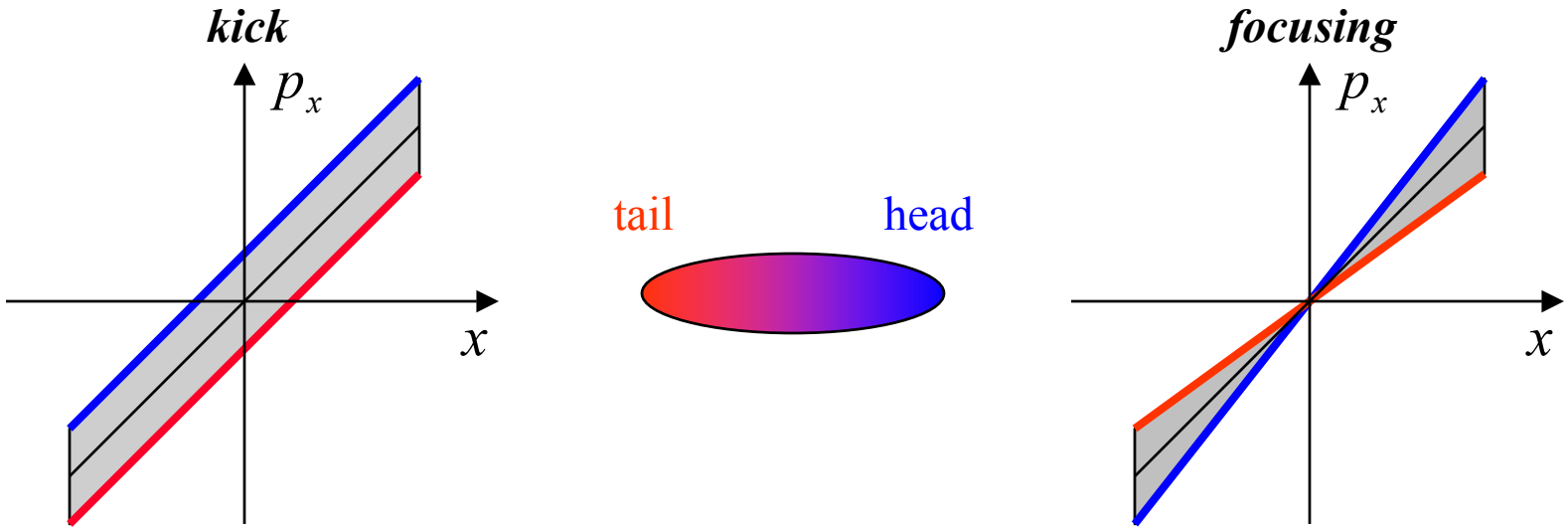
RF emittance growth in the injector

- Cryomodule is integral part of the injector
- Must support small emittance
- Scale here is set by ≤0.1 mm-mrad
- RF emittance growth is due to time dependant transverse fields over nonzero bunch length (RF focusing, coupler kicks, tilted cavity)

RF kick and focusing contributions

$$\varepsilon_n = \frac{1}{mc}\sqrt{\langle x^2\rangle\langle p_x^2\rangle - \langle xp_x\rangle^2}$$

$$p_x(x,z) = p_x(0,0) + \frac{\partial p_x}{\partial x}x + \underbrace{\frac{\partial p_x}{\partial z}z}_{kick} + \underbrace{\frac{\partial^2 p_x}{\partial x \partial z}xz}_{focusing} + \ldots$$



Some comments

$$\varepsilon_n^2 = \varepsilon_0^2 + \varepsilon_{kick}^2 + \varepsilon_{focus}^2$$

- Kick effect on emittance is energy independent and can be cancelled downstream
- RF focusing effect scales $\propto \frac{1}{\gamma}$ and generally is not cancelled

$$\varepsilon_{kick} = \frac{1}{mc}\left|\frac{\partial p_x}{\partial z}\right|\sigma_x\sigma_z$$

$$\varepsilon_{focus} = \frac{1}{mc}\left|\frac{\partial^2 p_x}{\partial z \partial x}\right|\sigma_x{}^2\sigma_z$$

