Question 1: Assess and document target preheat effects from beams and plasma for the various options

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What is the tolerable amount of preheat?

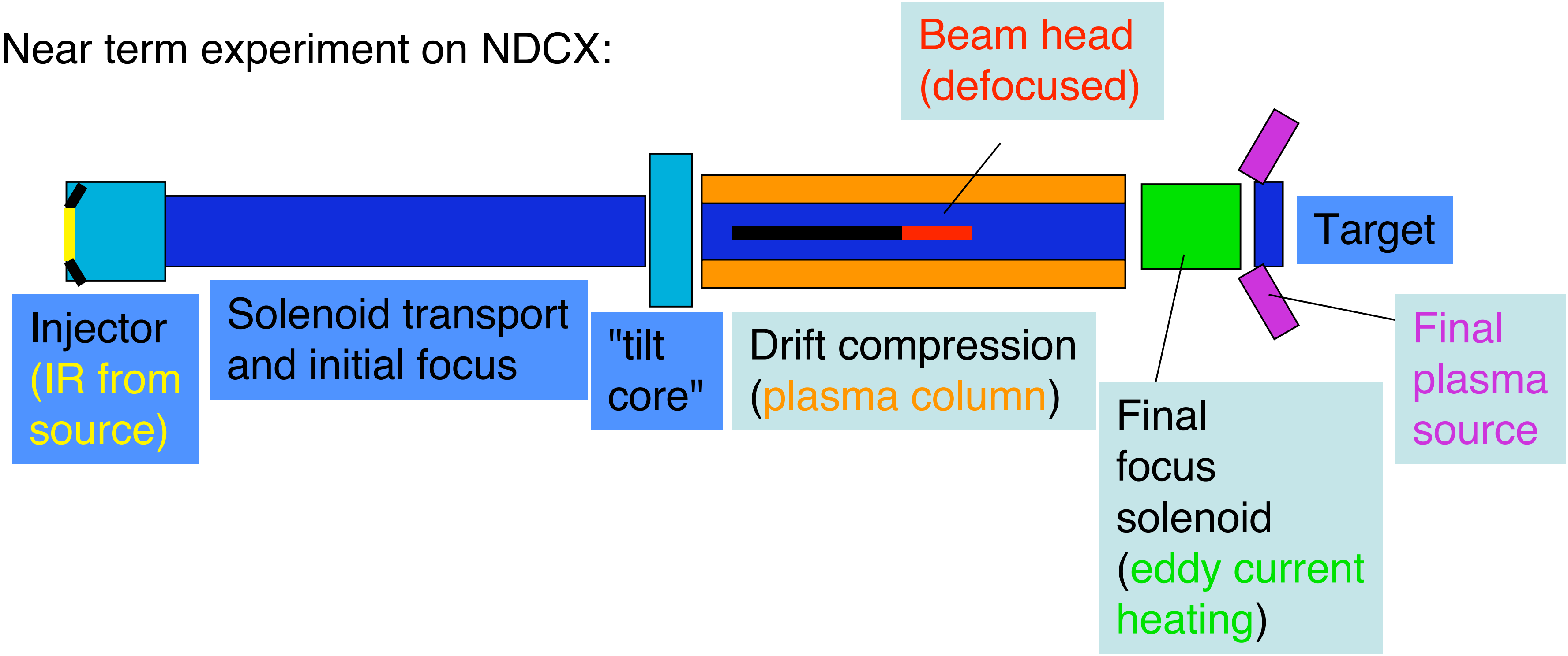
The main pulse duration is chosen so that hydrodynamic motion is small during the time over which the energy is deposited.

If the material remains in solid state prior to the main pulse, negligible hydro motion is maintained.

