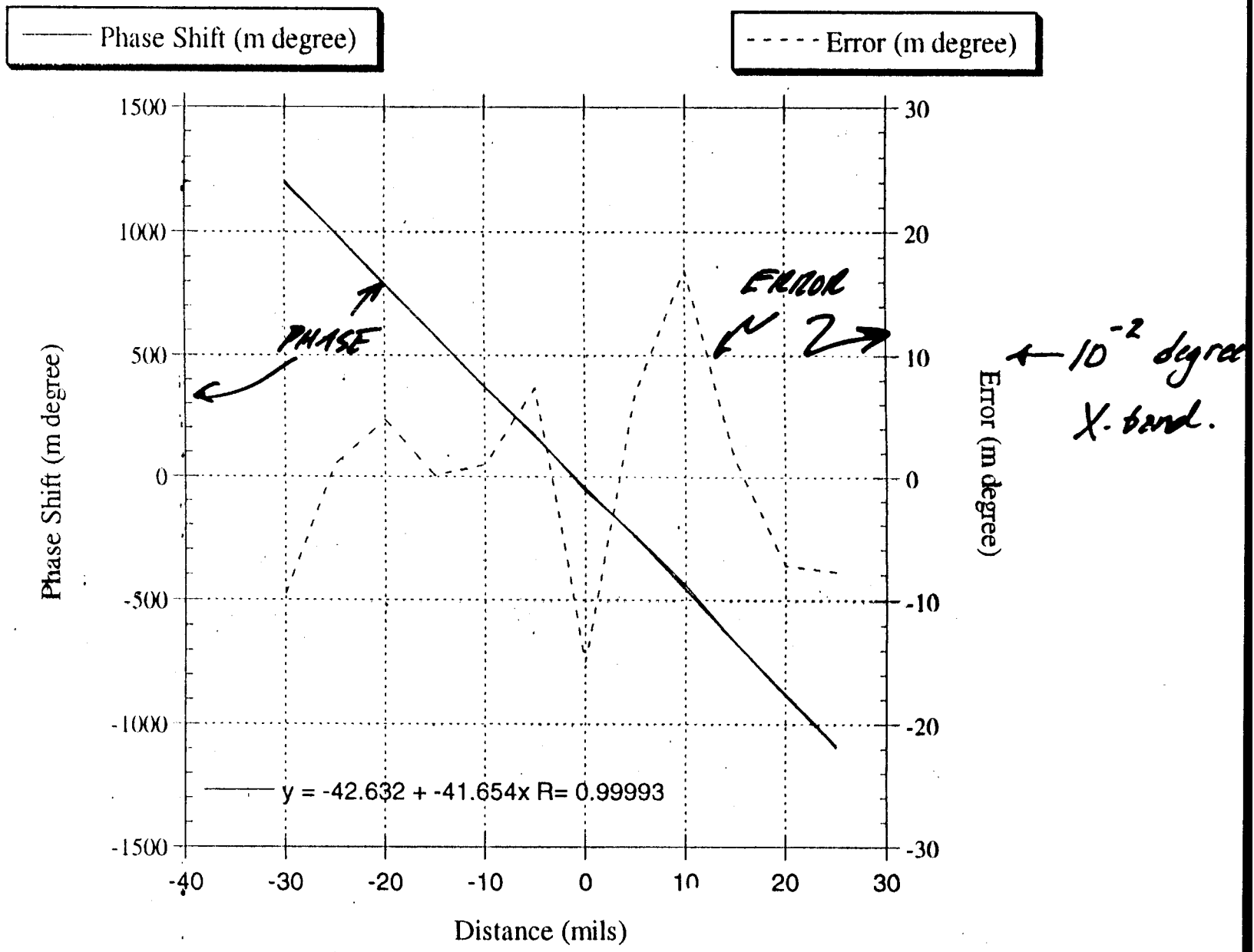




Reflective phase Shifter

CRAB CAVITY EXPERIMENT

SAMI TANTAWI



SAMI TANTAWI

2) EQ. 1

CHARGE/BUNCH IN LENS BEAM

ASSUME UNIFORM DISK - RADIUS R_Q

$$\frac{1}{f_M} = \frac{2\, N_{QD}\, r_e}{\gamma_M\, R_Q^2} \cdot \frac{1}{\ell^*}$$