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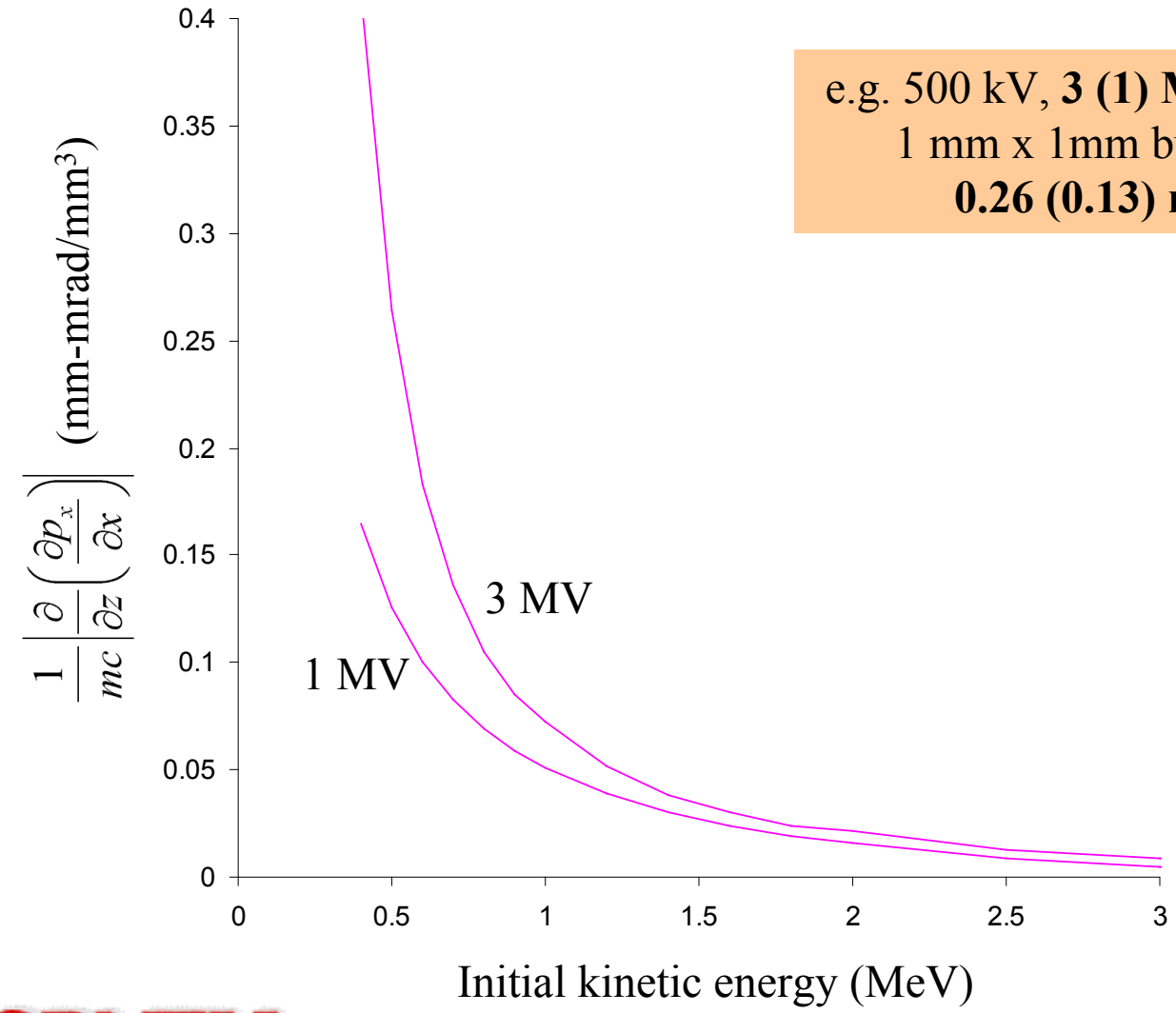
RF focusing in 2-cell cavity (on crest!)



e.g. 500 kV, **3 (1) MV** in the 1st cell,
1 mm x 1mm bunch receives
0.26 (0.13) mm-mrad

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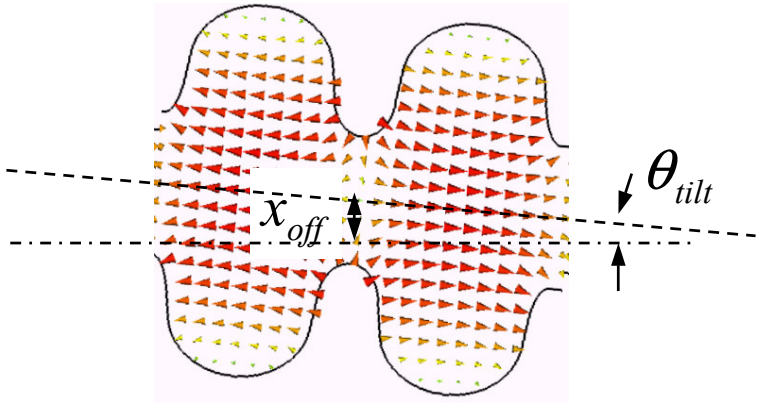
RF kick (coupler kick is zero)

