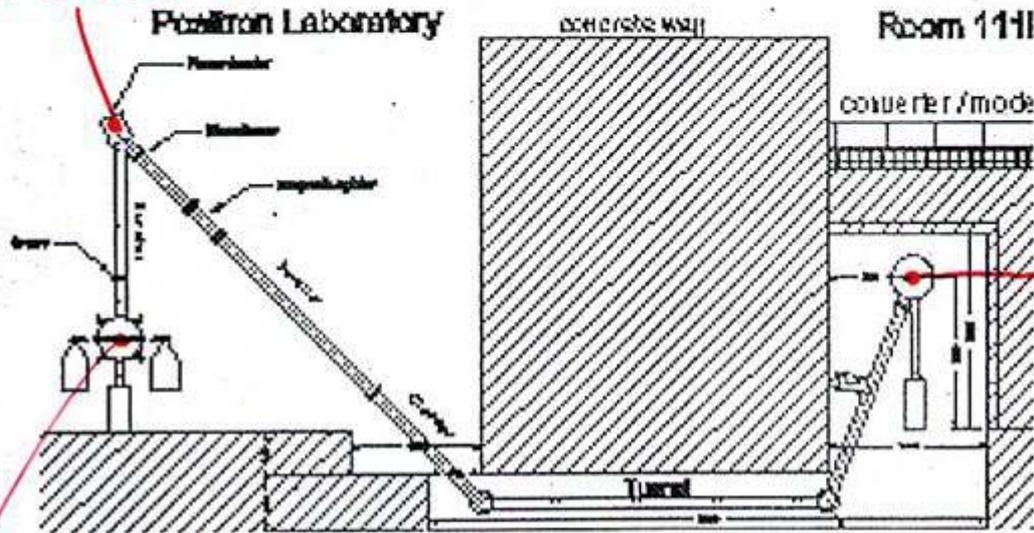


Prologue

remoderator

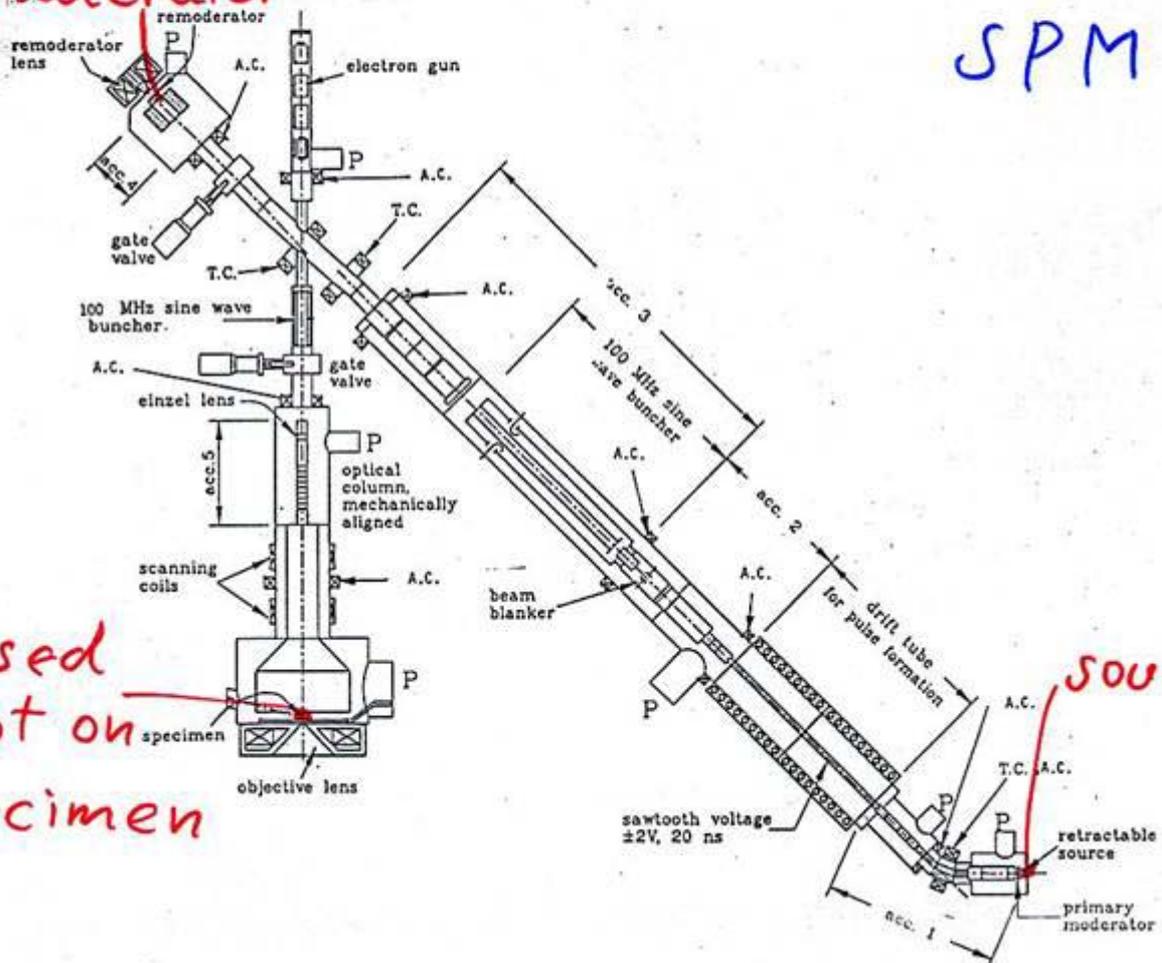


EPOS

source

pulsed spot
on specimen

remoderator



SPM

source

pulsed spot
on specimen

Optics of the Munich Scanning Positron Microscope (SPM)

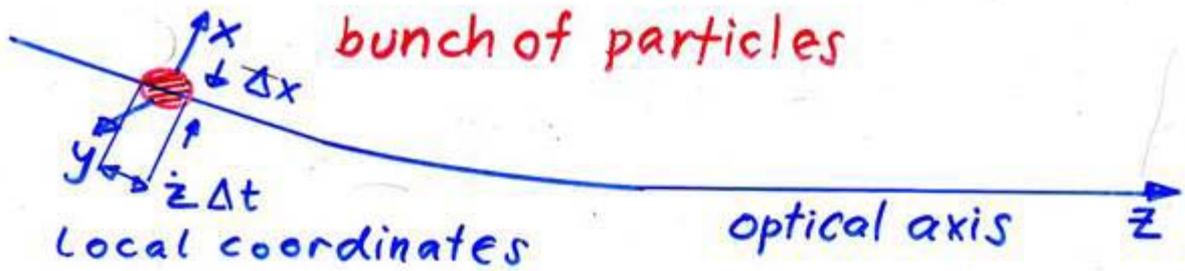
and necessary changes for EPOS

G. Kögel

Institut für Nukleare Festkörperphysik
Universität der Bundeswehr München

- Some remarks on particle optics
- The Munich SPM
- EPOS
- Conclusions

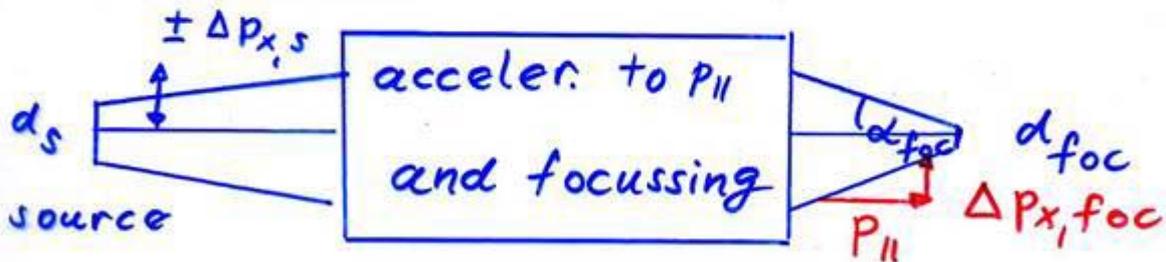
Remarks on particle optics



In paraxial approx. all trajectories are linear comb. of 2 principal rays

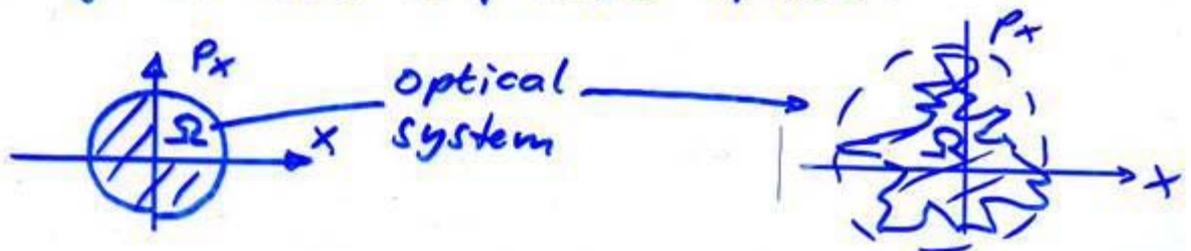
Liouville's Theorem $\Delta p_k \Delta q_k = \Omega_k = \text{const.}$
 $p_k = \frac{\partial L}{\partial \dot{q}_k}$
 $\Delta x \Delta p_x, \Delta E \Delta t$