$$N_{QD} = \underbrace{\left(\frac{\gamma_M\, \sigma_M^2}{r_e\, \ell^*}\right)}_{\equiv\, N_{Q_0}} \cdot \underbrace{\left(\frac{R_Q^2}{2\, \sigma_M^2}\right)}_{=\, N_{QD}/N_{Q_0}} = \frac{\sigma_Q^2}{\sigma_M^2}$$

$$N_{Q_0} = \frac{\gamma_M\, \sigma'^{*2}\, \ell^*}{r_e} = \frac{\overbrace{(\gamma\varepsilon)_M}^{\frac{1}{3}\cdot 10^{-6}}}{r_e} \cdot \overbrace{\left(\frac{\ell^*}{\beta_M^*}\right)}^{\xi \approx 20}$$

$$N_{Q_0} \approx 2.4 \cdot 10^9$$

NOTE: AT HIGHER ENERGIES - $(\gamma\varepsilon)_M \sim \gamma_M^{-5/4}$ & N_M is fixed

$\rightarrow \frac{N_{Q_0}}{N_M}$ is decreasing rapidly - ! Less fractional power in lens beam

EG 1

22)

CHARGE/BUNCH IN LENS BEAM

$$e^{-R_Q^2/2\sigma_M^2} = \left[\begin{array}{l}\text{FRACTION OF MAIN BEAM} \\ \text{OUTSIDE OF DISK.}\end{array}\right] = \frac{\Delta N}{N}$$

$$\left(\frac{\Delta L}{L}\right)_{\substack{\text{OUTSIDE} \\ \text{DISK.}}} = 2\,\frac{\Delta N}{N}.$$

$$\frac{\sigma_Q^2}{\sigma_M^2} = \frac{N_{QD}}{N_{QO}} = \begin{cases} 3.0 & \text{FOR } \begin{cases} 10\% & \text{LUM. LOSS} \\ 5\% & \Delta N/N. \end{cases} \\ 3.5 & \text{FOR } \begin{cases} 6\% & \text{LUM LOSS} \\ 3\% & \Delta N/N. \end{cases} \end{cases}$$

EXTRA WALL-PLUG POWER = (LUM. LOSS MAKE-UP) + (LENS-BEAM POWER USEAGE)

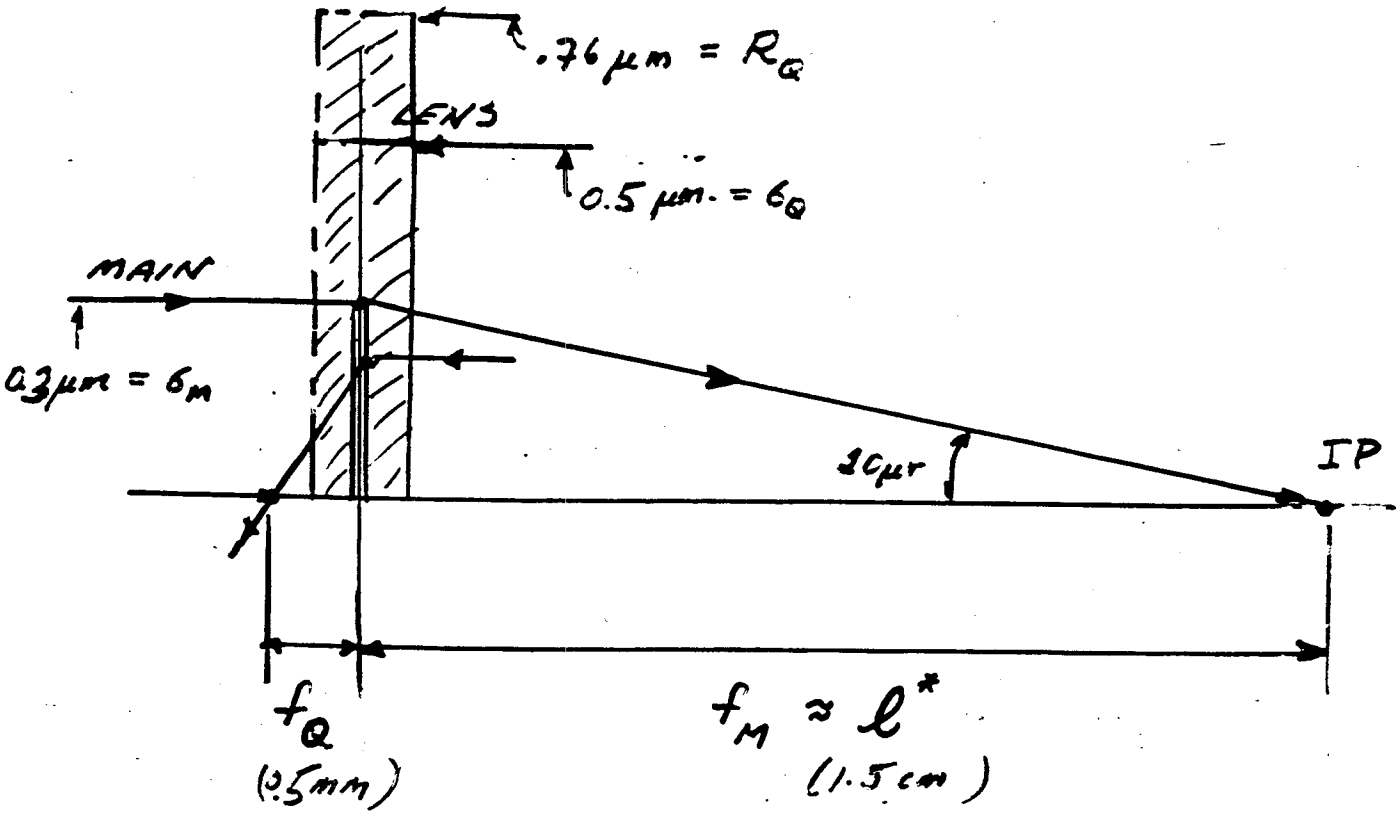
$$\sim \frac{\gamma_M N_M}{\eta_M} + \frac{\gamma_Q N_{QTOT}}{\eta_Q}$$