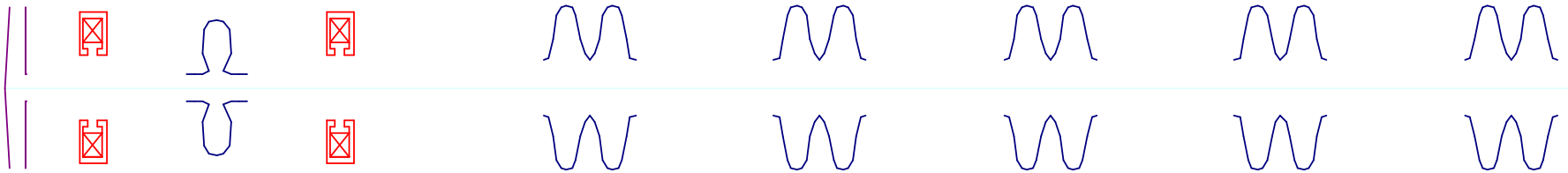
$$\varepsilon_{kick} \approx \sigma_x \sigma_z \left[\underbrace{\theta_{tilt} \frac{\Delta E}{mc^2} k_{RF} \sin\varphi}_{\text{tilt}} + \underbrace{x_{off} \frac{1}{mc} \frac{\partial}{\partial z} \left(\frac{\partial p_x}{\partial x} \right)}_{\text{offset}} \right]$$

e.g. **3 MeV** energy gain for 1 mm x 1mm yields **0.16 sin φ mm-mrad** per mrad of **tilt**



- One would prefer on-crest running in the injector (and elsewhere!) from tolerances' point of view

Typical injector settings in sims



	Peak E_z field (MV/m)	Phase (deg)
Gun	10	n/a
Buncher	3.0	–90
Cavity 1	12.3	–3
Cavity 2-5	25.3	–1.5