Target material	Initial temp (eV)	Latent heat of melt (eV/atom)	Melting temp (eV)	Final target temp	Prepulse energy (to melt) (eV/atom)	Final pulse energy (eV/atom)	Ratio of prepulse/ final pulse
Gold	0.025	0.132	0.115	1.5	0.402	4.155	0.097
Aluminum	0.025	0.112	0.080	1.5	0.277	4.26	0.065
Bromine	0.0055	0.0548	0.023	0.5	0.1073	1.43	0.075
Hydrogen	0.00035	6.22E-04	0.0012	2.0	0.003172	6.00	0.001

There are several sources of preheat with different associated timescales

Near term experiment on NDCX:



Beam head (defocused)

Target

Injector (IR from source)

Solenoid transport and initial focus

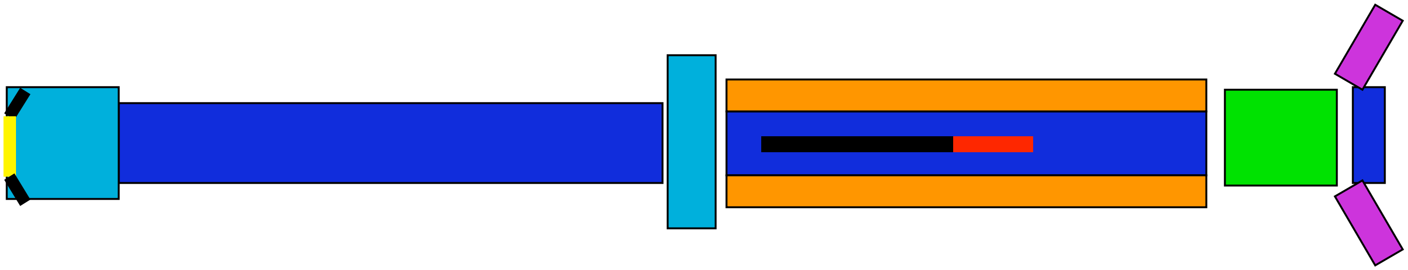
"tilt core"

Drift compression (plasma column)

Final focus solenoid (eddy current heating)

Final plasma source

For NDCX-I, contributions from preheat are small compared to allowances for the metallic targets



Source	Timescale	Deposited energy	Deposited energy (eV/atom)
Beam main pulse	2 ns	1.2 mJ (1.5 A, 400 kV, 2 ns)	1.3 (peak)
Beam pre pulse	~150 ns	~0.12 mJ (1,2)	0.13
Plasma column	~ 4 μs	10^{-4} to 10^{-3} mJ	$4.\times10^{-5}$ - 4×10^{-4}
Plasma column UV	~ 4 μs	< 10^{-4} mJ	< $4.\times10^{-5}$
Final plasma source	~ 180 μs	~0.07 mJ (3)	0.076
Eddy current heating	>~ 100 μs	10^{-4} mJ to 0 J (sc)	4×10^{-5} to 0 (sc)

1. Based on Welch et al, 2/22/2006
2. Sefkow, Leitner, Seidl, and Welch, 10/25/2006
3. Kaganovich,8/15/2006

sc = superconducting magnet

Summary: preheat continues to be assessed, but appears manageable

For NDCX-1, largest contributions to preheat are from the beam head and from the final plasma source. For some experiments prepulse levels (~10%) are acceptable

For NDCX-2 (e.g. Li ATA-cell based machine) a short pulse injector is being considered that would essentially eliminate beam prepulse.

For machine options with a prepulse, time dependent focusing will be an additional tool to defocus head and/or tail of the pulse

Estimates of plasma flow onto target are probably worst case. Careful magnetic field design can lower plasma flux, but designs must be carried out.

