Winterseminar Riezlern 2007

Beam Transport and Diagnostic for „FRANZ“

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Motivation

Institut für Angewandte Physik ⟷ Stern-Gerlach-Zentrum

concept studies of accelerators for intense ion beams	intense ion beams are needed for several experiments

Overview

neutron generator

low energy proton beam

beam energy: 120 keV

current: 200 mA

pulse width: 50 - 150 ns

→

proton beam

final energy: 1,9 - 2,4 MeV

repetition rate: 20 - 250 kHz

pulse width at the target: 1 ns

↓

neutron production target

$$^{7}Li(p,n)\rightarrow {}^{7}Be$$

in cooperation with FZ Karlsruhe

→

neutrons

energy: 100 – 500 keV

produktion rate:

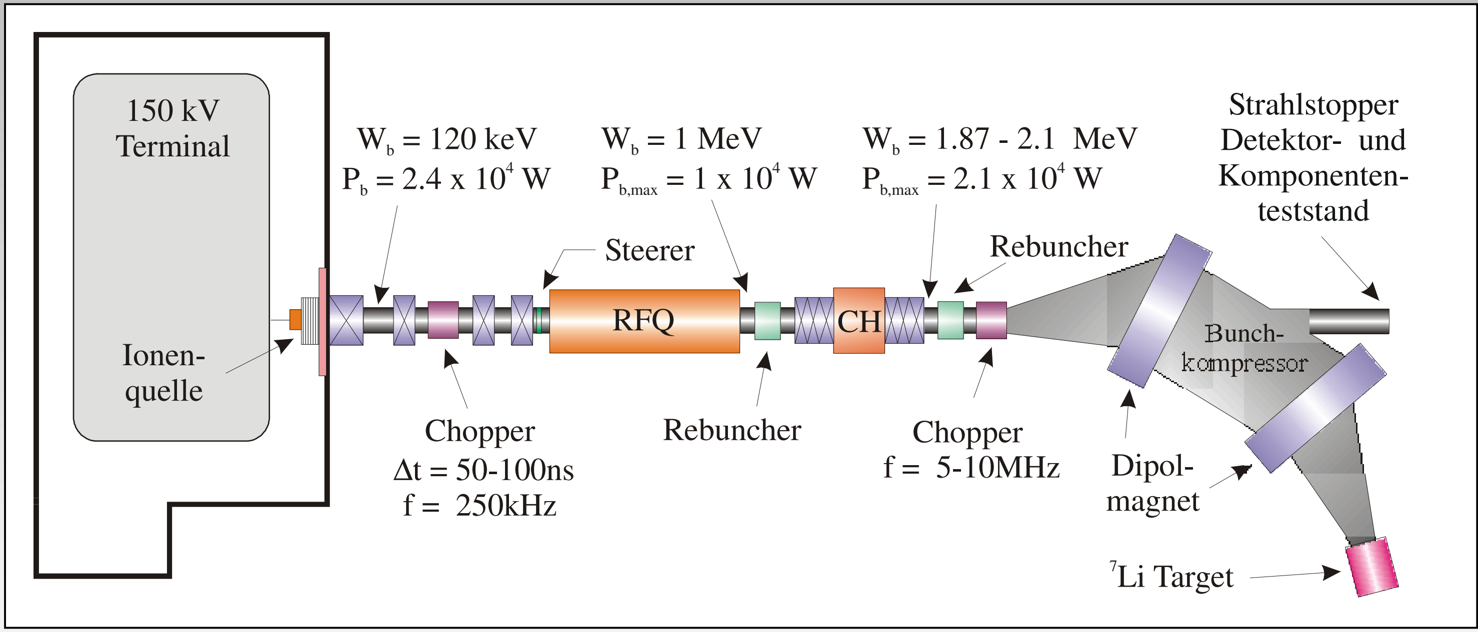
$$\leq 2\cdot 10^{5}\,\mathrm{n/pulse} \rightarrow \leq 5\cdot 10^{10}\,\mathrm{n/s}$$

neutrons at the target:

$$\leq 120\,\mathrm{n/pulse} \rightarrow \leq 3\cdot 10^{7}\,\mathrm{n/s} \rightarrow \leq 1\cdot 10^{7}\,\mathrm{n/cm^2 s}$$

Overview

scheme of the proton driver LINAC



technical layout of the driver accelerator

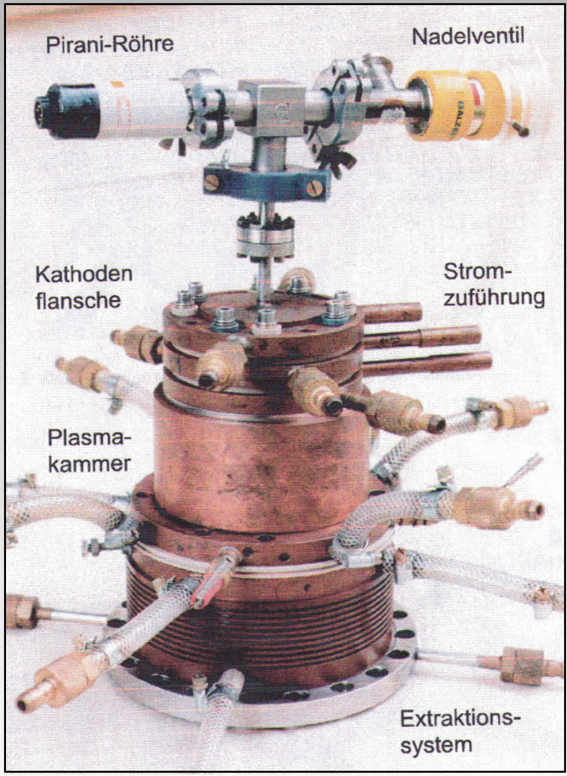
HV - Terminal and Ion Source

requirements

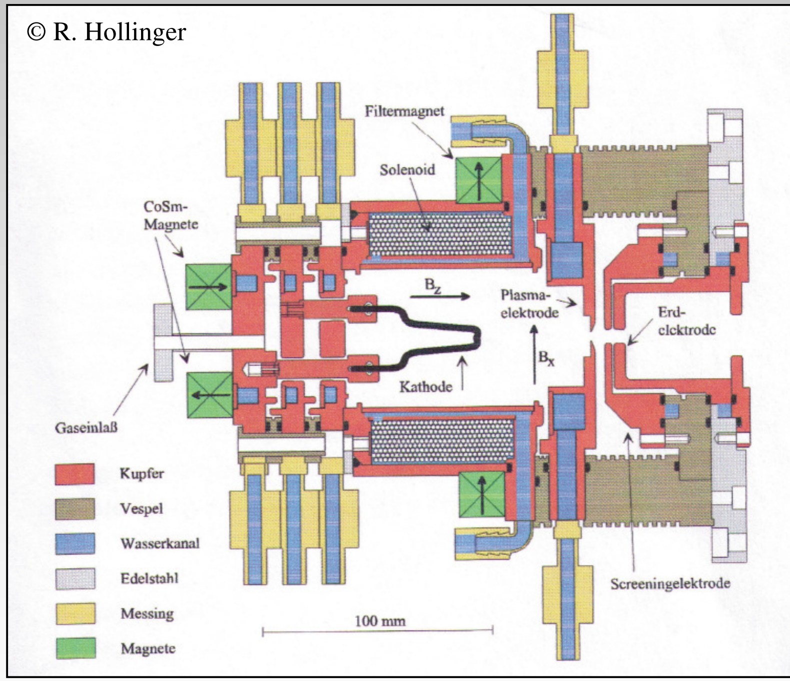
current I = 200 mA (DC)

Proton fraction ~ 90 %

emittance (rms, norm.) $\varepsilon_{rms} < 0{,}15\ \pi$ mm mrad



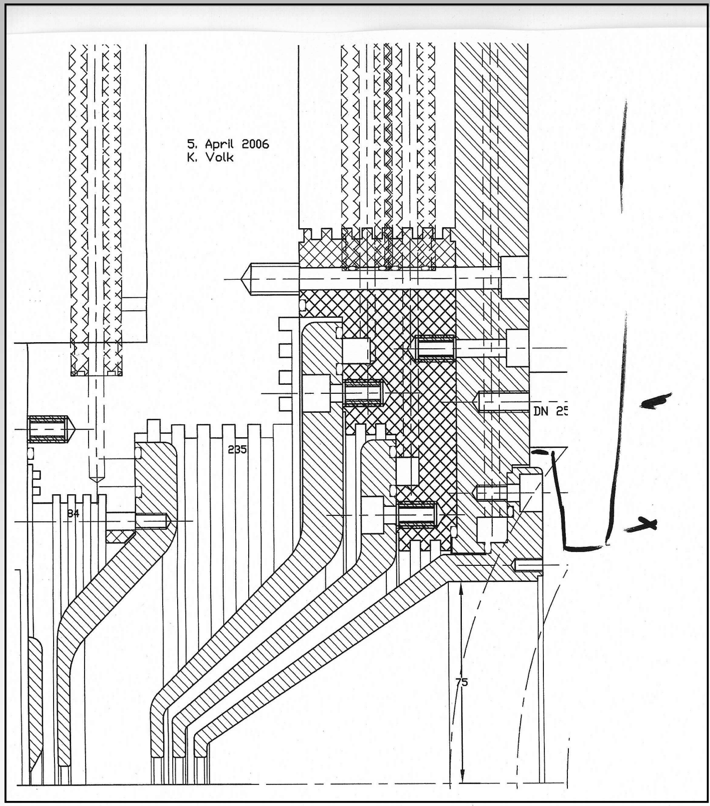
prototype of the high current proton source



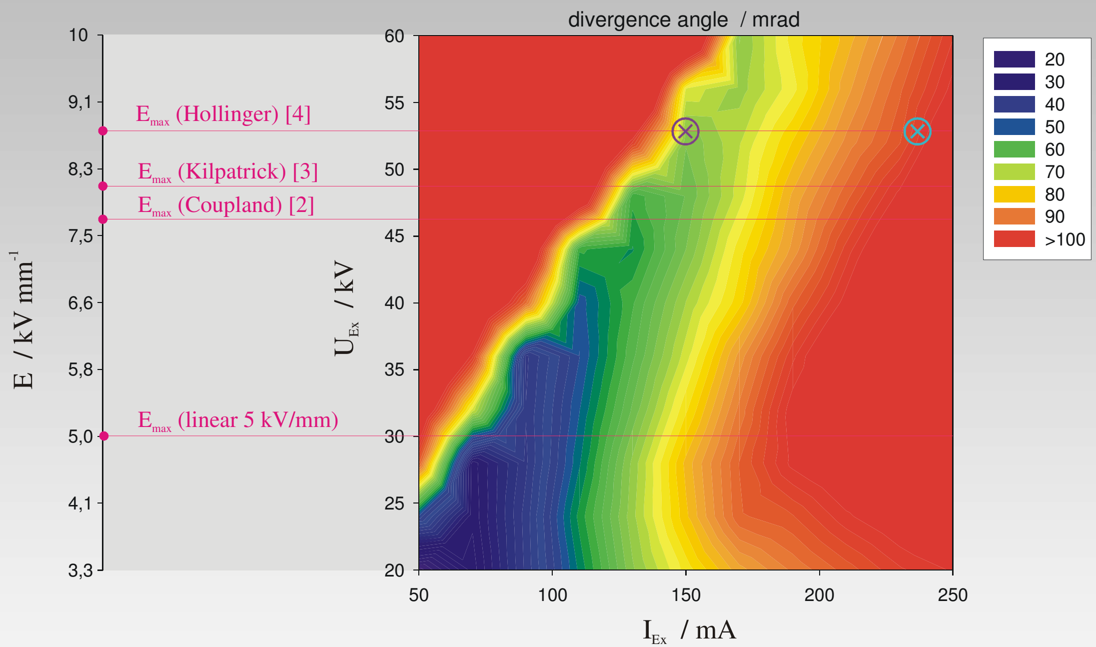
crossectional view of the proton source

HV - Terminal and Ion Source

design of the penthode extraction system



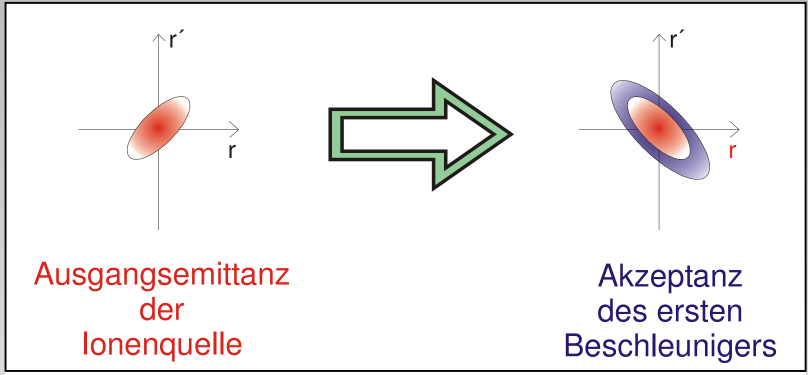
Scheme of the extraction system



Calculated transverse momentum as a function of gap field strength and beam current

