Title
Time Dependent Focusing

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Time Dependent Focussing

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VNL Physics Meeting

Background

Focussing Concept

NDCX II

Fusion Driver

Background

The VNL program now hinges on beam manipulations similiar to those of light ion fusion:

neutralized drift compression
neutralized final focus

To be attractive WDM and fusion system concepts have evolved:

low ion kinetic energy
low ion mass
high line charge density
modular accelerators
few (~20) drift lines
high longitudinal compression
highly stripped ions

→ Perveance > 10^{-3} doesnt allow quadrupole transport in vacuum

Perveance may actually exceed unity in final focus!

Solenoidal transport in vacuum can handle much larger perveance, but there is a space charge limit:

$$\lambda < \left(10\,\frac{\mu C}{m}\right)\left(\frac{B}{10T}\right)^2\left(\frac{a}{10\,cm}\right)^2\left(\frac{133}{A/g}\right)$$

+ high space charge potential:

$$\delta\phi_{\substack{center\\-to-edge}} = (90\,kV)\left(\frac{\lambda}{10\,\mu C/m}\right)$$

- Use electron neutralization in solenoids — from plasma or co streaming

Not yet clear this really works when electrons must cross field lines

{ If a design did not use neutralization, Grant would improve it by increasing λ so it did require neutralization

Some consequences of neutralization:

Momentum tilt is not removed by space charge prior to final focus

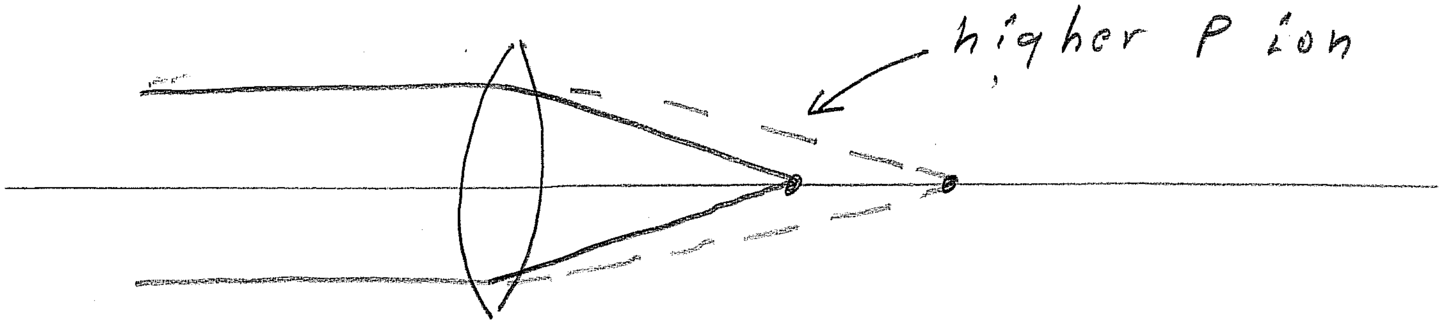
Strong quadrupoles probably can't be used — problem for electron flow

Solenoids may be "ok" — what happens to electrons when beam does not follow field lines?

Large tilts ($\Delta P/P_0 \sim \pm .05$) for large compression and short drift length

A static final focus system has a severe chromatic aberration ("second order")

The focal spot position depends on momentum



parallel-to-point focus

(We are actually considering
thick solenoidal lenses)

Random momentum spread blows up spot radius — can't fix with SLC type scheme using sextupoles

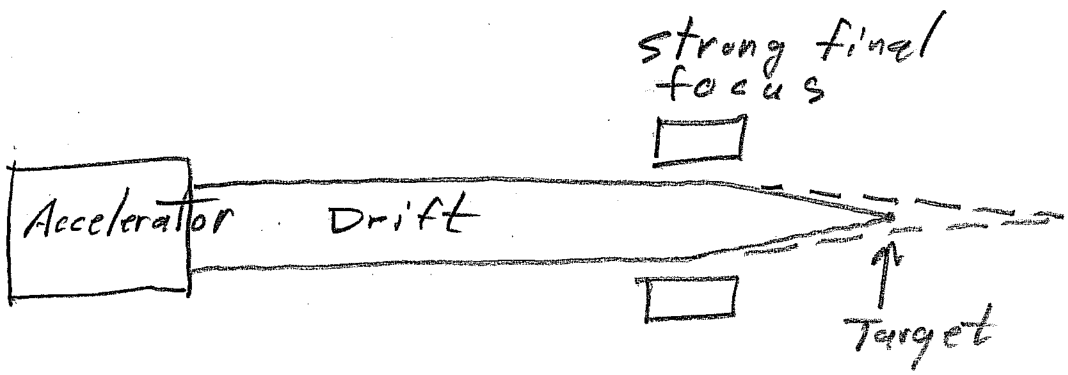
→ Must have sufficiently cold beam before compression