$N_{QD} = 7 \cdot 10^9$

OPTIMUM AT $\frac{N_{QD}}{N_{QO}} \approx 4$ ... IS BROAD.

$$\boxed{\text{BEST TO CHOOSE } \frac{N_{QD}}{N_{QO}} \leq 3.0 \quad \text{.. LESS HARDWARE "CREATION"}}$$

GEOMETRY OF LENS - MAIN COLLISION



$$\frac{1}{f_Q} = \frac{N_M r_e}{\gamma_Q \sigma_M^2} \qquad \frac{1}{\ell^*} = \frac{N_{QD} r_e}{\gamma_M \sigma_M^2}$$

$$\boxed{\frac{\ell^*}{f_Q} = \frac{\gamma_M N_M}{\gamma_Q N_{QD}} = \frac{P_M}{P_{QD}}} \qquad (\approx 30!)$$

NOTE:

$$N_Q = \left(\frac{N_Q}{N_{QD}}\right) N_{QD} = \left(\frac{N_Q}{N_{QD}}\right)\left(\frac{\sigma_Q^2}{\sigma_M^2}\right) N_{QD}$$

$N_Q \approx 10^{10}$, $\frac{N_Q}{N_{QD}} \approx 1.3$, $\frac{\sigma_Q^2}{\sigma_M^2} \approx 3$, $N_{QD} \approx 2.5 \cdot 10^9$

