Helmholtz International Center HIC for FAIR

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

Riezlern 2010

Beam Dynamics and Emittance Growth

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Motivation

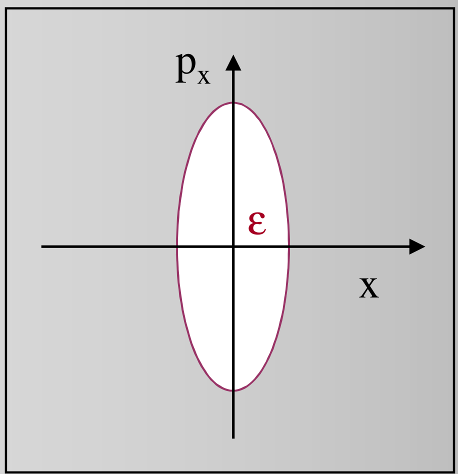
Requirements on Accelerator physics
- Luminosity

$$L = \frac{\dot{N}}{\sigma_S}$$

Current density at
„Final Focus“

$$J = \frac{1}{A} \cdot \dot{N}$$

Beam emittance



minimum spot size

Beam current I_s

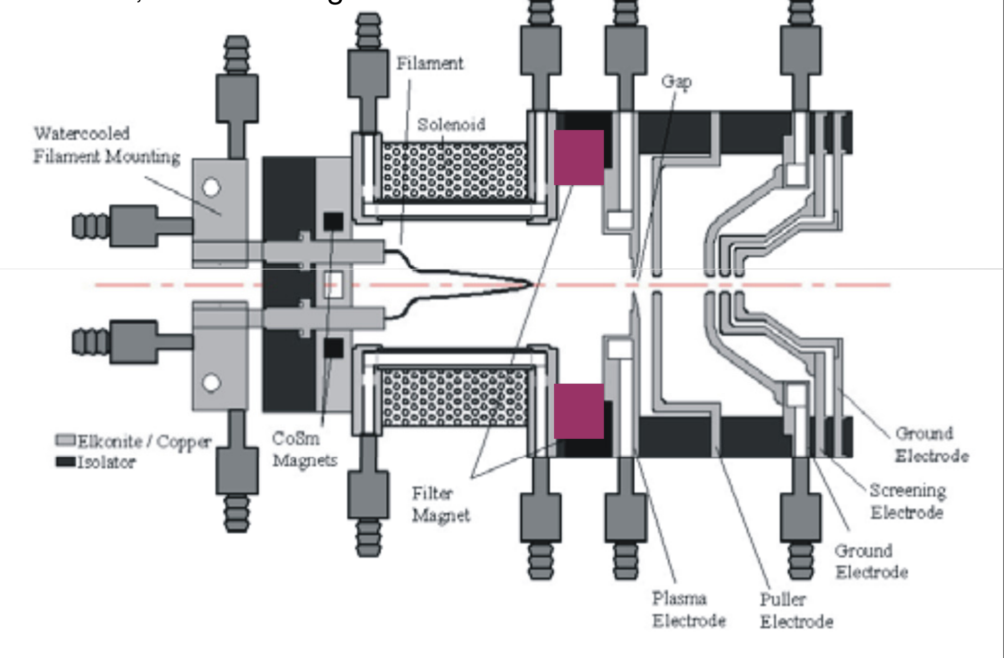
$$r_{\min} = \frac{\varepsilon_\perp}{p_\perp}$$

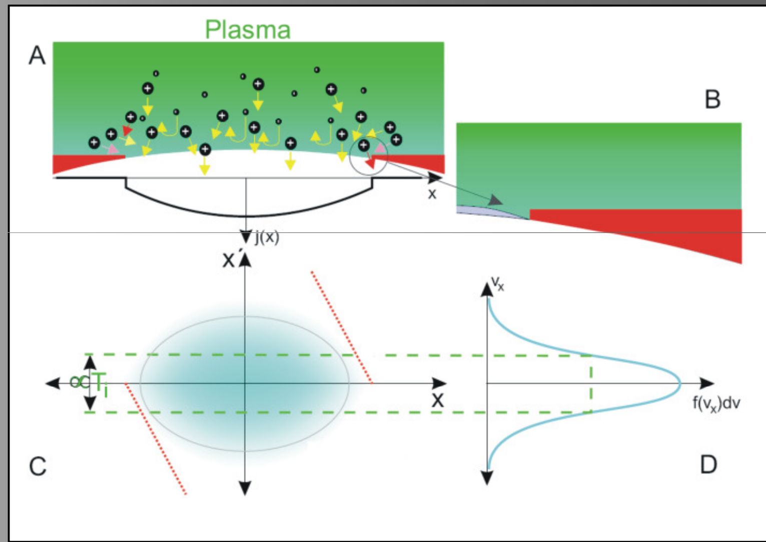
Space Charge !

