γ_t Jump Design Considerations for the Fermilab Main Injector

Stephen D. Holmes

APS Meeting

April 18, 1994

DESIGN CRITERIA

Main Injector Parameters:

$N_p = 6 \times 10^{10}$/bunch

$\varepsilon_L = 0.25$ eV-sec

$Z_L/n = (5 + 716/\gamma^2)\ \Omega$

Vrf = 4 MV

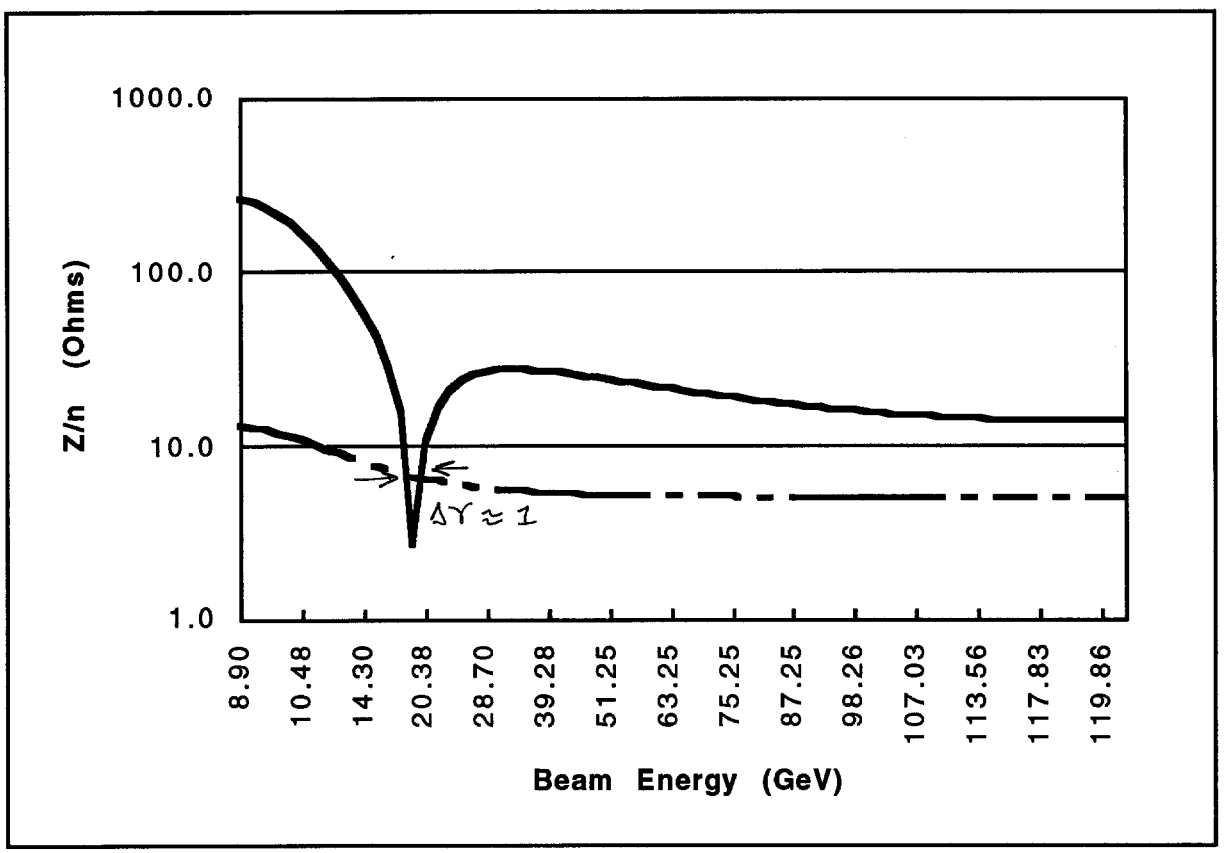
$\dot{E}(\gamma_t) = 144$ GeV/sec

C= 3319 m

$\gamma_t = 20.4$

Microwave Instability

Keil-Schnell: $$\left|\frac{Z_L}{n}\right| < \frac{2\pi\eta\beta^2 E}{eI_p}\left(\frac{\sigma_p}{p}\right)^2$$



