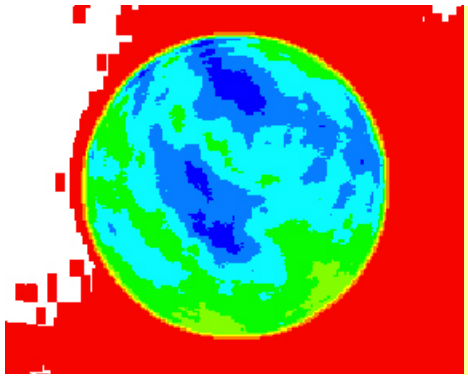
Emittance growth from non-uniform beam distributions



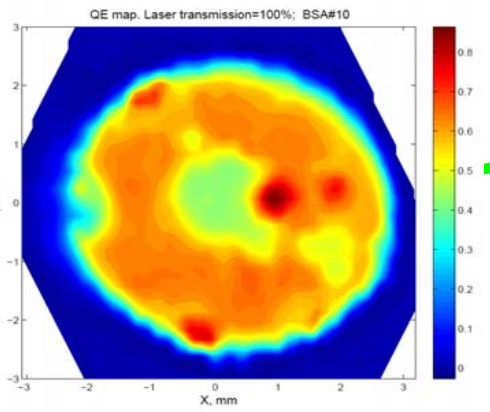
Chase Boulware

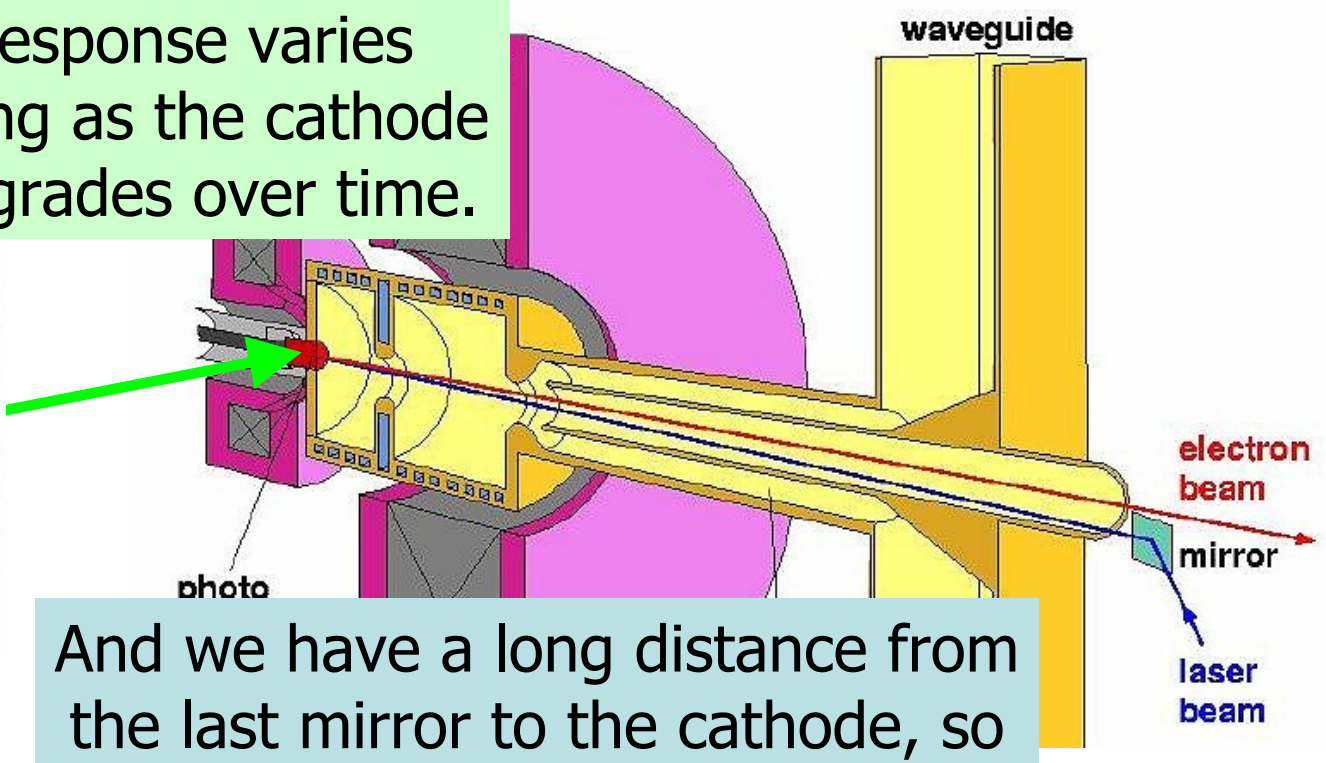
Photo Injector Test facility in Zeuthen (DESY)

Characterization of High Brightness Beams Mini-Workshop – May 30, 2008

The initial shape of the beam is a combination of the cathode response and the drive laser profile.