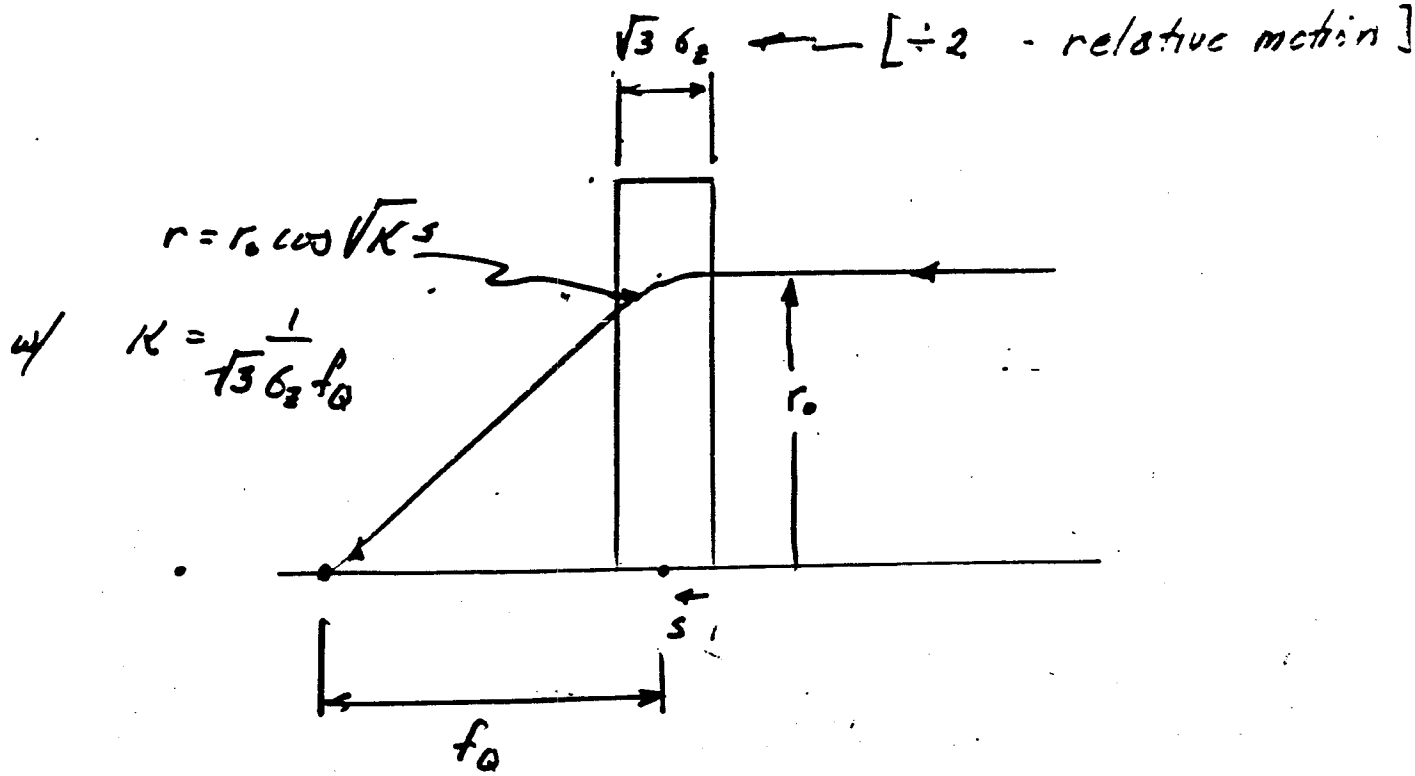
$$N_{QD} = \frac{\gamma_M \xi}{r_e}$$

Eb. 3

(27

32)

PINCH EFFECT



BACK OF MAIN BEAM EXPERIENCE GREATER DENSITY —

$$f_M = f_0 \cos^2\sqrt{K}\,s$$

$$\Delta f = \Delta f_0 - f_0 \sin^2\sqrt{K}\,s$$

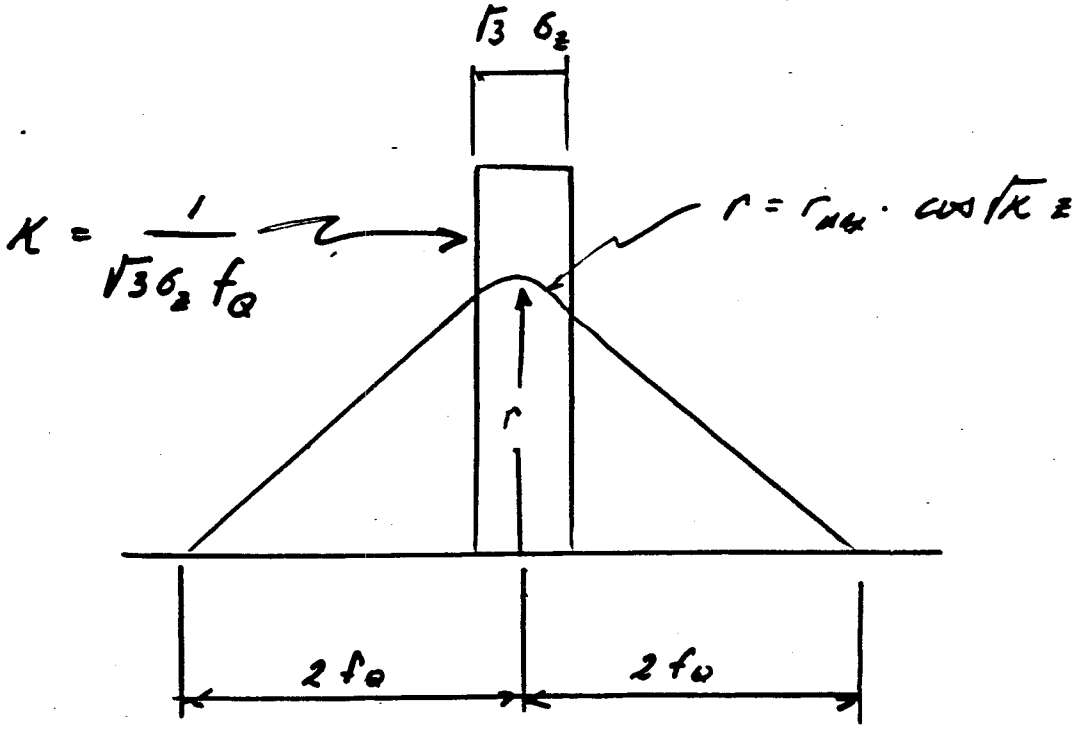
$$\langle \Delta f^2 \rangle = f_0^2 \left(\langle s^4 \rangle - \langle s^2 \rangle^2 \right)$$