Focussing ($\Delta x \Delta p_x$)

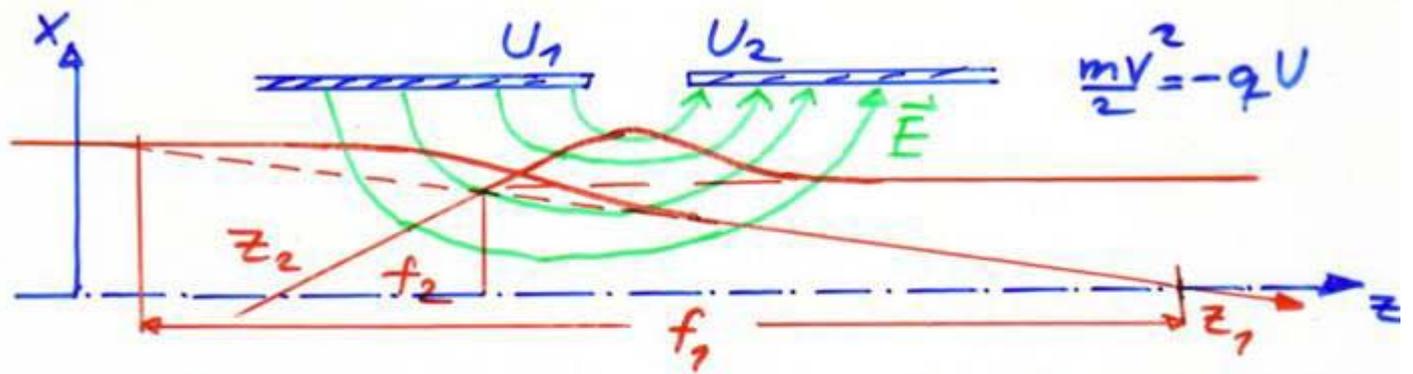


L. Th $\underline{d_{foc}} \geq d_s \frac{\Delta p_{x,s}}{\Delta p_{x,foc}} = d_s \frac{\Delta p_{x,s}}{P_{||}} \cdot \frac{P_{||}}{\Delta p_{x,foc}} = d_s \underline{\frac{\alpha_s}{\alpha_{foc}}}$

L. Th \approx lower limit of d_{foc} because of irregular def. in phase space:



Round electric lens



principal rays in paraxial approximation

$\text{div } \vec{E} = 0$ and cylindr. symmetry \rightarrow

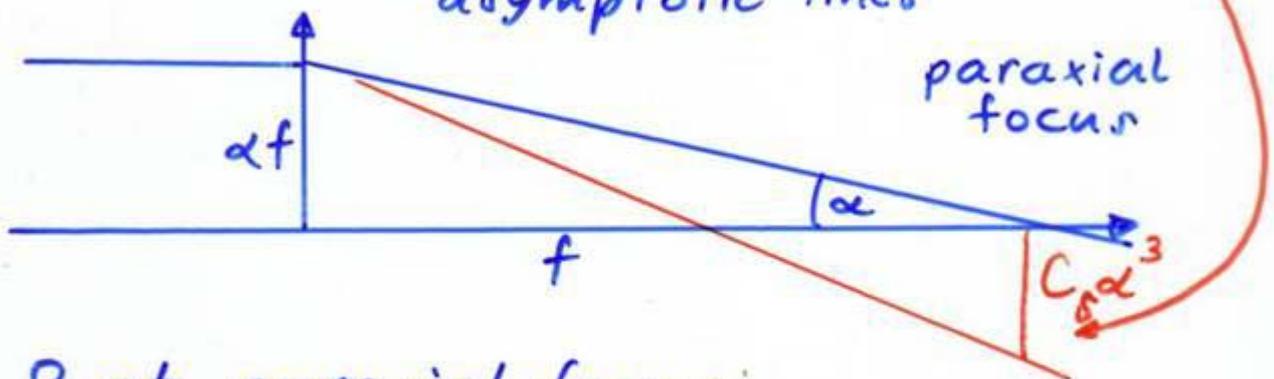
$$E_x = -\frac{x}{2} \frac{dE_z}{dz} + \frac{1}{16} x^3 \frac{d^3 E_z}{dz^3} + \dots$$

paraxial approx.

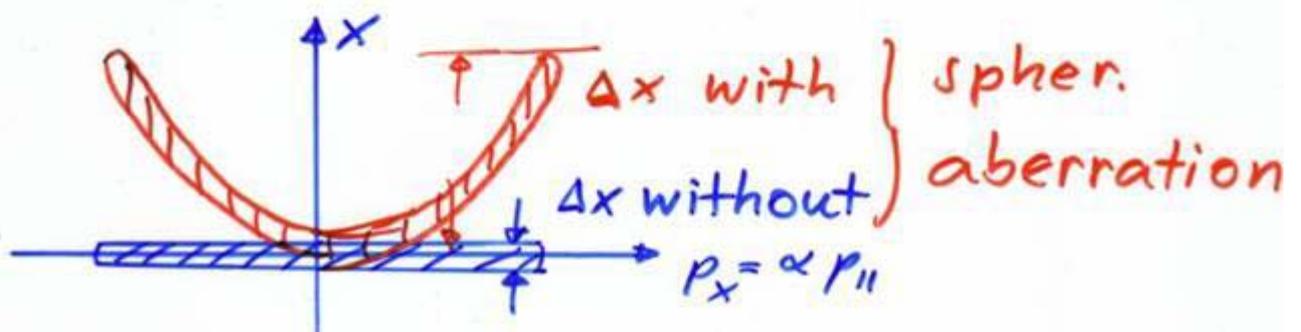
$$\frac{d^2 x}{dz^2} + f(z, E_z) x = 0$$

spherical aberration

actual rays replaced by asymptotic lines

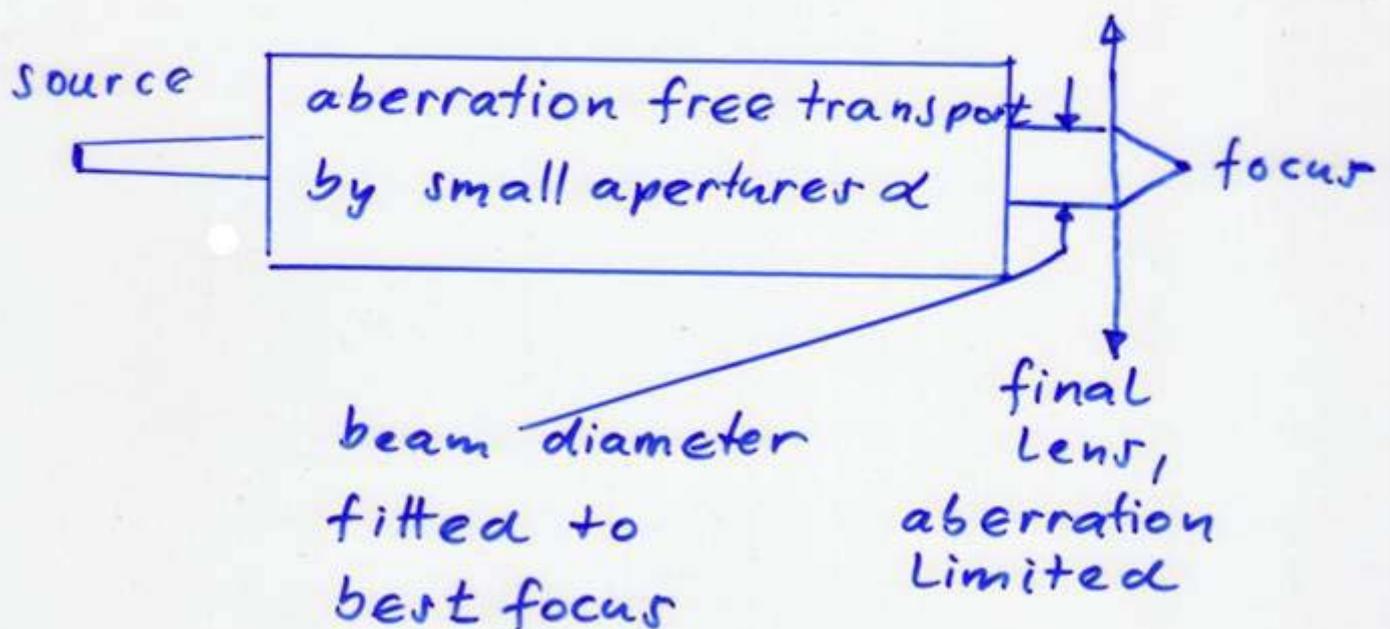


Ω at paraxial focus:



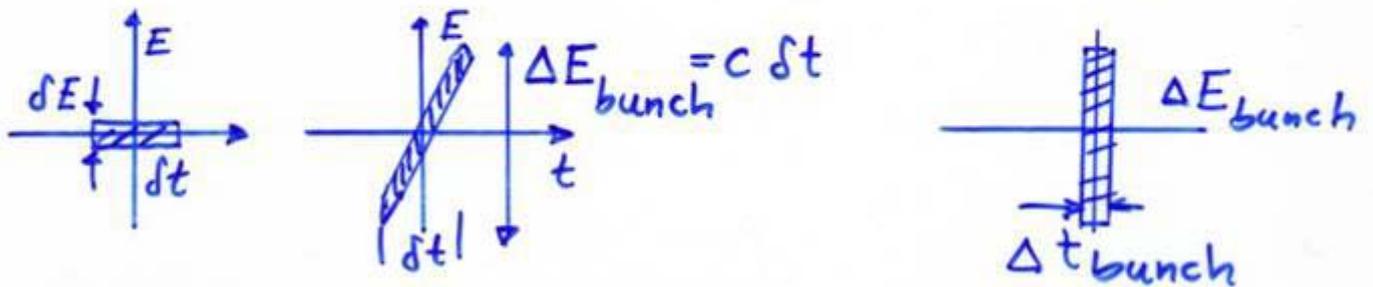
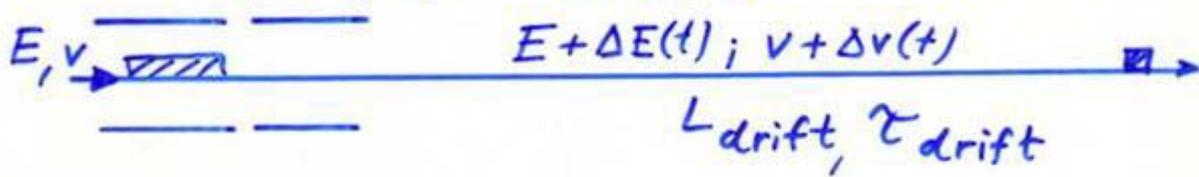
situation	C_s (order of magn.)
focus in field free space	$C_s \geq 10f$
best position of focus close to max. field strength	$C_s \approx f$
magnetic single pole lenses of SPM	$C_s \approx f/2$

C_s always positive; aberrations are accumulated in particle optics
(Scherzer 1937) ~ best strategy:



"Bunching"

buncher gap \sim energy modulation $E + c \cdot t$



$$\text{L.Th: } \Delta t_{\text{bunch}} \geq dt \cdot \frac{\delta E}{\Delta E_{\text{bunch}}}$$

$$\Delta E_{\text{bunch}} \leq 0.1 E \quad (\text{aberrations})$$

$$\frac{\delta v}{v} = \frac{\delta t}{\tau_{\text{drift}}} = \frac{1}{2} \frac{\Delta E_{\text{bunch}}}{E}$$

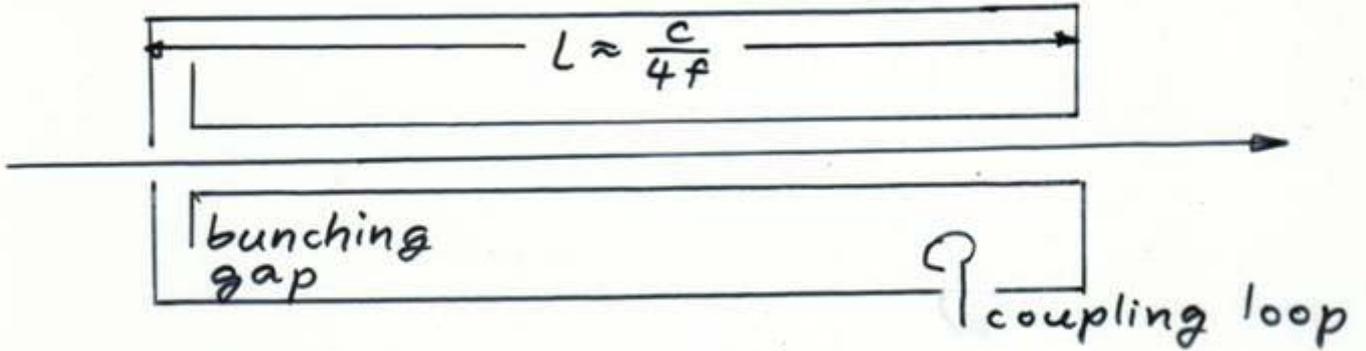
\sim L_{drift} determined by $\delta E, dt, \Delta t_{\text{bunch}}$

$$\tau_{\text{drift}} = 2 dt \frac{E}{\Delta E_{\text{bunch}}} > 20 dt$$

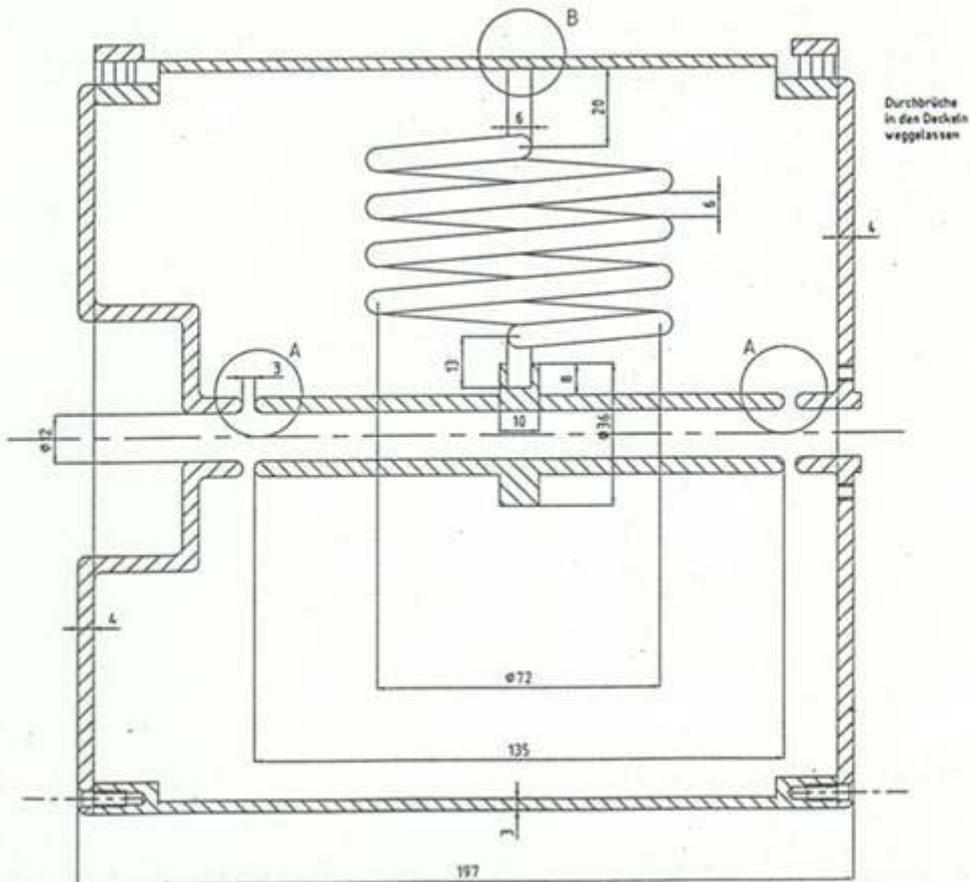
$$\sim L_{\text{drift}} [\text{cm}] \geq 37.5 dt [\text{ns}] \sqrt{E [\text{kV}]}$$