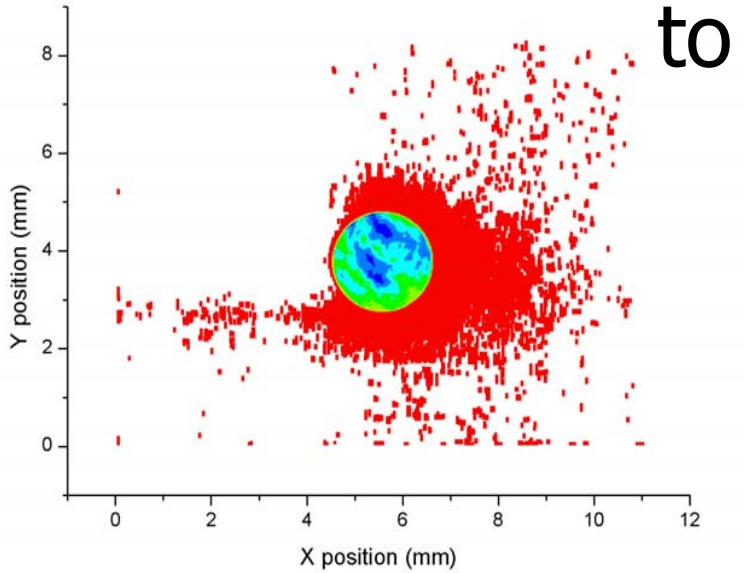
The cathode response varies spatially, changing as the cathode performance degrades over time.

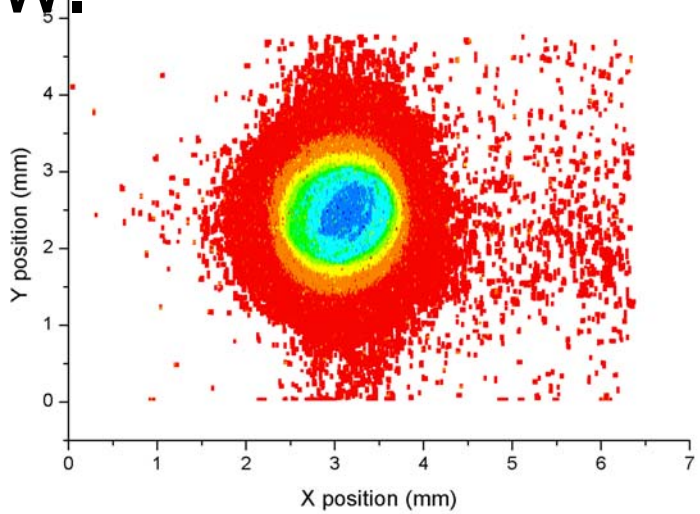


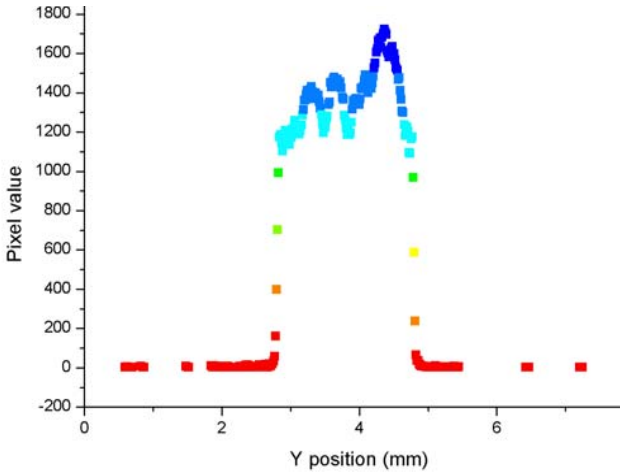


And we have a long distance from the last mirror to the cathode, so the transverse flat-top is tricky.

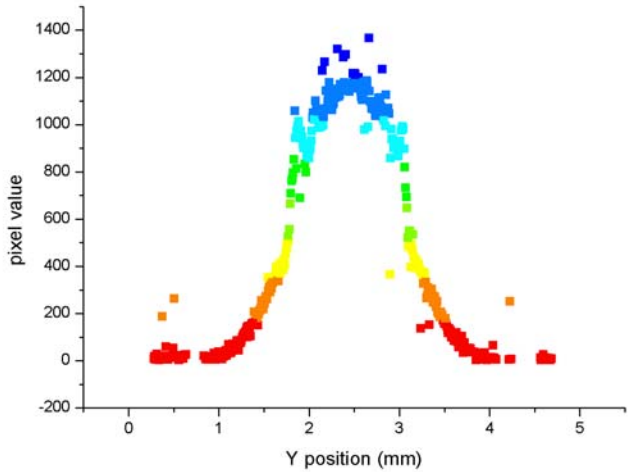
Nonuniform transverse distributions are nonlinear lenses that cause the rms emittance to grow.







