Coupler kicks in high Q_{ext} linacs

LASSE

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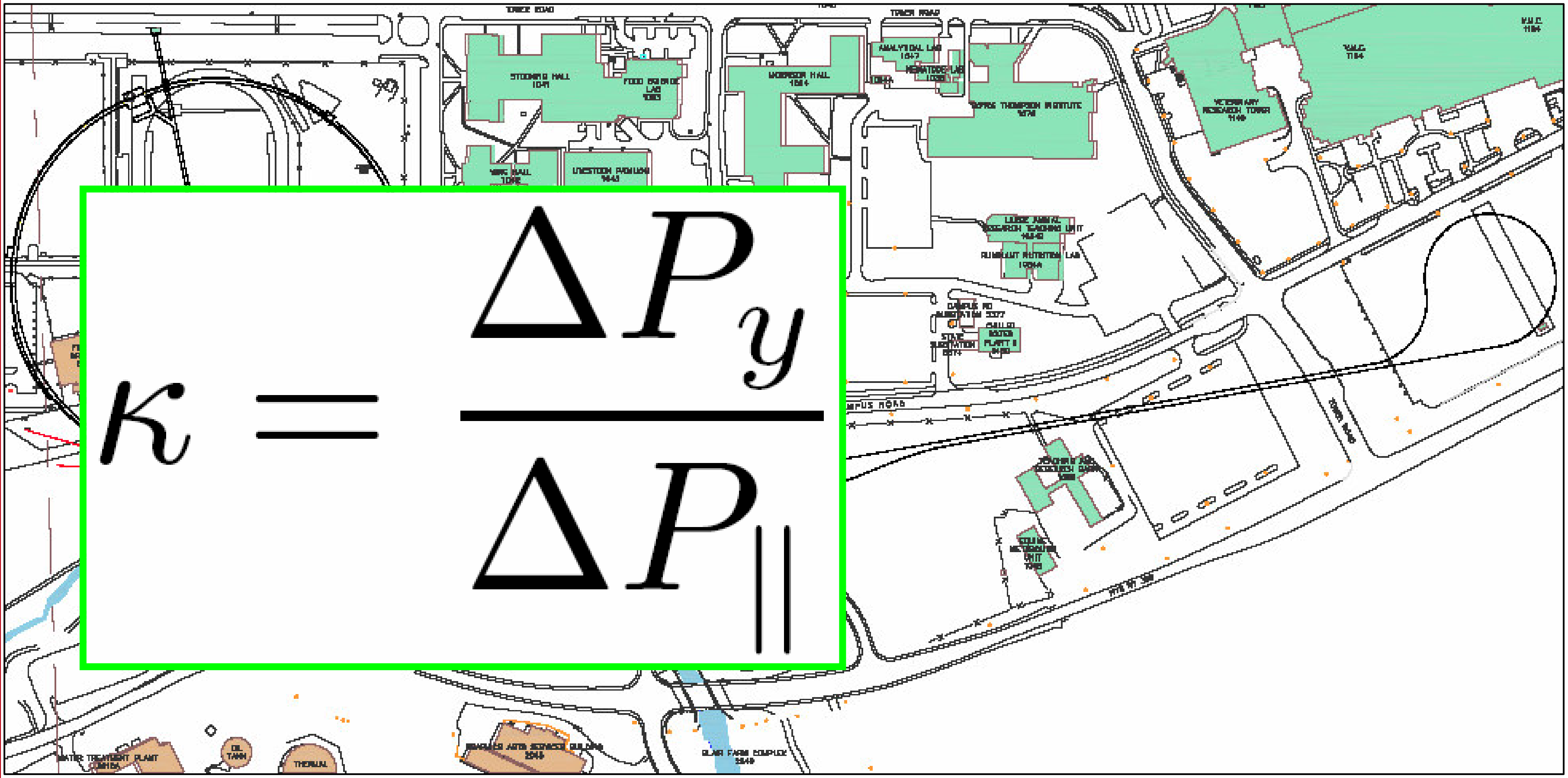
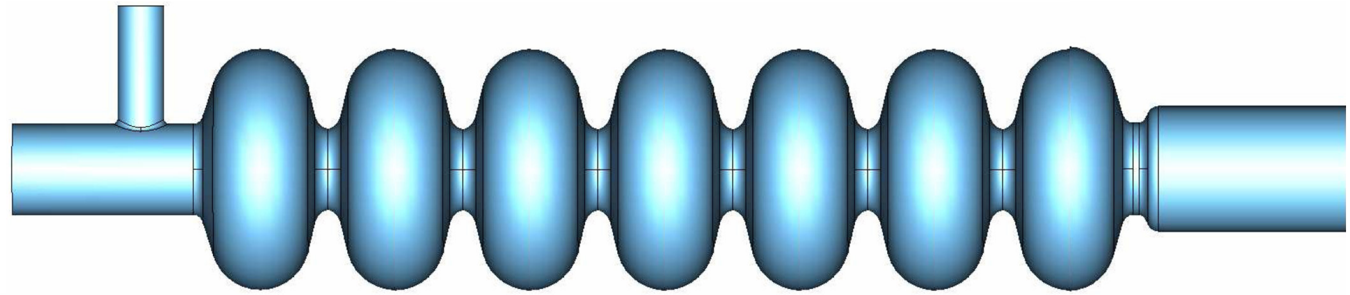
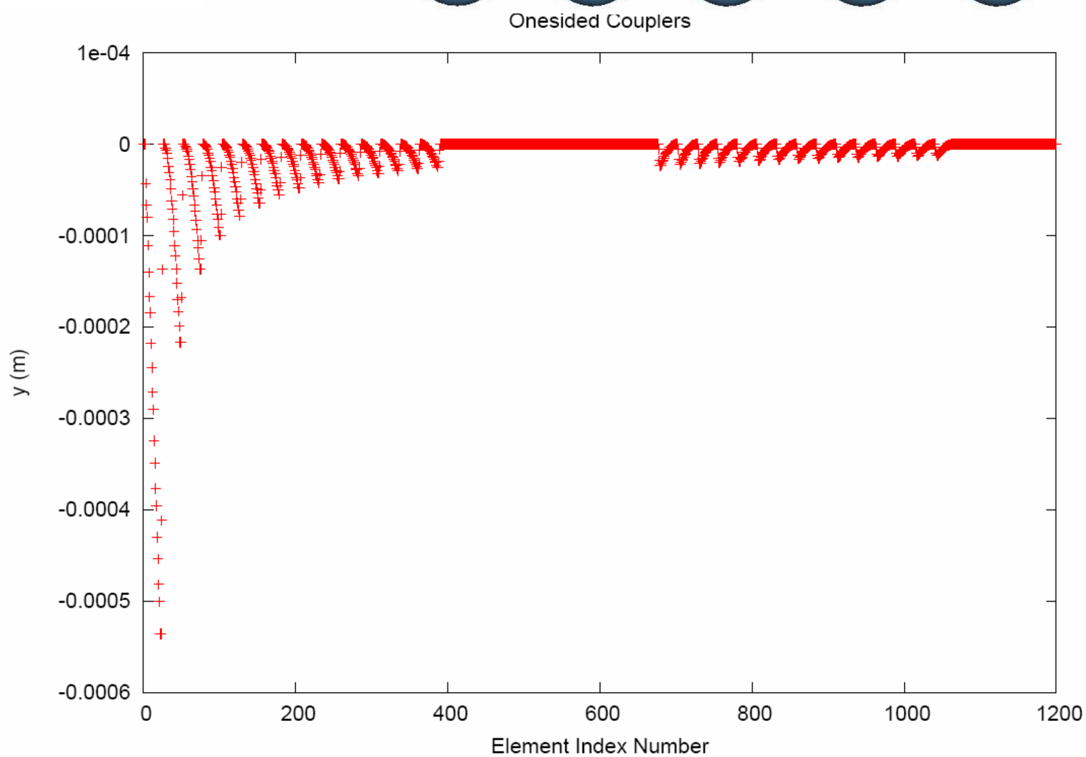