Bunchers

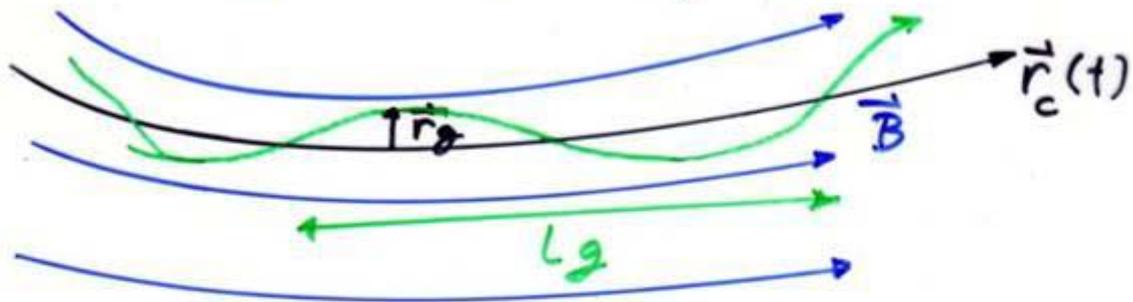
$\lambda/4$ resonator: Length depends on RF,
sensitive to temperature variations



double gap buncher (D. Paszbach)



Magnetic guiding field



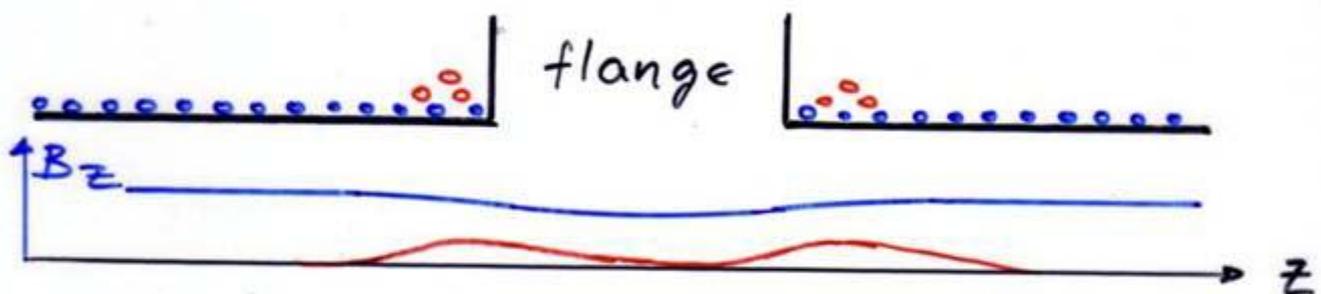
$$\vec{B}^2(\vec{r}_c) \cdot r_g^2 = \text{adiabatic constant}$$

if $(\vec{r}_g \cdot \nabla \vec{B}) / |\vec{B}| \ll 1$ and $\frac{|\nabla \vec{B}|}{|\vec{B}|} \cdot L_g \ll 1$

Problems: injection/extraction,
accumulation of small deviations

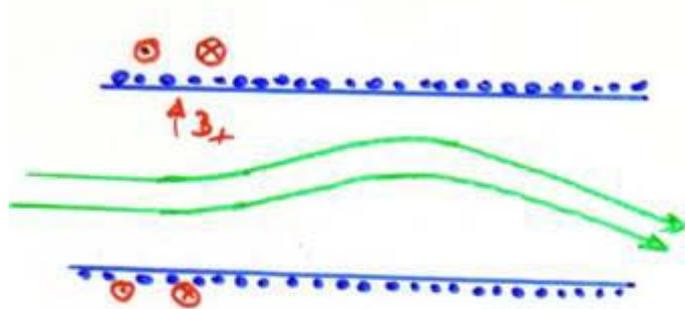
Cylindrical symmetry \leadsto

- canonical mom. $p_\varphi = mr^2\dot{\varphi} + qB_z r^2/2 = \text{exact const.}$
 - $\text{div } \vec{B} = 0 \leadsto$ paraxial region $B_r = -\frac{r}{2} \frac{dB_z}{dz}$
- \leadsto simple evaluation and correction
of effects from field variations



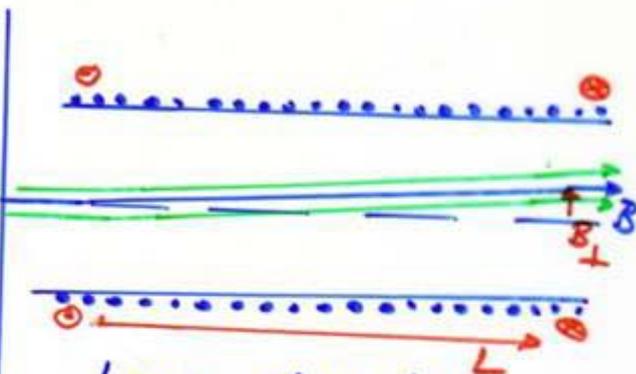
separately
excited correction coil

Correction coils



short dipole

→ collective gyration of the beam



long dipole

tilt the magnetic field → displacement

$$\text{by } L \cdot \frac{B_{\perp}}{B_{\parallel}}$$

without induced gyrations

saddle coils for a beam bend:

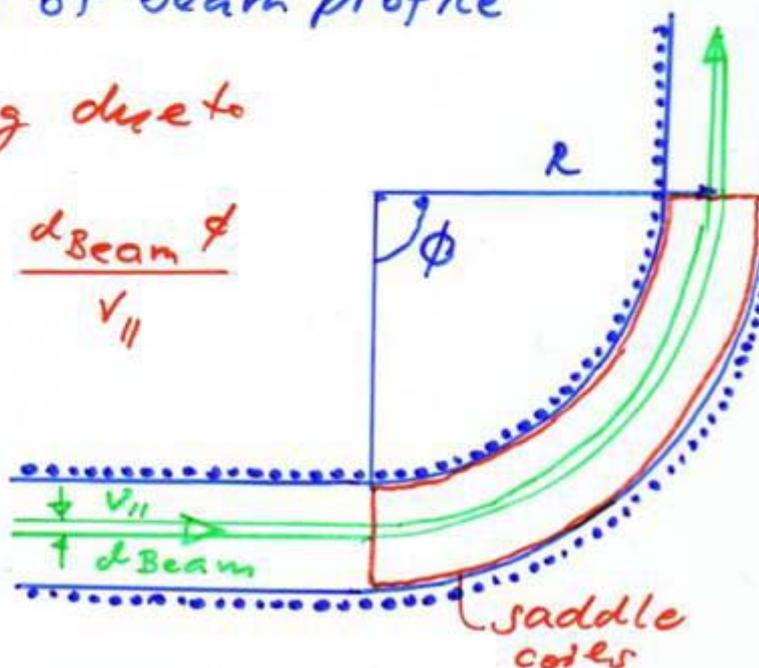
$$B_{\text{saddle}} = \frac{m v_{\parallel}^2}{q R} \approx$$

- negligible induced gyration
- slight distortion of beam profile

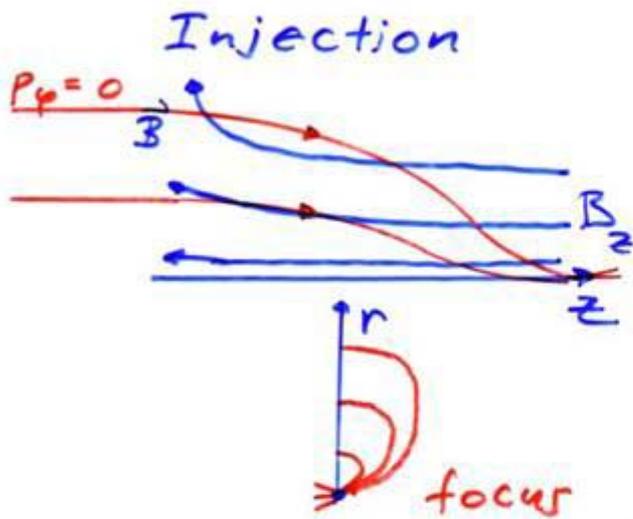
- pulse broadening due to

difference in time of flight

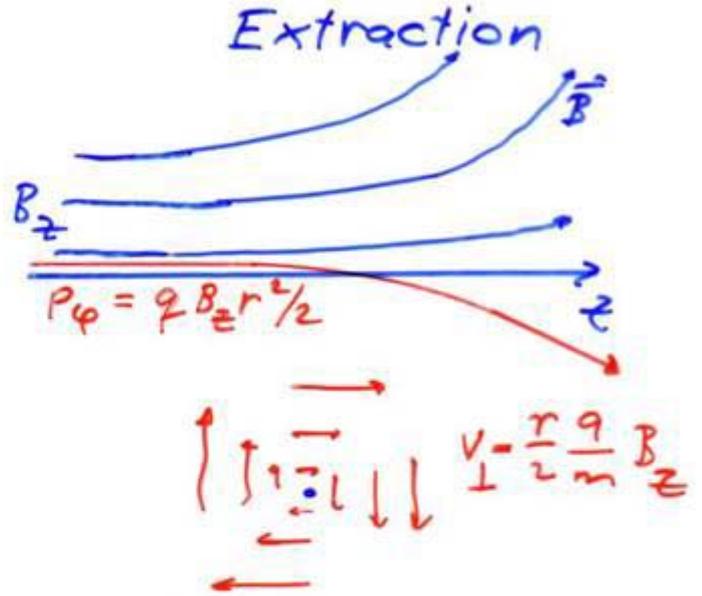
$$\frac{\Delta \text{Beam } \phi}{v_{\parallel}}$$