Images of the PITZ laser beam at different screens.



How do we quantify the effect of the transverse distribution on the emittance?

electrostatic energy in the transverse electric fields

transverse kinetic energy of the electrons

Only a nonuniform distribution of the beam causes in rms emittance growth.

We can calculate the "transverse energy" in the distribution.

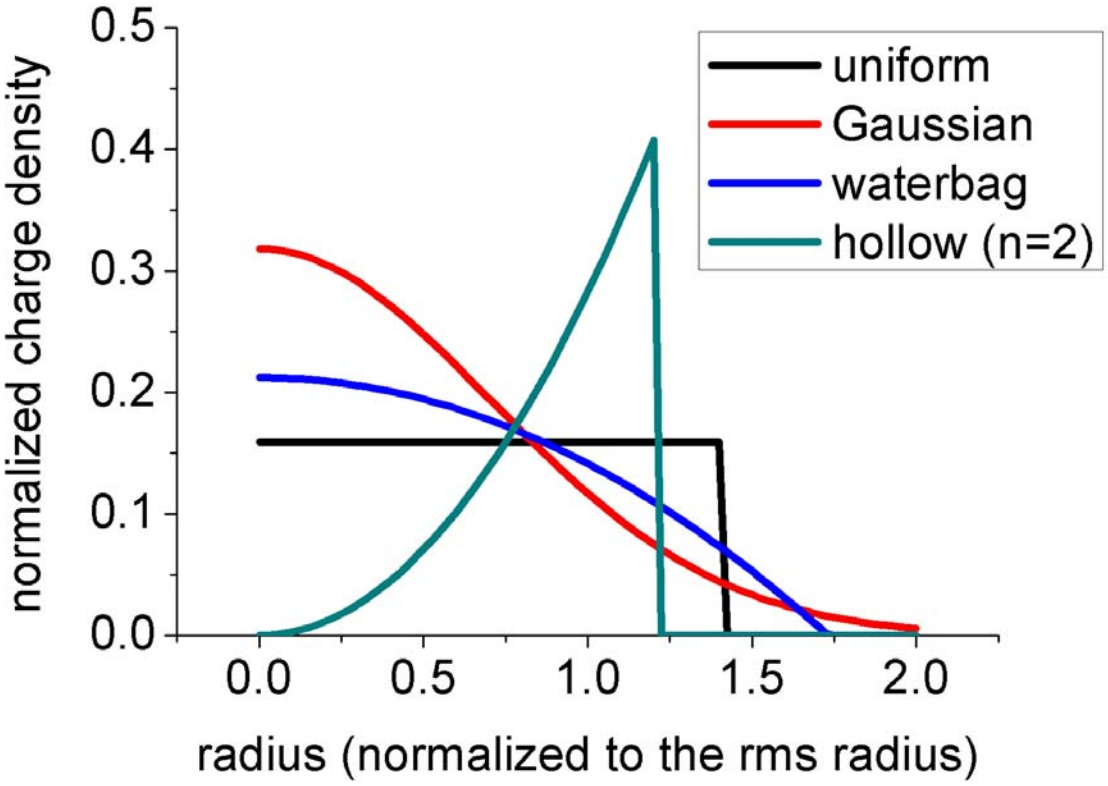
$$W = \frac{\varepsilon_0}{2} \int E_\perp^{\,2} dA$$

The *transverse* electric field appears here because I am only interested in the that part of the electrostatic energy.

energy in the transverse electric field

This is an old idea, starting to be discussed by Gluckstern et al. in 1970 and Lapostolle in 1971.

We can calculate U for various analytical distributions.