$$\kappa = \frac{\Delta P_y}{\Delta P_{||}}$$

Coupler Kicks cause orbit distortions

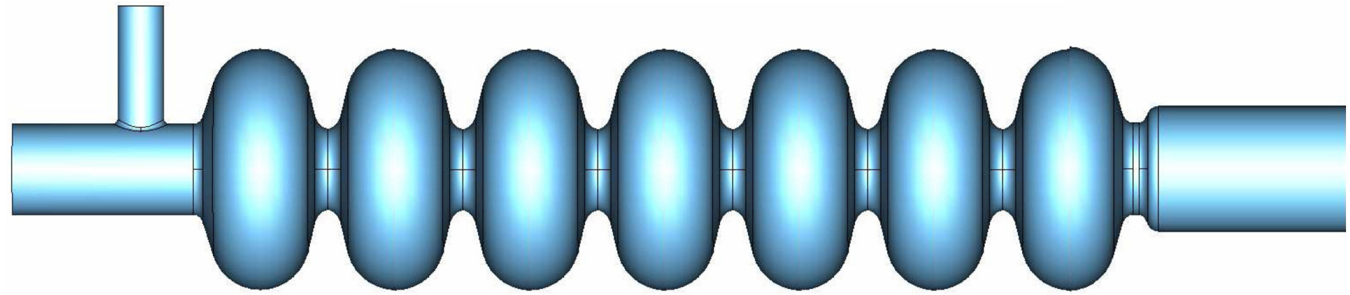


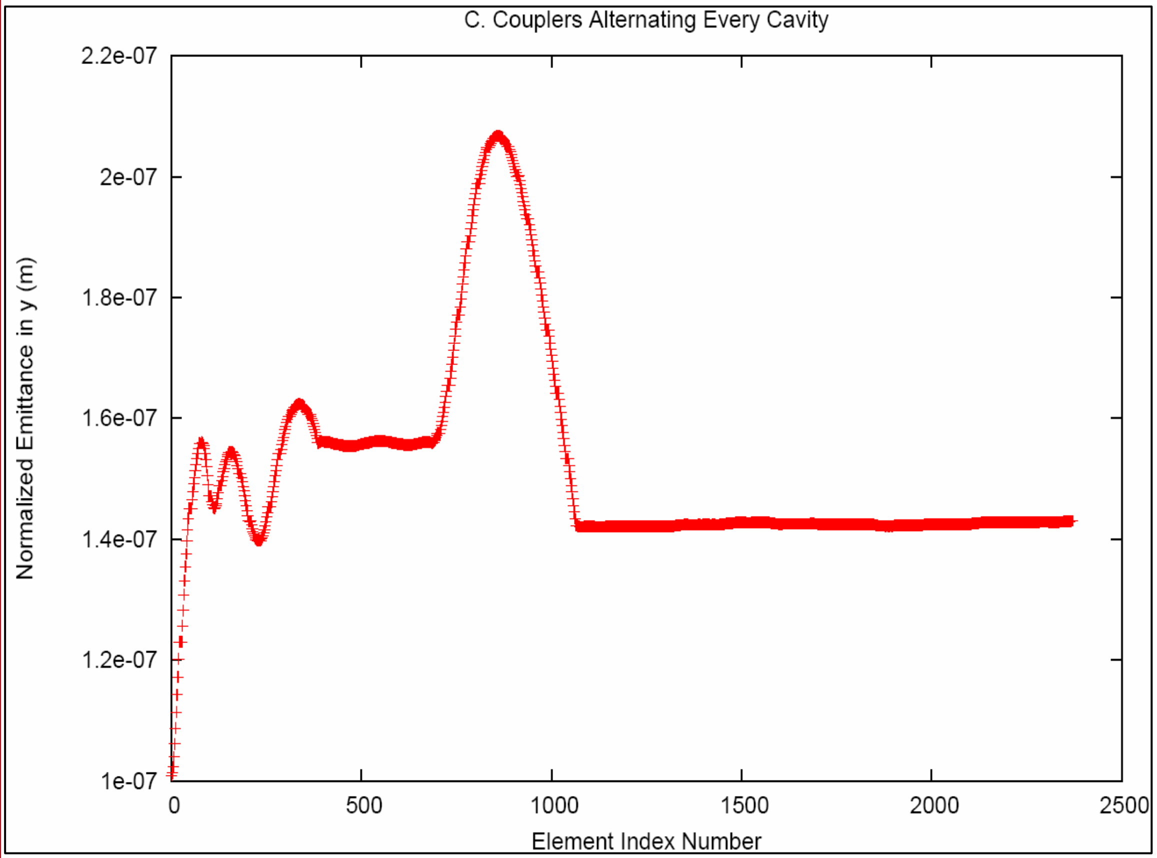


Especially if the coupler kick has 0 phase difference to the accelerating field.

FIG. 5: Orbit of one electron through the ERL lattice.

Coupler Kicks cause emittance growth

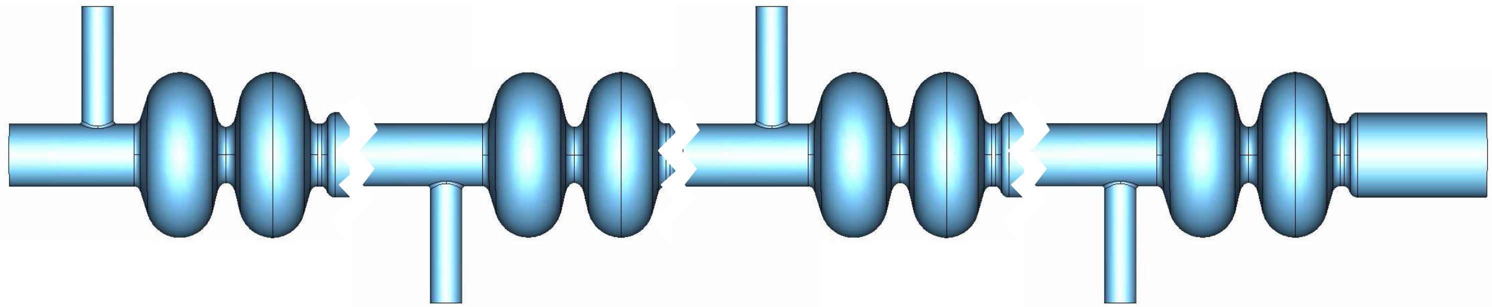




Especially if the coupler kick has 90^0 phase difference to the accelerating field.

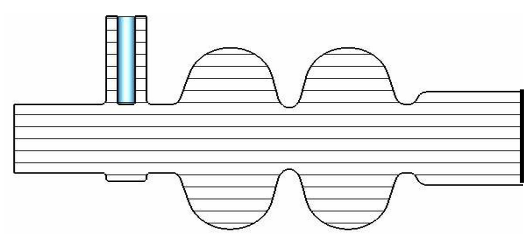
Ways to cancel coupler kicks

(1) Kick cancellation by symmetry



(2) Kick cancellation by changing the distance between coupler and cavity to make the phase of the coupler kick 90^0.

(3) Kick cancellation by a more symmetric coupler region



Cavity parameters

TABLE I: Parameters of accelerating cavities.