Low Energy Beam Transport

aim of the transport channel



matching of the source emittance into the acceptance of the RFQ

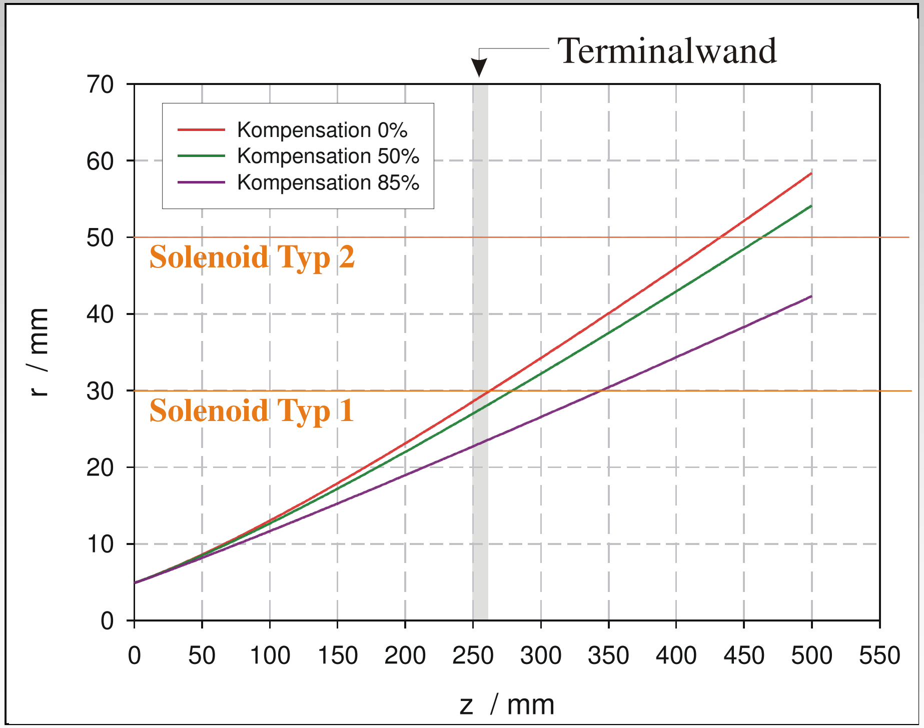
$$\frac{d^2}{dz^2} r_S = \frac{\varepsilon^2}{r_S^3} + \frac{K}{r_S} - \kappa(z) r_S$$

KV envelope equation describes the beam transport

Low Energy Beam Transport

beam intensity – space charge

$$K = \frac{1}{4\pi\varepsilon_0} \cdot \sqrt{\frac{m_i}{2q}} \cdot \frac{I}{U^{3/2}}$$



W_b = 120 keV

I = 200 mA

K = $3{,}12 \cdot 10^{-3}$

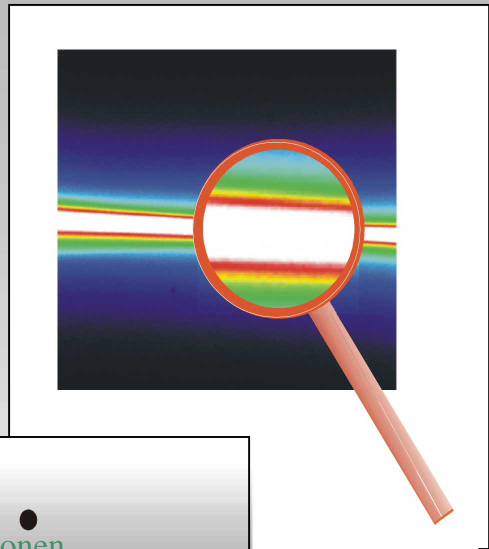
equivalent electron current
8,56 A

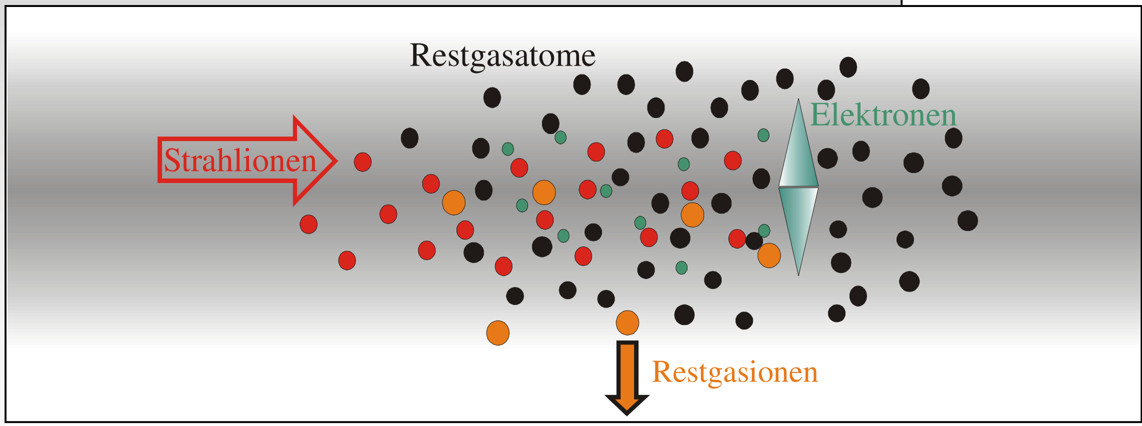
Beam radius as a function of path length for different space charge forces

Low Energy Beam Transport

space charge compensation

reduction of the beam potential by capturing compensation electrons → space charge compensation

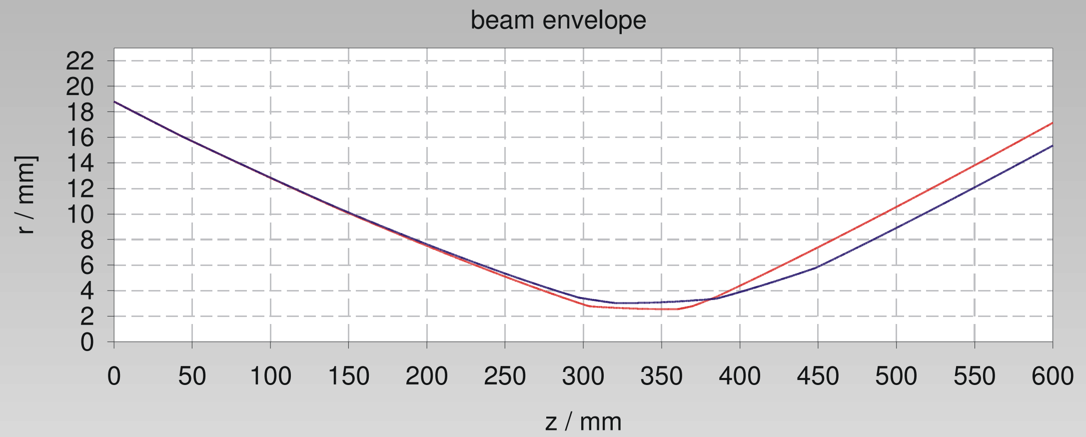


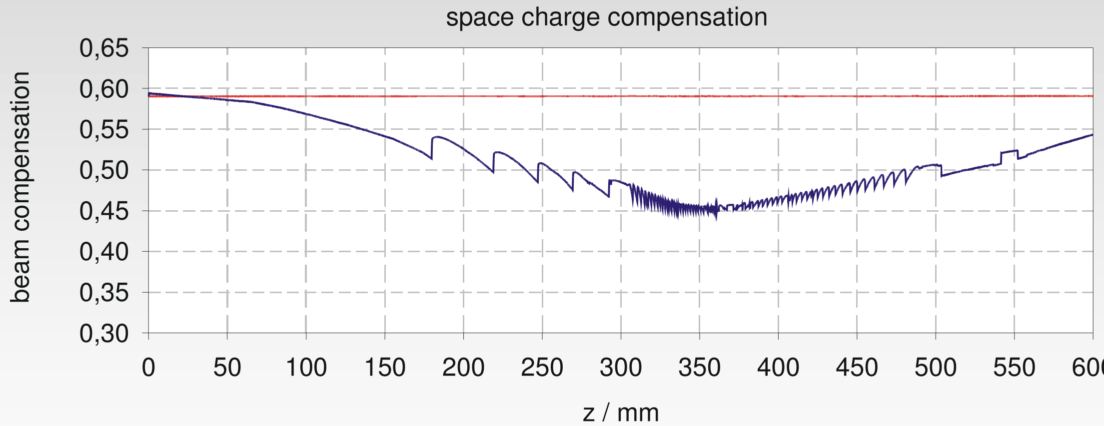


particle distribution inside of the beam volume

Low Energy Beam Transport

temperature of the compensation electrons





beam transport simulation using a fixed compensation degree (red) and an electron temperatur of T_e = 6 eV (blue)

$$n_e(r) = n_e(r = \Phi_{b,\max}) \cdot e^{-\left(\frac{\Phi_b}{kT_e}\right)}$$

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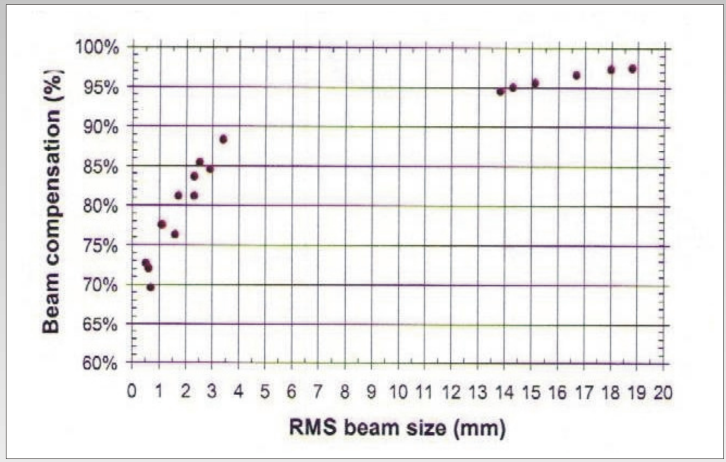
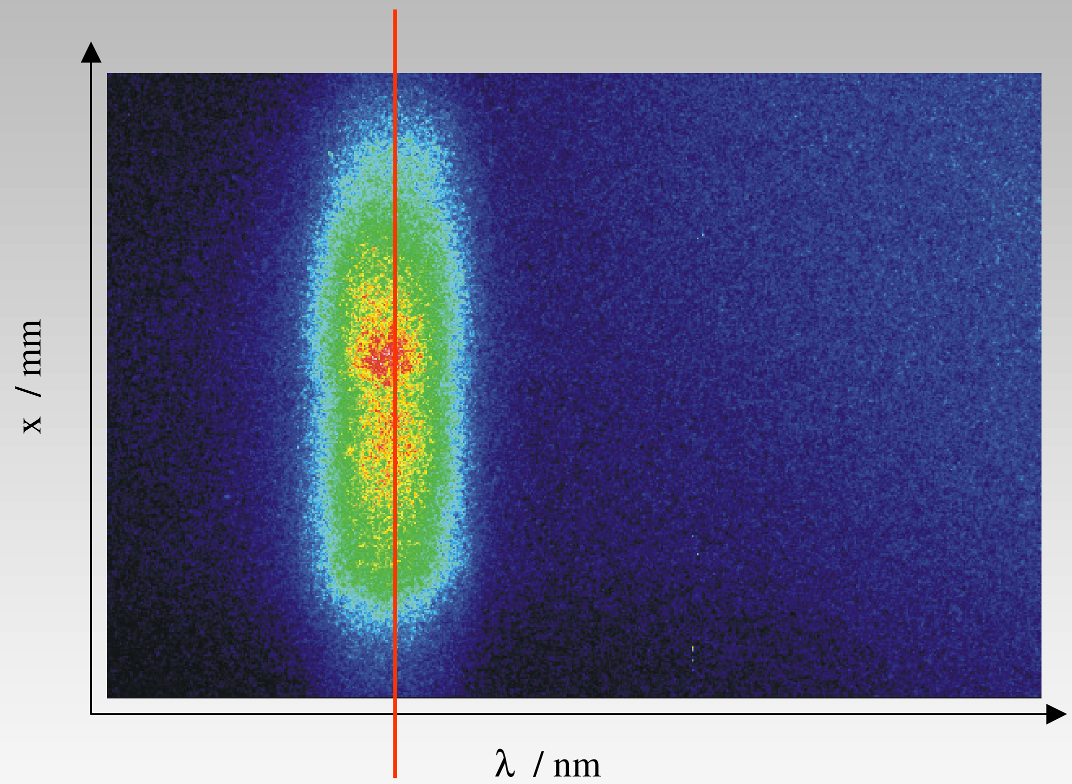
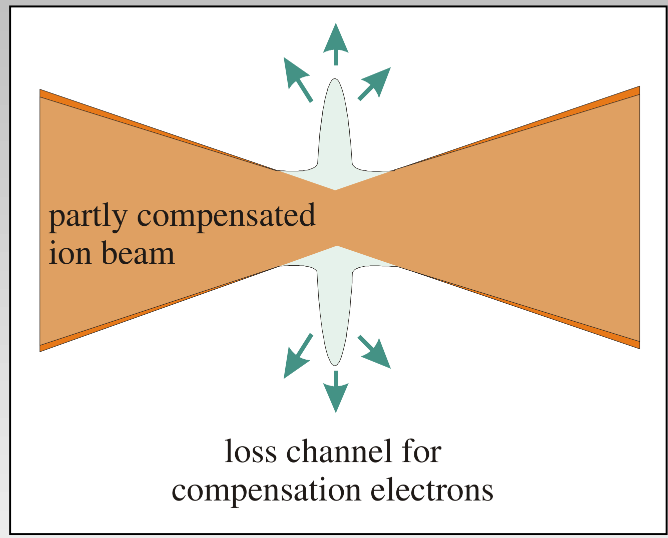