Beam emittance vs. Beam current

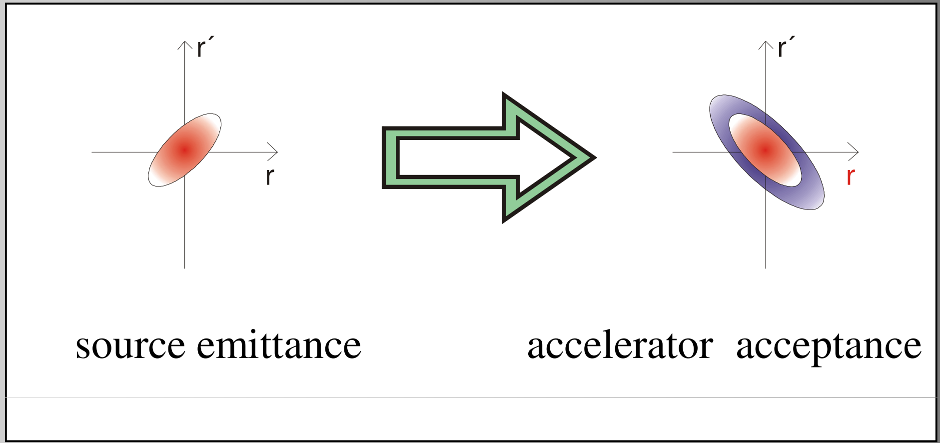
Beam Extraction

© K. Volk, R. Nörenberg





Beam Transport



small emittance:

- low T_i (laminar beam)
- distribution function

Assumptions:

- transverse plane
- coasting beam
- no external field
- decompensated

Emittance growth:

- external fields (lens aberreation)
- collisionless relaxation
- compensation process

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Non Linear Field Energy

$$\varepsilon_{x,rms} = \sqrt{\langle x^2\rangle\langle x'^2\rangle - \langle xx'\rangle^2}$$

Sacherer

$$\frac{d}{dz}\langle\varepsilon_{x,rms}\rangle^2 = 2\frac{q}{Amv_i^2}\left(\langle x^2\rangle\langle x' E_x\rangle - \langle xx'\rangle\langle xE_x\rangle\right)$$

Th. Weis

$$\langle x' E_x\rangle = \frac{1}{Nqv_i}\iint E_x j_x dxdy$$

Wangler

$$\iint Ejdxdy = -v_i\frac{d}{dz}W$$

$$\boxed{\langle x' E_x\rangle \sim \frac{d}{dz}W}$$

$$\frac{1}{\langle x^2\rangle}\frac{d\langle x^2\rangle}{dz}\langle xE_x\rangle + \frac{1}{\langle y^2\rangle}\frac{d\langle y^2\rangle}{dz}\langle yE_y\rangle = -\frac{2}{Nq}\frac{d}{dz}W_h$$

Anderson

Non Linear Field Energy

$$\frac{1}{\langle x^2 \rangle}\frac{d}{dz}\langle \varepsilon^2_{rms,x} \rangle + \frac{1}{\langle y^2 \rangle}\frac{d}{dz}\langle \varepsilon^2_{rms,y} \rangle = -\frac{2}{Amv_i^2 N}\frac{d}{dz}(W - W_h)$$

$$\downarrow$$

$$\frac{d}{dz}\varepsilon^2_{rms,x} = -\frac{1}{8}\langle x^2 \rangle K \frac{d}{dz} W_{nl}$$

$$\Delta\varepsilon_{rms,x} = \sqrt{\varepsilon^2_{rms,x,final} - \varepsilon^2_{rms,x,start}} = \sqrt{\frac{\langle x^2 \rangle K \Delta W_{nl}}{8}}$$

