Measurement of Resistivity Dominated Collimator Wakefield Kicks at the SLC

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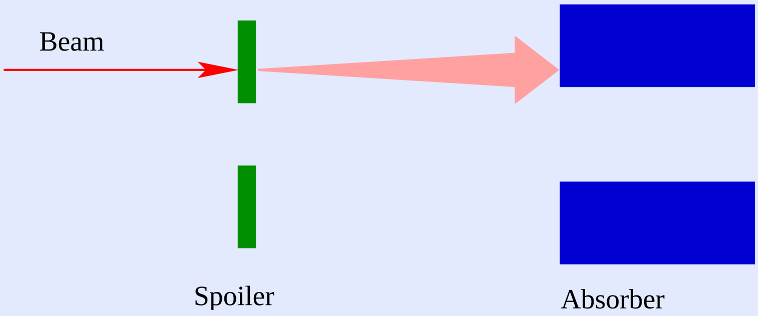
Motivation

- in linear colliders (also FEL's) small gap collimation is needed; induced wakefields (geometric, resistive) are critical for beam emittance and lead to jitter amplification
- theory of short range wakefields is complicated; numerical calculations are difficult
- measurements, if possible, are more direct !
- graphite as spoiler material is excellent from mechanical point of view; low conductivity is one of the problems → reliable prediction of resistive wall wakefield is important

Spoiler and Absorber Concept



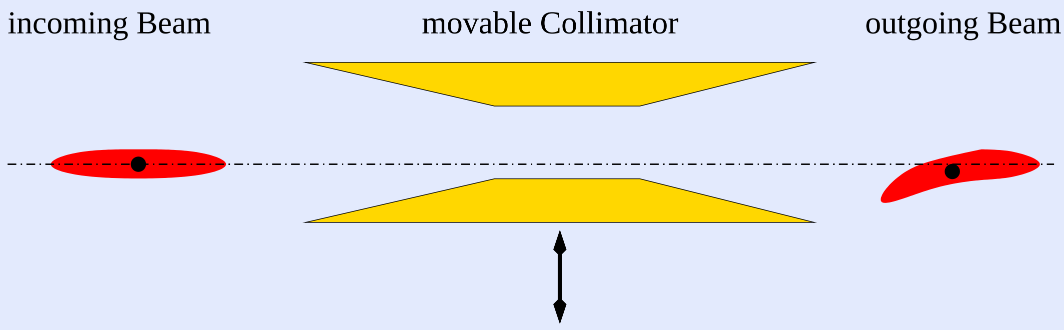
function: halo cleaning; machine protection
problems: full beam survival; transverse wakefields

Typical Parameters at spoiler:

$$
\begin{aligned}
E &\approx 250\,\mathrm{GeV} \\
P &\approx 10\,\mathrm{MW} \\
\sigma_x \times \sigma_y &\approx 150 \times 7\,\mu\mathrm{m}^2 \\
\text{spoiler gap} &\approx 1\,\mathrm{mm} \\
\text{spoiler thickness} &\approx 0.5 \ \ \text{radiation length}
\end{aligned}
$$

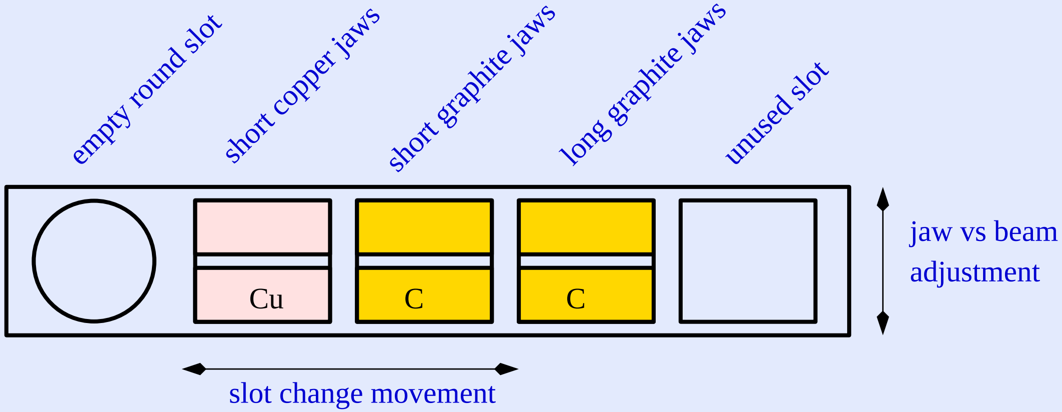
Principle of the Experiment

- use the high quality damped SLC beam in sector II
- beam trajectory is measured upstream and downstream of the collimator pair
- center of mass kick at collimator is determined for different vertical center offsets of the collimator