measured space charge compensation as a function of the beam radius

Low Energy Beam Transport

decompensation in the near of the beam focus

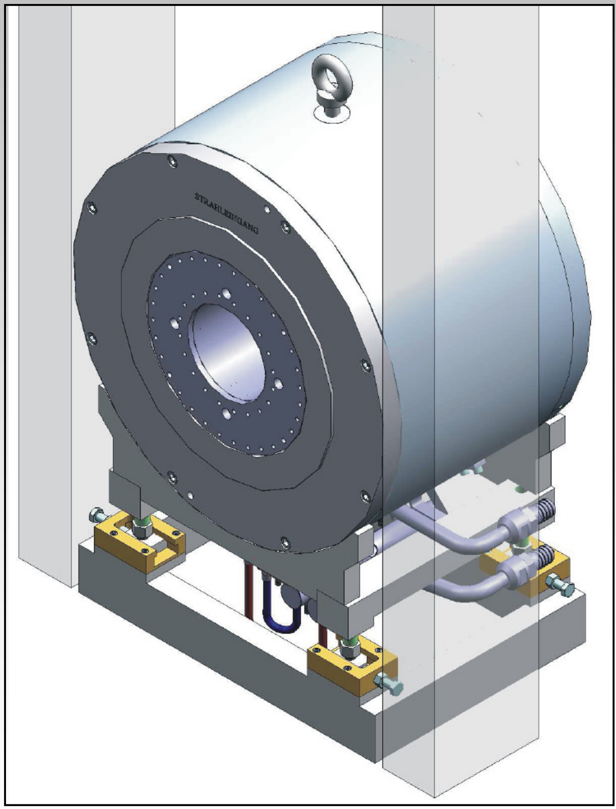




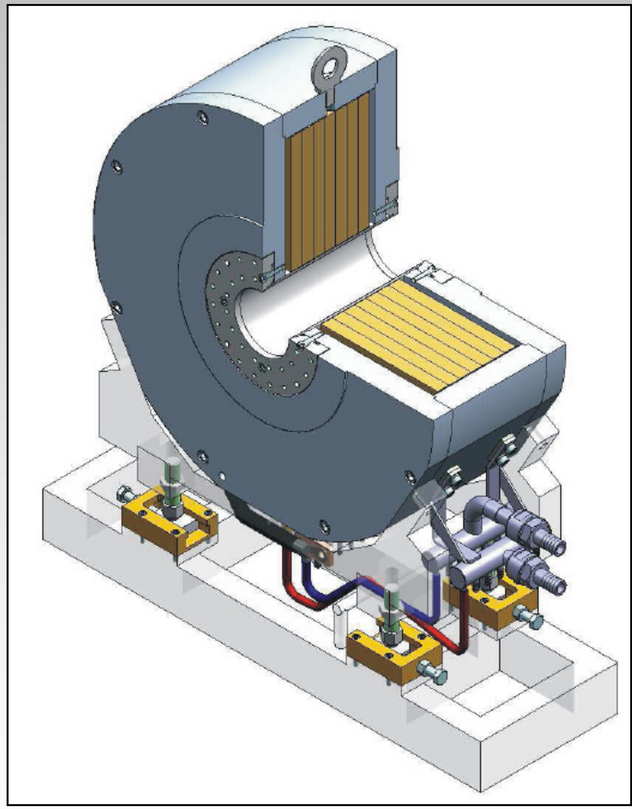
λ = 820 nm interaction of loss electrons with vacuum window

Low Energy Beam Transport

the use of solenoids guaranteed space charge compensation

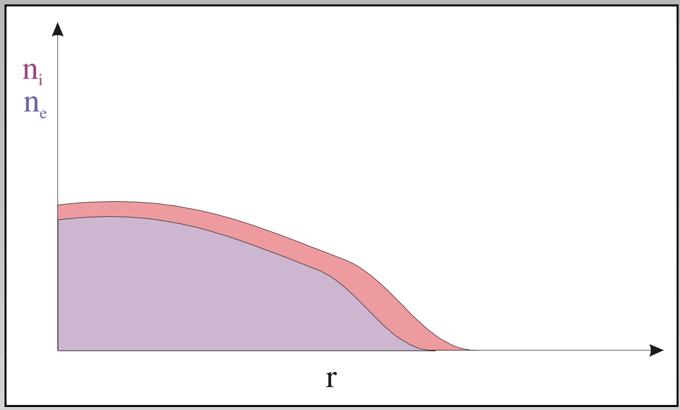


GSI-Typ2, Apertur 150 mm, $B_z = 0,6$ T

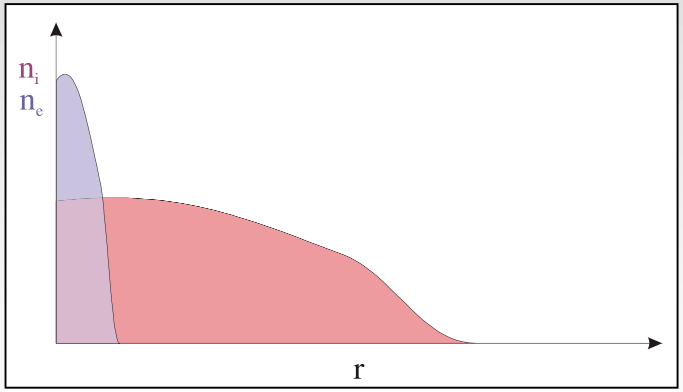


GSI-Typ1, Apertur 100 mm, $B_z = 0,6$ T

Low Energy Beam Transport

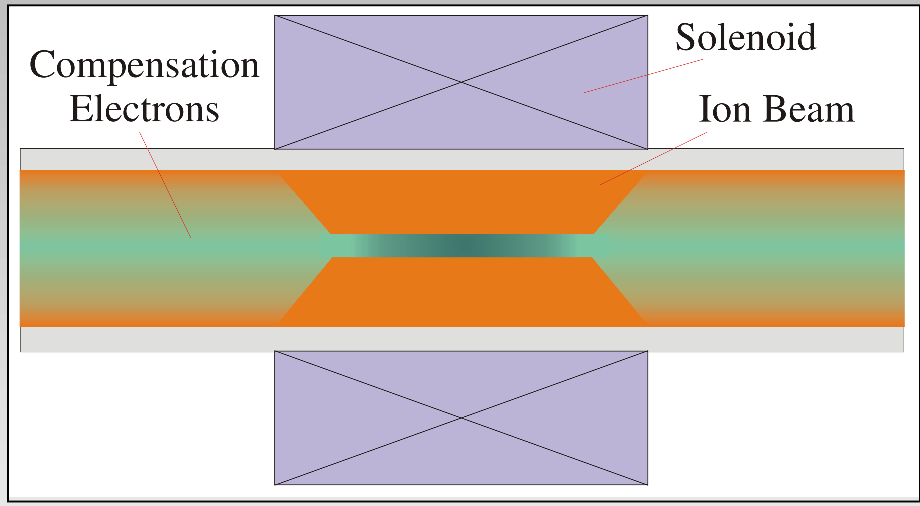


ion and electron density distribution without magnetic field



ion and electron density distribution inside of the solenoid

space charge compensation with external magnetic fields



Change of the electron density distribution as a function of beam potential and magnetic field

$$\Phi_b = \frac{e r_b^2}{8 m_e} \cdot B_z^2$$

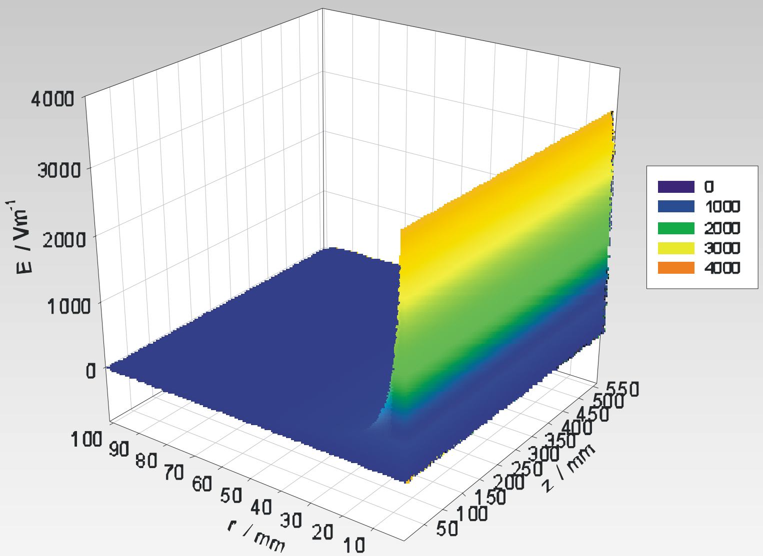
Low Energy Beam Transport

emittance growth do to compensation effects

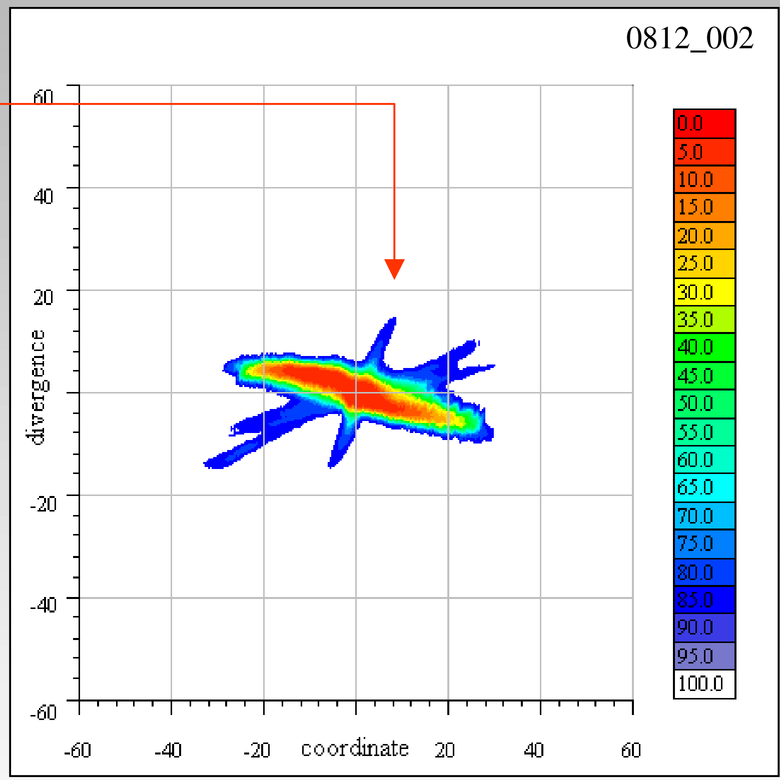
$n_e = 3.12 \cdot 10^{14}\ m^{-3}$

$r_e = 1\ mm$

leads to „sattellites“



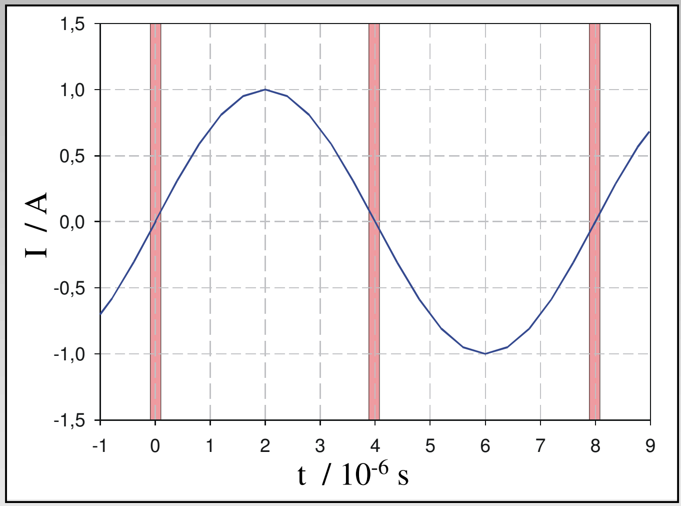
electric field of the confined electron column



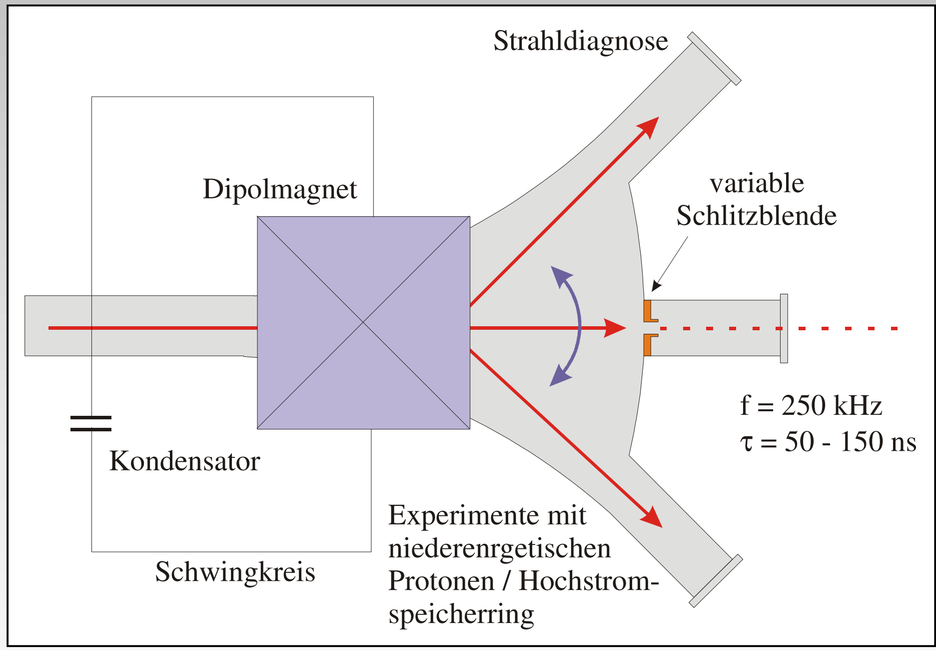
Measurde phase space distributionof a proton beam
W_b = 95 keV I = 98 mA