Requires $\Delta\gamma_t = 1$

Microwave Growth Time

$$\tau_{rise} = \sqrt{\frac{2\pi\beta^2 E}{\eta\omega_o^2 e Z_L I_p}}$$

= 5 msec near transition (for Z/n = 5 Ω @ 4GHz)

Johnsen Effect

$$T_{non-linear} = \frac{\left(\frac{3}{2} + \frac{\alpha_1}{\alpha_o}\right)\gamma_t}{\dot{\gamma}}\left(\frac{\sigma_p}{p}\right) \approx 1.0ms$$

$$T_{non-adiabatic} = \left(\frac{\pi\beta^2\gamma^3 E}{h\omega_o^2\dot{\gamma} e V_{rf}\cos\phi_s}\right)^{\frac{1}{3}} \approx 1.7ms$$

$$\frac{\Delta\varepsilon}{\varepsilon} \approx \left(\frac{.76 * T_{non-linear}}{T_{non-adiabatic}}\right) - 1 \approx 60\%$$

For $\dot{\gamma}$ = 1144: $T_{non\text{-}adiabatic}$ = 0.81msec $T_{non\text{-}linear}$ = 0.13 msec

$$\boxed{\text{Requires } \dot{\gamma}_t = 1/1\text{msec}}$$

SYSTEM SPECIFICATION

$$\Delta\gamma_t = 1$$
$$T = 1 \text{ msec}$$

To first order:

$$\Delta\left(\frac{1}{\gamma_t^2}\right) = \sum_q \frac{\Delta q \eta_q^2}{C_o} \qquad \text{where} \qquad \Delta q = \frac{\Delta k L}{(B\rho)}$$

Second Order Jump (Traditional)

Tune fixed

Beta functions locally disturbed

Dispersion resonantly perturbed but,

γ_t varies as second order of perturbation

Schematic-

First Order Jump (Peggs, Tepikian, Trbojevic)

Tune fixed globally but phase advance redistributed between dispersive and non-dispersive regions.