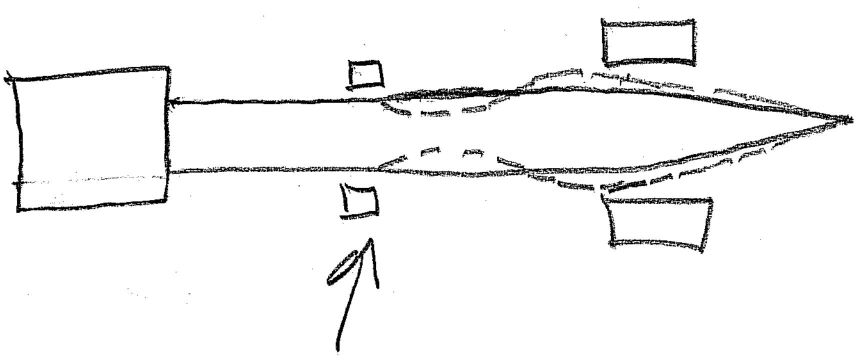
Systematic tilt moves focal spot — blows up the mean spot radius at fixed position

But systematic tilt can be compensated by time dependent upstream lenses (TDL)

(spot motion from tilt) + (spot motion from TDL) = 0

Focussing Concept (Drawing by GL)





Make ions with ΔP > 0 enter final focus with a finite converging angle

~ One period of envelope oscillation from pulsed lens to final focus

There is a connection between beam radius in drift and drift distance from pulsed lens to final focus!!

$$\frac{d^2 a}{dz^2} = -\left[\frac{B_d}{2(B\rho)}\right]^2 a + \frac{\epsilon^2}{a^3}$$

B_d = drift field

$(B\rho) = \beta\gamma \frac{Mc}{qe}$ = ion rigidity

a = beam radius

equilibrium $a = \sqrt{\frac{2(B\rho)\epsilon}{B_d}} \sim \sqrt{\frac{m\,\epsilon_n}{q\,B_d}}$

envelope oscillation:

$$\frac{d^2 \delta a}{dz^2} = -\left[\frac{B_d}{2(B\rho)}\right]^2 \delta a - \frac{3\epsilon^2}{a^4}\,\delta a$$

$\delta a \sim \cos(kz)$

$k^2 = 4\left[\frac{B_d}{2(B\rho)}\right]^2 \quad (= 4k_\beta^2)$

Set $k = 2\pi / L_{drift}$ <u>Pulse Tail</u>

$\rightarrow B_{drift} = k(B\rho) = \frac{2\pi (B\rho)}{L_{drift}}$

Summary of concept:

Pulse head goes straight through

Pulse tail gets inward envelope kick + goes through one envelope oscillation

In between parts of the pulse get kicked and have less than one oscillation

For a given final strong lens find out how hard each part of pulse must be kicked to compensate focal position motion

This is not a linear dependence on ΔP

→ Find how the pulsed field must be ramped + see if it is possible

NDCX II Example

Ion = Na^{+9} (A = 23)