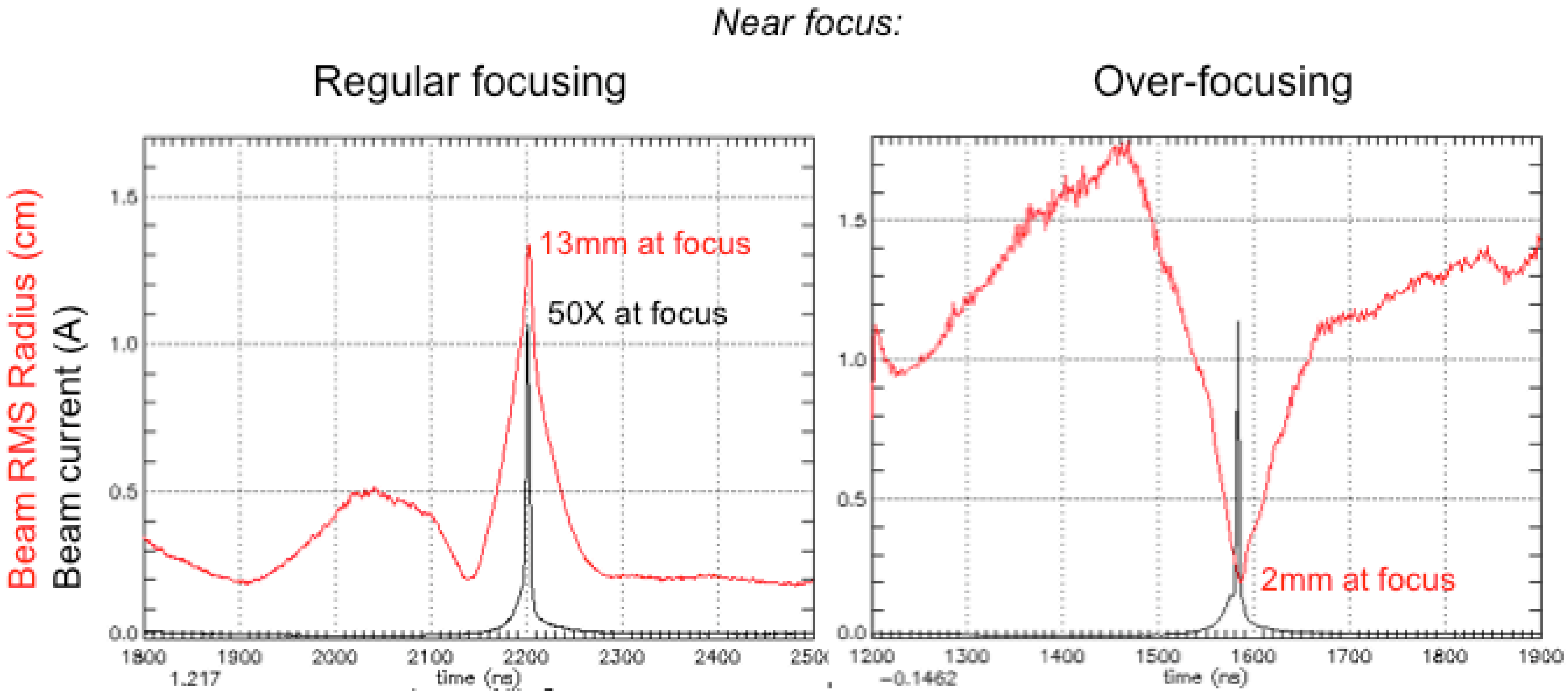
Cryogenic or frozen halogen targets are much more susceptible to preheat, and so special care must be taken to avoid preheat

Simulations by Sefkow are in progress to clarify design choices

EXTRA SLIDES

“Overfocusing” compensates for defocusing effect of gap

From A. Sefkow, NDCX meeting, June 22, 2005



Near focus:

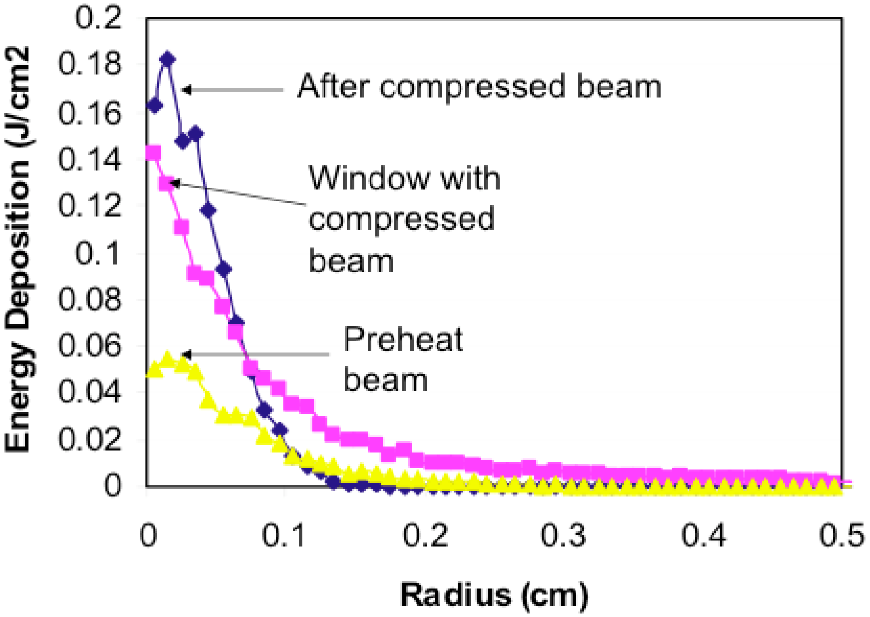
Regular focusing

Over-focusing

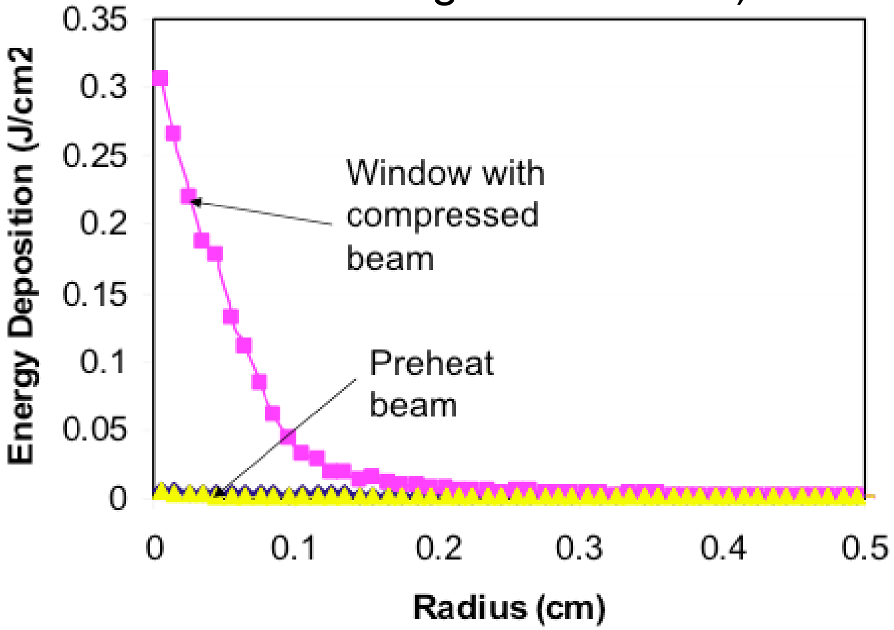
Simulations by Welch and Sefkow show that overfocusing can reduce preheat from non-compressed part of pulse

From Dale Welch's talk at Pleasanton workshop Feb. 2006:

"Nominal focus" (without taking account of defocusing from tilt core).

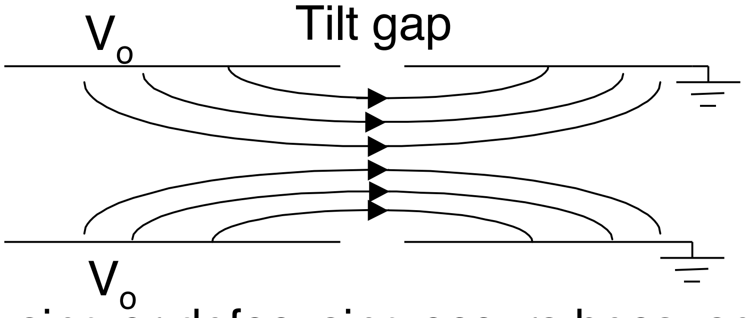


"Overfocusing" (taking account of defocusing from tilt core)



Preheat ~ 1% (eyeball estimate)

Defocusing from the tilt gap helps reduce preheat effects



Focusing or defocusing occurs because, although field is symmetric, ion velocity changes (so time for impulse changes) or voltage changes during transit