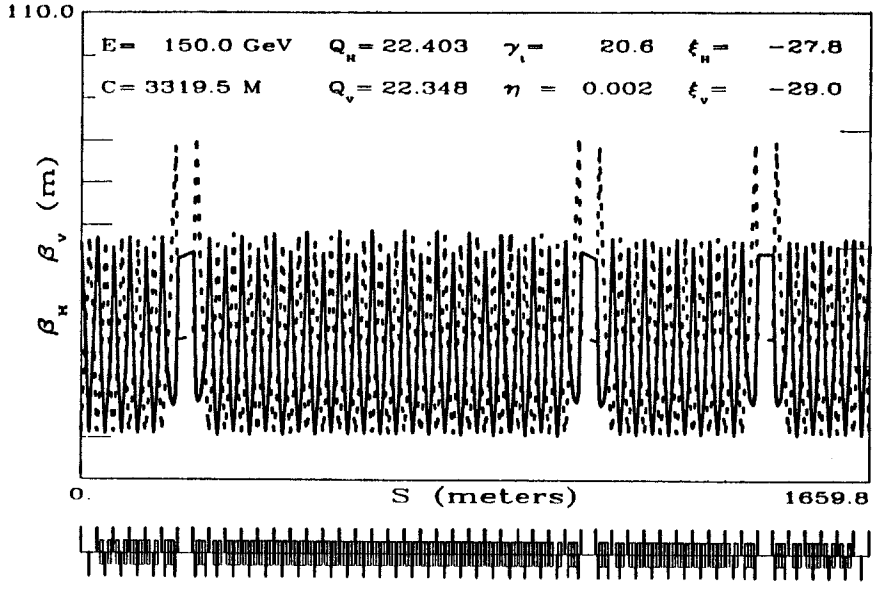
Beta functions locally disturbed

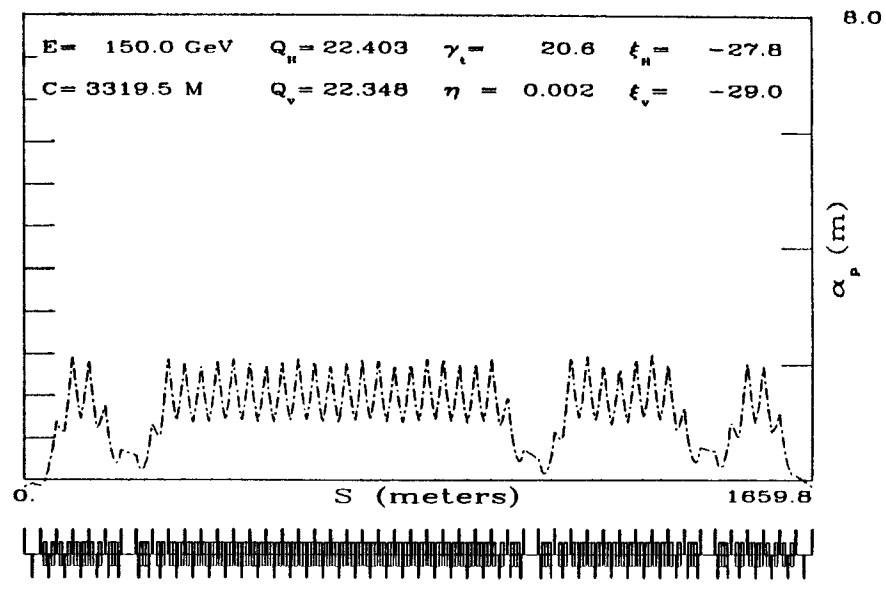
Dispersion perturbed naturally

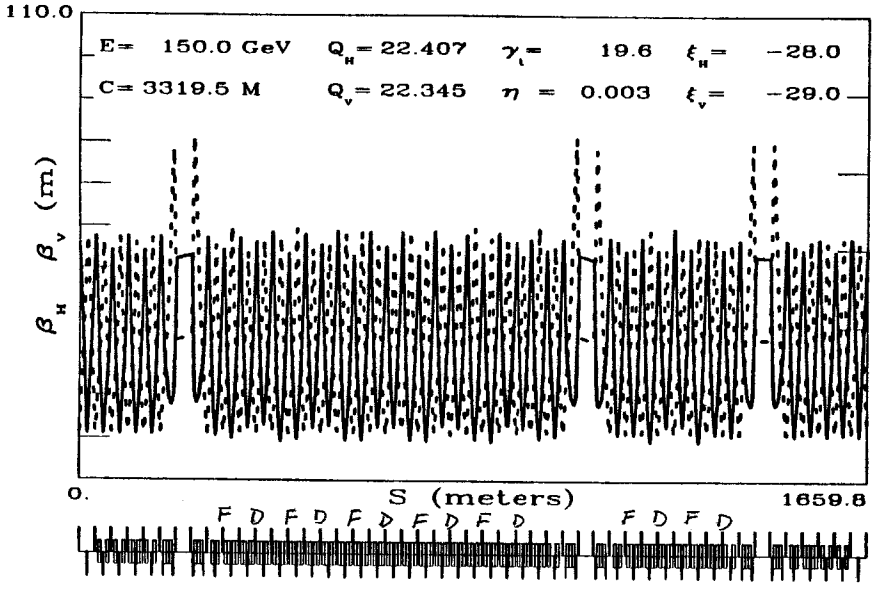
γ_t varies as first order of perturbation