E_{head} = 20 MeV
E_{tail} = 24 MeV } tilt ≈ .095

ϵ_n = 2.3×10^{-6} m-r

L_{drift} = 4.0 m

B_{drift} = .59 T

a_{drift} = .0079 m

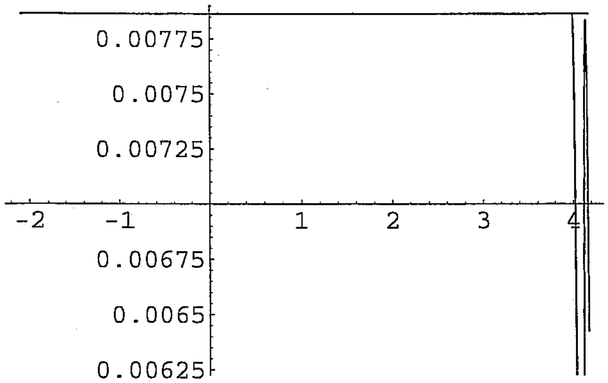
$B_{final\ focus}$ = 15 T

Pulse Magnet length = .2 m

Spot radius of head = .00031 m

Cone Half angle of FF ≈ 150 mr

(9.1)



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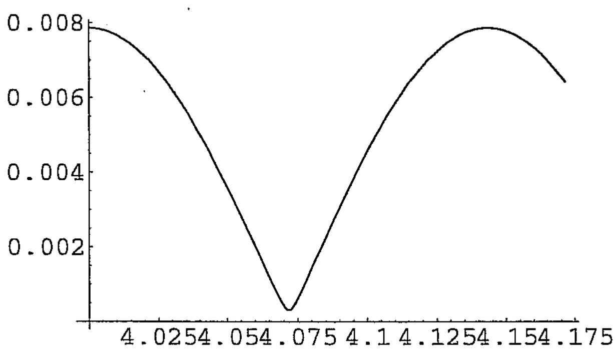

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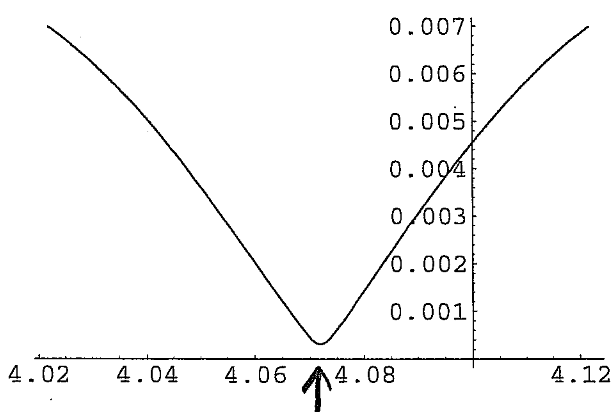

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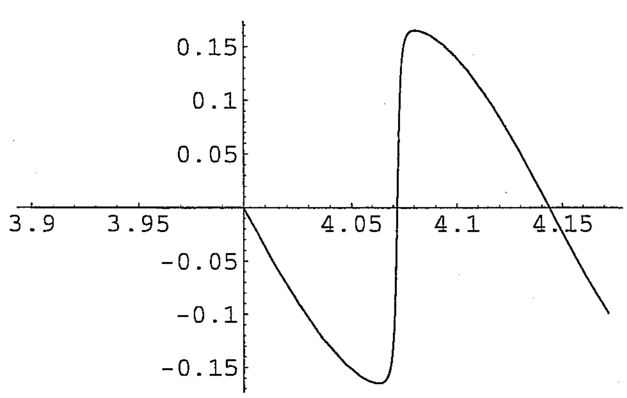

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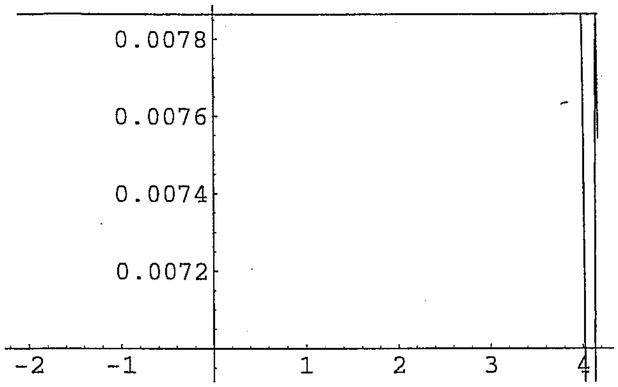