Welch et al showed that[1]:

$$\Delta r' = \frac{r}{4v_0}\frac{dV}{dt}\frac{1}{V_0}$$

We may estimate the effect at the focal spot:

$$r_{pre} \approx \sqrt{\varepsilon^2/\theta^2 + f^2 \Delta r'^2}$$

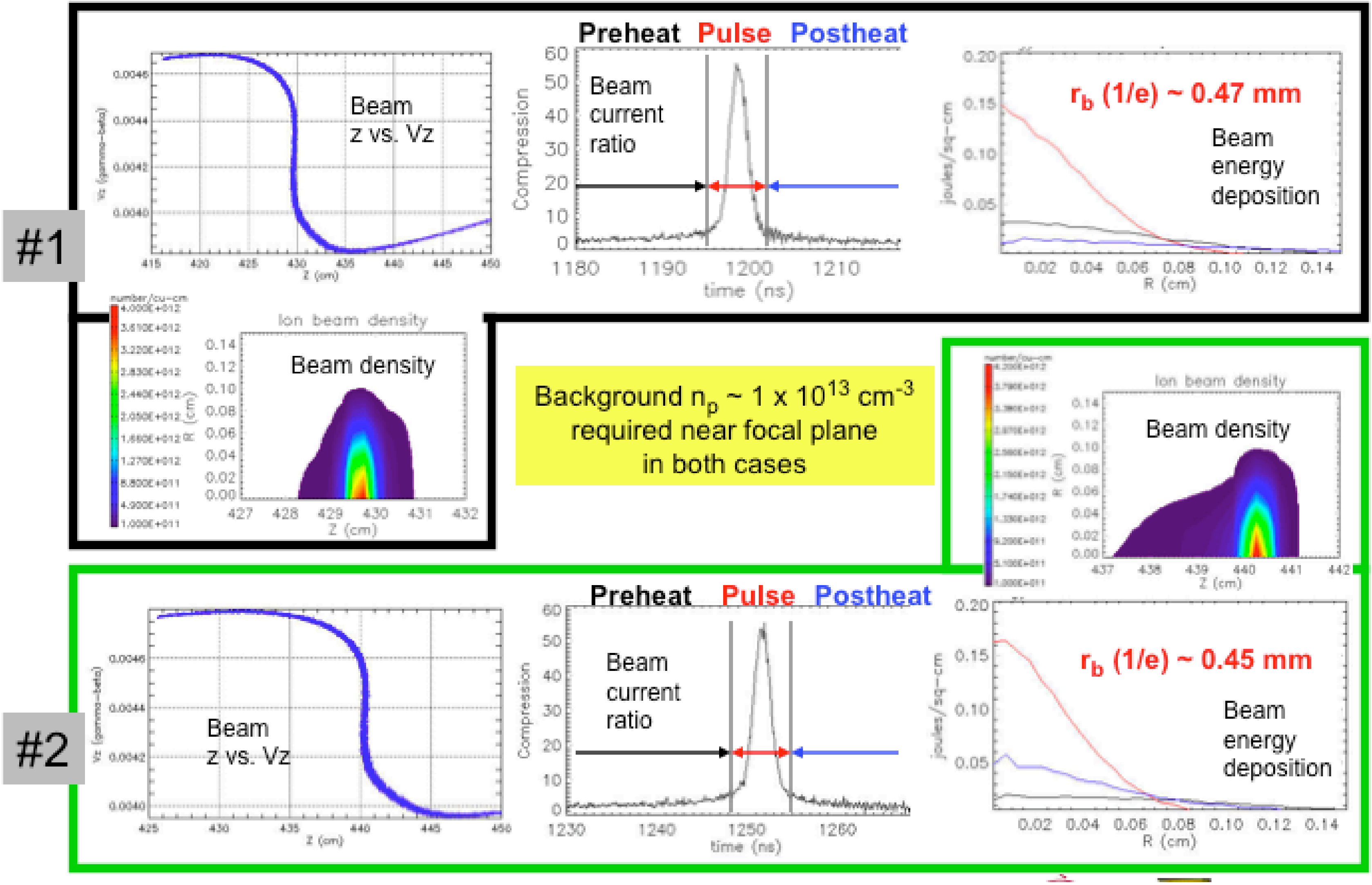
Simple Excel spreadsheet estimate:

	r_{spot}	$\Delta r'$	f	r_{pre}	dt_{pre}	dt_{main}	Comp ratio	Cent Peak factor	B solenoid	T_{pre}/T_{main}
	mm	mrad	cm	mm	ns	ns			T	
NDCX	0.4	2.2	36	0.9	200	2	50	2.4	5	0.17
HCX	0.7	3.9	72	2.9	200	2	25	2.4	5	0.10

1. Welch, Rose, Seidl, and Sefkow, "Beam preheat reduction with time dependent focus on HCX," NDCX meeting, May 10, 2006.

Simulations by Sefkow, Leitner, Seidl, and Welch (10/25/06) show NDCX I preheat levels ~ 10%

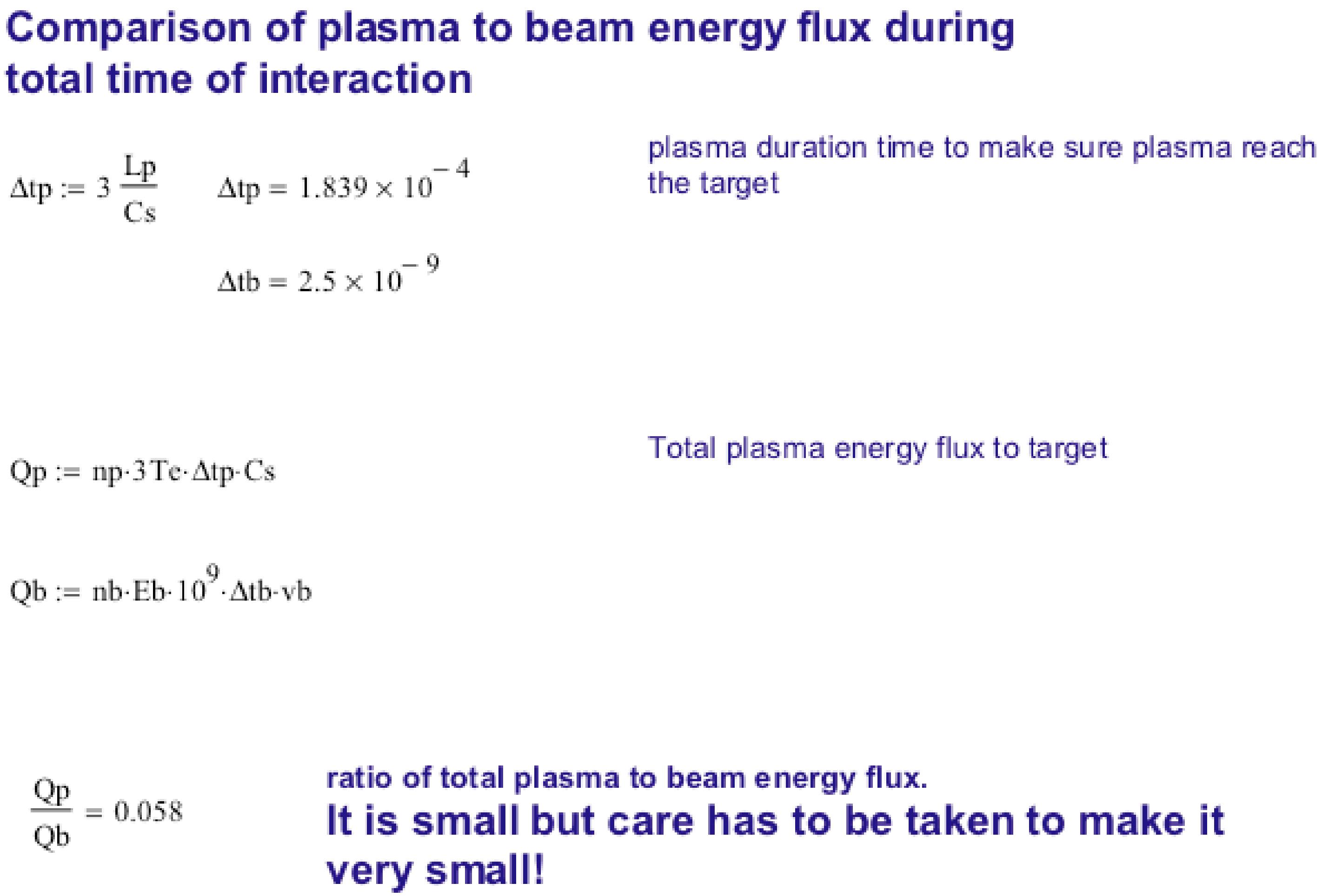
Sub-mm simultaneous transverse spot using either solenoid