$$\left(\frac{\Delta L}{L}\right)_{PINCH} \approx \frac{\langle \Delta f^2 \rangle}{\beta^{*2}} = \frac{4}{15} \left(\frac{\ell^*}{\beta^*} \cdot \frac{\sigma_z}{f_Q} \right)^2$$

$$s^2 = \sigma_0^2 \left(1 + \left(\frac{s}{\beta^*}\right)^2\right)$$

$$\left(\frac{f}{\beta^*}\right)^2 \qquad \frac{\langle \Delta f^2 \rangle}{f^2}$$

PINCH EFFECT



$$f \sim r^2 \quad \Rightarrow \quad f = f_{max} \cos^2 \sqrt{K}\, z$$

$$\frac{\langle \Delta f^2 \rangle_{min}}{f^2} = \frac{1}{60} \left(\frac{\sigma_z}{f_Q} \right)^2$$

{ GAIN FACTOR OF 16 HERE.

$$\sigma^2 = \sigma_0^2 \left[1 + \left(\frac{s}{\beta^2} \right)^2 \right]$$

$$\Rightarrow \frac{\langle \Delta f^2 \rangle}{\beta^2} = \frac{\langle \sigma^2 \rangle - \sigma_0^2}{\sigma_0^2}$$

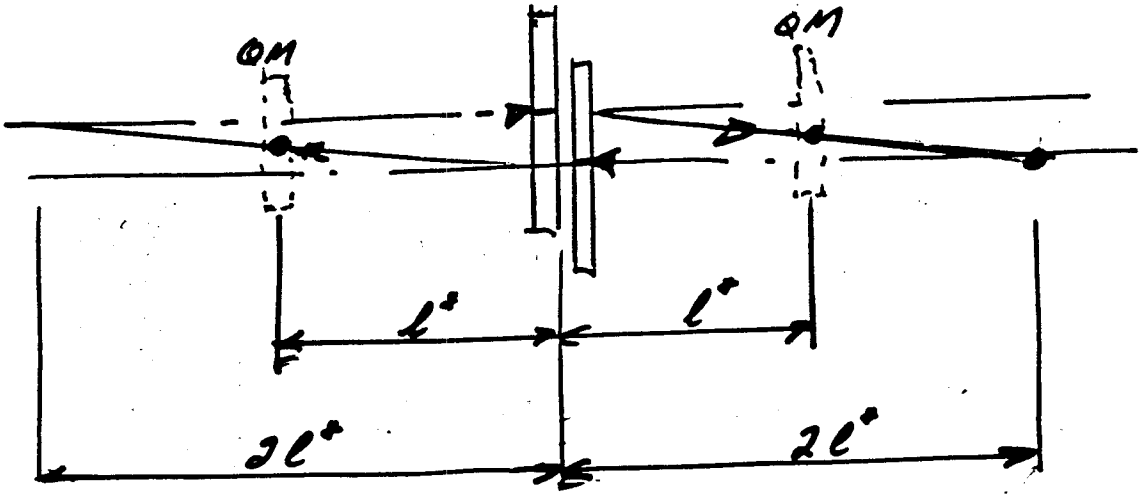
$$\frac{1}{f_Q} = \frac{N_M r_e}{\gamma_Q \sigma_M^2} = \frac{1}{\xi^2} \frac{N_M r_e}{\gamma_Q \sigma_0^2}$$