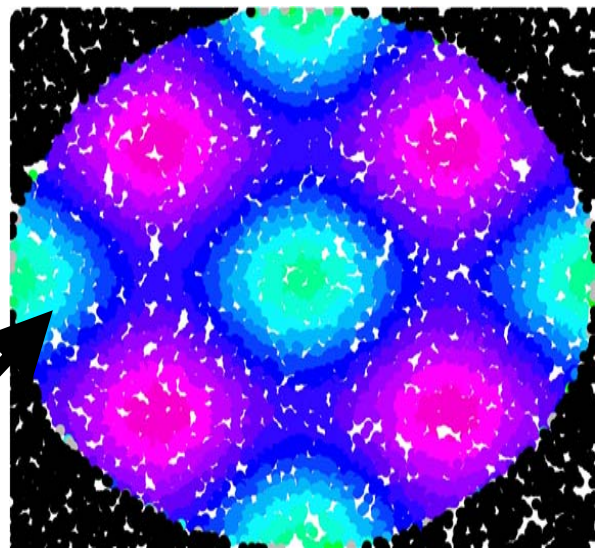


distribution	U
uniform	0
Gaussian	0.15
waterbag	0.022
hollow (r^2)	0.075

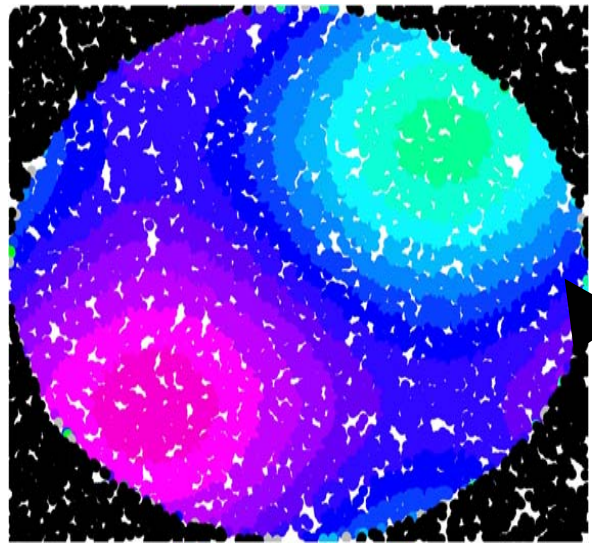
$$U \propto \int E_r{}^2 dA$$

Simulations using TREDI (at ENEA) have analyzed emittance growth from nonlinear distributions *at the cathode*.

$$k_n = n\frac{2\pi}{R}$$



$n = 1$



$n = 0.5$

$$\rho_p(x,y) = \rho_0\left[1+\delta\cdot\cos(k_n x)\right]\left[1+\delta\cdot\cos(k_n y)\right]$$

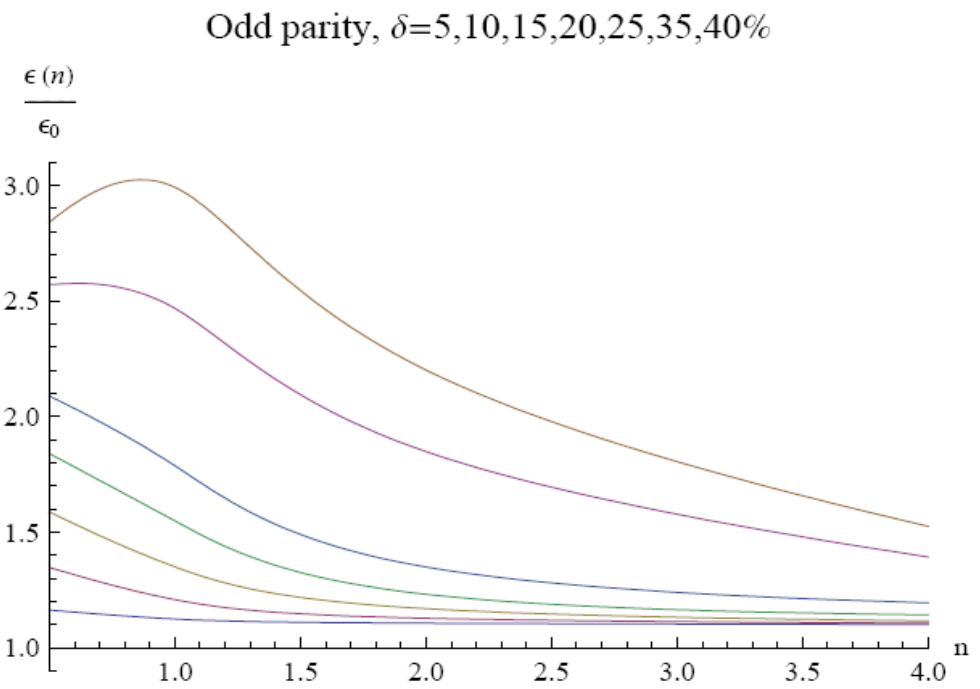
$$\rho_p(x,y) = \rho_0\left[1+\delta\cdot\sin(k_n x)\right]\left[1+\delta\cdot\sin(k_n y)\right]$$

Quattromini, Giannessi, and Ronsivalle, ENEA, EuroFEL report, 2008

The sine modulations (odd parity) show that the emittance growth becomes less as the transverse spatial frequency increases.