Background $n_p \sim 1 \times 10^{13}$ cm^{-3}
required near focal plane
in both cases

Kaganovich estimated ratio of plasma flux relative to beam flux hitting the target

From I. Kaganovich's 8/15/2006 presentation to WDM group:



Comparison of plasma to beam energy flux during total time of interaction

$\Delta tp := 3\,\frac{Lp}{Cs}$ $\qquad \Delta tp = 1.839 \times 10^{-4}$

plasma duration time to make sure plasma reach the target

$\Delta tb = 2.5 \times 10^{-9}$

$Qp := np \cdot 3Te \cdot \Delta tp \cdot Cs$

Total plasma energy flux to target

$Qb := nb \cdot Eb \cdot 10^{9} \cdot \Delta tb \cdot vb$

$\frac{Qp}{Qb} = 0.058$

ratio of total plasma to beam energy flux.

It is small but care has to be taken to make it very small!

Eddy current heating estimate

curl $E = -\partial B/\partial t$

Heating rate $j \cdot E = \sigma L^2 B^2 / \tau^2$ where L is the length scale over which B varies, and τ is the time scale over which it varies.

Total energy deposited from eddy currents = $(\sigma L^2 B^2 / \tau)$ * target volume

For $B=0.008$ T, $\tau = 100 * 10^{-6}$ s, $L = 0.02$ m

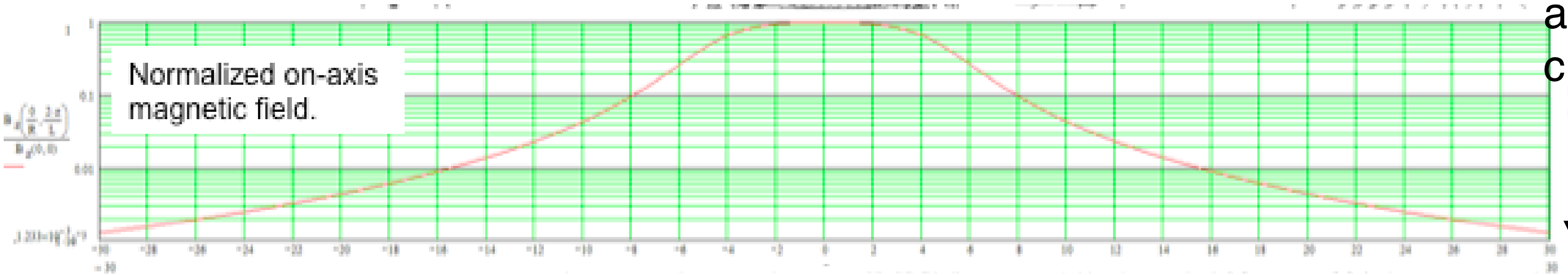
Volume = π (1 mm)^2 * 3 micron = 10^{-11} m^3

σ (Aluminum) = 3.77 10^7 (Ohm m)$^{-1}$

Total Joules deposited = $3.77 * 10^7 (.02)^2 (.008)^2 * 10^{-11} / 10^{-4}$

= 9.7 10^{-5} mJ

From E. Gilson's talk on 1/10/07:



Target at 31.5 cm

~.008 T