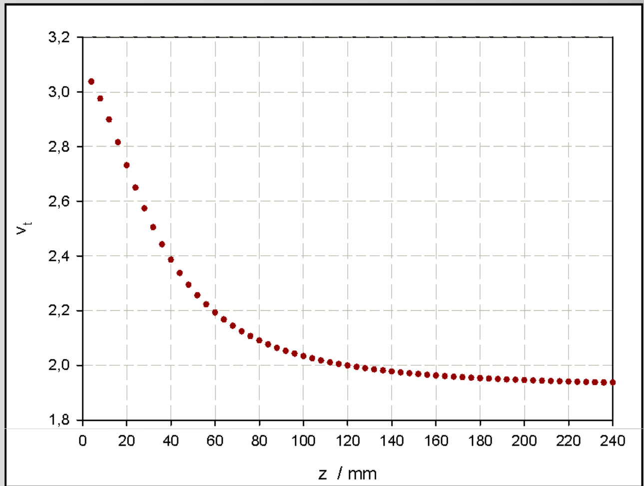
relaxation time

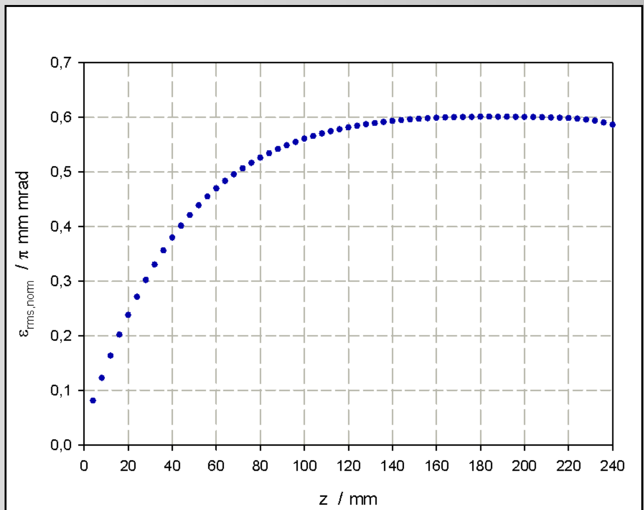
$$\lambda_p = \frac{\omega_p}{2\pi v_i}$$

ion distribution

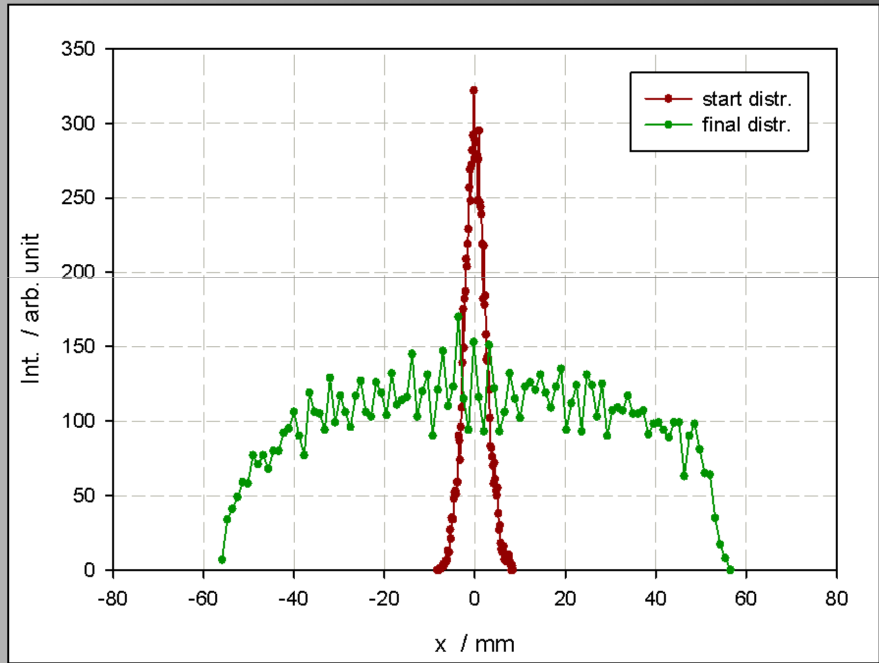
$$v_t = \frac{\overline{x}^4}{\overline{x^2}^2}$$