TREDI results

Quattromini et al., ENEA



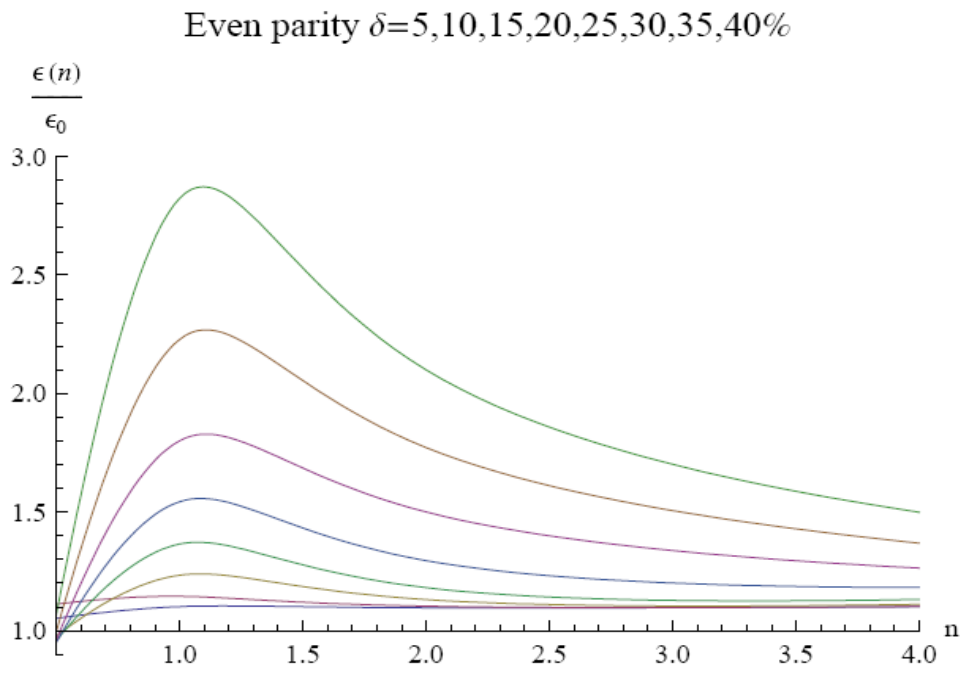
$$k_n = n\frac{2\pi}{R}$$

$$\rho_p(x,y) = \rho_0\left[1+\delta\cdot\sin(k_n x)\right]\left[1+\delta\cdot\sin(k_n y)\right]$$

The cosine modulations (even parity) show, strangely, that there is no emittance growth for n =0.5, regardless of modulation depth.