Frequency	1300 MHz
Number of Cells	7
Cavity Shape	TESLA type
Accelerating Voltage	15 MV/m
Q_0	10^{10}
Q_{ext}	$\in \{2 \times 10^7, 10^8\}$
Coupler Type	Coax
Coaxial Impedance	50 Ω

Modeling the coupler kick

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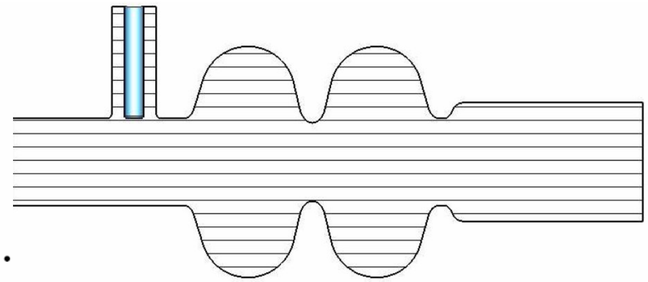
(1) Insert inner conductor of the coax coupler until the desired Q_{ext} is obtained.

(2) Compute standing wave patterns E^m ,$B^m$for magnetic boundary conditions at the coupler boundary.

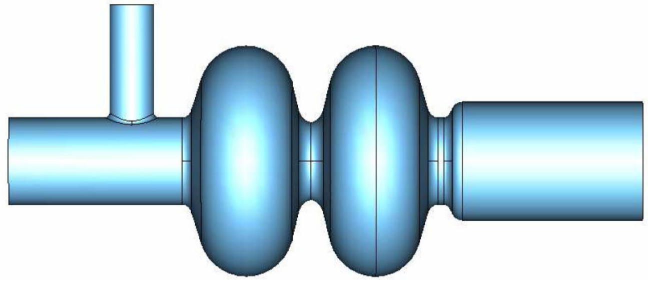
(3) Compute standing wave patterns E^e and B^e for electric boundary conditions at the coupler boundary.

These Boundary conditions are those of a traveling wave in the coax at two different times, ¼ oscillation apart.

$$\mathbf{E}^{\pm}(\mathbf{r},t) = Re\{(\xi\mathbf{E}^m(\mathbf{r}) \pm i\mathbf{E}^e(\mathbf{r}))e^{-i(\omega t-\phi_\pm)}\},$$
$$\mathbf{B}^{\pm}(\mathbf{r},t) = \pm Re\{(\mathbf{B}^e(\mathbf{r}) \pm i\xi\mathbf{B}^m(\mathbf{r}))e^{-i(\omega t-\phi_\pm)}\}.$$



$$\mathbf{E}_0^{\pm}(s,t) = Re\{(\xi\mathbf{E}_0^m(s) \pm i\mathbf{E}_0^e(s))e^{-i(\omega t - \phi_\pm)}\}$$
$$\mathbf{B}_0^{\pm}(s,t) = \pm Re\{(\mathbf{B}_0^e(s) \pm i\xi\mathbf{B}_0^m(s))e^{-i(\omega t-\phi_\pm)}\}$$



Why are fields e and m fields equivalent ?

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$$\mathbf{E}_0^{\pm}(s,t) = Re\{(\xi\mathbf{E}_0^m(s) \pm i\mathbf{E}_0^e(s))e^{-i(\omega t} - \phi_{\pm})\}$$

$$\mathbf{B}_0^{\pm}(s,t) = \pm Re\{(\mathbf{B}_0^e(s) \pm i\xi\mathbf{B}_0^m(s))e^{-i(\omega t - \phi_{\pm})}\}$$

$$\mathbf{E}_0^e(s) \approx s^e\mathbf{E}_0^m(s), \mathbf{B}_0^e(s) \approx s^m\mathbf{B}_0^m(s)$$

(a) $Q_{ext} = 2 \times 10^7$ (b) $Q_{ext} = 10^8$

The standing wave approximation

Approximation:

Traveling waves in the coax excite standing waves in the cavity. For very large Q_{ext}, very little energy leaves the coupler, which validates this approximation.

$$\mathbf{E}_0^{\pm}(s,t) = Re\{(\xi \mathbf{E}_0^m(s) \pm i\mathbf{E}_0^e(s))e^{-i(\omega t} - \phi_{\pm})\}$$

$$\mathbf{B}_0^{\pm}(s,t) = \pm Re\{(\mathbf{B}_0^e(s) \pm i\xi \mathbf{B}_0^m(s))e^{-i(\omega t - \phi_{\pm})}\}$$

Standing wave:

The fileds must be a function of s times a function of t: f(s) g(t)

→ E_0^m must be proportional to E_0^e

→ B_0^m must be proportional to B_0^e

$$\mathbf{E}_0^e(s) \approx s^e \mathbf{E}_0^m(s), \mathbf{B}_0^e(s) \approx s^m \mathbf{B}_0^m(s)$$

The fileds are normalized to the same energy → $|s^e| = |s^m| = 1$.

$$\mathbf{E}_0^{\pm}(s,t) \approx Re\{\mathbf{E}_0^m(s)(\xi \pm i s^e)e^{-i(\omega t - \phi_{\pm})}\},$$

$$\mathbf{B}_0^{\pm}(s,t) \approx \pm Re\{\mathbf{B}_0^m(s)(\pm i)(\xi \mp i s^m)e^{-(i\omega t - \phi_{\pm})}\}.$$

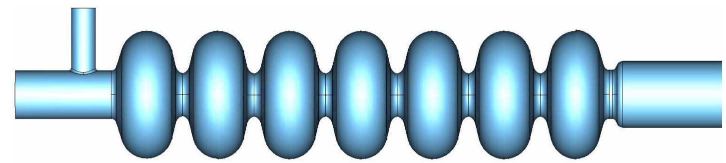
To satisfy Maxwell's equations, both complex factors must be the same.