$$D_f \frac{\gamma_M}{\gamma_Q} \frac{1}{\xi} = \sqrt{60 \frac{\left(\frac{s^2}{\sigma_0^2} - 1 \right)}{\left(s^2/\sigma_0^2 \right)^2}} + \sqrt{15}$$

$$= 3.65 \quad @ \quad \frac{s^2}{\sigma_0^2} = 1.5$$

AUTO - ALIGNMENT

FROM Q·Q COLLISION



IF $f_{QQ} = 2\ell^*$

Q LENSES ARE ON SAME AXIS AT QM COLLISION

$f_{QQ} = 2\ell^*$ IF AND ONLY IF

$$\frac{\ell^*}{f_Q} = 2\sqrt{2\frac{\gamma_M}{\gamma_Q}} + 2$$

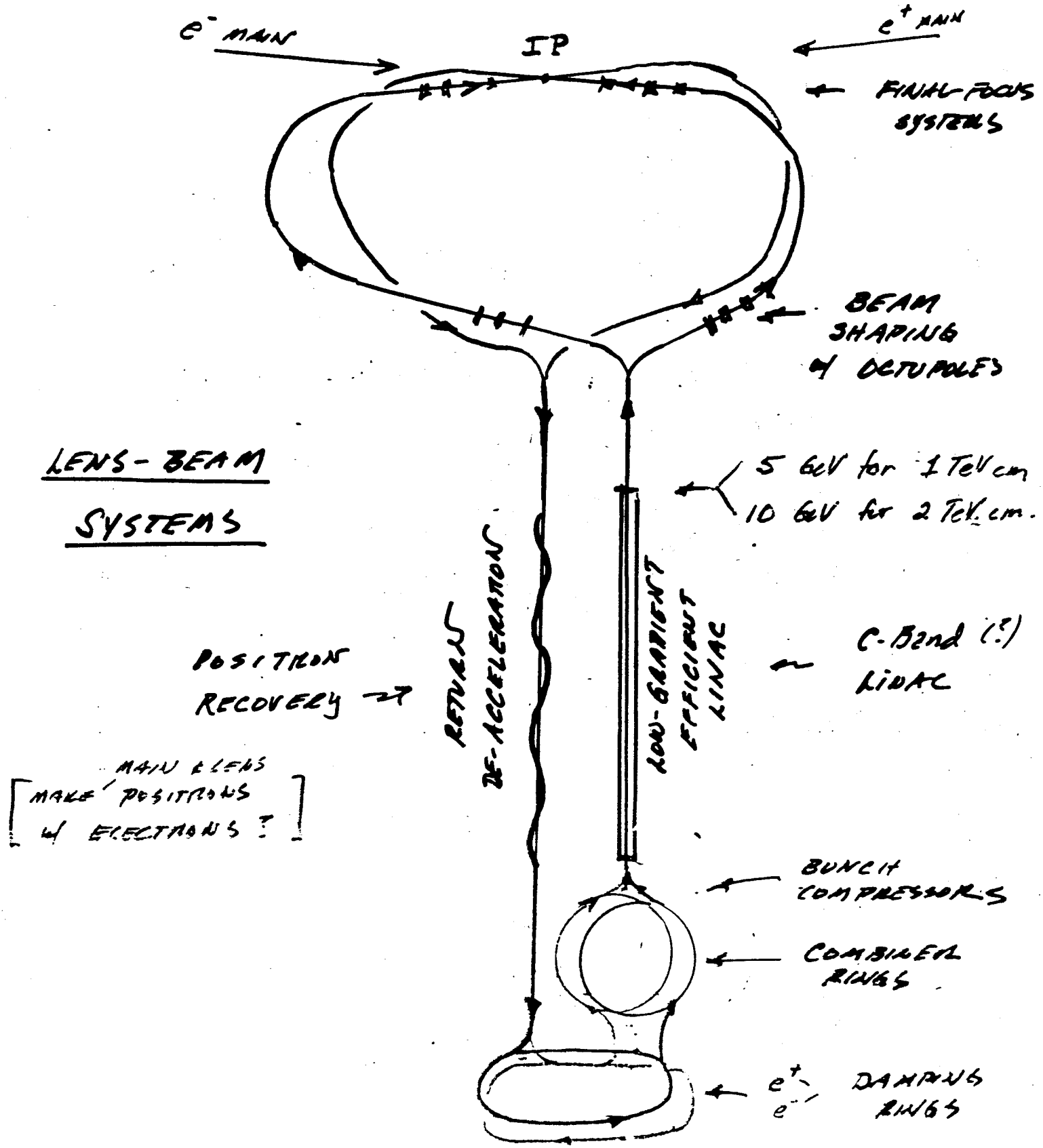
$$2\cdot\sqrt{200} + 2 \approx \underline{30}\ !$$

$$\frac{P_M}{P_{Q_0}} = 30 \Rightarrow \frac{P_M}{P_Q} \approx 8 \quad \& \quad \frac{\gamma_M}{\gamma_Q} = 100 \Rightarrow \frac{N_M}{N_Q} \approx 12$$