TREDI results

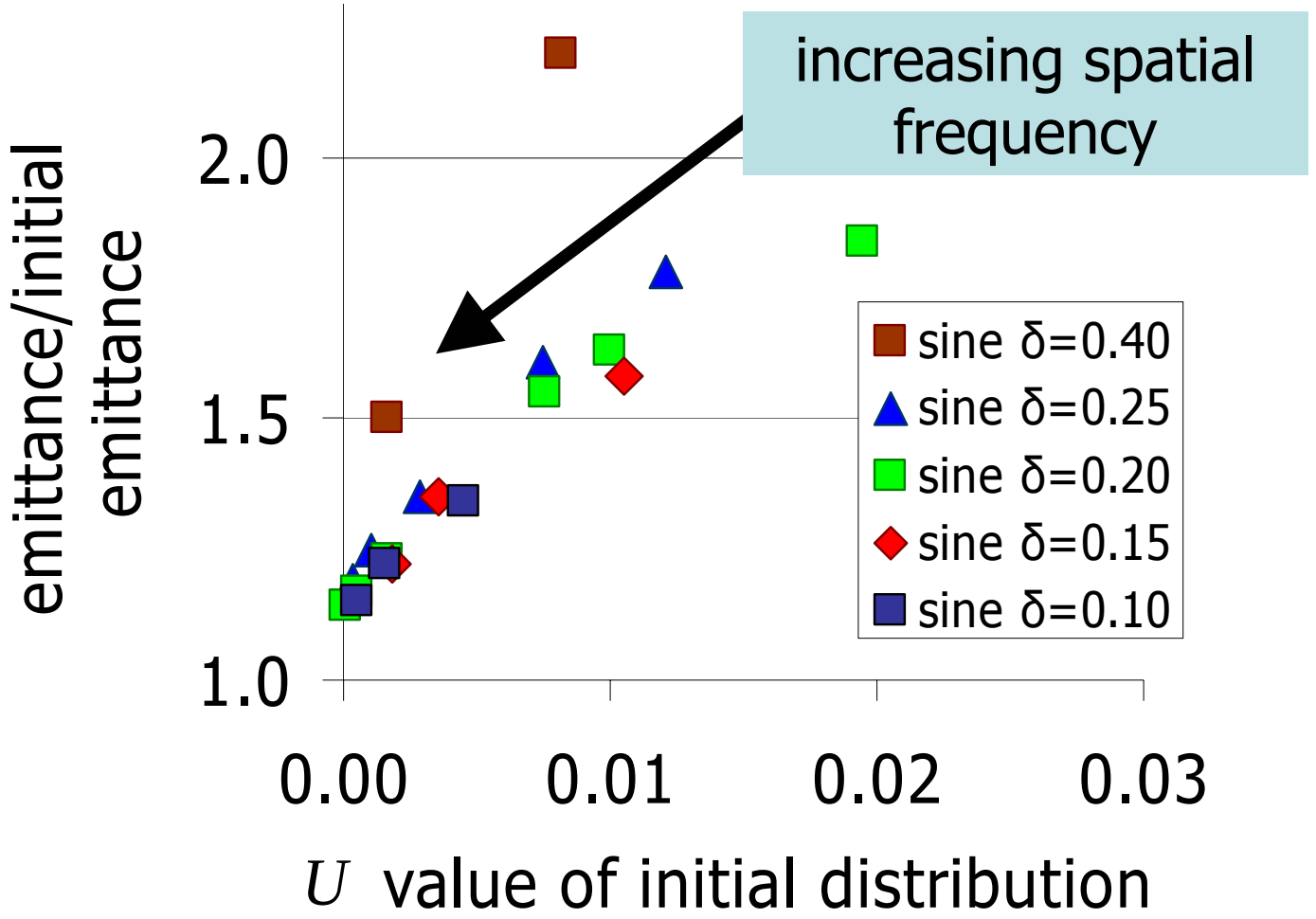
Quattromini et al., ENEA



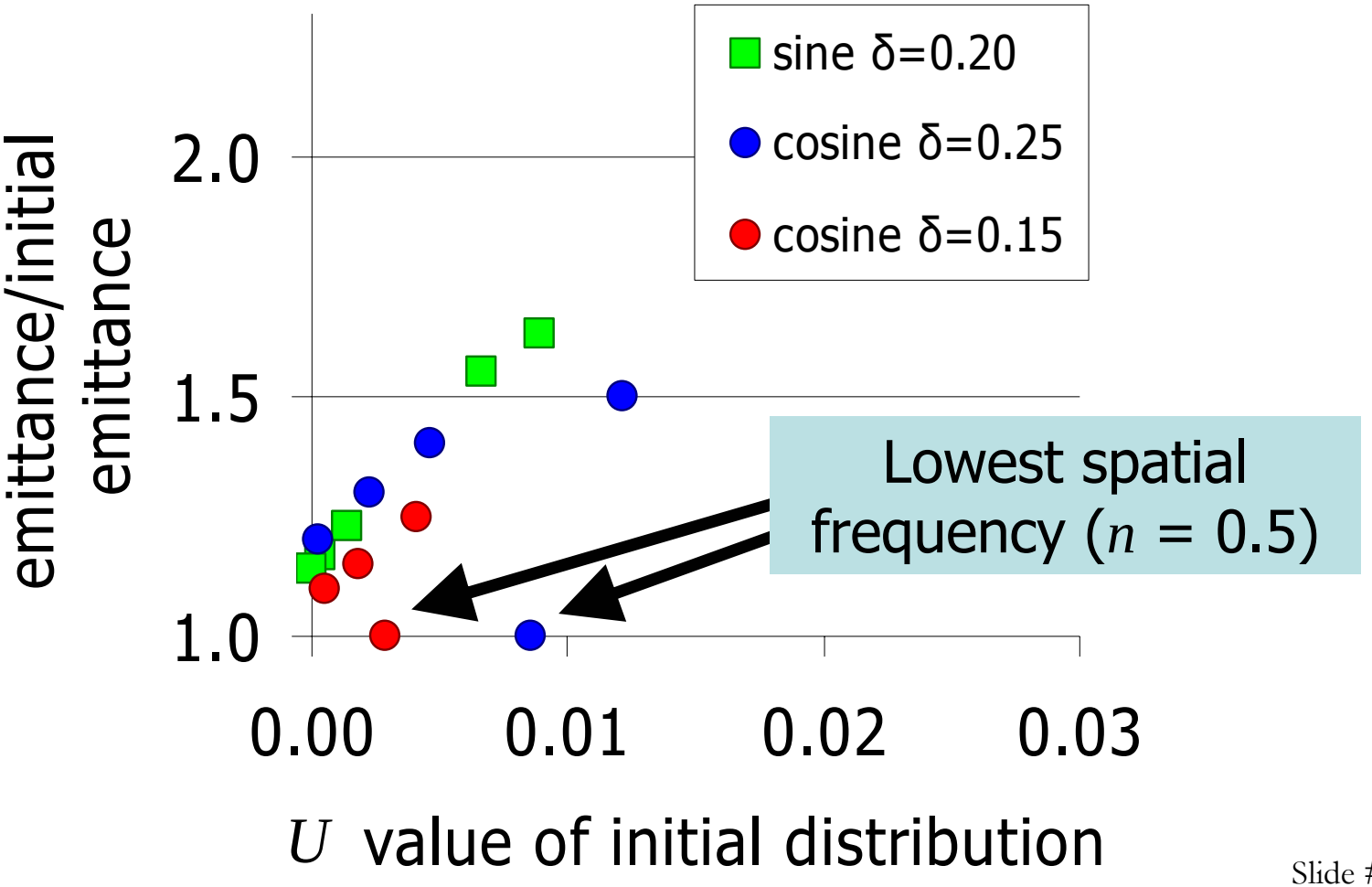
$$k_n = n\frac{2\pi}{R}$$

$$\rho_p(x,y) = \rho_0\left[1+\delta\cdot\cos(k_n x)\right]\left[1+\delta\cdot\cos(k_n y)\right]$$