→ $s^m = 1, s^e = -1$, or $s^m = -1, s^e = 1$

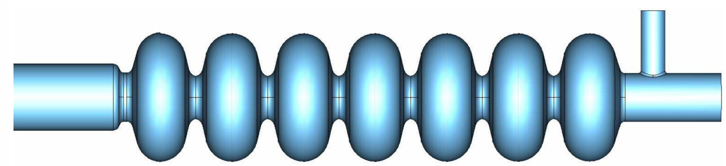
Coupler kicks of reversed cavities

$$\Delta \mathbf{P}^+ = q\int_{t_i}^{t_f}[\mathbf{E}_0^+(s,t) + v\mathbf{e}_s \times \mathbf{B}_0^+(s,t)]dt$$

$$\Delta \mathbf{P}^+ = e^{i\phi_+}\frac{q}{v}\int_0^L \{[\xi \mathbf{E}_0^m(s) + i\mathbf{E}_0^e(s)] + v\mathbf{e}_s \times [\mathbf{B}_0^e(s) + i\xi \mathbf{B}_0^m(s)]\}e^{-i\omega\frac{s}{v}}ds.$$



$$\Delta \mathbf{P}^{+\prime} = e^{i\phi_+}\frac{q}{v}\int_0^L \{[\xi \mathbf{E}_0^m(L-s) + i\mathbf{E}_0^e(L-s)] - v\mathbf{e}_s \times [\mathbf{B}_0^e(L-s) + i\xi \mathbf{B}_0^m(L-s)]\}e^{-i\omega\frac{s}{v}}ds.$$



$$\kappa^{+\prime} \approx (\kappa^+)^*$$

	$Q_{ext} = 2\times 10^7$		$Q_{ext} = 1\times 10^8$	
	Before Cav	After Cav	Before Cav	After Cav
$\lvert\kappa\rvert(10^{-4})$	.9651	.9891	1.039	1.027
ϕ_c (rad)	2.838	-2.793	2.819	-2.816

Emittance growth for on crest acceleration

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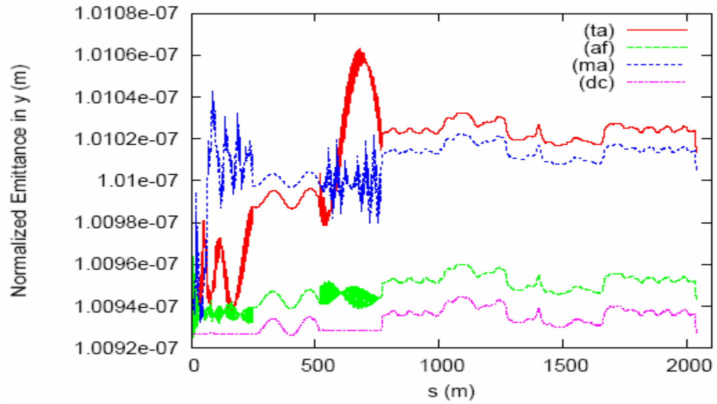
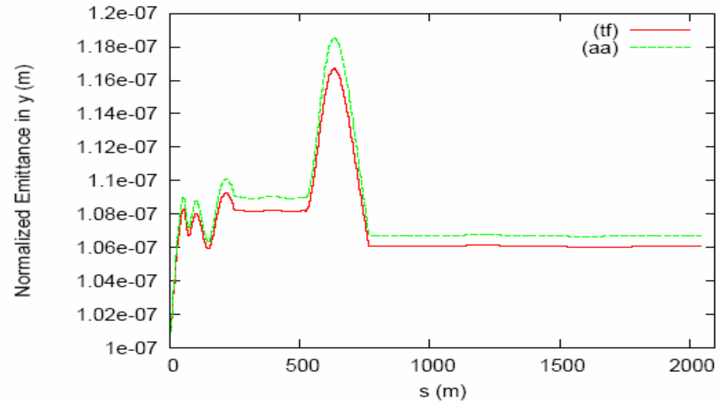
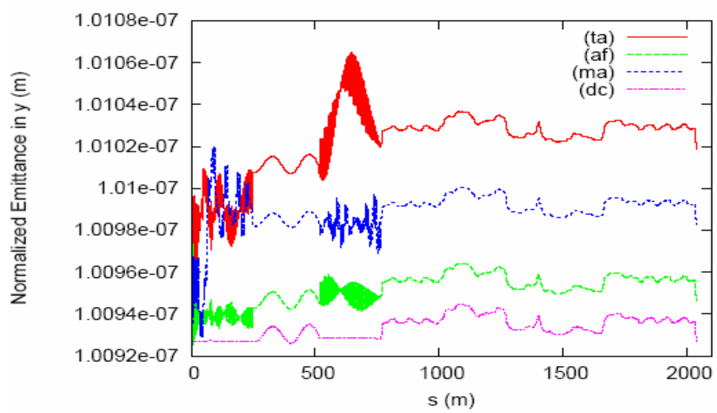
$$\Delta y' \approx 2\Delta y_0' - 2\frac{\Delta E_0}{E}|\kappa|\omega\cos(\phi_c)\sin(\psi)\Delta t.$$