	Peak B_z field (kG)
Solenoid 1	0.58
Solenoid 2	0.42

Charge / bunch (pC)	80
Distribution (x, t)	uniform
σ_x (mm)	0.6
σ_t (ps)	12

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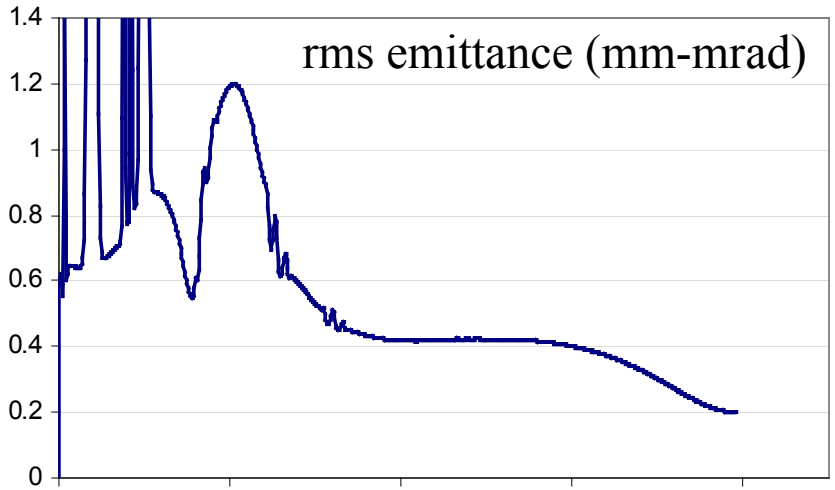
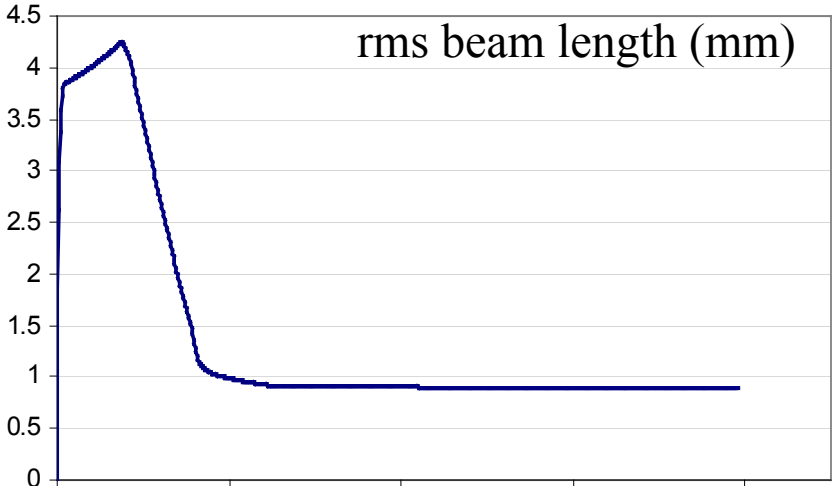
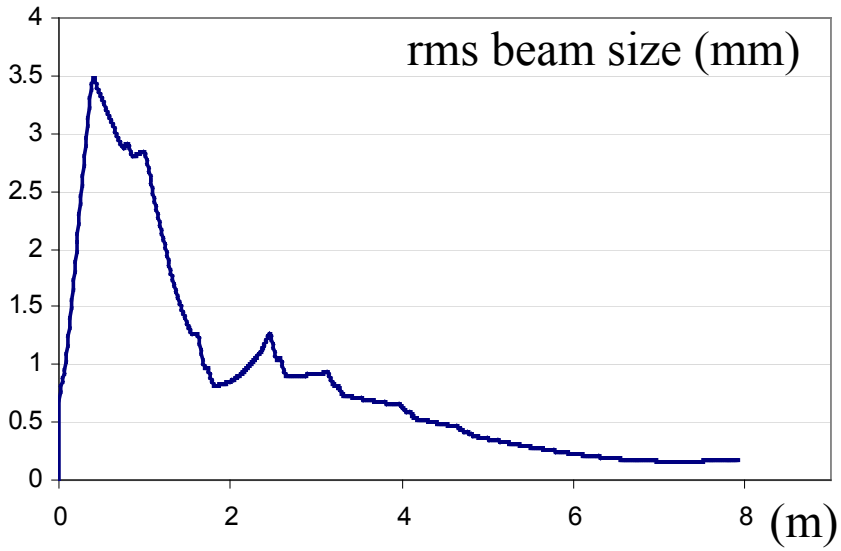
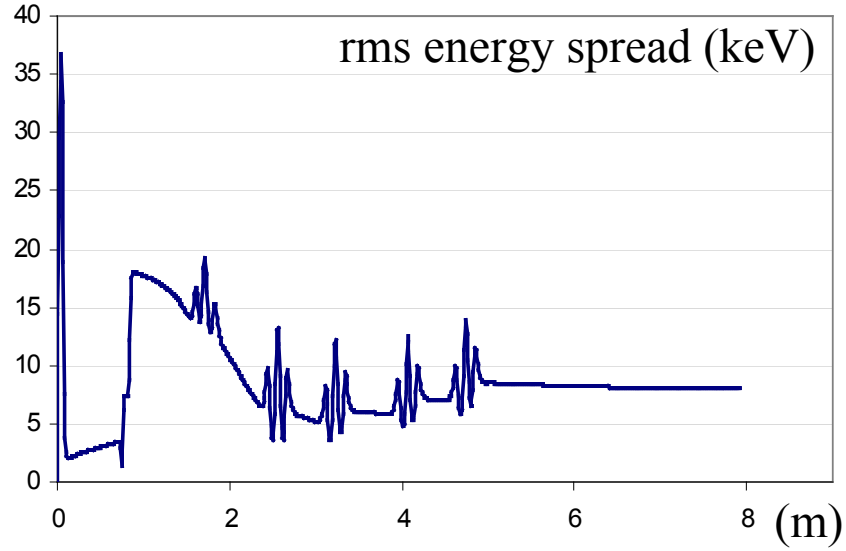
Beam parameters in the injector (80 pC, 13.5 MeV)