Low Energy Beam Transport

magnetic chopper system



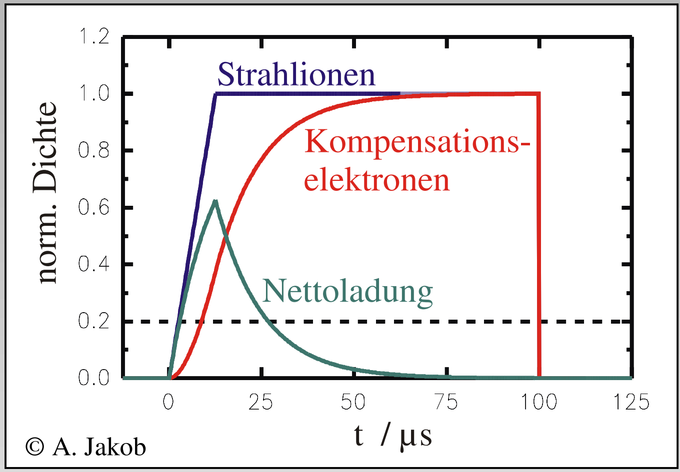
induction current as a function of time



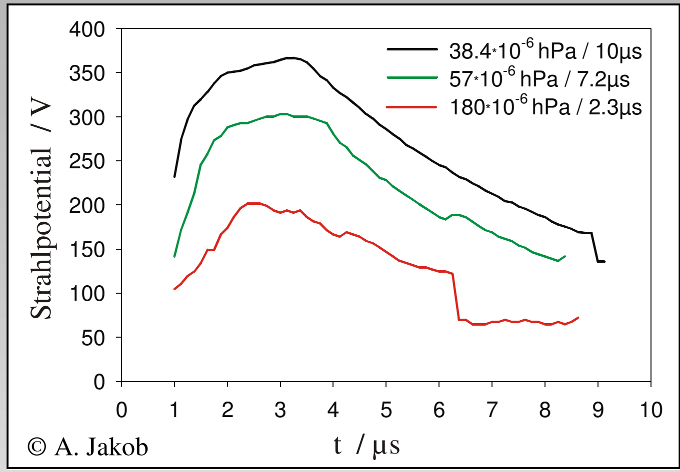
scheme of the magnetic chopper system

Low Energy Beam Transport

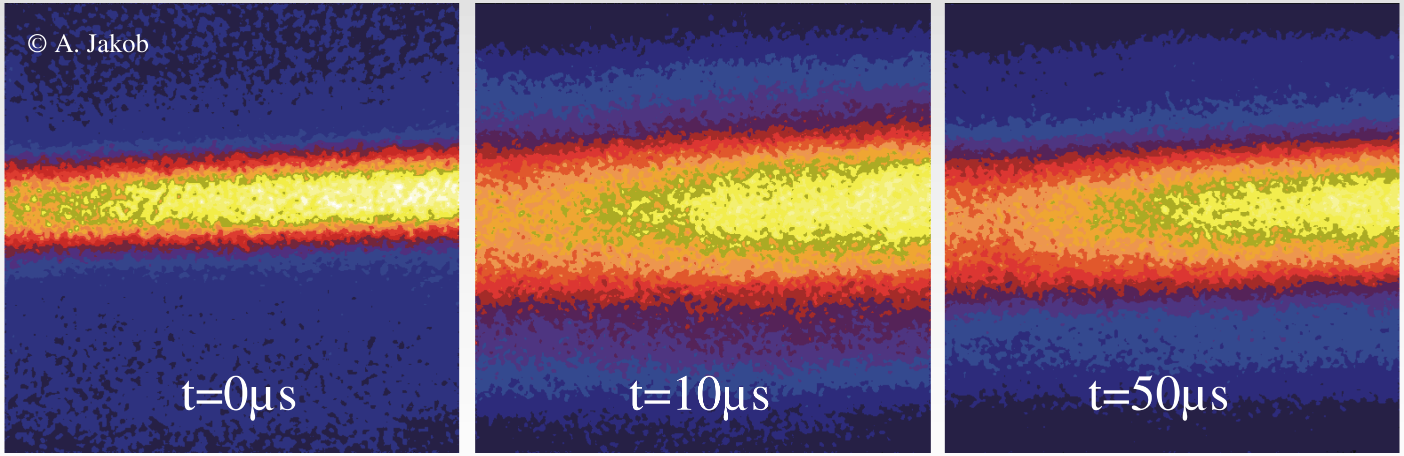
space charge compensation of pulsed beams



Compensation process as a function of time

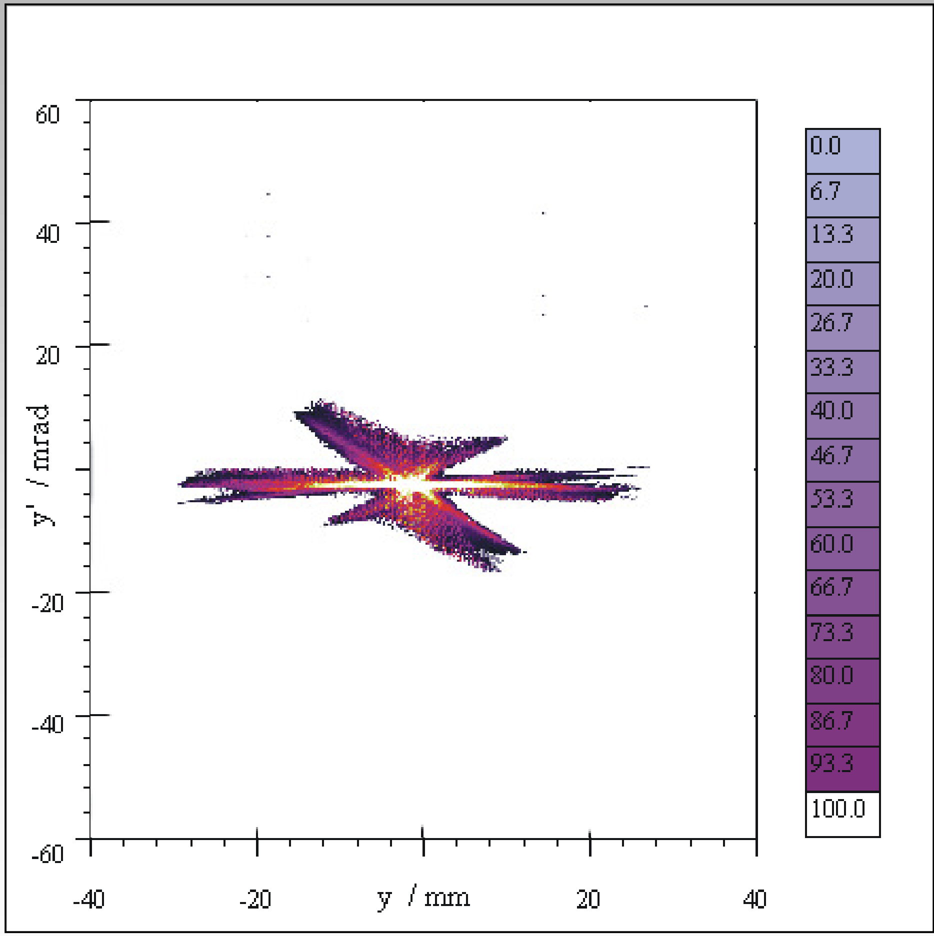


beam potential as a function of time

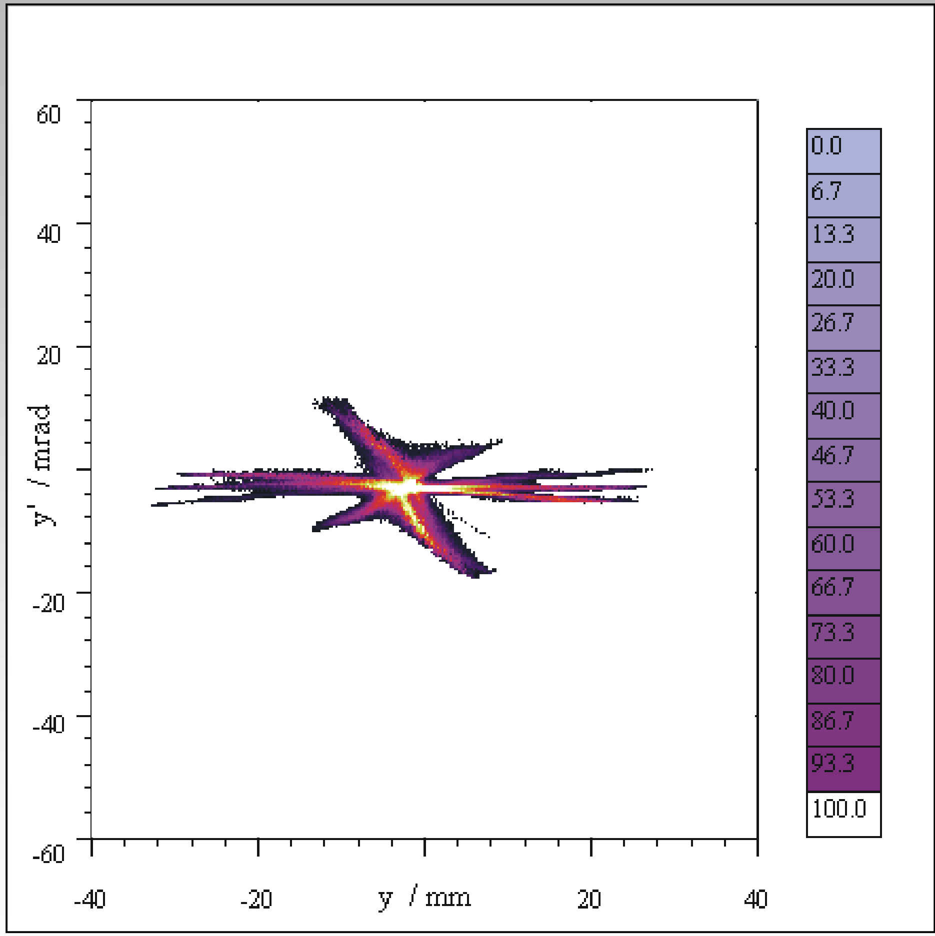


measured beam profiles as a function of time, W_b = 92 keV, I= 62 mA, H^+ ?

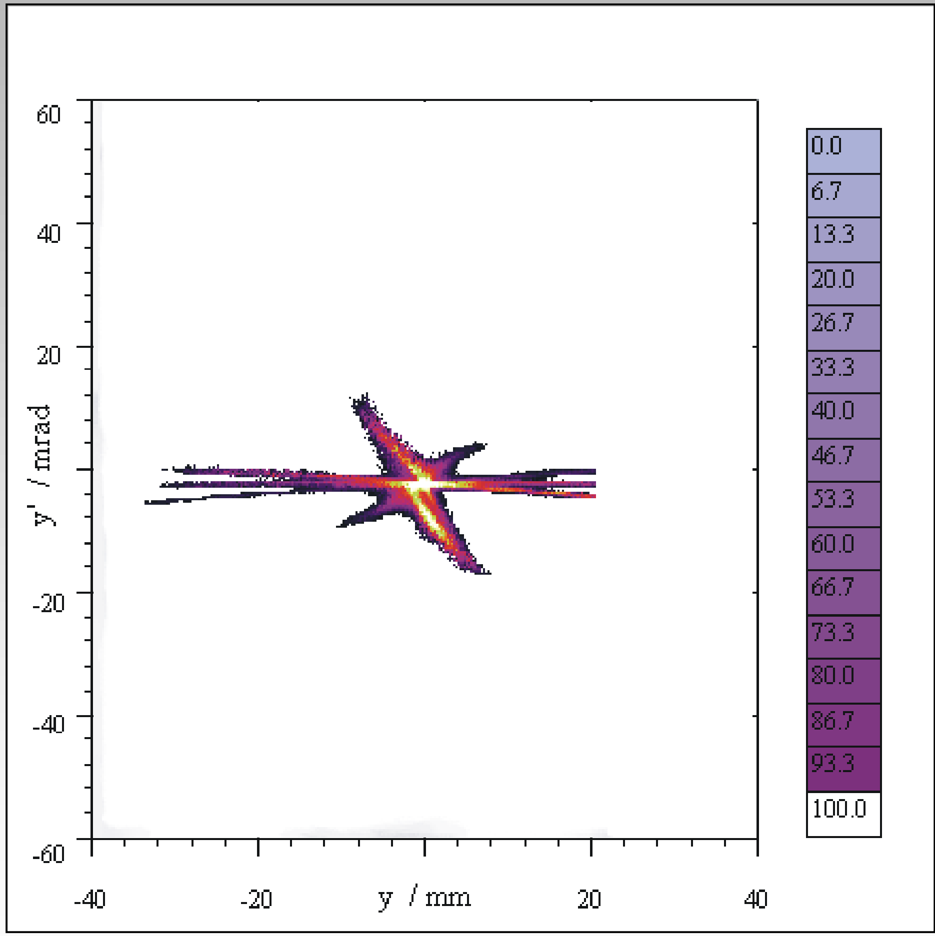
Puls length 2.2ms, Delay 0µs, Gate 25µs



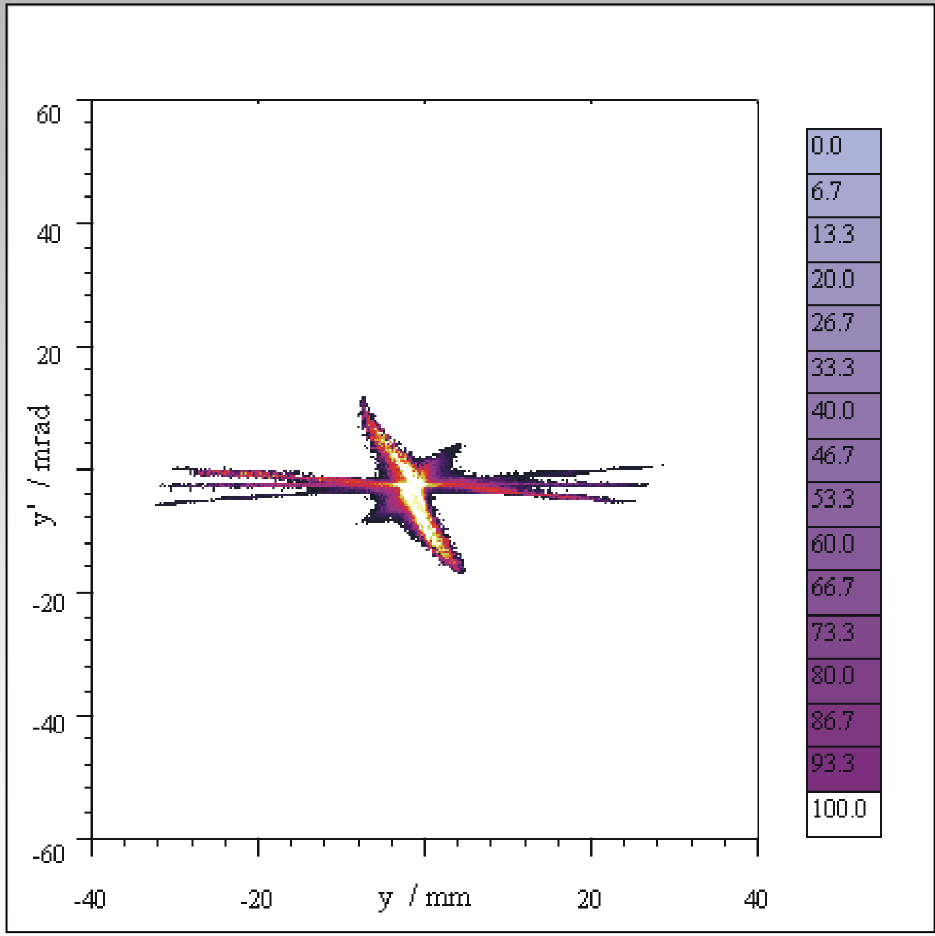
Puls length 2.2ms, Delay 25µs, Gate 25µs