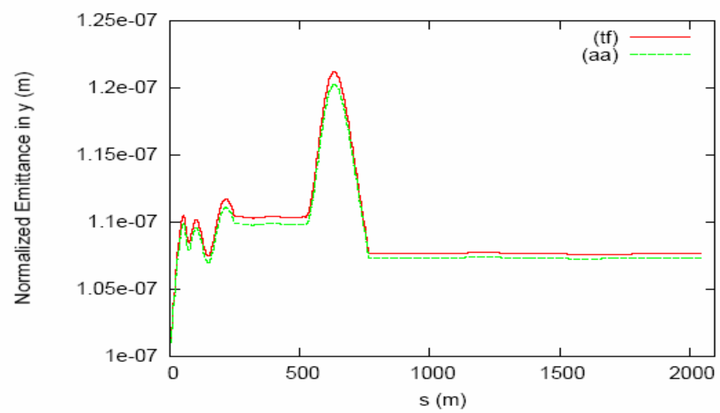
(a) Small emittance growth configurations, $Q_{ext} = 2 \times 10^7$



(b) Large emittance growth configurations, $Q_{ext} = 2 \times 10^7$



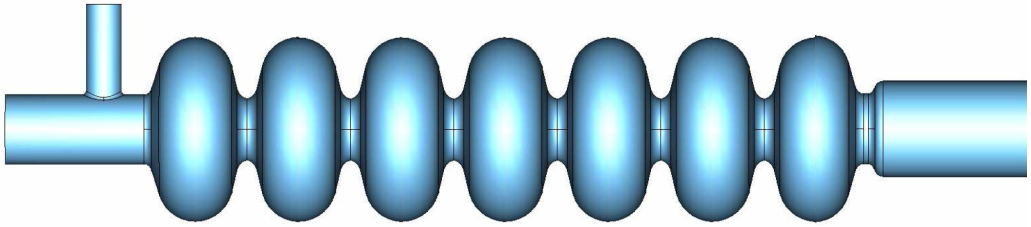
(c) Small emittance growth configurations, $Q_{ext} = 10^8$



(d) Large emittance growth configurations, $Q_{ext} = 10^8$

Detuning, reflection, and coupler kicks

P^+ P^- with phase difference α



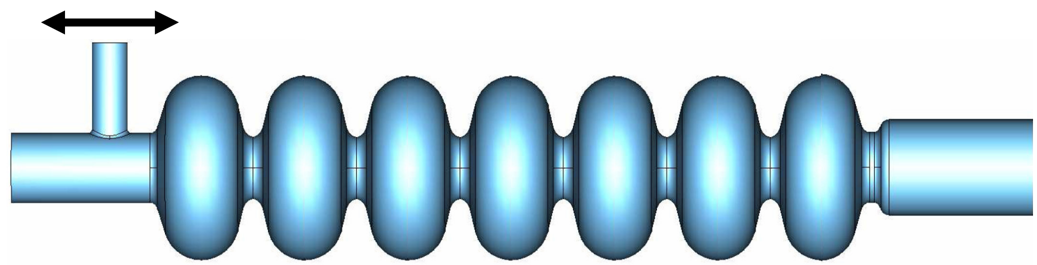
$$\kappa = \frac{\Delta P_y^+ + \alpha \Delta P_y^-}{\Delta P_s^+ + \alpha \Delta P_s^-}$$

$$\kappa' \approx \kappa^*$$

(even for all phases of the reflected wave)

Moving the coupler to have 0 phase kick

The coupler was moved from 4.5cm to 5.3cm off the first cell.



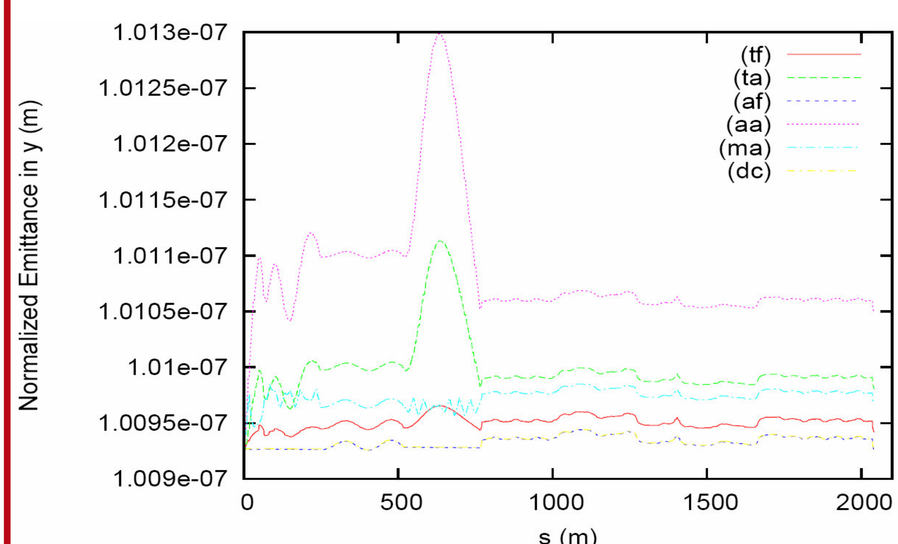


FIG. 8: Normalized emittance in the y direction for the six coupler configurations for $Q_{ext} = 2 \times 10^7$. (a)