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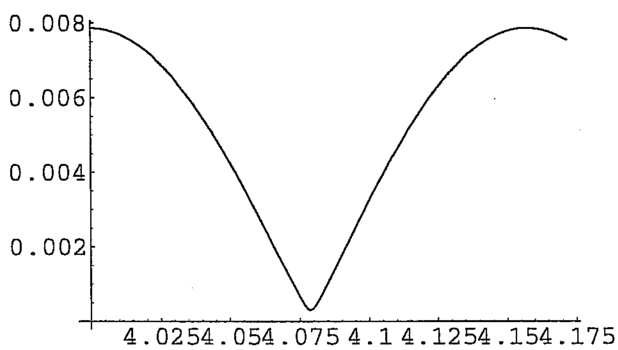

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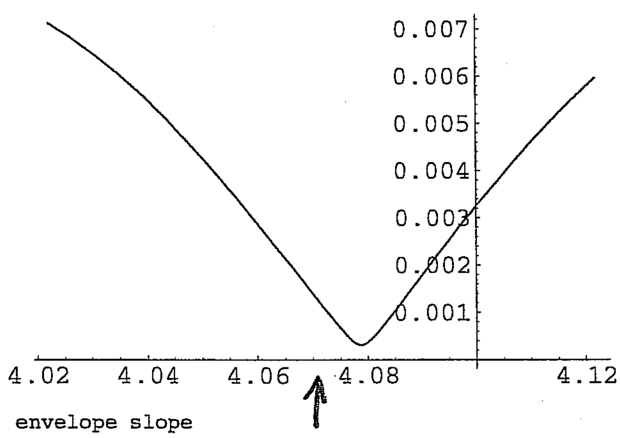
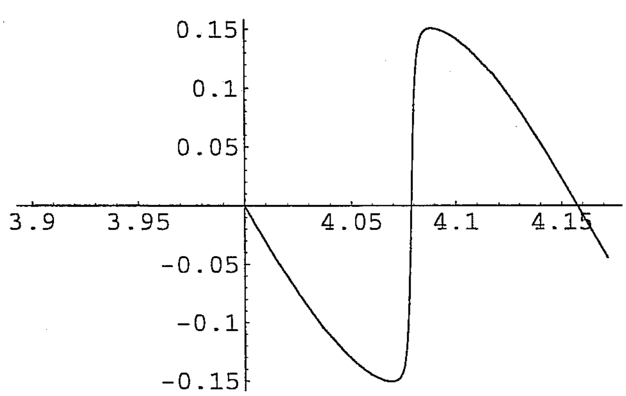


Uncompensated Envelope

envelope slope



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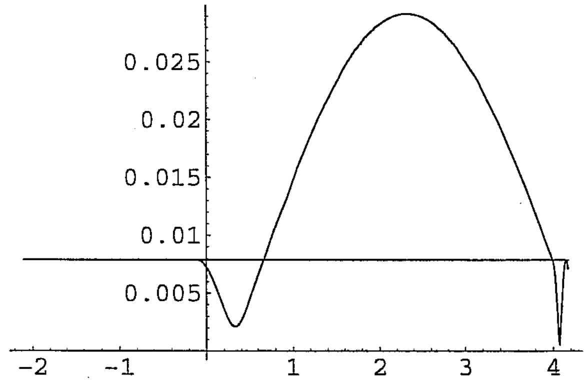

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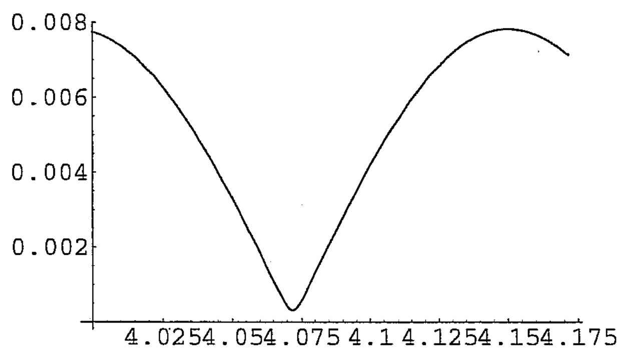