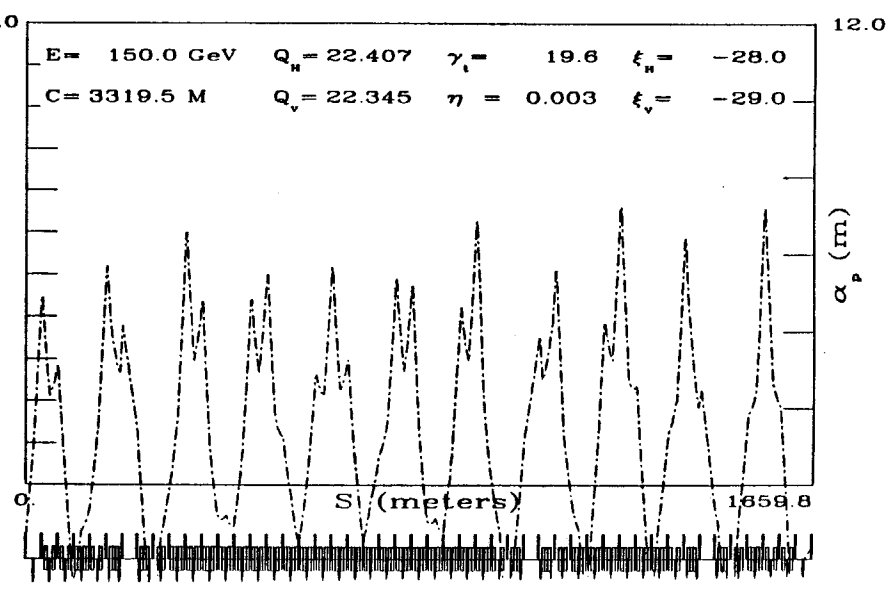
Schematic-

$\Delta\gamma_t$	First Order			Second Order	
	F/D (kG)	η_{max} (m)		F/D (kG)	η_{max} (m)
0	0.0/0.0	2.4		0.0/0.0	2.2
-.5	6.9/2.4	3.0		2.7/2.6	5.6
-1.0	12.3/4.3	3.5		3.8/3.7	7.0


110.0
E= 150.0 GeV
Q_H= 22.403
γ_t= 20.6
ξ_H= -27.8
C= 3319.5 M
Q_v= 22.348
η = 0.002
ξ_v= -29.0
β_H β_v (m)
0.
S (meters)
1659.8


8.0
E= 150.0 GeV
Q_H= 22.403
γ_t= 20.6
ξ_H= -27.8
C= 3319.5 M
Q_v= 22.348
η = 0.002
ξ_v= -29.0
α_p (m)
0.
S (meters)
1659.8


110.0
E= 150.0 GeV
Q_H= 22.407
γ_t= 19.6
ξ_H= -28.0
C= 3319.5 M
Q_v= 22.345
η = 0.003
ξ_v= -29.0
β_H β_v (m)
0.
S (meters)
1659.8
F D F D F D F D F D
F D F D


.0
12.0
E= 150.0 GeV
Q_H= 22.407
γ_t= 19.6
ξ_H= -28.0
C= 3319.5 M
Q_v= 22.345
η = 0.003
ξ_v= -29.0
α_p (m)
0.
S (meters)
1659.8

SYSTEM SPECIFICATION

$$\Delta\gamma_t = 1$$
$$T = 1 \text{ msec}$$

To first order:

$$\Delta\left(\frac{1}{\gamma_t^2}\right) = \sum_q \frac{\Delta q \eta_q^2}{C_o} \qquad \text{where} \qquad \Delta q = \frac{\Delta k L}{(B\rho)}$$

Second Order Jump (Traditional)