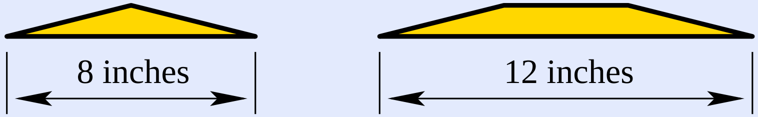


Mechanical Layout

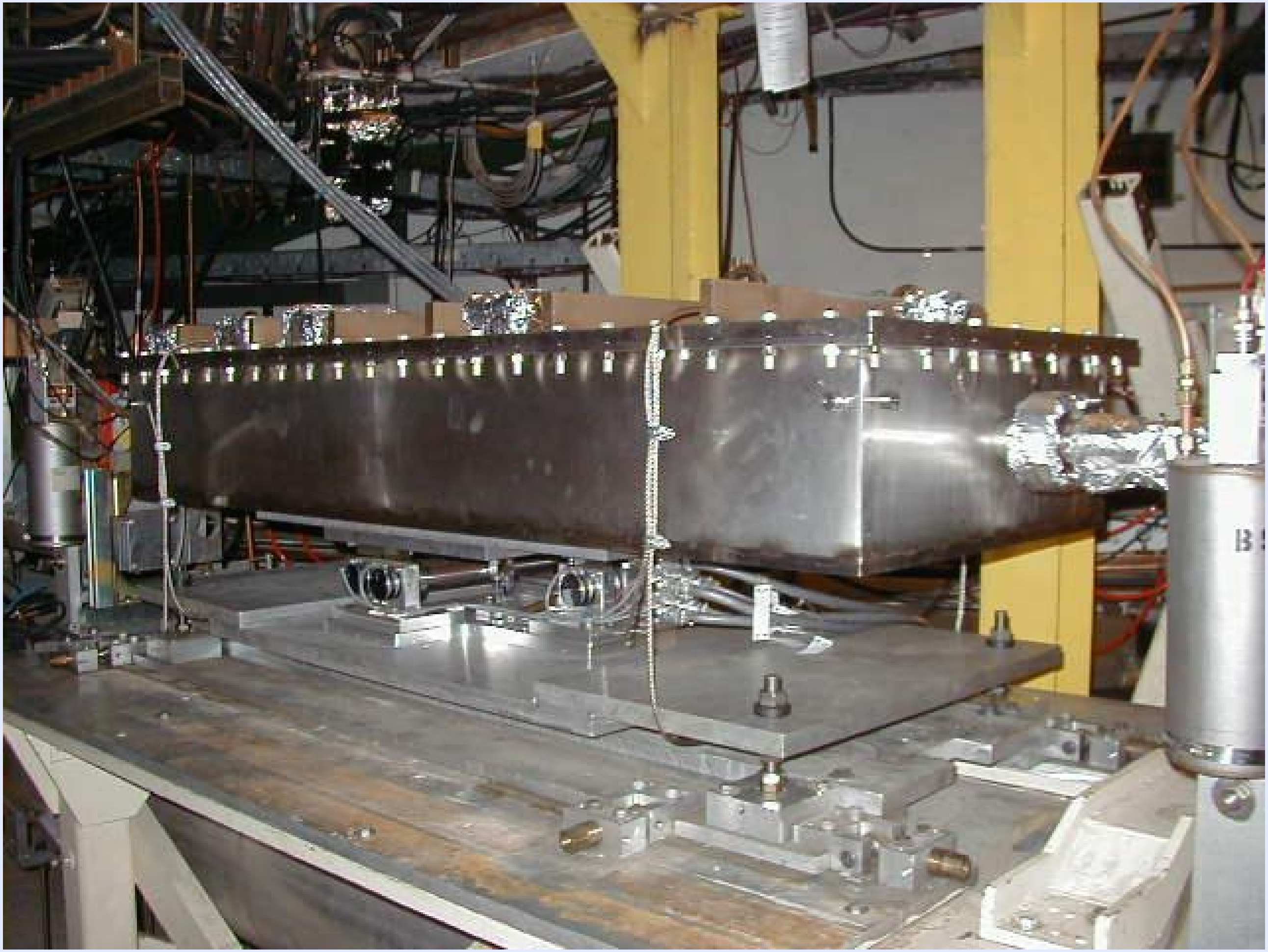
- aluminum cassette with 5 remotely interchangeable inserts
- precision vertical position adjustment
- beam view:



- short and long jaws:

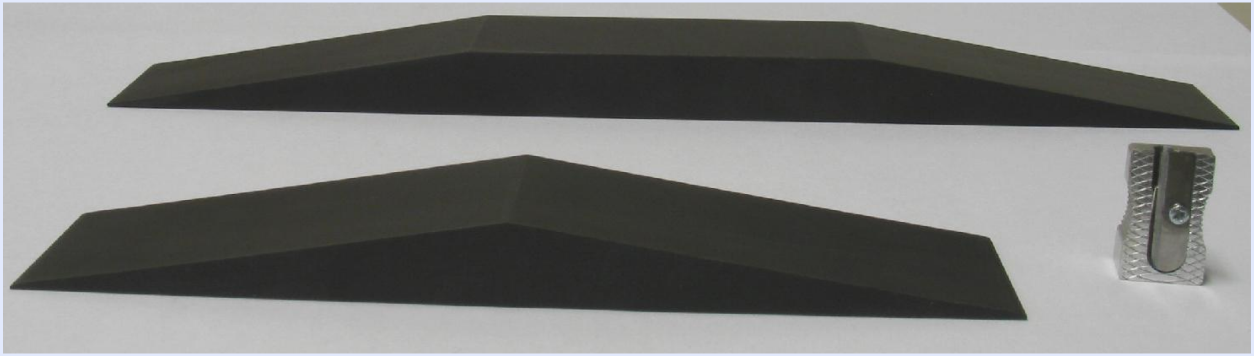


In Reality. . .



Material Properties

we use a high density graphite with good vacuum properties
(after baking at 400°C)



Selected parameters for copper and graphite.

	density [g/cm^3]	conductivity [Ω^{-1}m^{-1}]	skin-depth at 500 GHz [μm]
Copper	8.9	$5.9 \cdot 10^7$	0.1
Graphite	1.95	$5.5 \cdot 10^4$	3.0

Beam Properties

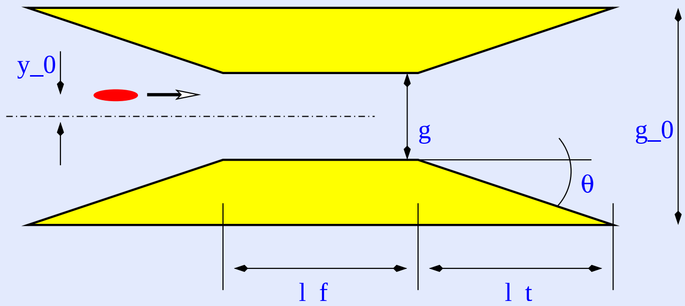
- damped SLC beam at 1.19 GeV, $\gamma = 2330$

$$\varepsilon_x = 15\,\text{nm} \quad \varepsilon_y = 0.8\,\text{nm}$$
$$\sigma_x = 200\,\mu\text{m} \quad \sigma_y = 50\,\mu\text{m}$$
$$\sigma_z = 650\,\mu\text{m}$$

- bunch charge: $2 \cdot 10^{10}$, 9Hz
- typical scan: 15 (vertical motion) $\times$ 25 (pulses); all automated with correlation plot feature of operating system

Geometric Wakefield Kick

Transverse Geometric Wakefield Kick, averaged over Gaussian Bunch, see G. V. Stupakov, SLAC-Pub-8857 (2001)



long taper:

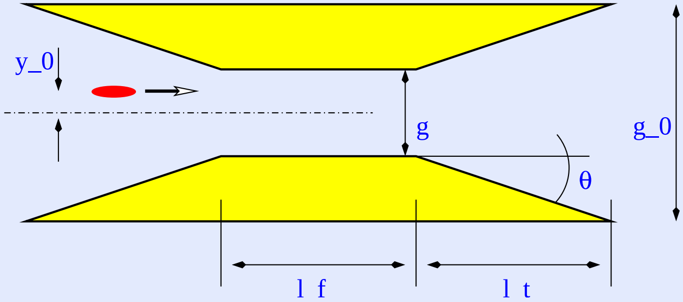
$$\text{for} \quad 0.2\frac{\theta_t h^2}{\sigma_z g}(\approx 18!) \; < \; 1 : \qquad \frac{\langle \Delta y' \rangle}{y_0} = \frac{2\sqrt{\pi}\theta_t h N_p r_e}{\sigma_z \gamma g^2}$$

short taper - diffraction, neglects taper $\longrightarrow$ expect overestimation:

$$\frac{\langle \Delta y' \rangle}{y_0} = \frac{4 N_p r_e}{\gamma g^2}$$

Resistive Wakefield Kick

see A. Piwinski, DESY-94 068 (1994):