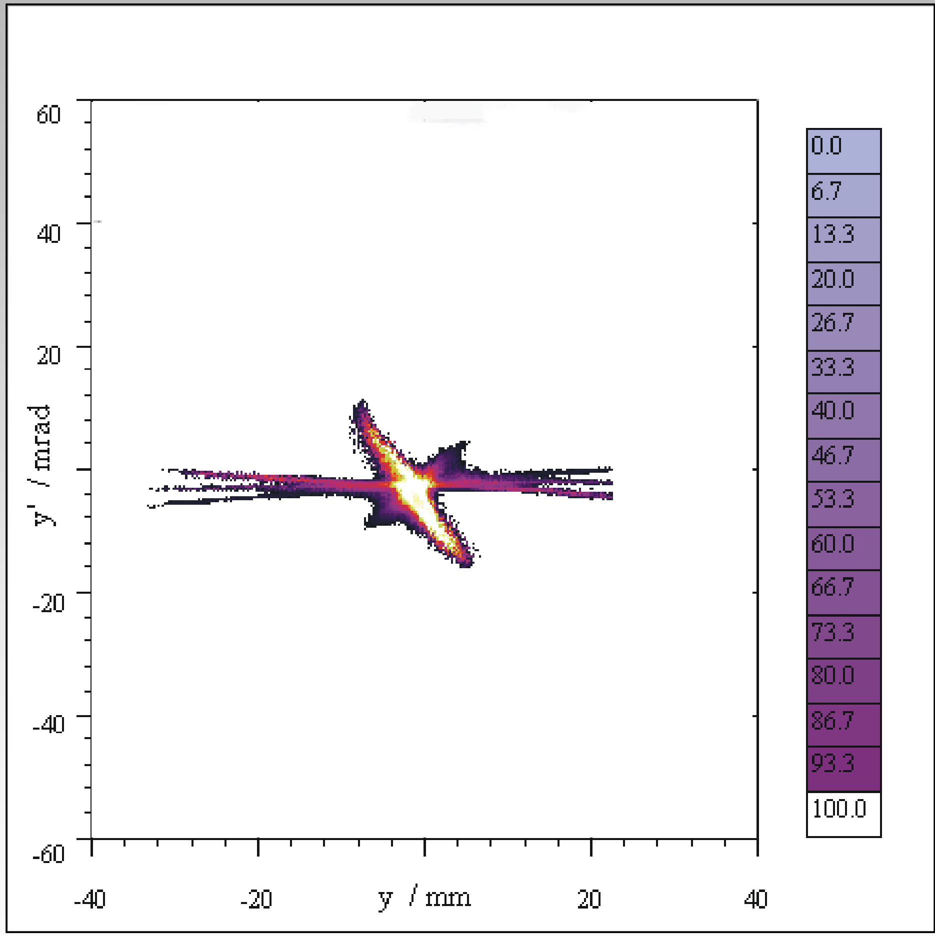
Puls length 2.2ms, Delay 50µs, Gate 25µs



Puls length 2.2ms, Delay 75µs, Gate 25µs

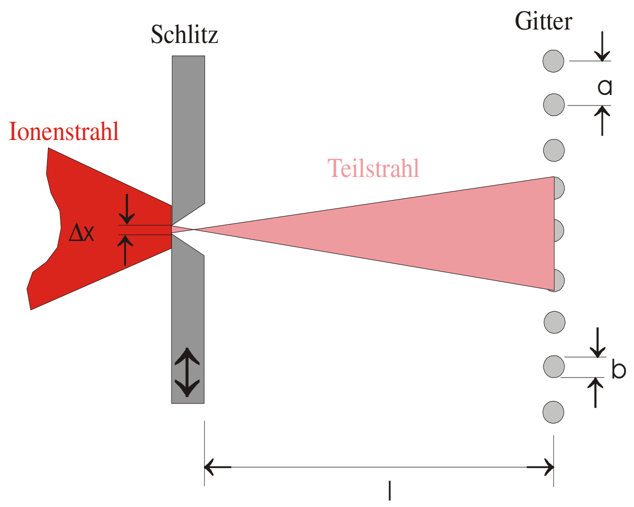


Puls length 2.2ms, Delay 100µs, Gate 25µs



Beam Diagnostic

slit grid emittance scanner

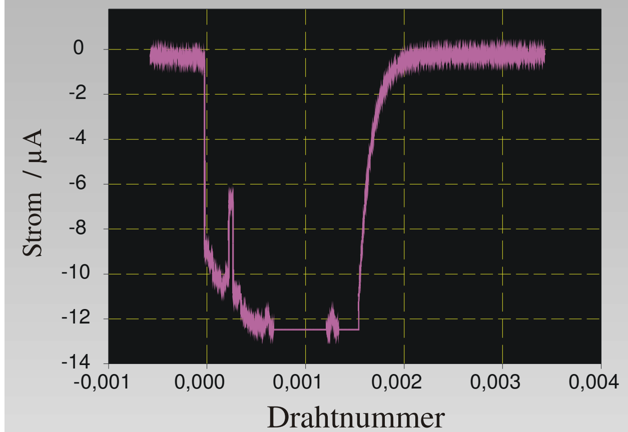


scheme of the slit grid emittance scanner

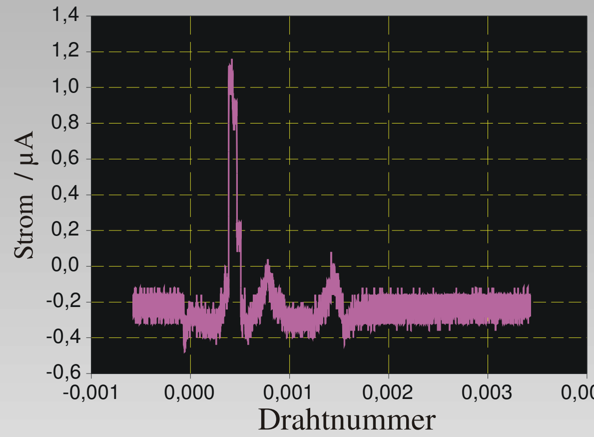
Slit Grid Emittance Scanner

production of scondary electrons

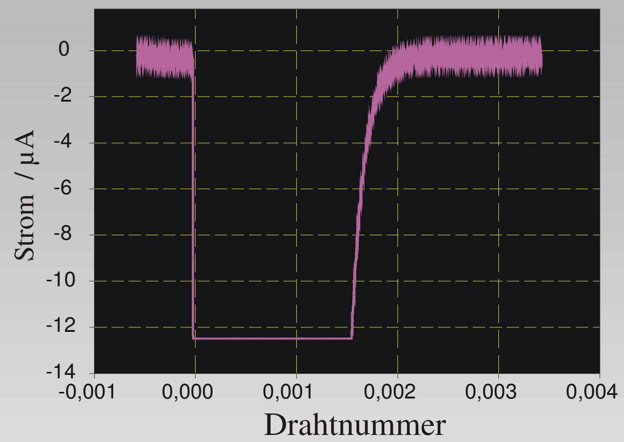
Position P1

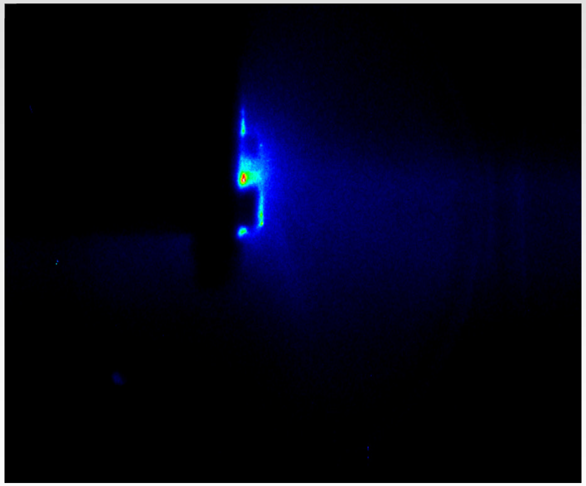


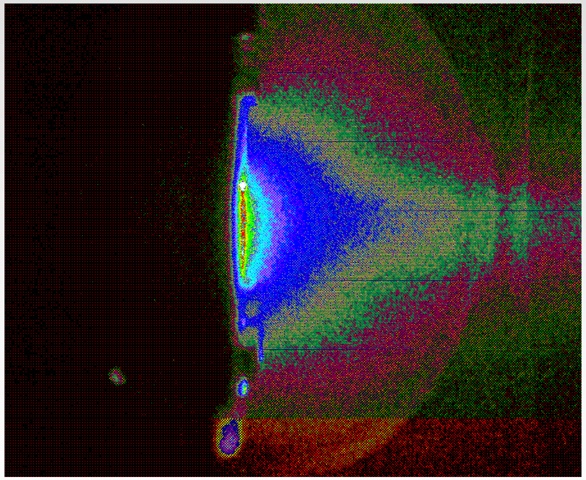
Position P2

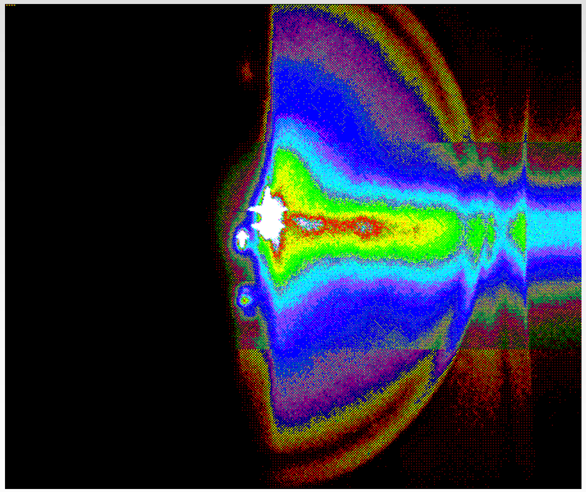


Position P3





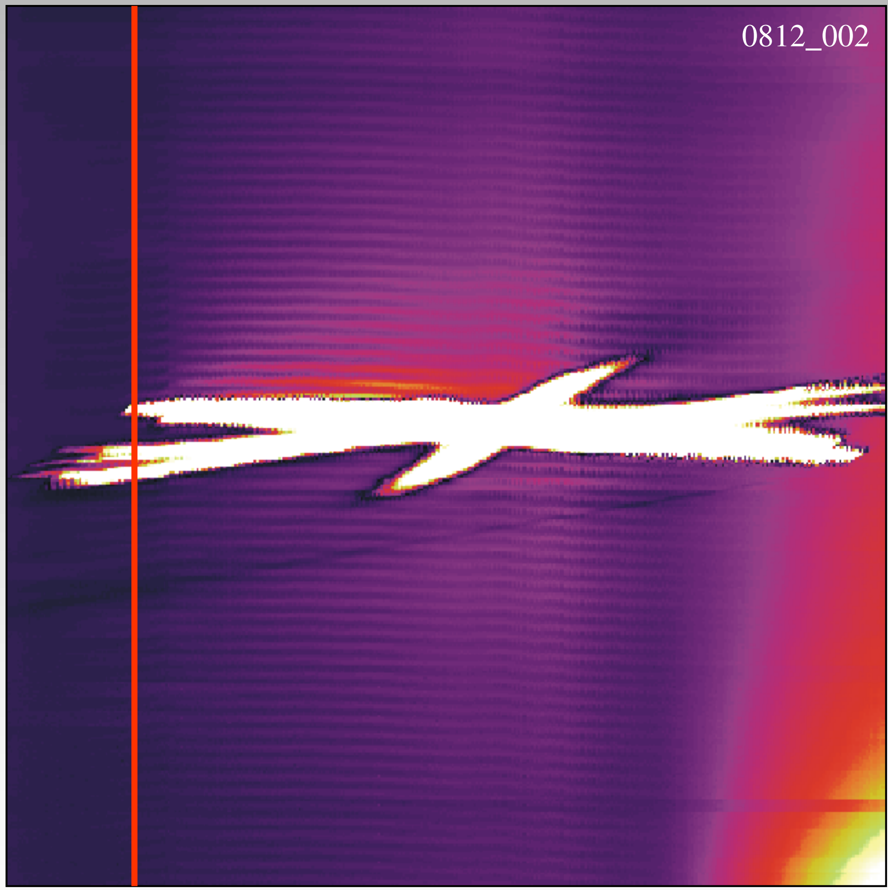




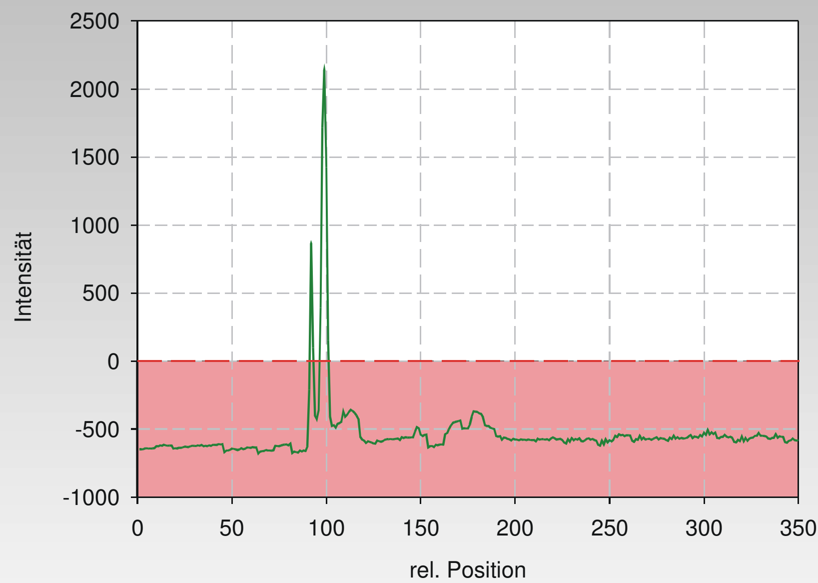
in cooperation with R. Boywitt GSI & R.J. Gobin CEA-Saclay