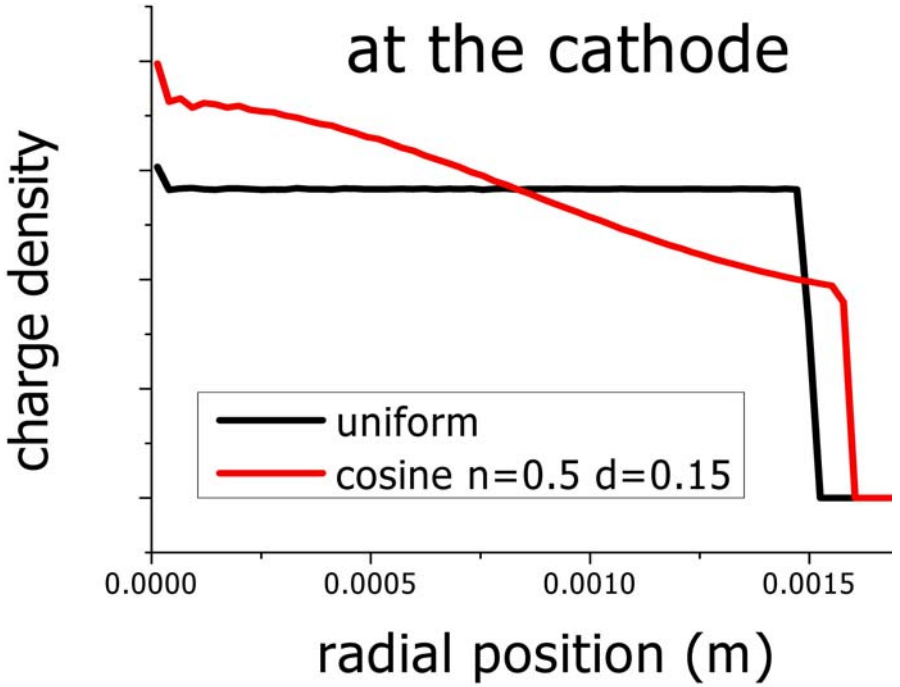
For modest sine modulations, the transverse energy correlates to the emittance growth.

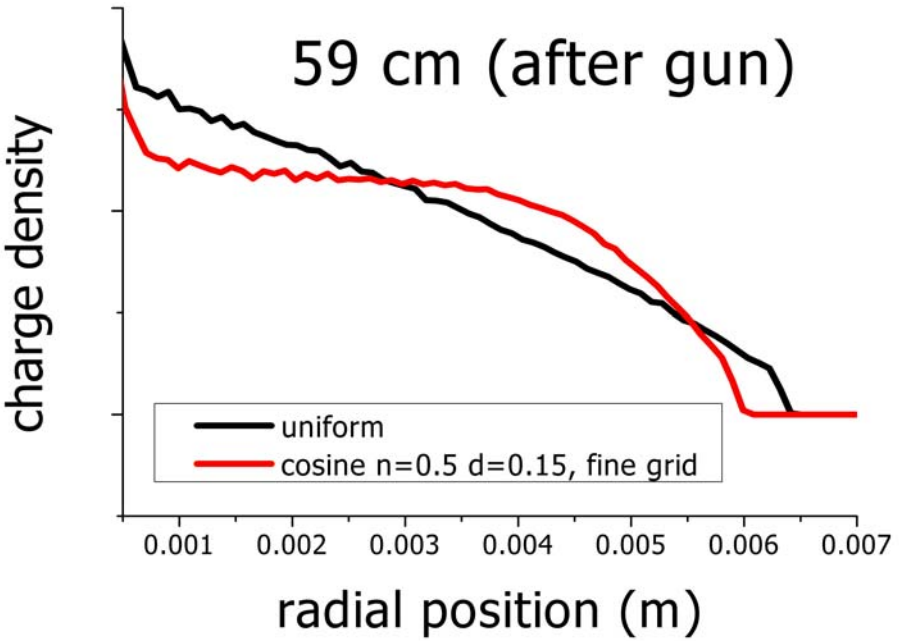


For the cosine modulations, the energy clearly does not predict the emittance growth.