Termination of B-field



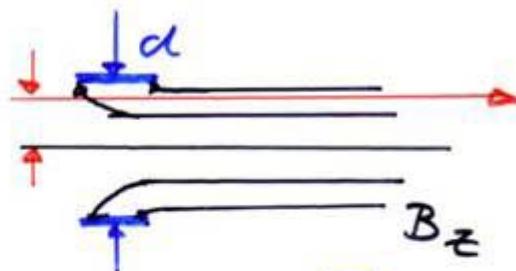
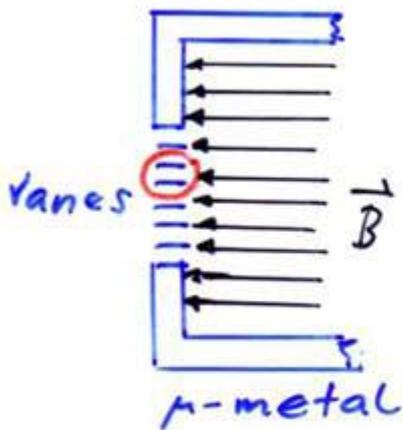
"magnetic lens"



→ extraction dominates transverse energy spread ΔE_\perp of source, if source radius exceeds

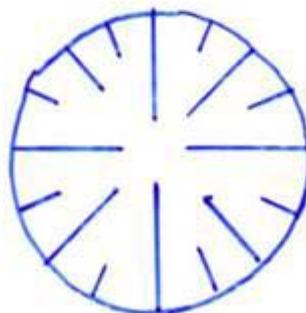
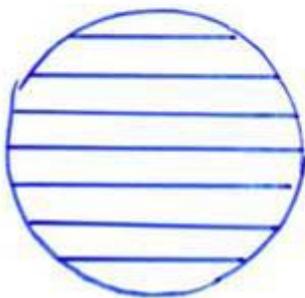
$$r_{\max} = \frac{\sqrt{8m \Delta E_\perp}}{q B_z}$$

Ferromagnetic field terminator

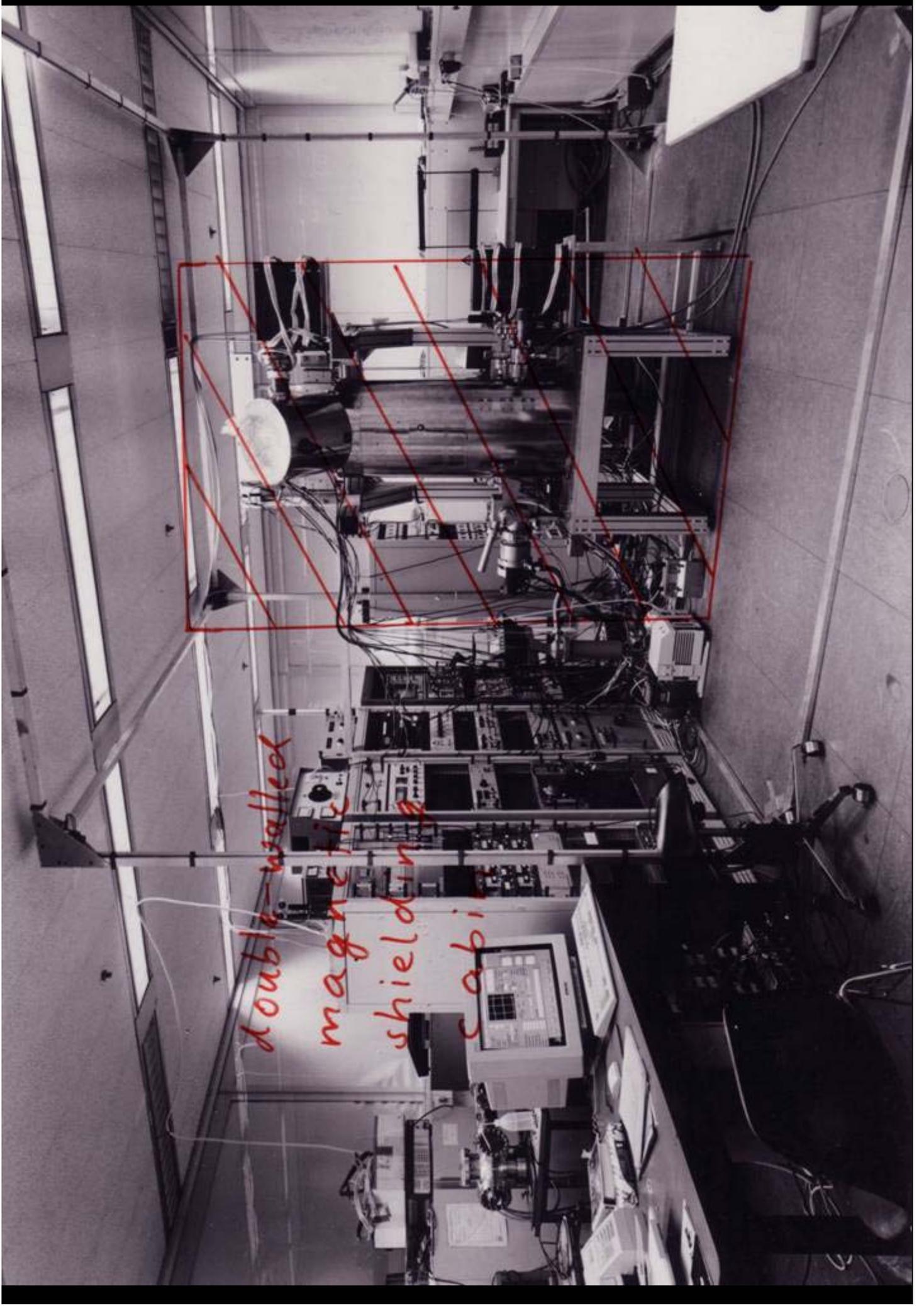


since $\text{div } \vec{B} = 0$:

$$\Delta p_\perp = q \gamma B_z, \quad -\frac{d}{2} < \gamma < \frac{d}{2}$$



"spider"



double-walled
magnetic
shielding
cabin



FIRST RESULTS FROM THE MÜNCHEN
SCANNING POSITRON MICROSCOPE

Collaborators :