Slit Grid Emittance Scanner

production of scondary electrons



98 mA p - Strahl W_b = 95 keV detected current at the op-amp's (raw data)

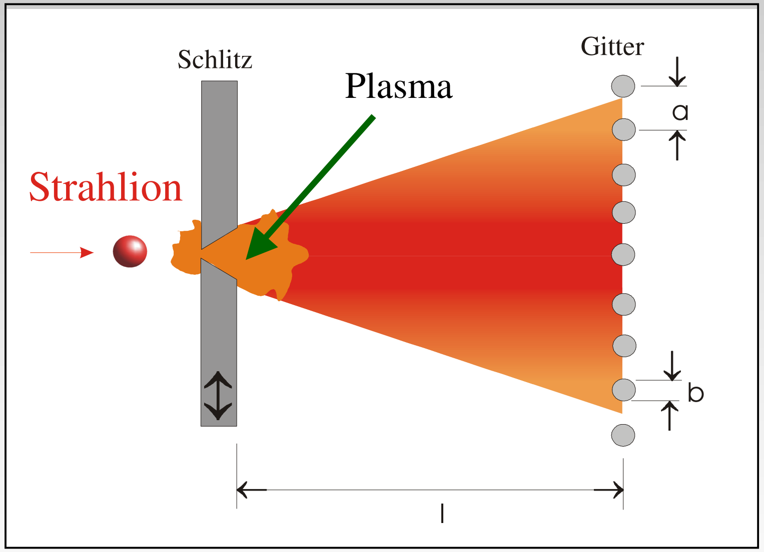


profile of the raw data

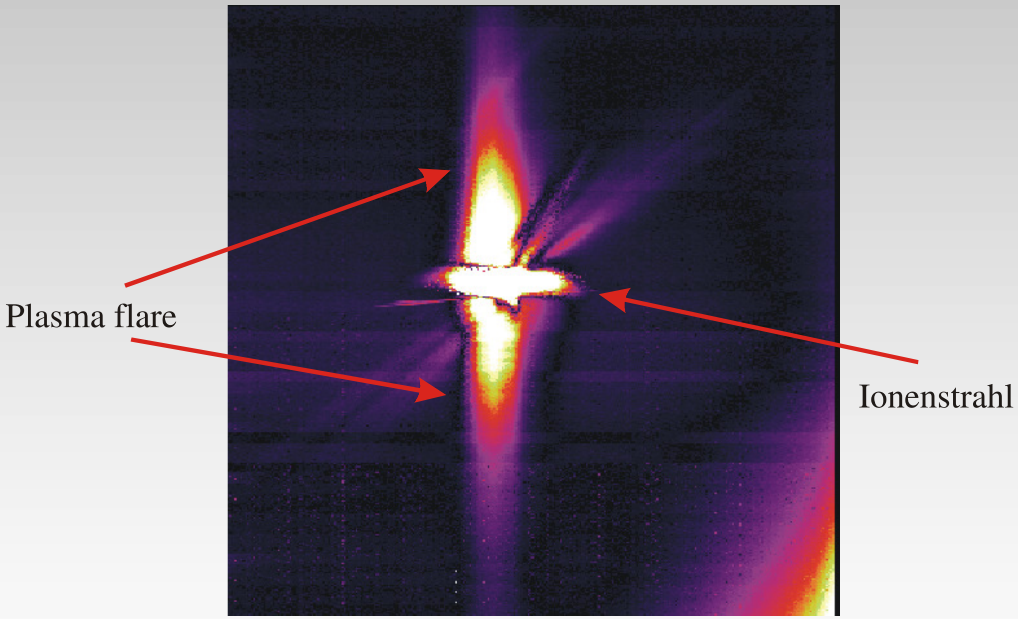
Slit Grid Emittance Scanner

Influence of secondaries on emittance measurements

- scattering
- focussing
- energy spread



Ion beam induced plasma on the sourface of the slit

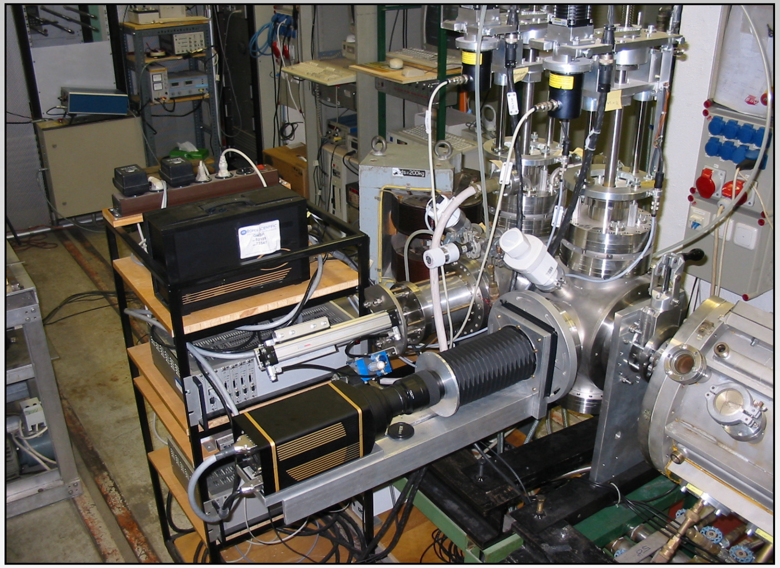


detected plasma ions overlapping the beam phase space distribution.

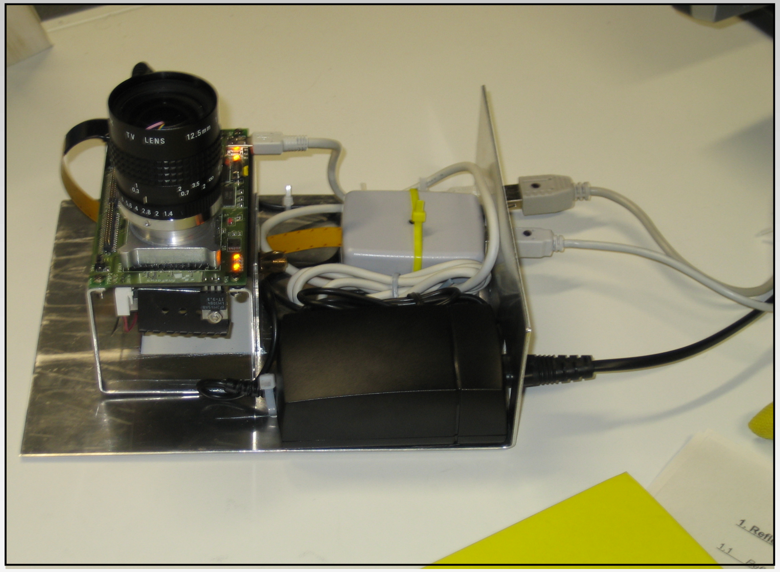
Beam Diagnostic

Nondestructive beam diagnostic

detection of residual gas
luminance



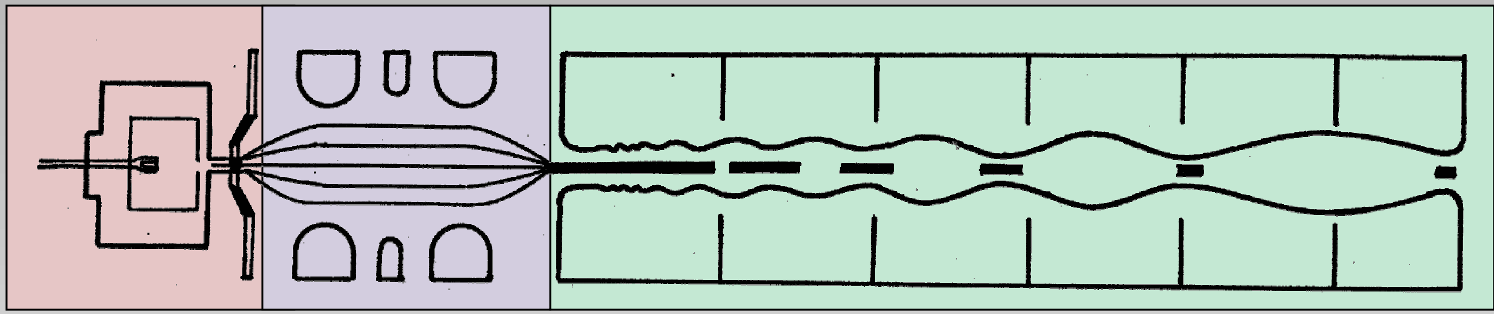
CCD-camera for the estimation of beam profile and emittance



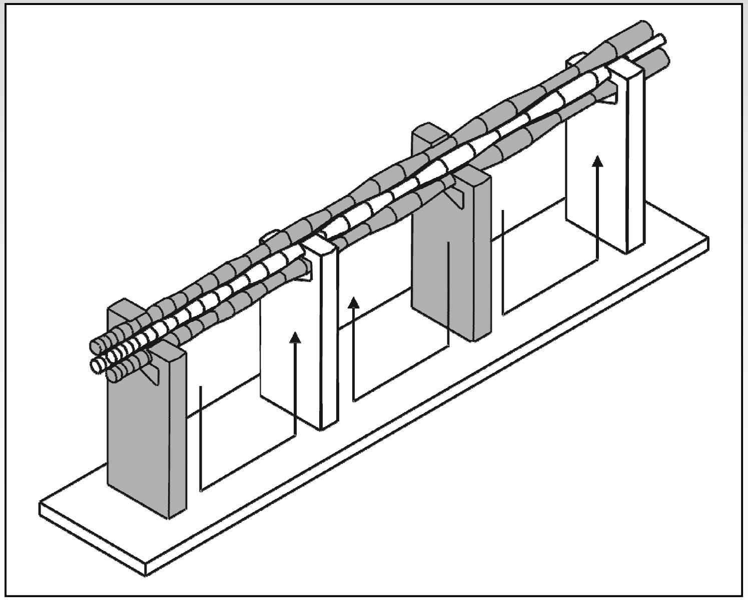
neuronales network with optical sensor IRIS V1.1 for fast measurement of beam behavior (Redundance)

RFQ-Accelerator

Radio Frequency Quadrupole



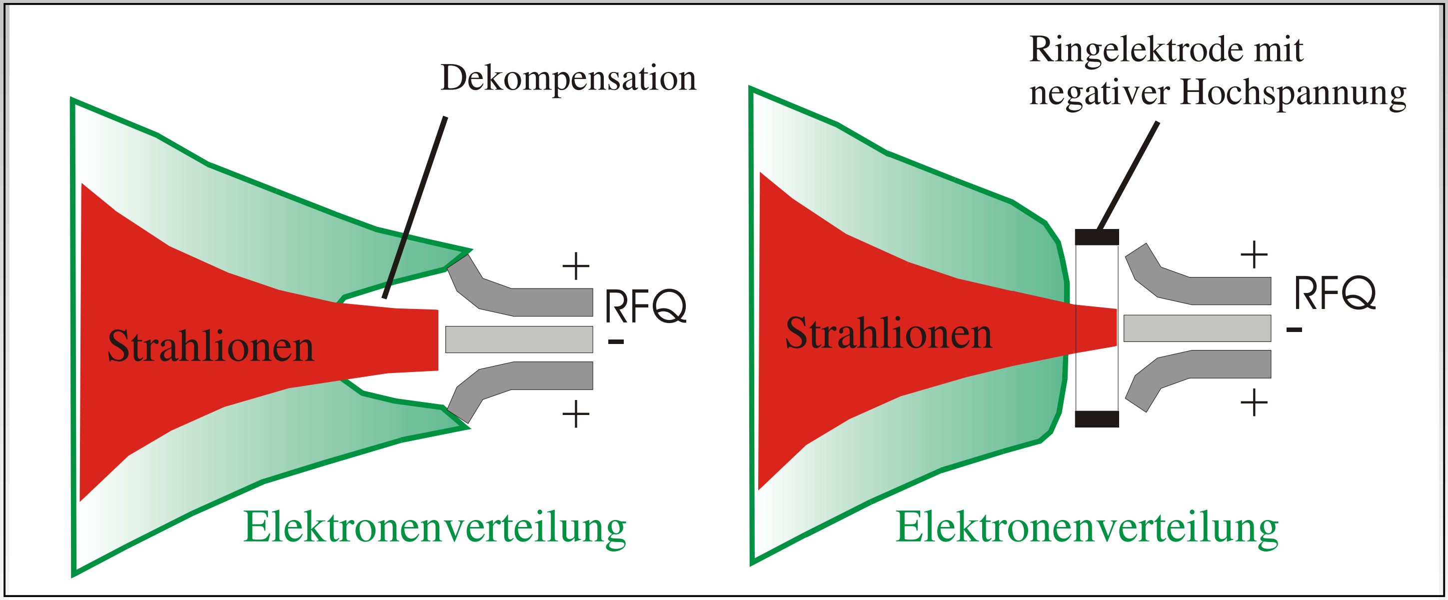
ion source | beam matching | RFQ - accelerator



scheme of the four rod system

RFQ-Accelerator

Injection into the RFQ



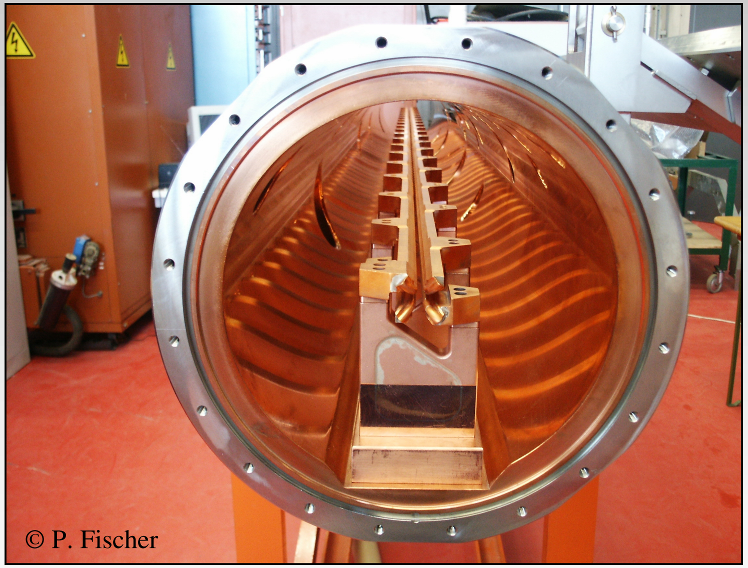
matching into the RFQ and the influence of space charge compensation