Thermalisation



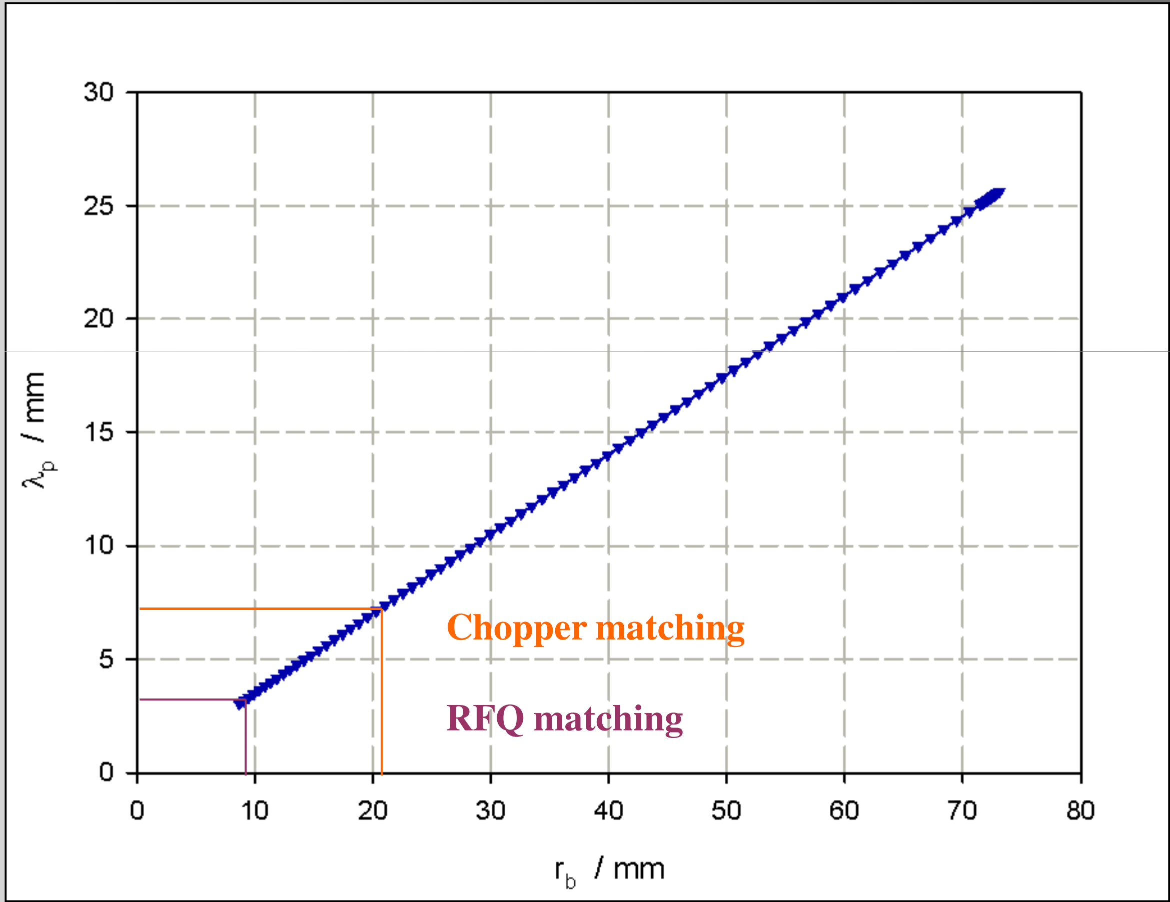


Example I: Gaussian start distribution

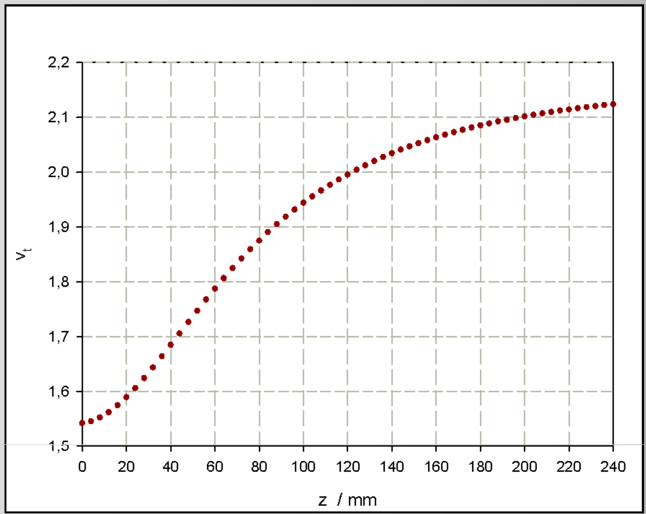


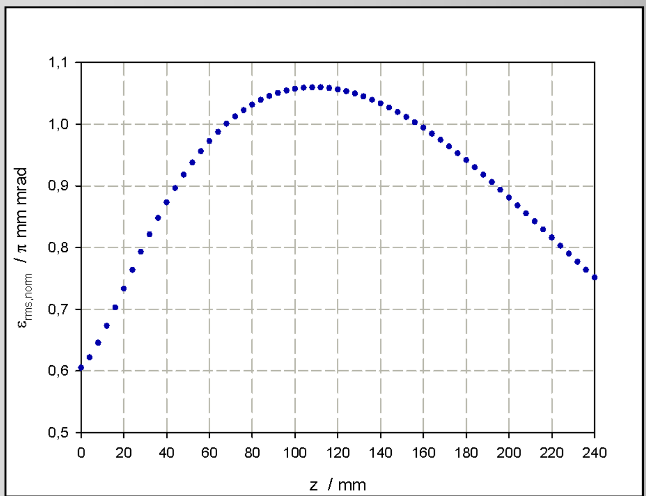
$\Delta\varepsilon_{rms,x} = 8$!