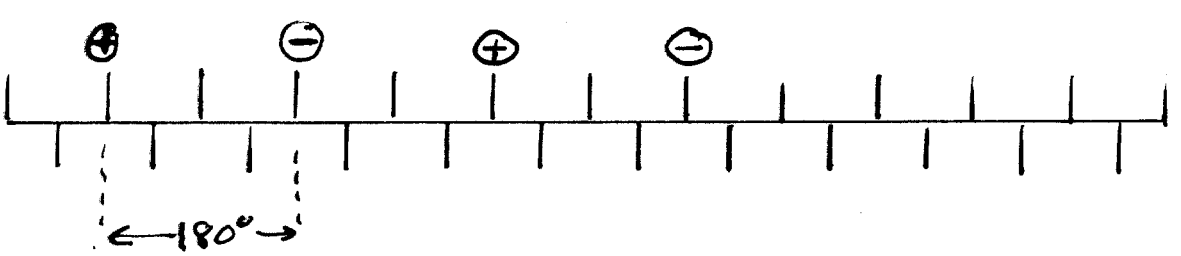
Tune fixed

Beta functions locally disturbed

Dispersion resonantly perturbed but,

γ_t varies as second order of perturbation

Schematic-



First Order Jump (Peggs, Tepikian, Trbojevic)

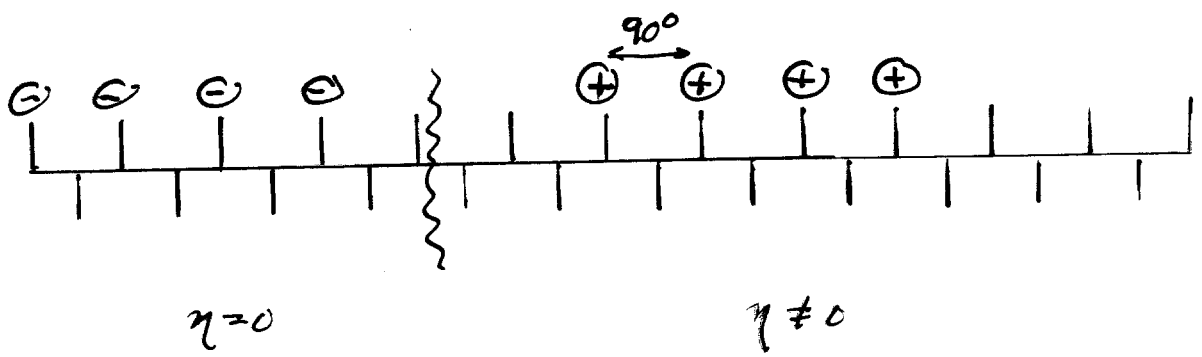
Tune fixed globally but phase advance redistributed between dispersive and non-dispersive regions.