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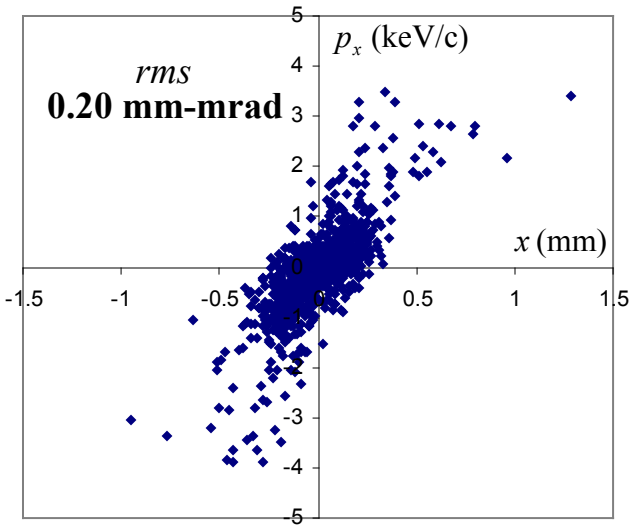
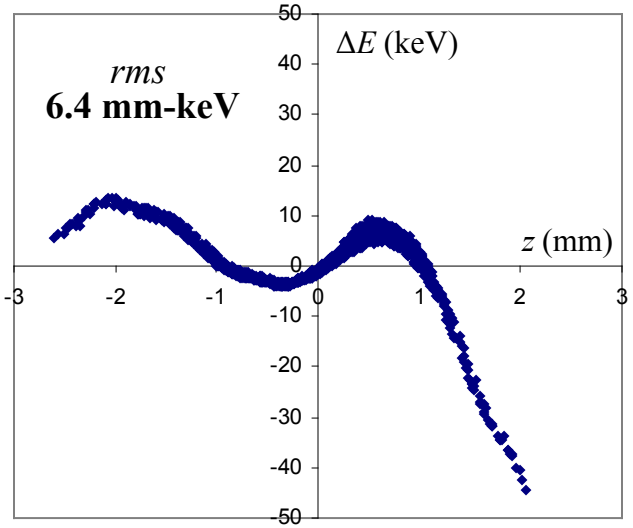
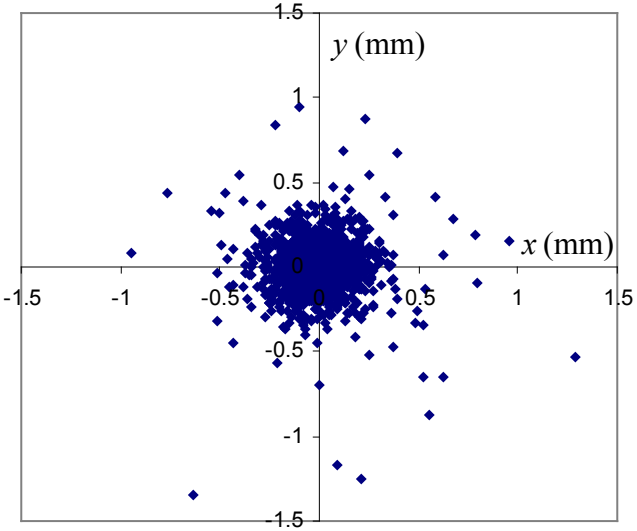
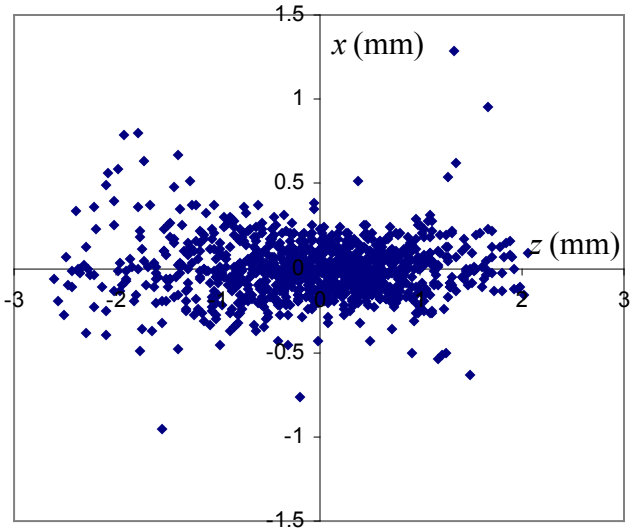
Bunch at the end









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Summary

- Tilt tolerance is phase dependant. Assuming 15 RF deg maximum off-crest angle, tolerance of ~ **mrad** is required. Several mrad might be fine if the beam is not run off-crest.
- RF focusing in the 1st cavity is a noticeable contributor to the emittance. It is good enough to make displacement of the 1st cavity to be half of the rms beam size, thus, **0.5 mm** for the 1st cavity position alignment should do the job. Other cavities can be worse than that.