From Universität der Bundeswehr München

W. Triftshäuser (project coordinator), G. Kögel (techn. officer)

P. Sperr, K. Uhlmann, D. T. Britton, P. Willutzki, R. Steindl, W. Junker,

A. David , W. Egger

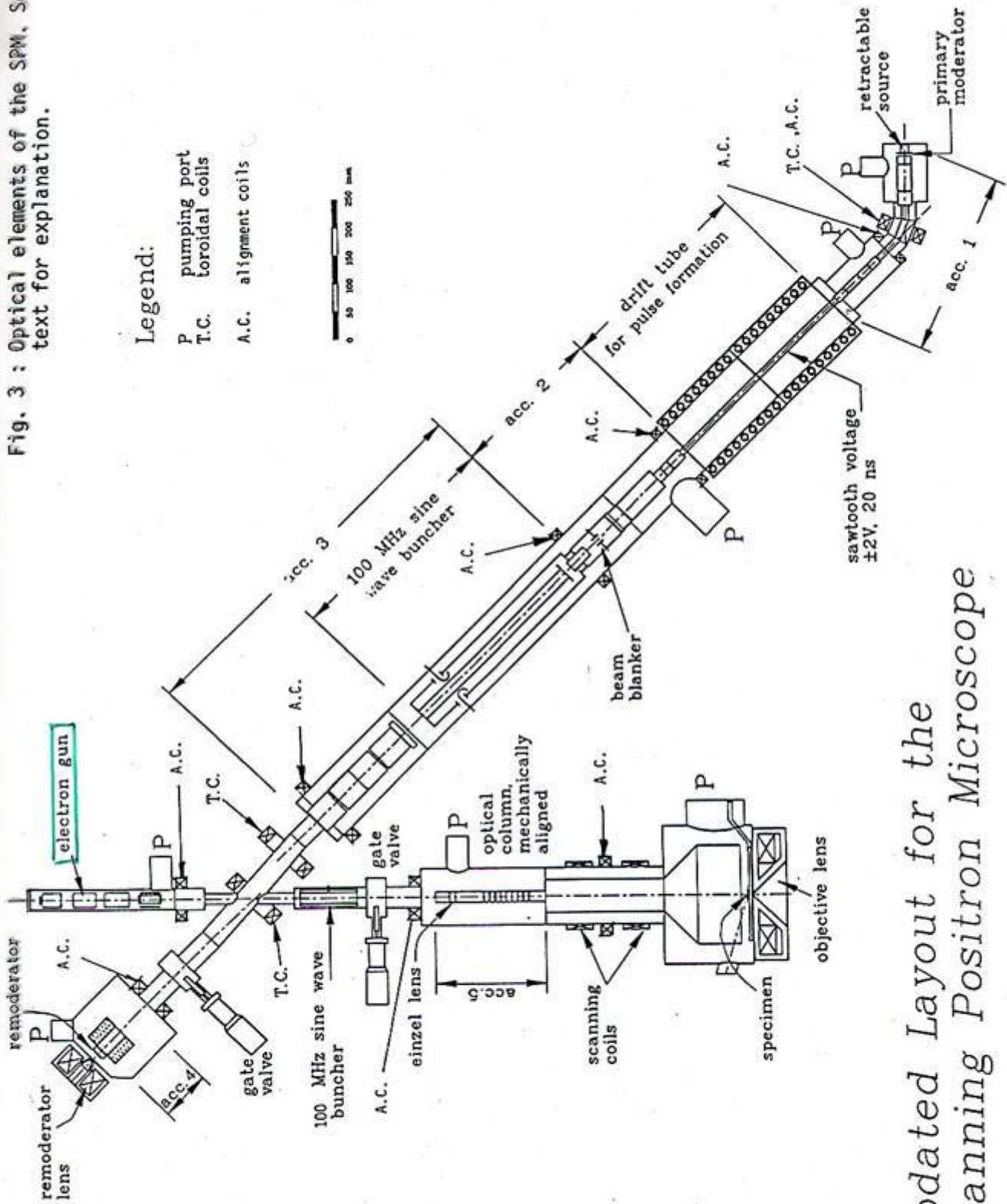
From Universita degli Studi di Trento

A. Zecca, R. S. Brusa, M. P. Duarte Naia, G. P. Karwasz, J. Paridaens,

A. Piazza

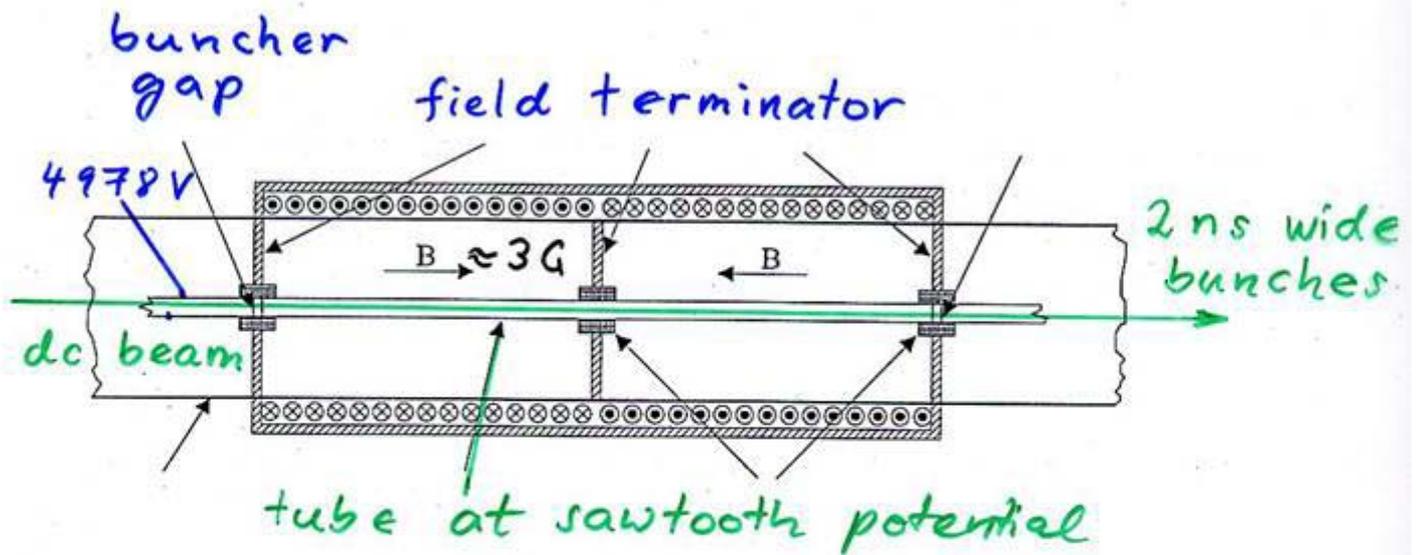
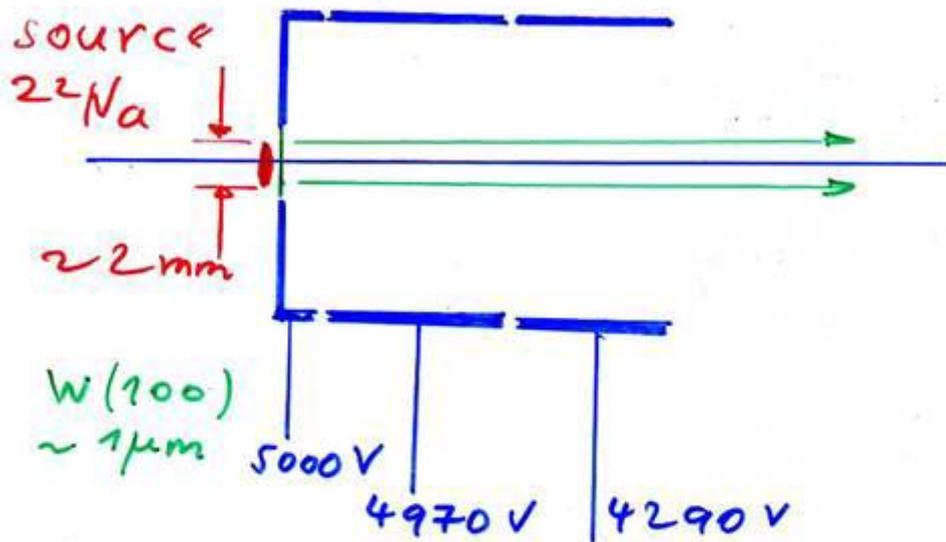
Supported by the European Union, contract BREU-CT90-0347

Fig. 3 : Optical elements of the SPM. See text for explanation.