RFQ-Accelerator

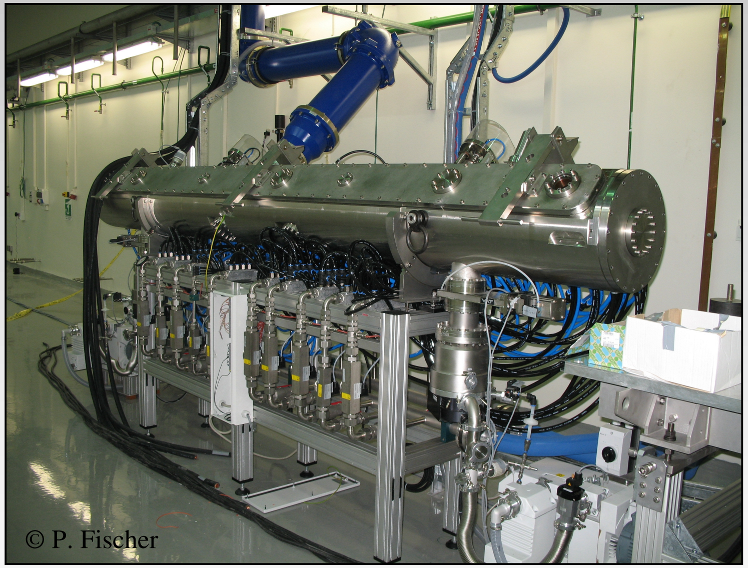
Four-Rod-RFQ for high beam intensities

SARAF – Project Israel

f_0 = 176 MHz, I = 50 mA, P = 64 kW/m, cw - operation



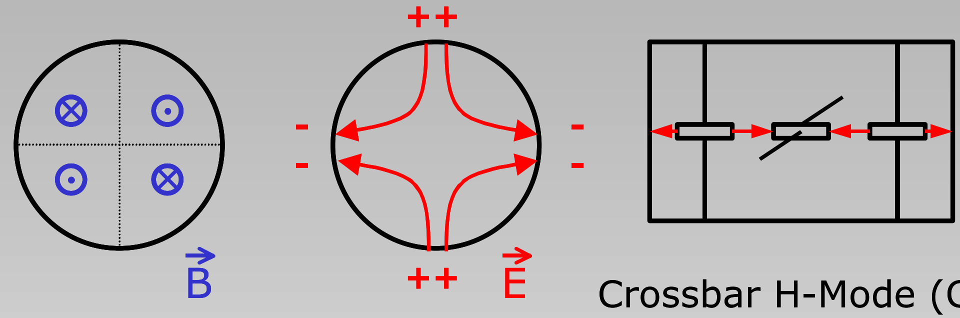
view inside of the RFQ



comissioning of the RFQ

CH-Cavity

drift tube accelerator



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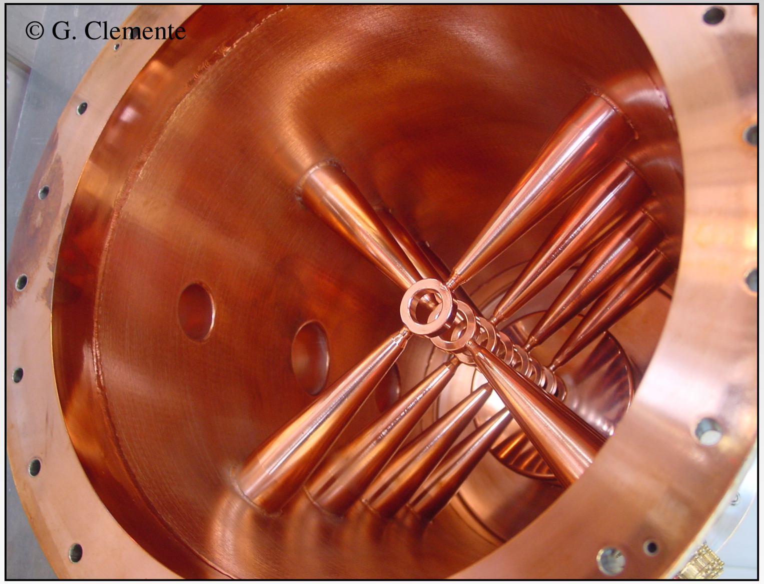
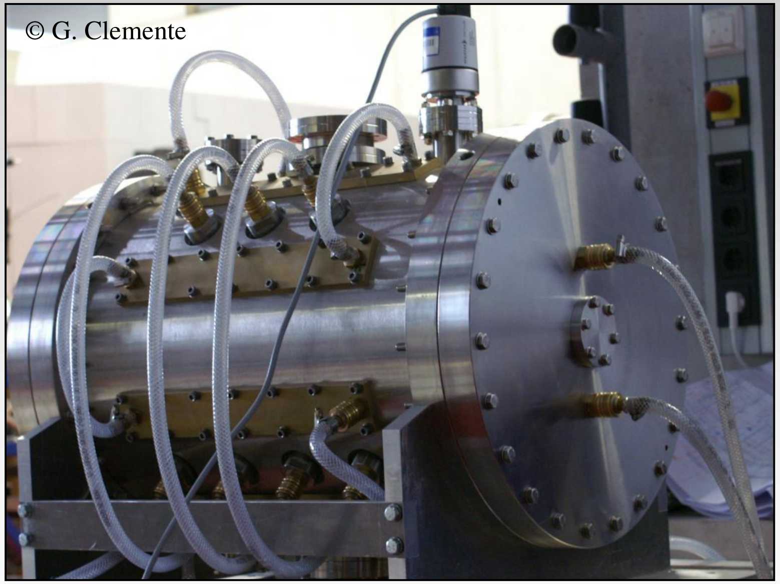
Crossbar H-Mode (CH)