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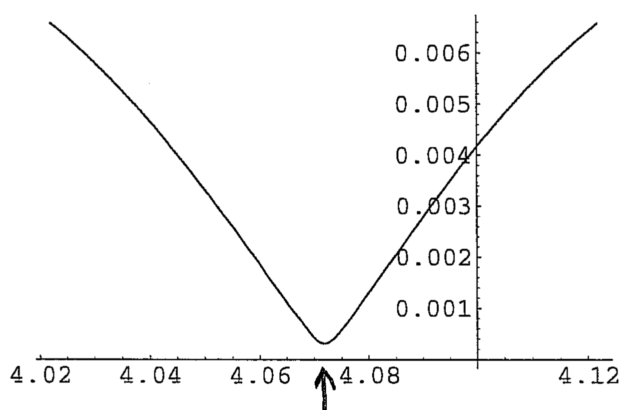
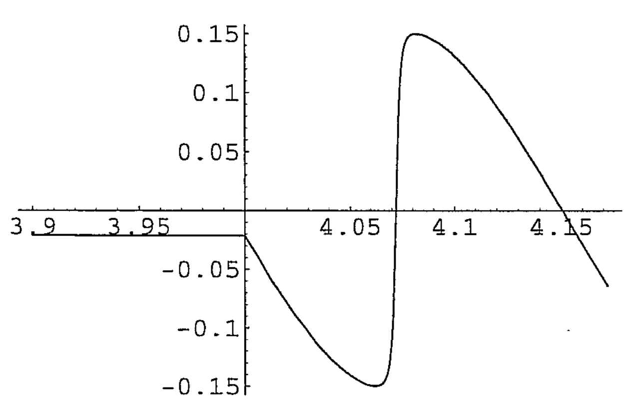


Compensated Envelope

envelope slope



NDCX - II Pulsed Fields:

% ΔP	B_{pulsed}	a_{spot}
0	0 (T)	.000309 (m)
20	.777	.000369
40	1.166	.000392
60	1.503	.000387
80	1.882	.000359
100	2.385	.000311

We have compensated spot position

If we minimize spot radius at target we can get a smaller spot!

- An increase in beam radius entering final focus can decrease the spot more than the shift of focus increases it.

Driver Example

Ion = K^{+19} (A = 39)

E_{head} = 611 MeV
E_{tail} = 739 MeV } Tilt ≈ .1

ϵ_n = 5×10^{-6} m-r

L_{drift} = 400 m

B_{drift} = .0203 T

a_{drift} = .056 m

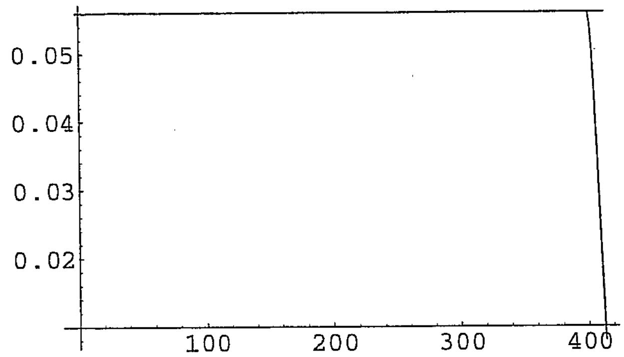
$B_{final\ focus}$ = .3 T

Pulsed magnet length = 1.0 m

spot radius of head = .00379 m

Cone Half angle of FF ≈ .006 radian

11.1



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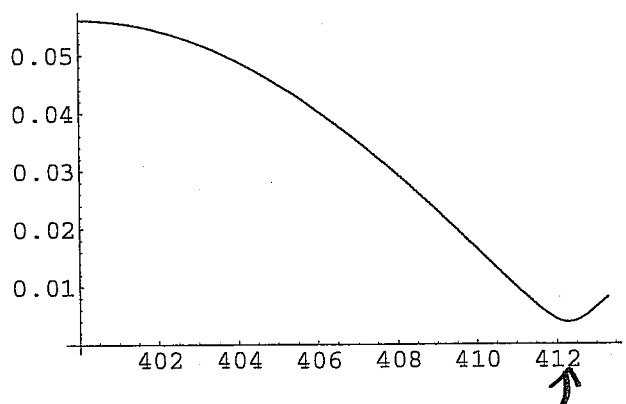