Relaxation Time

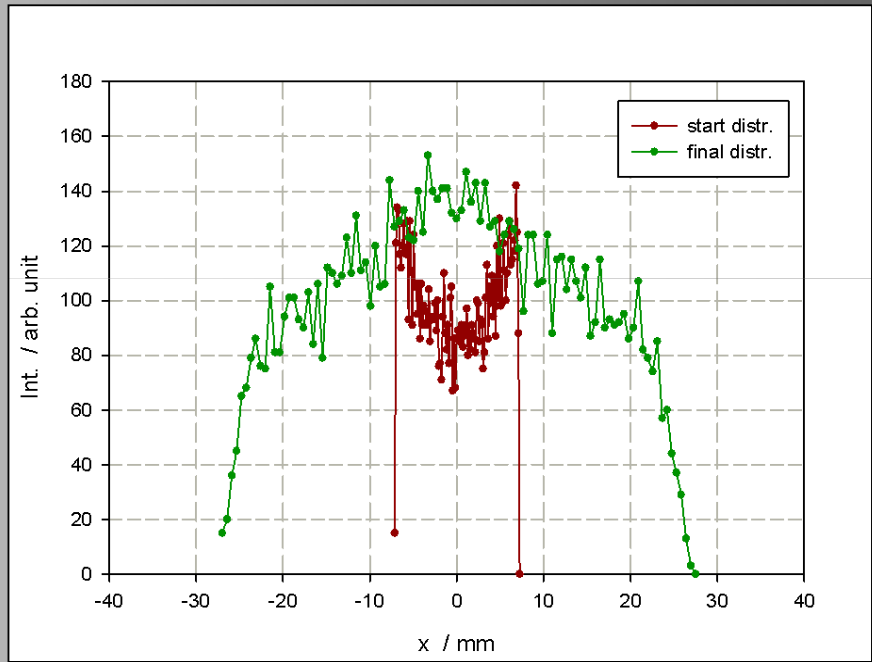


Thermalisation





Example II: hollow beam



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