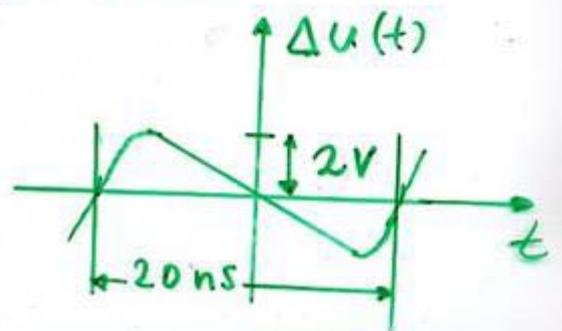


Updated Layout for the Scanning Positron Microscope

Triode gun



drift tube

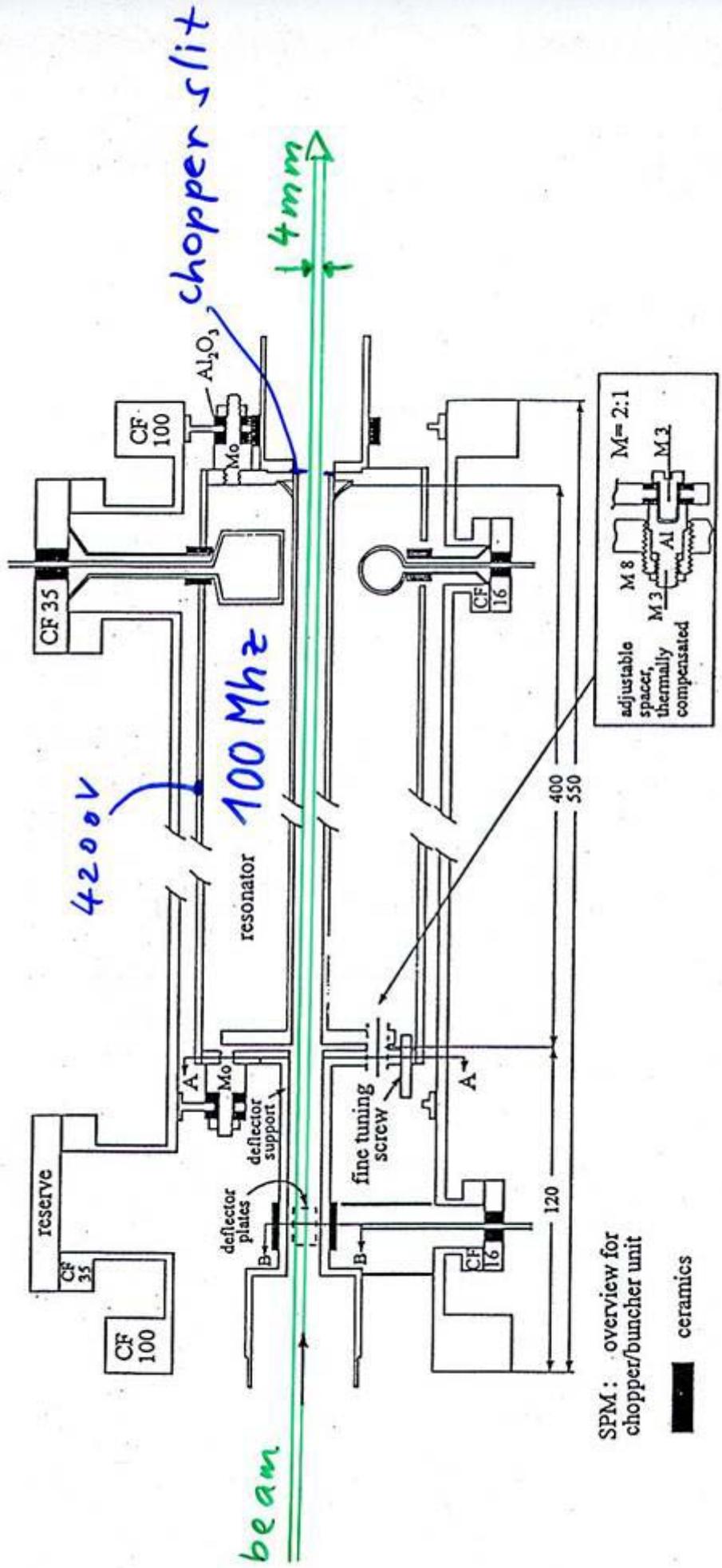


chopper/buncher unit

distance of chopper plates 5mm

width of chopper slit 4mm

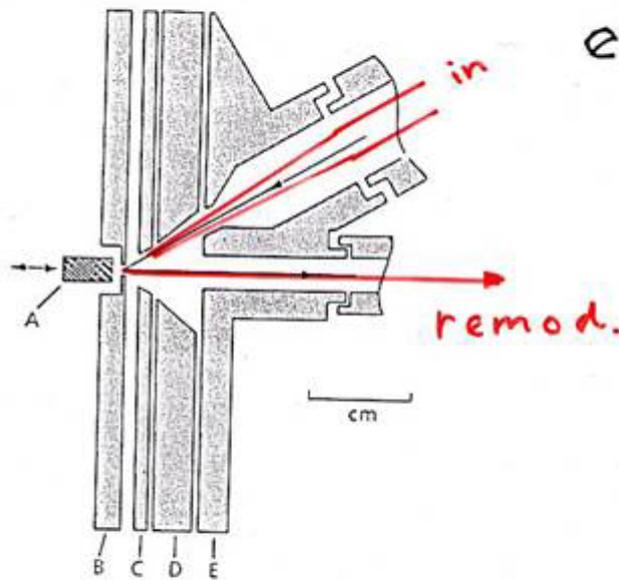
bunching amplitude ~ 100V ; deflection volt. ~ 4V



SPM: overview for chopper/buncher unit

■ ceramics

Remoderator Schemes



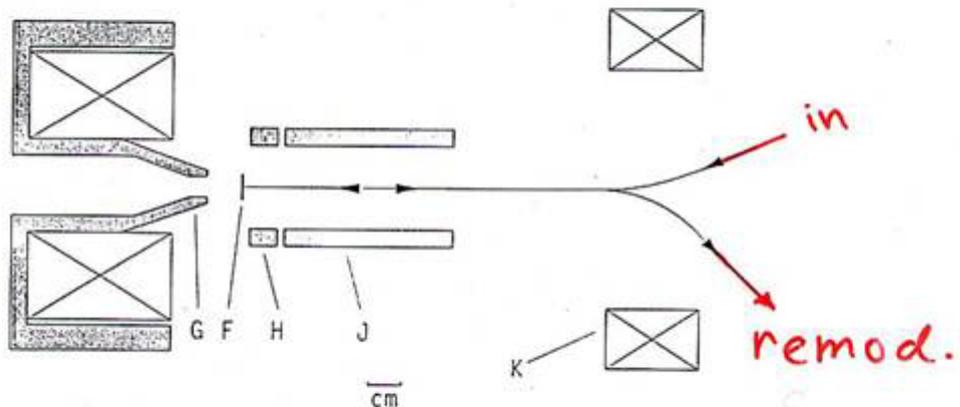
electrostatic
(standard)

diameter
reduction
 ≤ 10

~ density in phase space increased by ≤ 23

magnetic (only Munich)

diameter reduction ~ 100



~ density in phase space
increased by $2 \cdot 10^5$
(including puls compression)

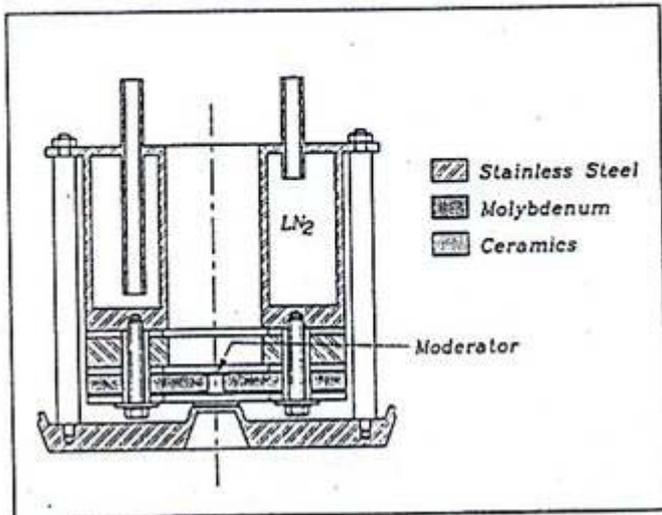


Fig. 4 : Internal mechanical construction of the remoderator assembly

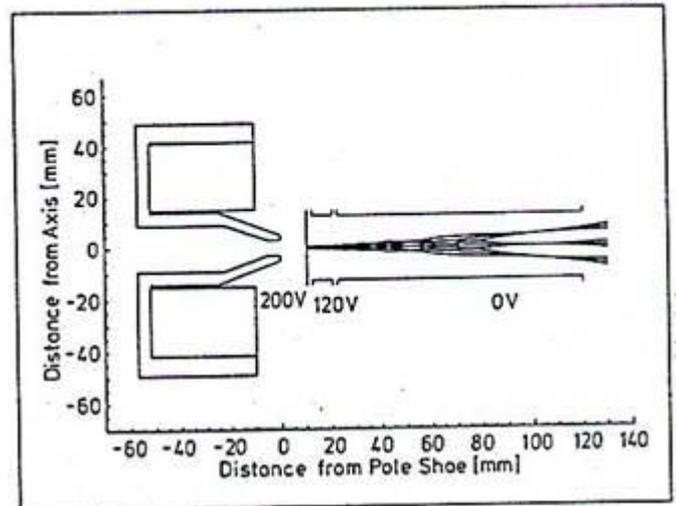


Fig. 5 : Remoderator system (lens and accelerator) with outgoing trajectories. The beam diameter has been expanded by a factor of 50.