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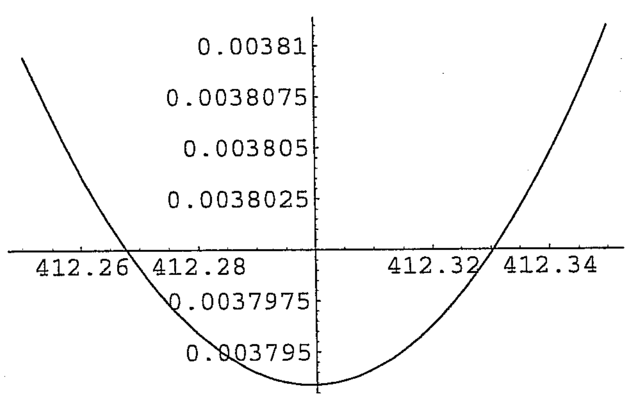

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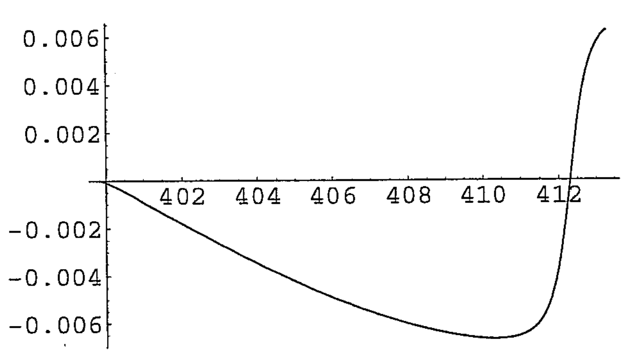
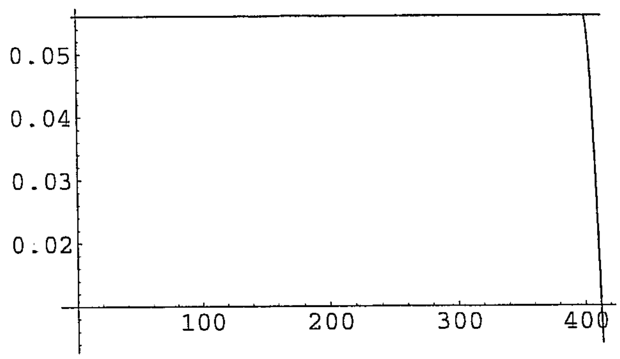


(11.2)



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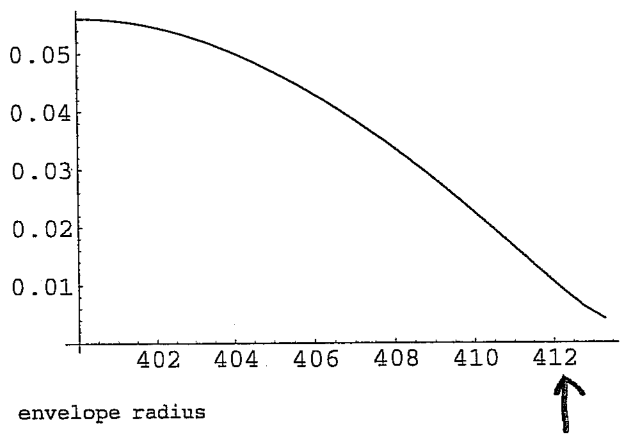
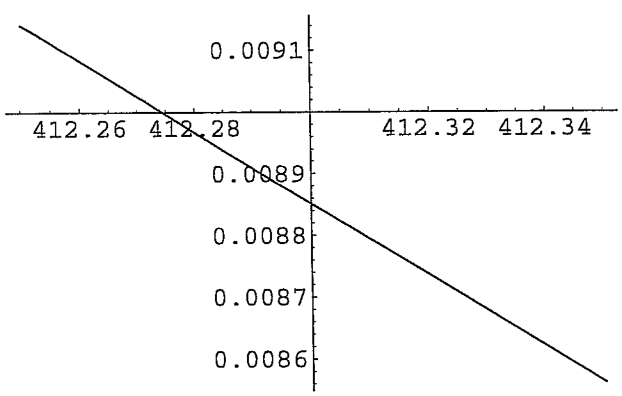