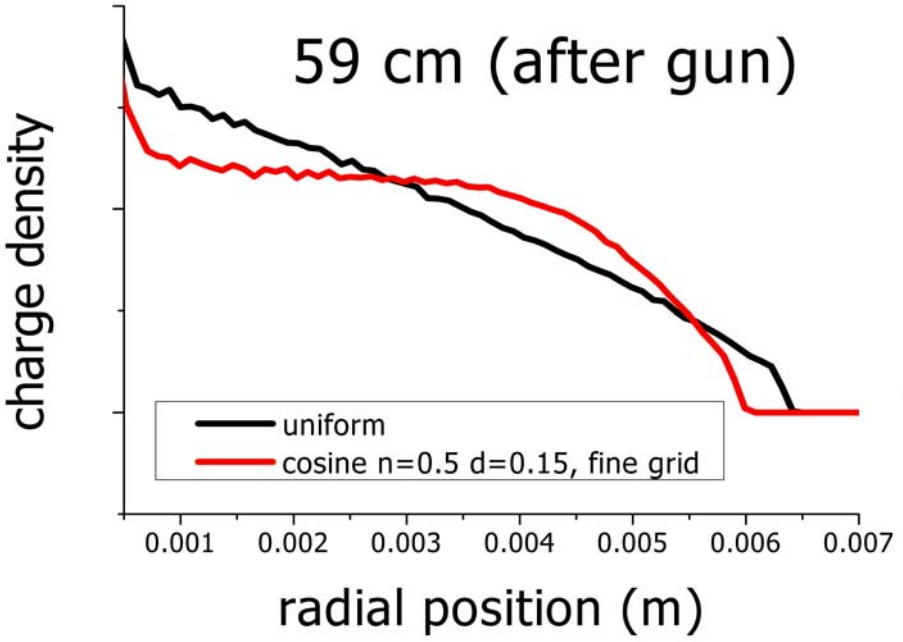
ASTRA simulations using the PITZ setup show that a uniform cathode profile doesn't stay uniform.

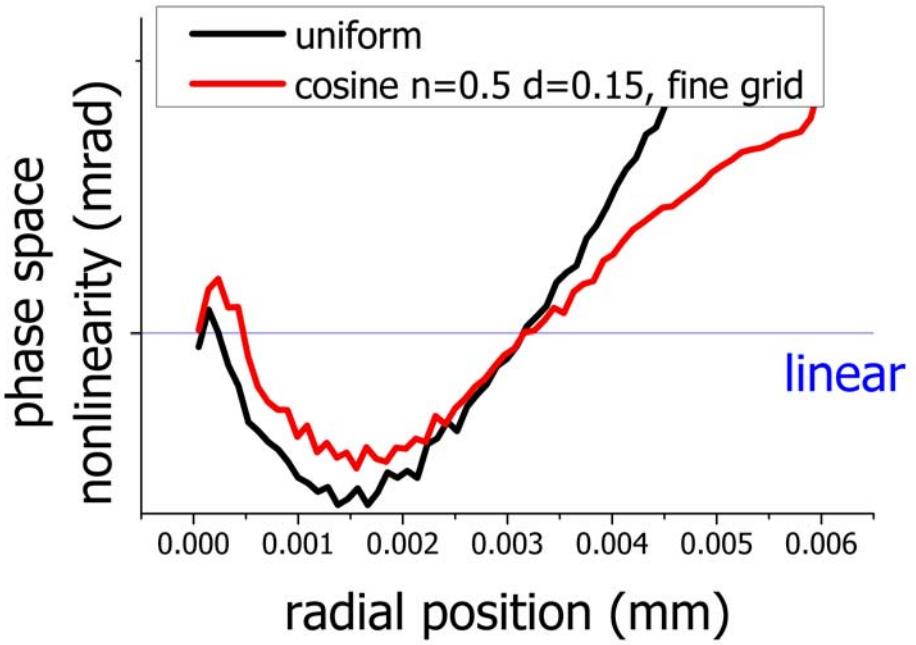




Space charge forces are not the only cause of nonlinear focusing.

By reducing the nonlinearity in the phase space, it seems possible to reduce the minimum emittance by 10%.





Preliminary ASTRA simulations, using the 2D space charge routines.

Emerging conclusions…

- Two methods are needed for evaluation of the potential for emittance growth from nonuniform initial distributions:

  the nonlinear transverse energy method for dealing with the uncorrelated modulations

  some other way for looking at the correlated emittance growth

- A uniform transverse laser distribution may not, in fact, be the best for creating low emittance beams.

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