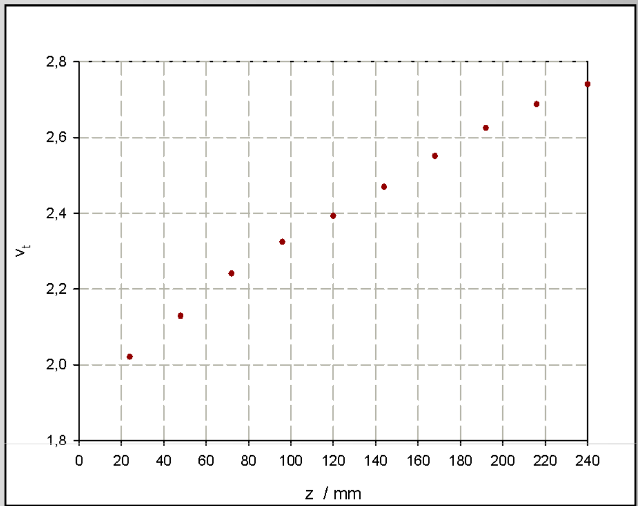
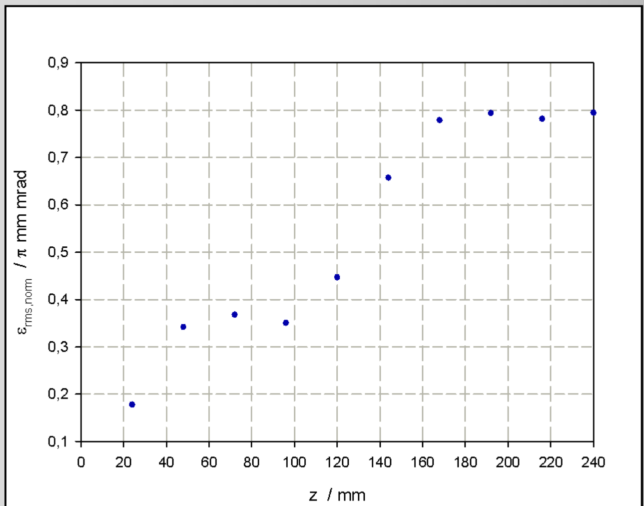
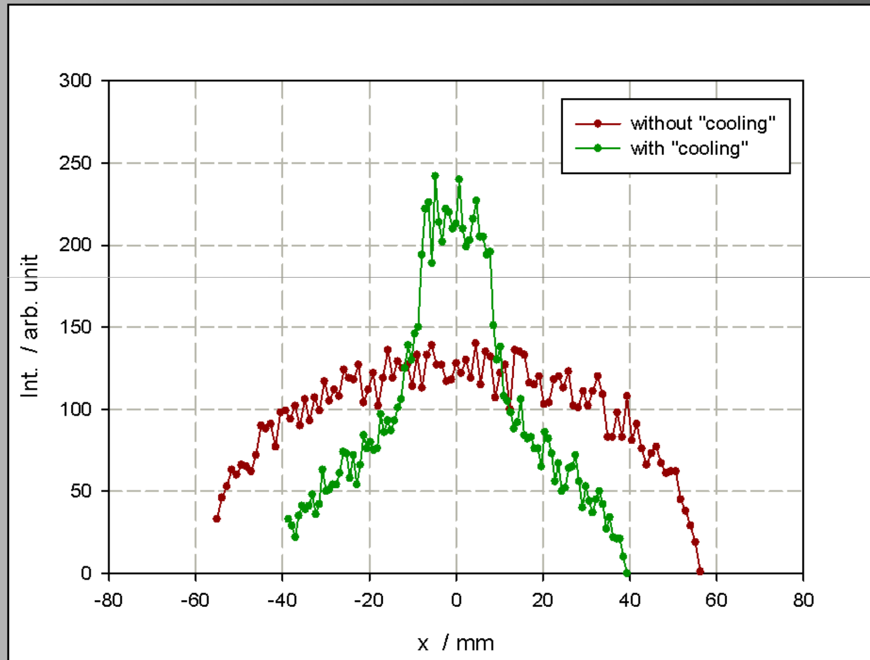
Thermalisation