Uncompensated Envelope

envelope radius



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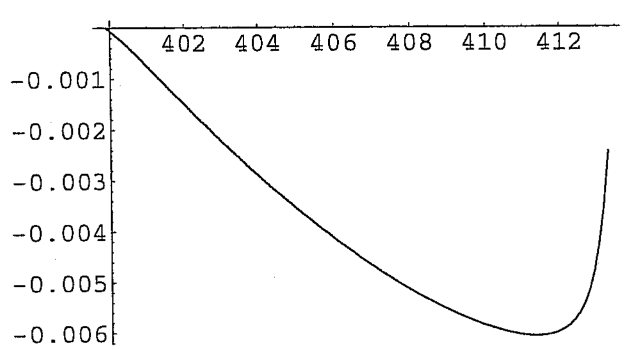

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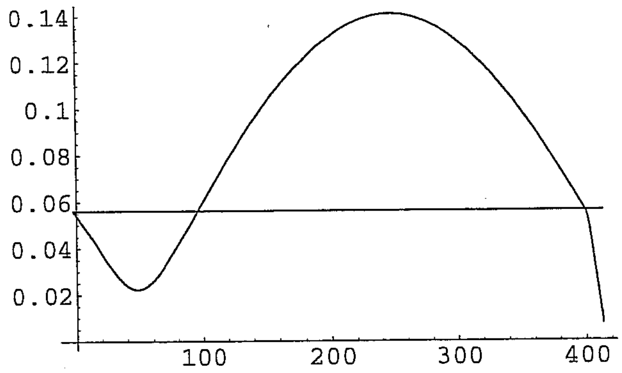

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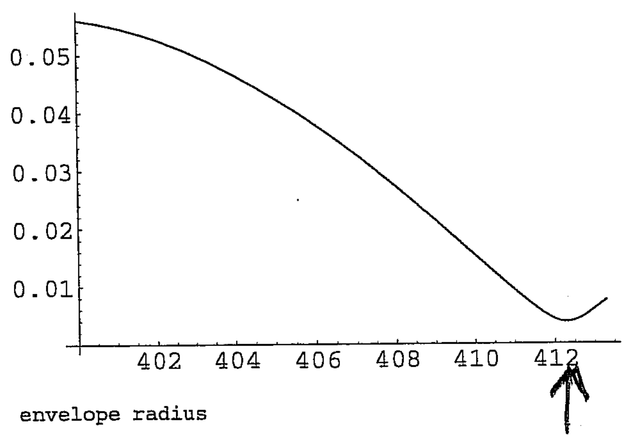
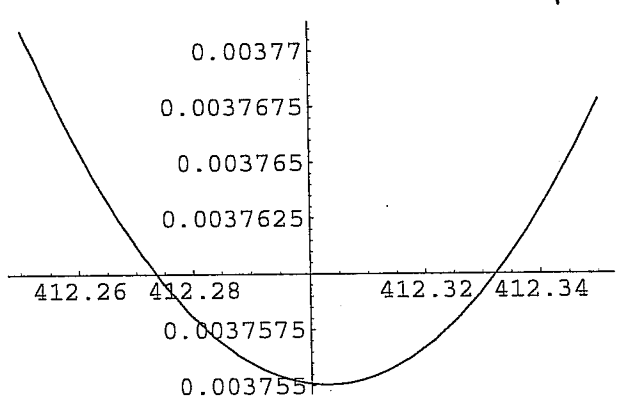


Compensated Envelope

envelope radius



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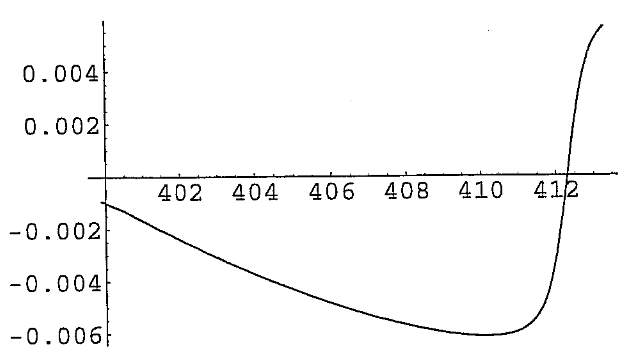

Note We need small cone angle to prevent very large amplitude envelope osscillations

Driver Pulsed Fields :

% ΔP	B_{Pulsed}	d_{spot}
0	0 (T)	.00379 (m)
20	.132	.00426
40	.183	.00443
60	.224	.00438
80	.266	.00415
100	.314	.00375