$I_M \approx 0.5$ Amp

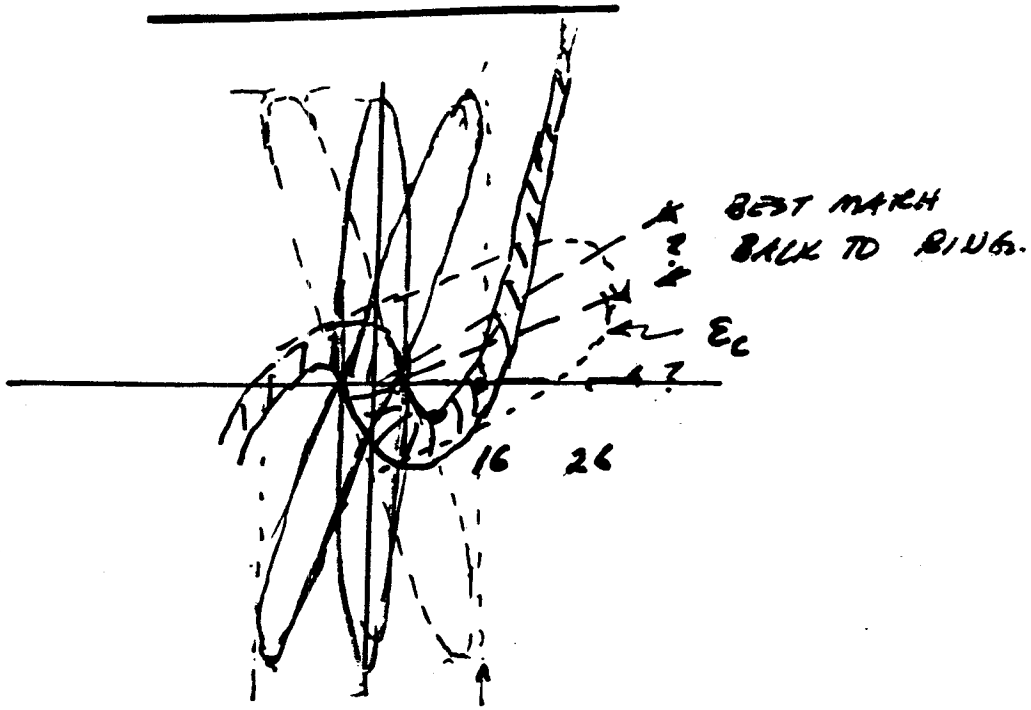
$\downarrow$

$I_Q \approx 6$ Amp!



[USE LINAC ALSO AS MAIN-BEAM PRE-LINAC ?]

RE-DAMPING



$$\varepsilon_{ac} \approx 3\,\varepsilon_{bc}$$

$$\varepsilon_{bc} = \varepsilon_f\left(1 - e^{-2n_\tau}\right) + \underbrace{(\varepsilon_c - \varepsilon_f)}_{\approx 2\varepsilon_f} e^{-2n_\tau}$$

$\varepsilon_c = 6\,\varepsilon_f$

TAKE $n_\tau = 1.5$?

[more $n_\tau \Rightarrow$ more P_{WQ}]

$\frac{1}{120} = 8$ ms

$T_{ring} = \frac{300}{3\cdot 10^8} \approx 1\,\mu s$

$\therefore \tau \approx 1$ ms

$n_\tau = 8$!

$$\varepsilon = \varepsilon_f + \varepsilon_f \underbrace{e^{-2n_\tau}}_{.05}$$

$\approx 1.05\,\varepsilon_f$.

LOOK OK!

ALSO $\frac{\Delta y_M}{f_Q} = \frac{\frac{1}{2}\sigma_M}{f_Q} = \frac{\frac{1}{2}\sigma_a}{f_M} = \frac{1}{2}\sigma_a'$ FROM JITTER OF MAN — $n_\tau = 2$?