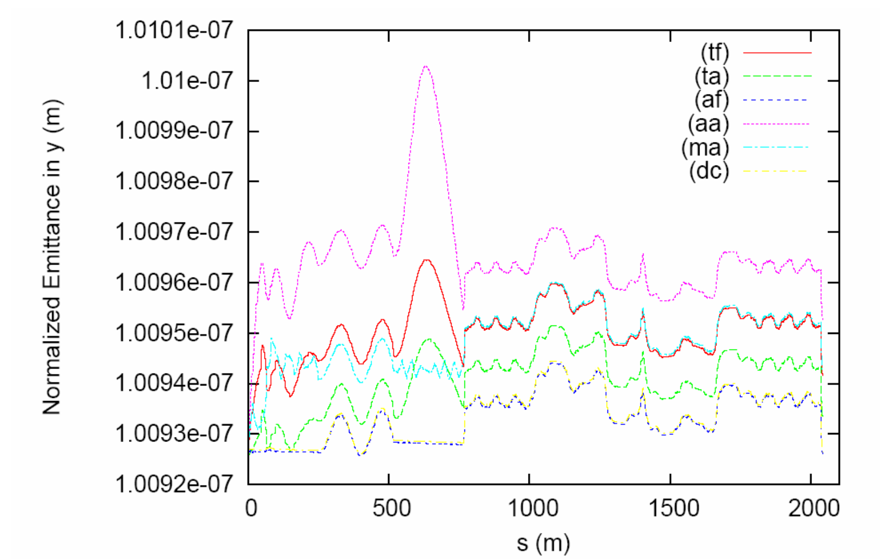
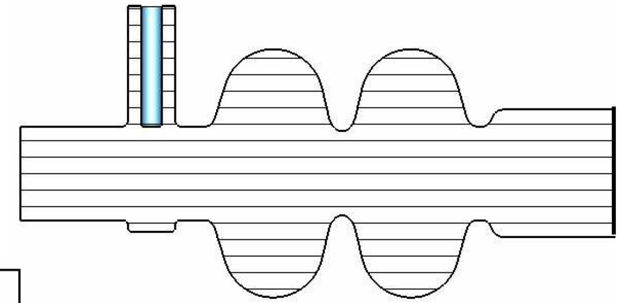
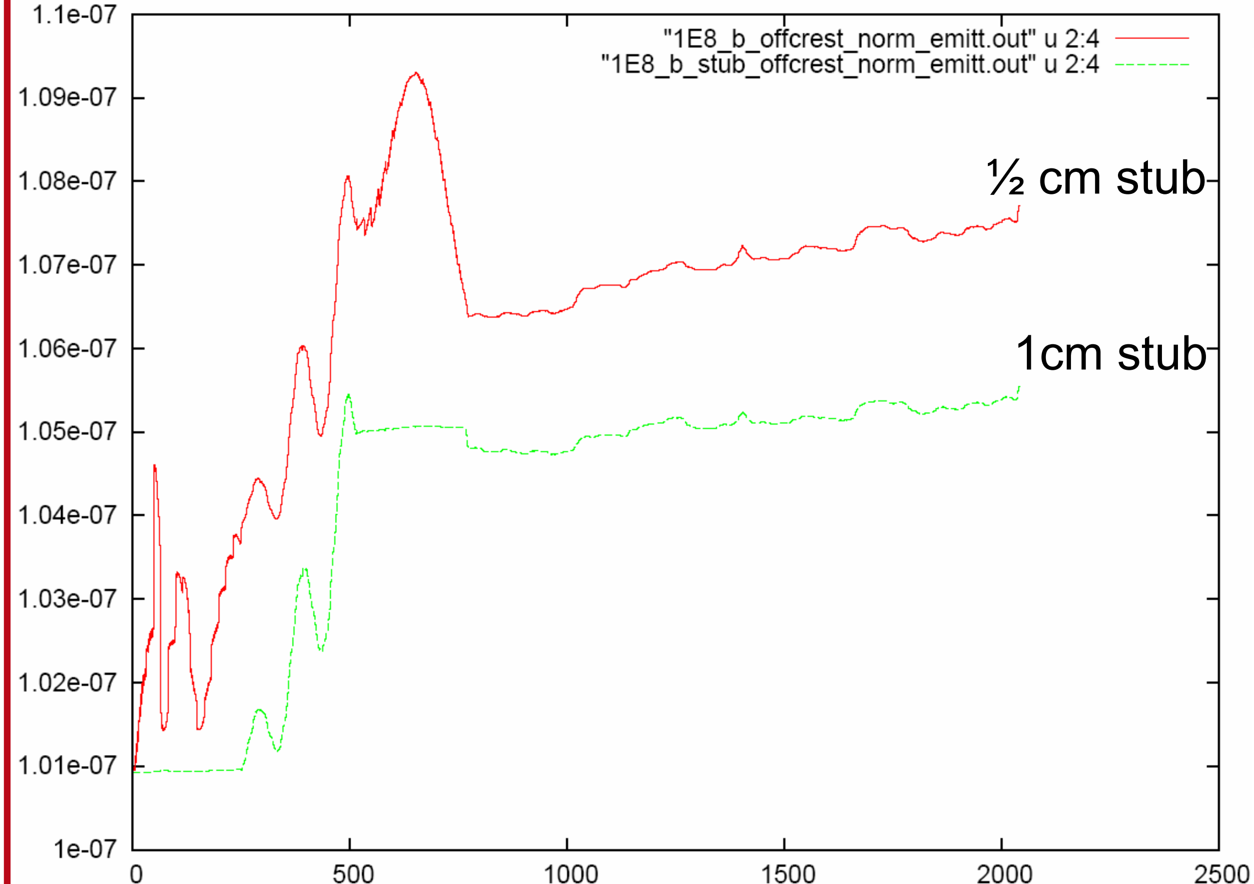


FIG. 9: Normalized emittance in the y direction for the six coupler configurations for $Q_{ext} = 1 \times 10^8$.