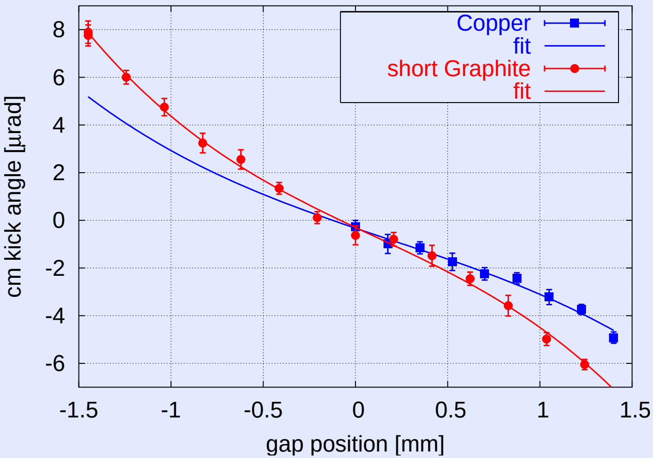
$$\langle \Delta y' \rangle = \frac{\Gamma(\frac{1}{4})}{\sqrt{2}} \frac{N_p r_e}{\gamma} \frac{1}{\sqrt{\sigma_z \sigma Z_0}} \cdot \left[l_f \frac{\sin\left(\frac{2\pi y_0}{g}\right) + \frac{2\pi y_0}{g}}{g^2 \left(1 + \cos\left(\frac{2\pi y_0}{g}\right)\right)} + \frac{2 l_t}{g_0 - g} \left(\frac{\tan\left(\frac{\pi y_0}{g}\right)}{g} - \frac{\tan\left(\frac{\pi y_0}{g_0}\right)}{g_0} \right) \right]$$

$$\langle \Delta y' \rangle = a \cdot y_0 + b \cdot y_0^3 + O\left(y_0^5\right)$$

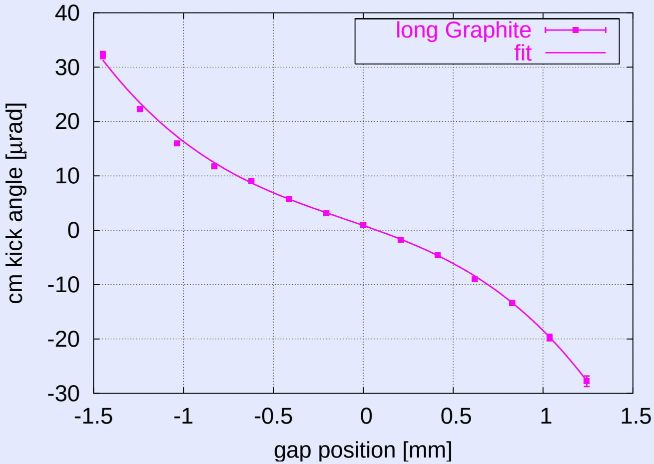
$\longrightarrow$ use cubic fit-function

Measured Deflection Curves

short graphite and Cu jaws



long graphite jaws



the fit functions contain a linear and a cubic term; the linear coefficient is compared to theory

Comparison with Theory

Predicted geometric and resistive kick angles in [μrad/mm]:

collimator	resistive part			geom part	sum
	taper	flat	tot		
short copper	0.001	0	0.001	6.7	6.7
short graphite	0.67	0	0.67	6.7	7.4
long graphite	0.67	6.1	6.8	6.7	13.5

Measured kick angles and inferred resistive part obtained by subtracting the kick of the copper jaws, in [μrad/mm]:

collimator	measured total	inferred resistive
short copper	2.6±0.3	(0)
short graphite	3.9±0.3	1.3±0.6
long graphite	10.8±0.4	8.2±0.7

Discussion

- result for graphite, gap width 3.8 mm, flat length of 4 inches, taper angle of 10°: $w_{\perp} = 3 \pm 0.3$ V/pC/mm.
- geometric theory not well applicable for this taper angle; diffraction formula overestimates; resistive theory agrees relatively well
- graphite wakefield may be too strong for linear collider application $\longrightarrow$ coating or different material
- better faith in theoretical predictions for other materials
- planned: dependence on bunch length; smaller taper angles

Thanks to the colleagues at SLAC for the great collaboration on this subject!