PARAMETERS

$\ell^*/f_Q = 30$ AUTO ALIGNMENT

E	1 TeV	3 TeV
D	1.3	1.3
H	3.7	3.7
σ_z	130 μm	80 μm.
n_b	1.0	1.0
N	$8.3 \cdot 10^8$	$2.8 \cdot 10^8$
γ	0.2	1.1
σ_f	15 nm	4 nm
$(\gamma\varepsilon)_Q$	10^{-6}	$0.4 \cdot 10^{-6}$
$(\gamma\varepsilon)_{Oide,M}$	$0.5 \cdot 10^{-6}$	$0.7 \cdot 10^{-7}$
ξ	35	35
γ_M/γ_Q	100	100
σ_M	.44 μm.	.12 μm
f_Q	.8 mm.	.5 mm.
β^*	.7 mm.	.46 mm.
ℓ^*	2.5 cm	1.6 cm
$(\gamma\varepsilon)_M$	$2.2 \cdot 10^{-7}$	$7.3 \cdot 10^{-8}$
N_a	10^{10}	$3.3 \cdot 10^{9}$

$\frac{\text{LUM}}{\text{LUM SCALE}} = 6.3.$

STATUS SUMMARY

1. UNIFORMITY AT QQ & MQ

NEEDS TO BE DEMONSTRATED

2. ACTUAL DESIGN FOR LENS-BEAM SYSTEM

INTEGRATE W/ CENTRAL INJECTOR CAMPUS

3. STUDY IMPACT OF ROUND PARAMETER SET

... OPTIMIZE LINAC...

... HIGHER GRADIENTS ?? (@ higher freq.)

DYNAMIC FOCUSING FOR MUON COLLIDER?

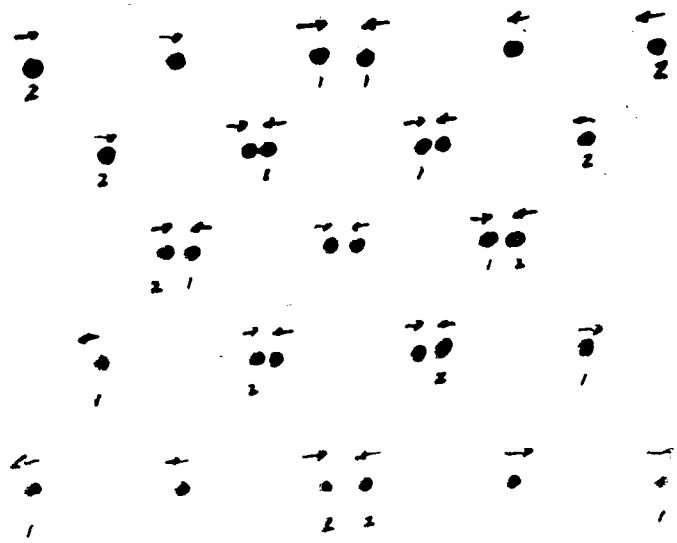
FOUR MAJOR PROBLEMS

N_Q • LENS BUNCH CHARGE IS HUGE ($\gtrsim 10^{13}$)
[σ_z ARE LARGE!]

PINCH • LONG $(\sigma_z)_M$ ⇒ LARGE f_Q ⇒ LARGE $\frac{P_Q}{P_M}$.

RING • IN ⟷ OUT FOCUSING SYMMETRY ⇒ 2 LENS BUNCHES

IMPLIES 6 CROSSINGS



• 1000 TURNS ⇒ LENS REUSE ~ 1000 ×

⇒ VERY BATTERED LENSES

FUTURE LINEAR COLLIDER PARAMETERS

Energy c.m.	TeV	1	3	10	30	100
Power	GWatt	0.1	0.17	0.32	0.55	1.0
Luminosity	10^{34} /(cm^2 sec)	1	10	10^2	10^3	10^4
Gradient	MV/m	60	120	200	300	500
Length	km	16	25	50	100	200
σ	nm	10	2	0.4	0.1	0.02
$\gamma\varepsilon$	nm r	300	30	3	0.4	0.05
σ_z	µm	70	40	14	6	2
D/H		1 / 2.5	1.5 / 5	2 / 8	3 / 12	4 / 18
Y(upsilon)		0.3	3	60	1000	3 10^4