Symmetryzing the coupler region





Conclusion

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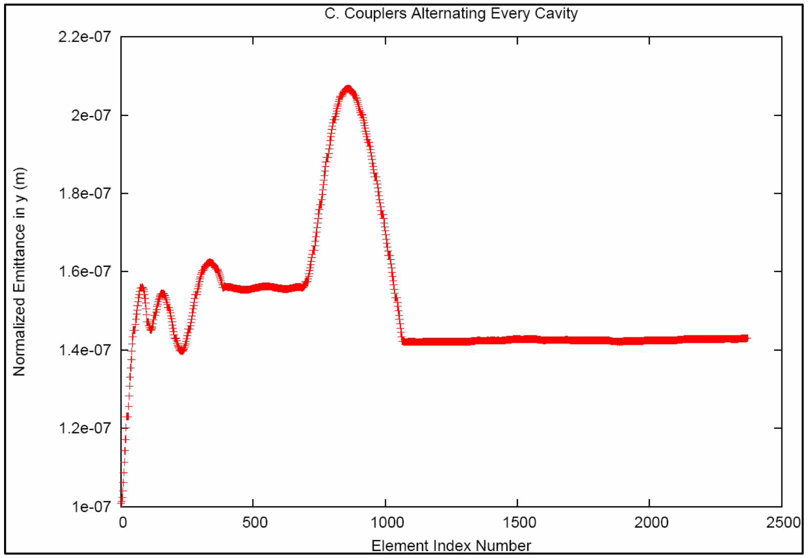
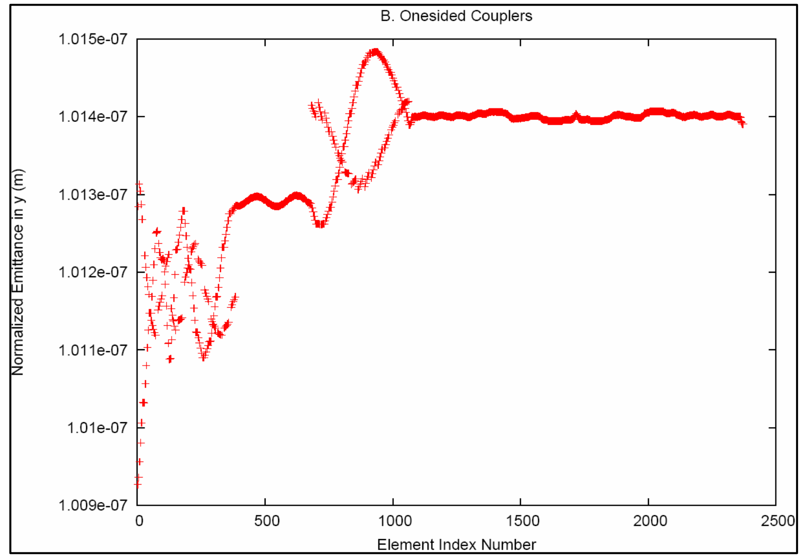
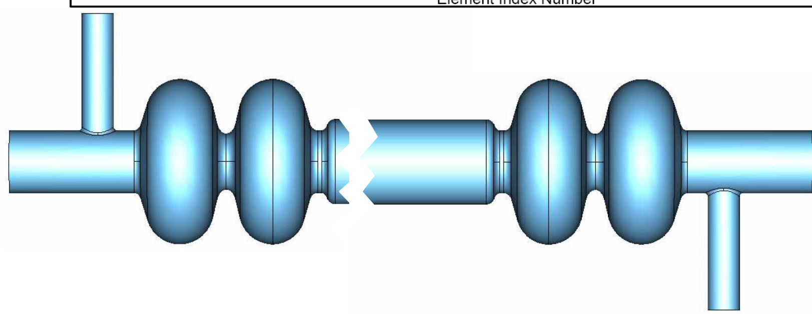
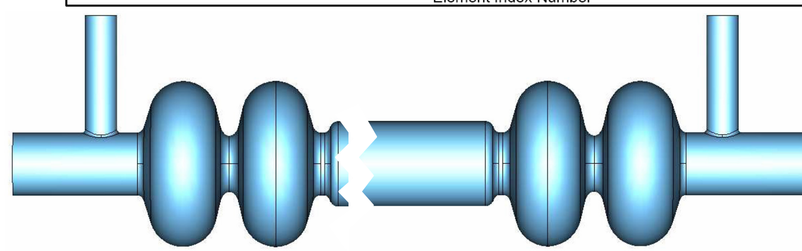
(1) Kick cancellation by symmetry









(2) Kick cancellation by 0^0 phase.

(3) Kick cancellation by a more symmetric coupler region