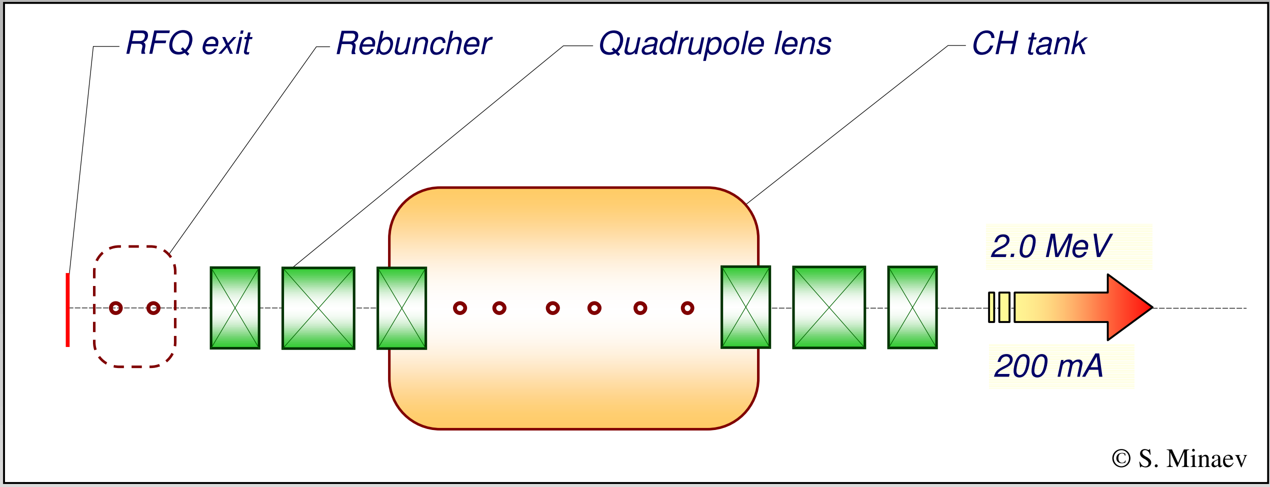


View into the CH cavity

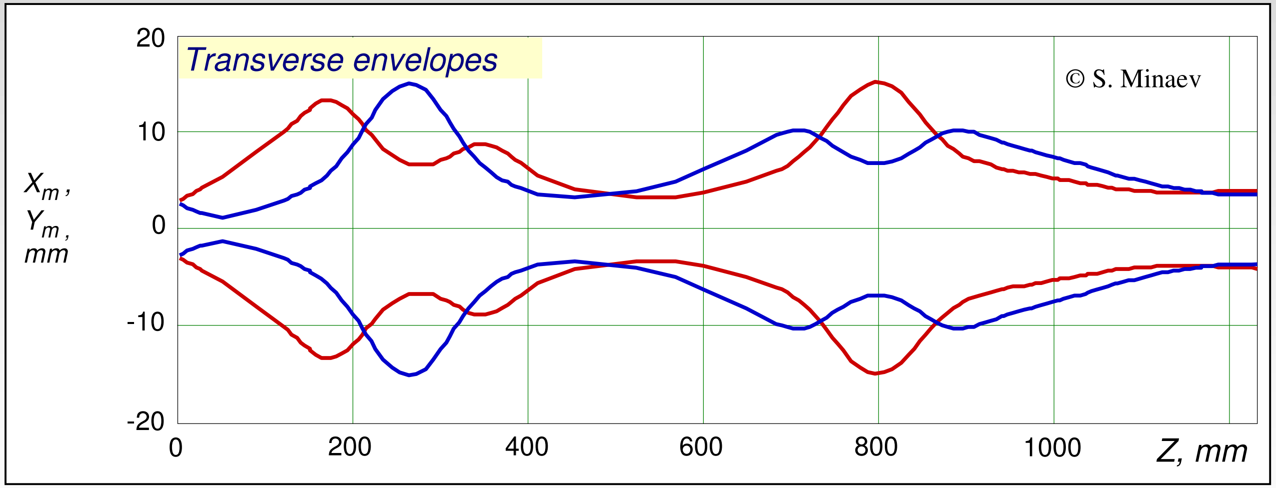


assembled CH cavity

CH Cavity



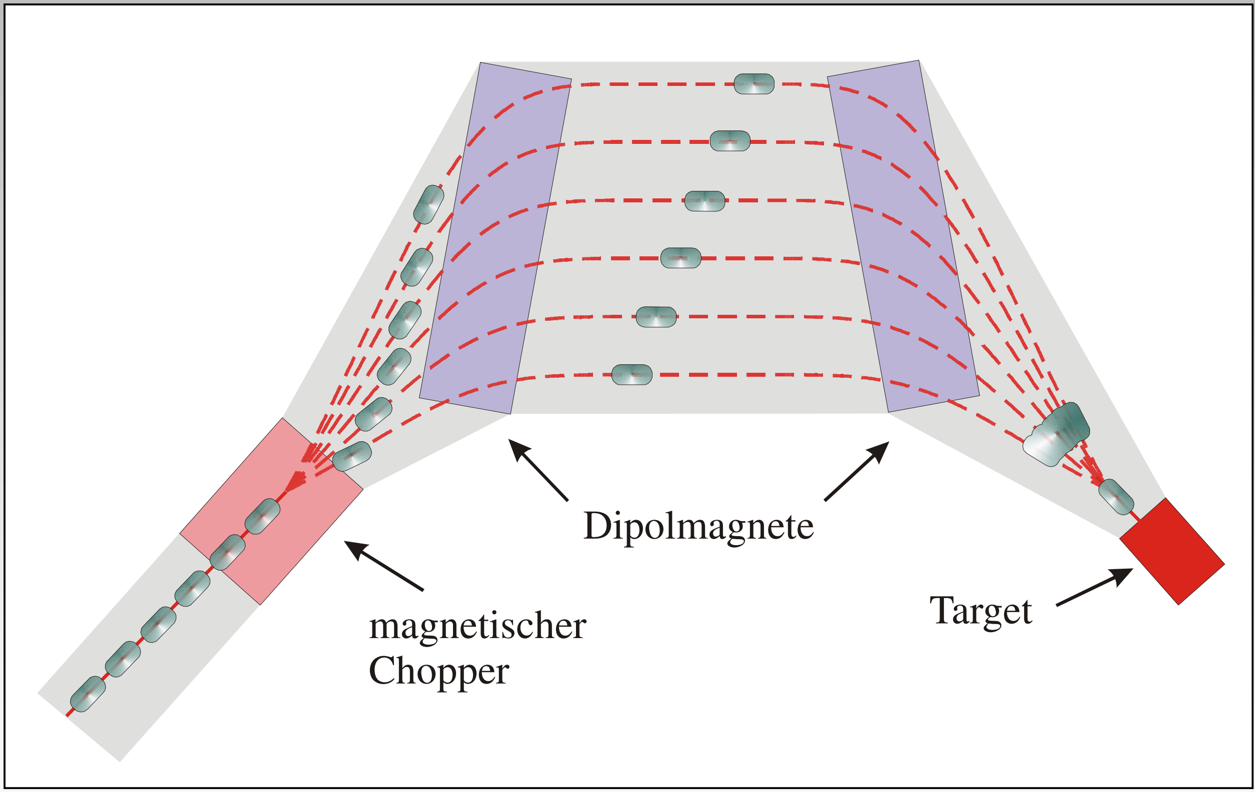
Scheme of the CH section



beam envelope

Bunch Compressor

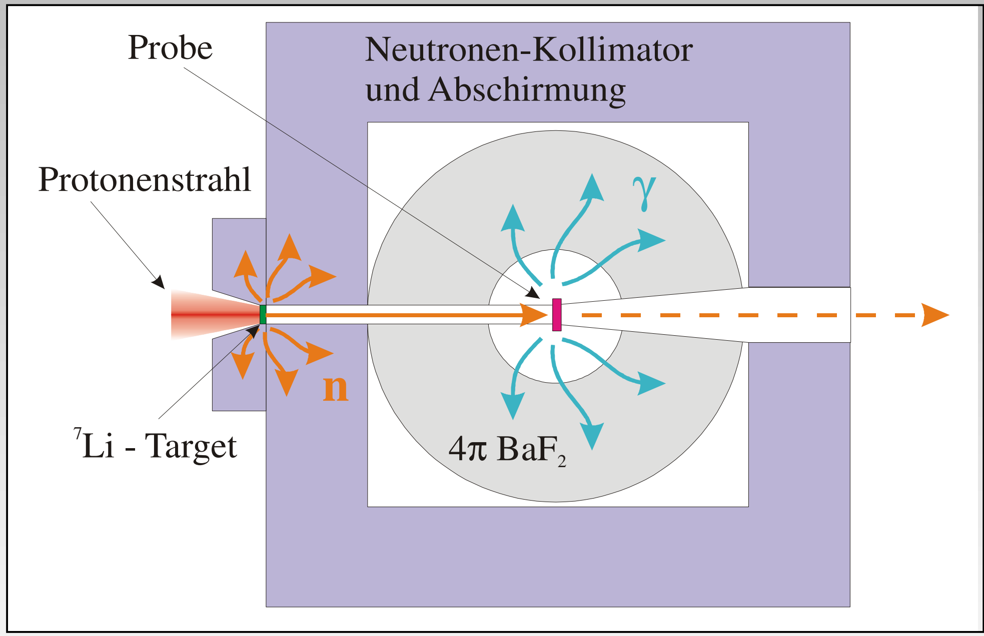
Mobley type bunch compressor



scheme of the Mobley type bunch compressor

Production target

Neutron production

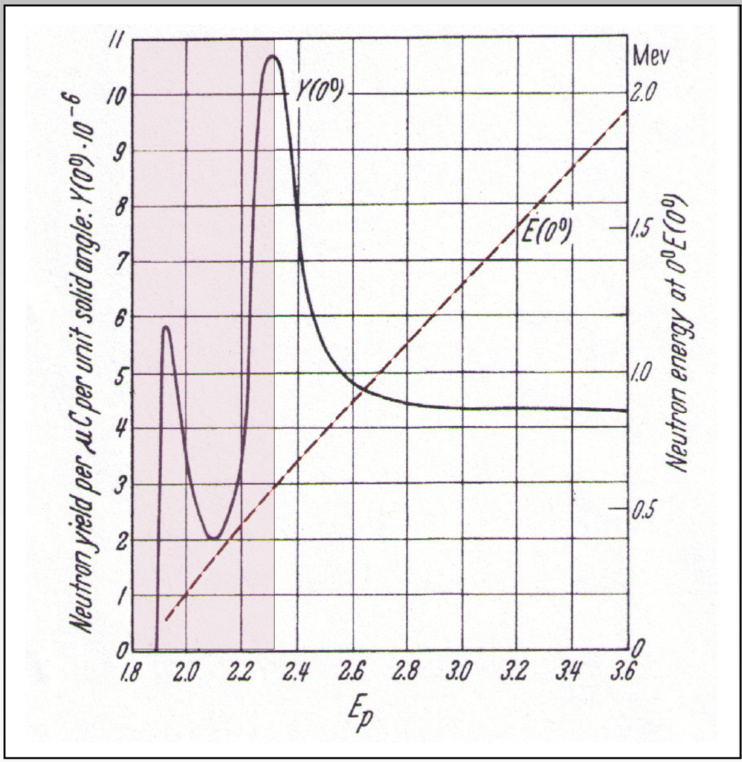


scheme of the target and detctor system

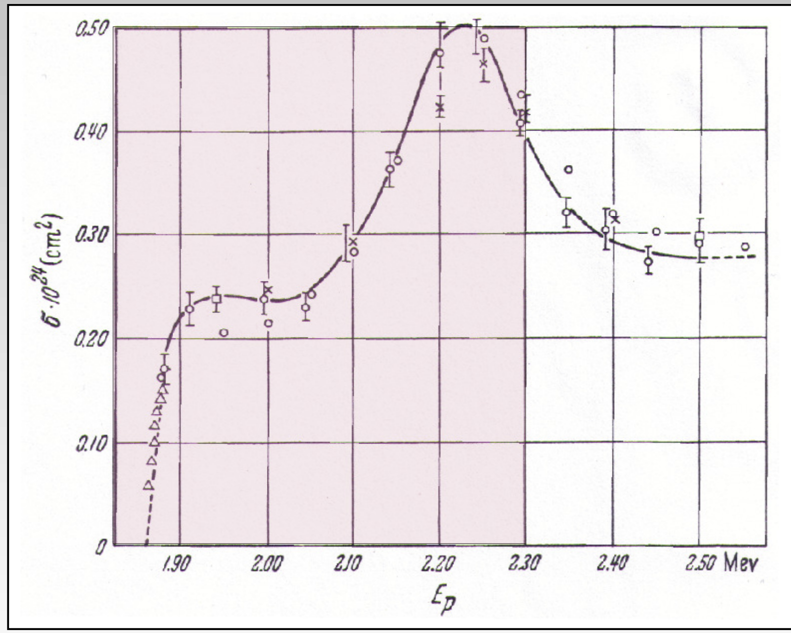
Produktionstarget

Produktionsreaktion

$$_{1}H^{1} + _{3}Li^{7} \rightarrow _{4}Be^{7} + _{0}n^{1} - 1{,}646\ \text{MeV}$$



Neutronen-Ausbeute und Neutronen-Energie als Funktion der Primärstrahlenergie

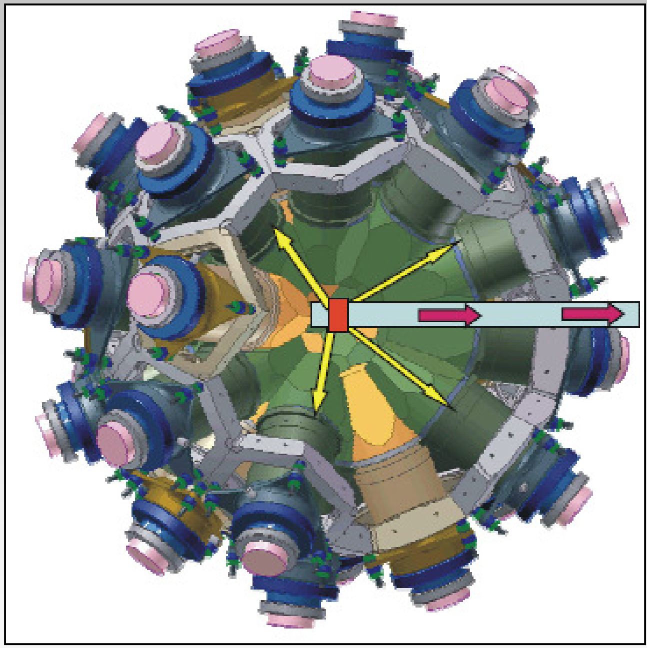


Wirkungsquerschnitte für die Produktion der Neutronen als Funktion der Primärstrahlenergie

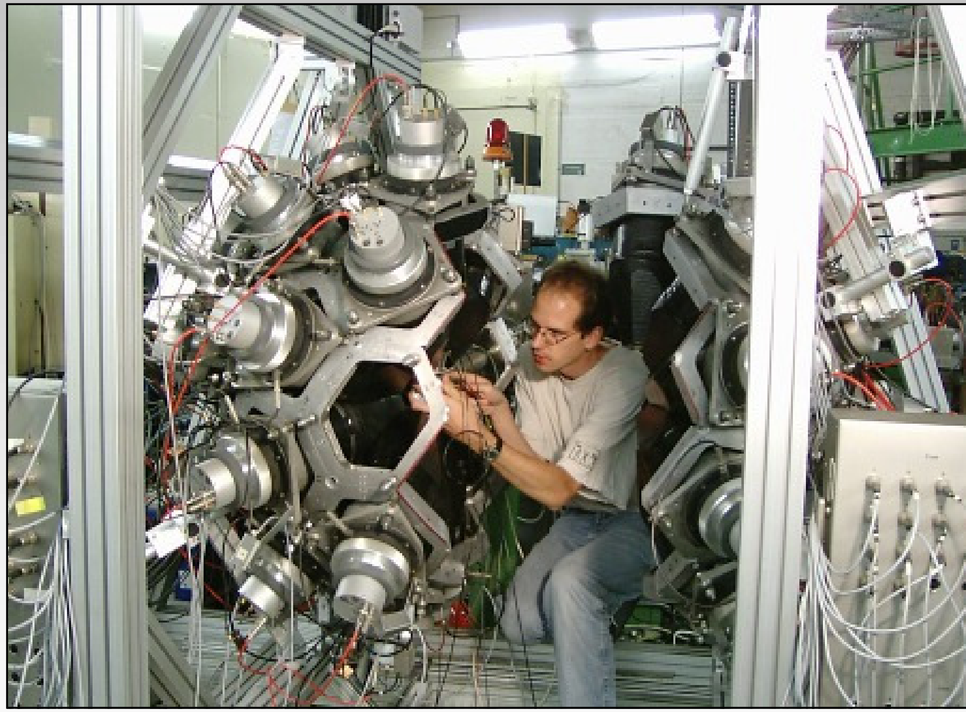
Detector system

4π BaF_2- Detector

In cooperation with FZ Karlsruhe



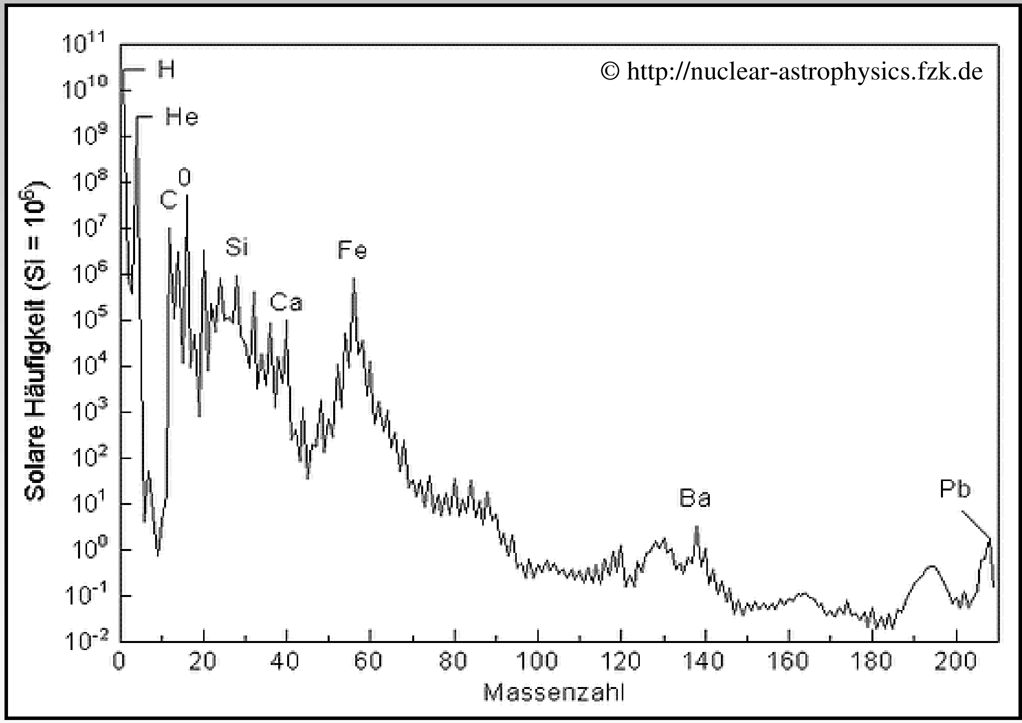
4π scintillator sphere for the detection of neutron capturing processes



Photography of the detector system in Karlsruhe

Experiments

What can we learn about the element synthesis?



relative incidence of isotopes in the solar system

Experiments

http://www.iaea.org/inis/aws/fnss/ **A**ccelerator **D**riven **S**ystems ADS transmutation of radiactive wast.
http://www.gsi.de/fair/experiments/CBM/ Detector developement at IKF e.g. test of the Monolithic Si - Pixel – Detectors (MAPS), is relevant for the FAIR - CBM - experiment
http://www.gsi.de/fair/experiments/superfrs/ Experiments using radioactive isotopes from FAIR - Super – FRS implanted in carbon foils $\geq 10^{15}$ atoms / unit
material scince, neutron radiography, etc.

Outlook

- all components of the driver Linac are a big challenge

- FRANZ will give the possibility for experiments with an intense proton beam

- FRANZ is a long term project and of course for the education of students

- the neutron generator leads into cooperation with e.g. IKF, GSI and FZ - Karlsruhe

Danke !

Für die Unterstützung danke ich:

LINAC-AG http://linac.physik.uni-frankfurt.de/

AG-Schempp http://iaprfq.physik.uni-frankfurt.de/

NNP-AG http://nnp.physik.uni-frankfurt.de/