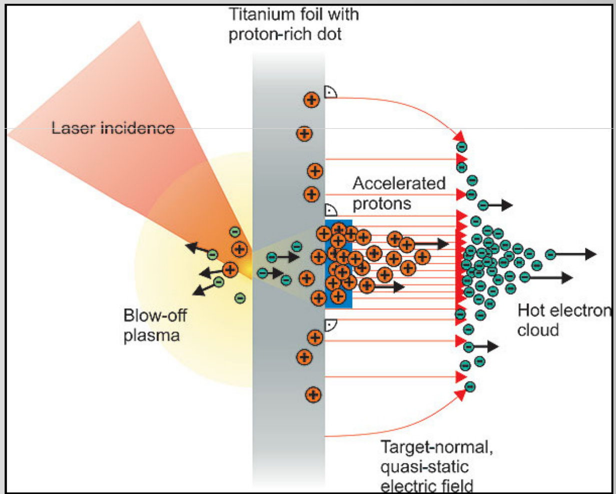


Example III: electron beam „cooling“

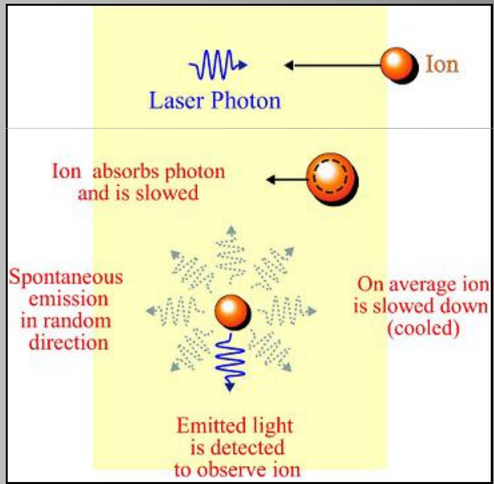


Cold Ion Beams

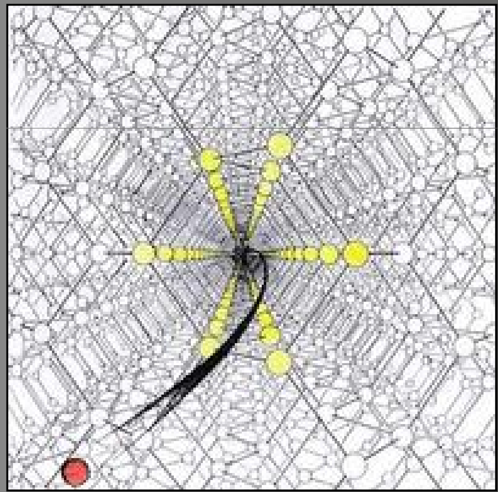
production of cold ion beams



LASER cooling



channeling



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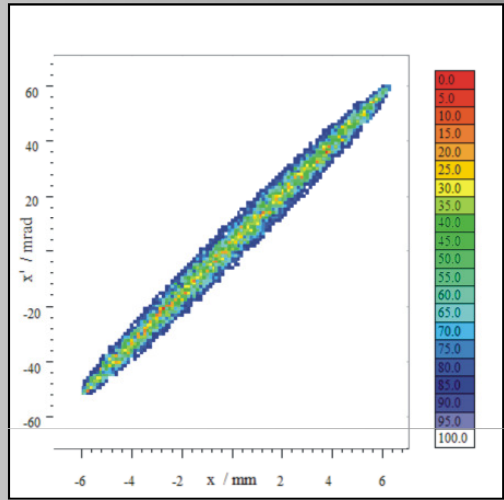
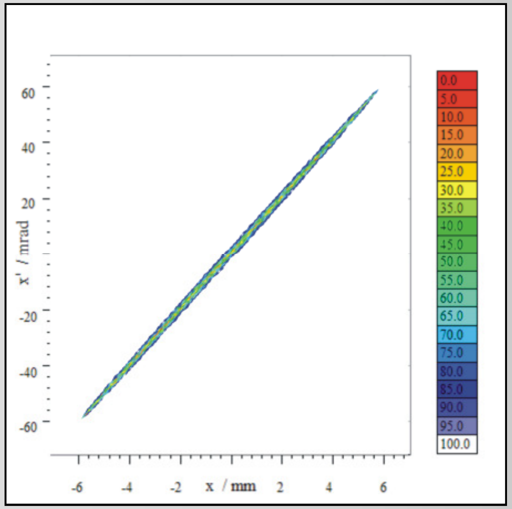
Reduction and Growth of Beam Emittance



Cooling

Compression



heating

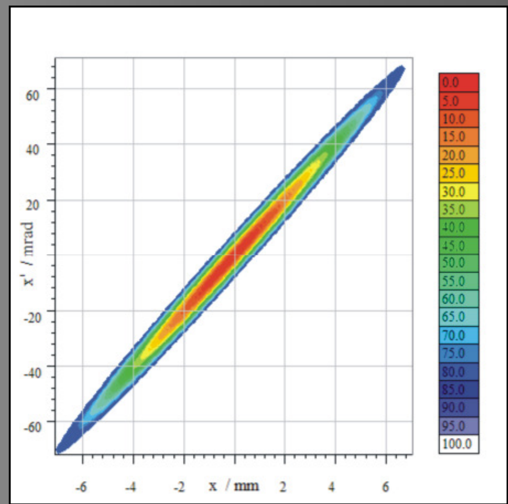
$$\tau_r = \frac{4{,}8 \cdot 10^{-14} \cdot n_i \cdot \ln\Lambda}{T_i^{3/2}}$$

1.78 ms

collisionless relaxation

$$\tau_p = \frac{2\pi}{\omega_p}$$

166 ns



Thank You!

Requirements on Accelerator physics

- Luminosity -

$$L = \frac{\dot{N}}{\sigma_S}$$