Beta functions locally disturbed

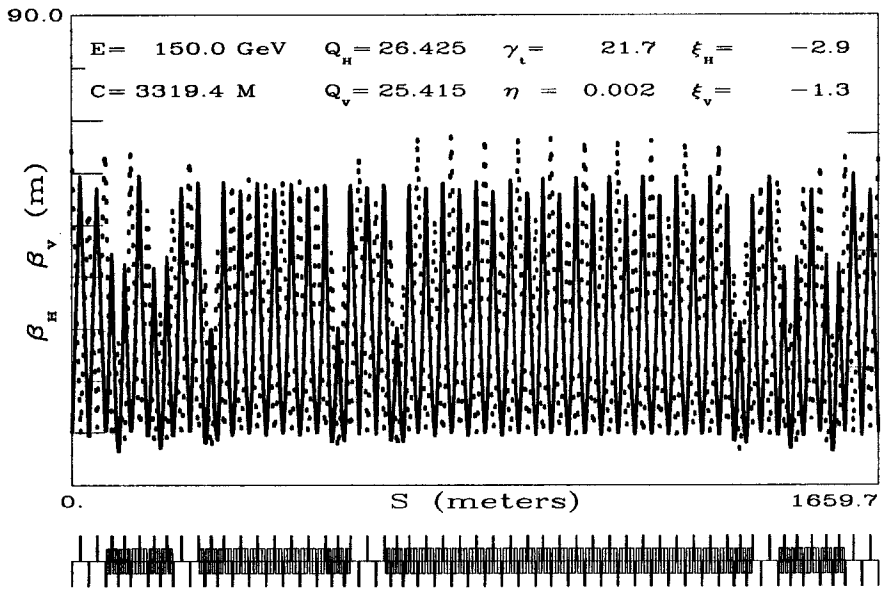
Dispersion perturbed naturally

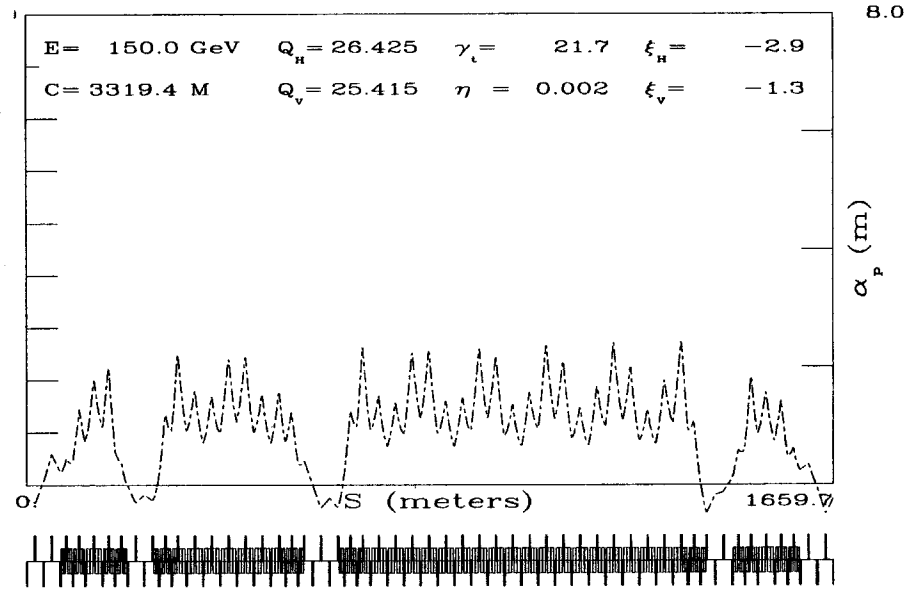
γ_t varies as first order of perturbation

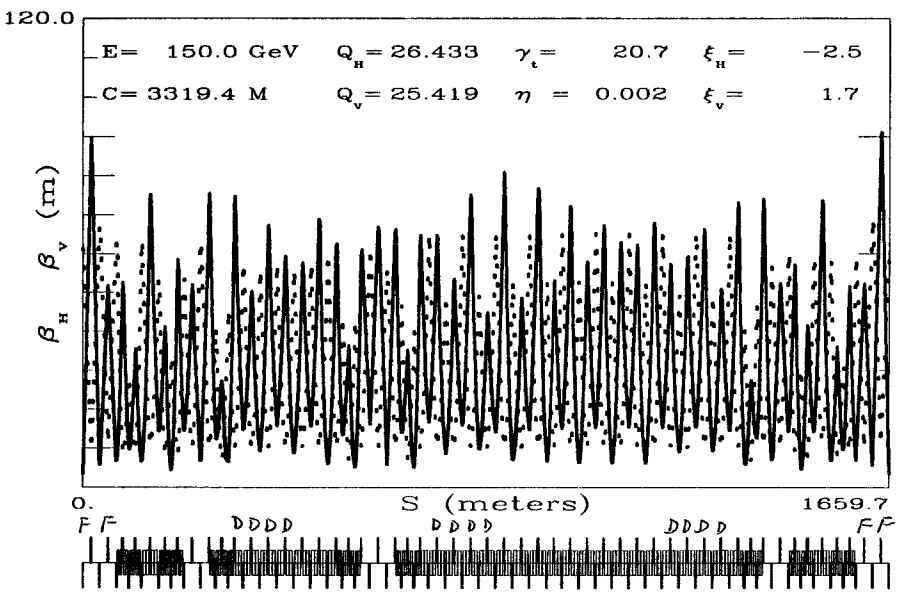
Schematic-

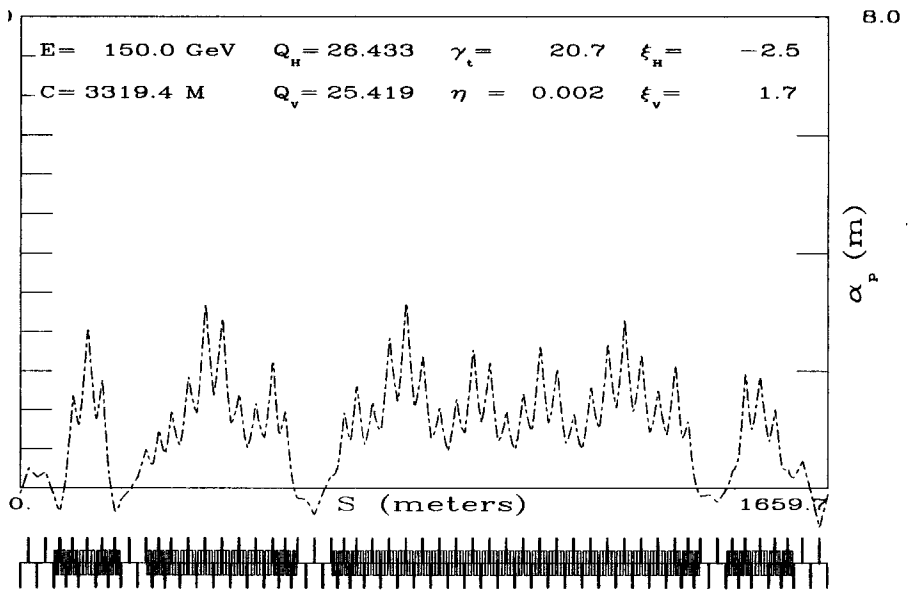


$\Delta\gamma_t$	First Order F/D (kG)	First Order η_{max} (m)		Second Order F/D (kG)	Second Order η_{max} (m)
0	0.0/0.0	2.4		0.0/0.0	2.2
-.5	6.9/2.4	3.0		2.7/2.6	5.6
-1.0	12.3/4.3	3.5		3.8/3.7	7.0


90.0
E= 150.0 GeV
Q_H= 26.425
γ_t= 21.7
ξ_H= −2.9
C= 3319.4 M
Q_V= 25.415
η = 0.002
ξ_V= −1.3
β_H β_V (m)
0.
S (meters)
1659.7


8.0
E= 150.0 GeV
Q_H= 26.425
γ_t= 21.7
ξ_H= −2.9
C= 3319.4 M
Q_V= 25.415
η = 0.002
ξ_V= −1.3
α_p (m)
0.
S (meters)
1659.7


120.0
E= 150.0 GeV
Q_H= 26.433
γ_t= 20.7
ξ_H= −2.5
C= 3319.4 M
Q_V= 25.419
η = 0.002
ξ_V= 1.7
β_H β_V (m)
0.
S (meters)
1659.7
FF
DDDD
DDDD
DDDD
FF


8.0
E= 150.0 GeV
Q_H= 26.433
γ_t= 20.7
ξ_H= −2.5
C= 3319.4 M
Q_V= 25.419
η = 0.002
ξ_V= 1.7
α_p (m)
0.
S (meters)
1659.7

SYSTEM DESIGN REQUIREMENTS

F/D Perturbation = 12.3/4.3 kG

Main quads have $\int B' dl$ = 55.5 kG (575 A @20 GeV)

Need to increase/decrease 127/44 A in 1 msec if add to existing quad:

V = Ldi/dt = 165 V (OK)

Skin depth (@1 KHz) = 1 cm (OK)

FUTURE DEVELOPMENT

Simulation - Need is borderline

Optimum distribution of perturbation

System design
- Eddy Current effects
- Optimum wave form
- Dedicated magnets?
- Excitation technique