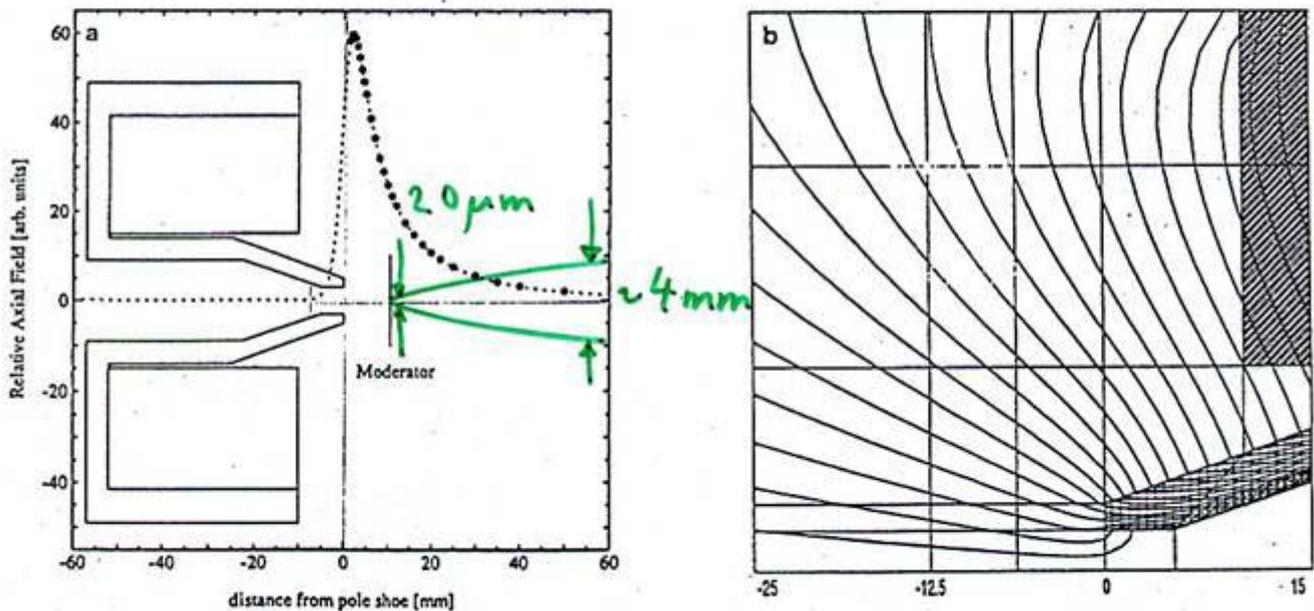
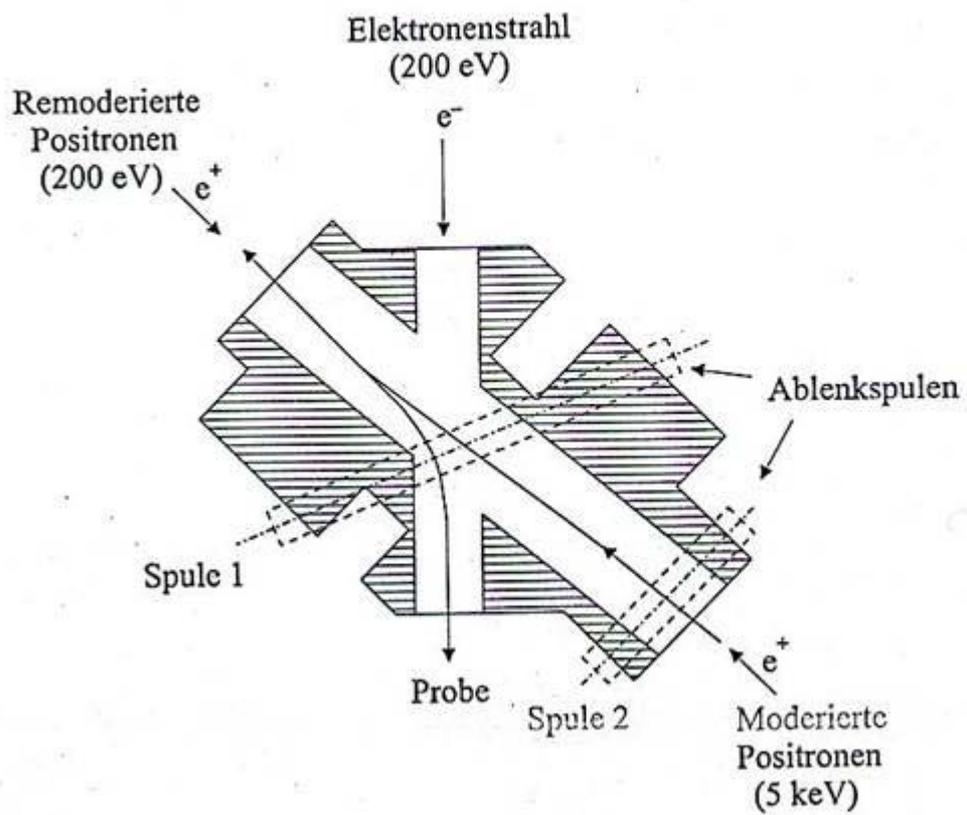
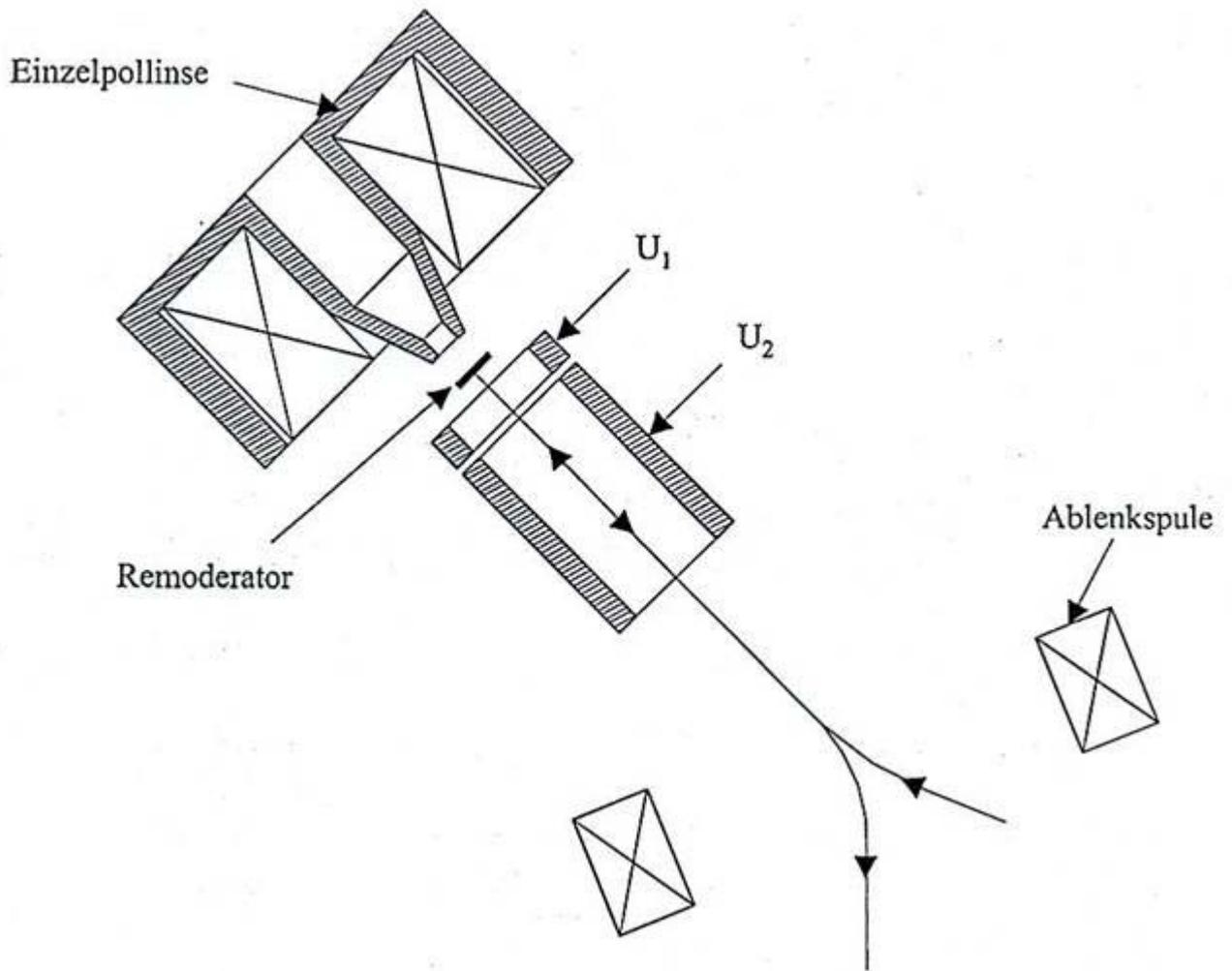


Fig. 6 : a) Geometry of the single pole lens and its relative axial magnetic field. The broken curve is calculated and the solid circles measured. b) Field lines near the remoderator position and pole shoe.



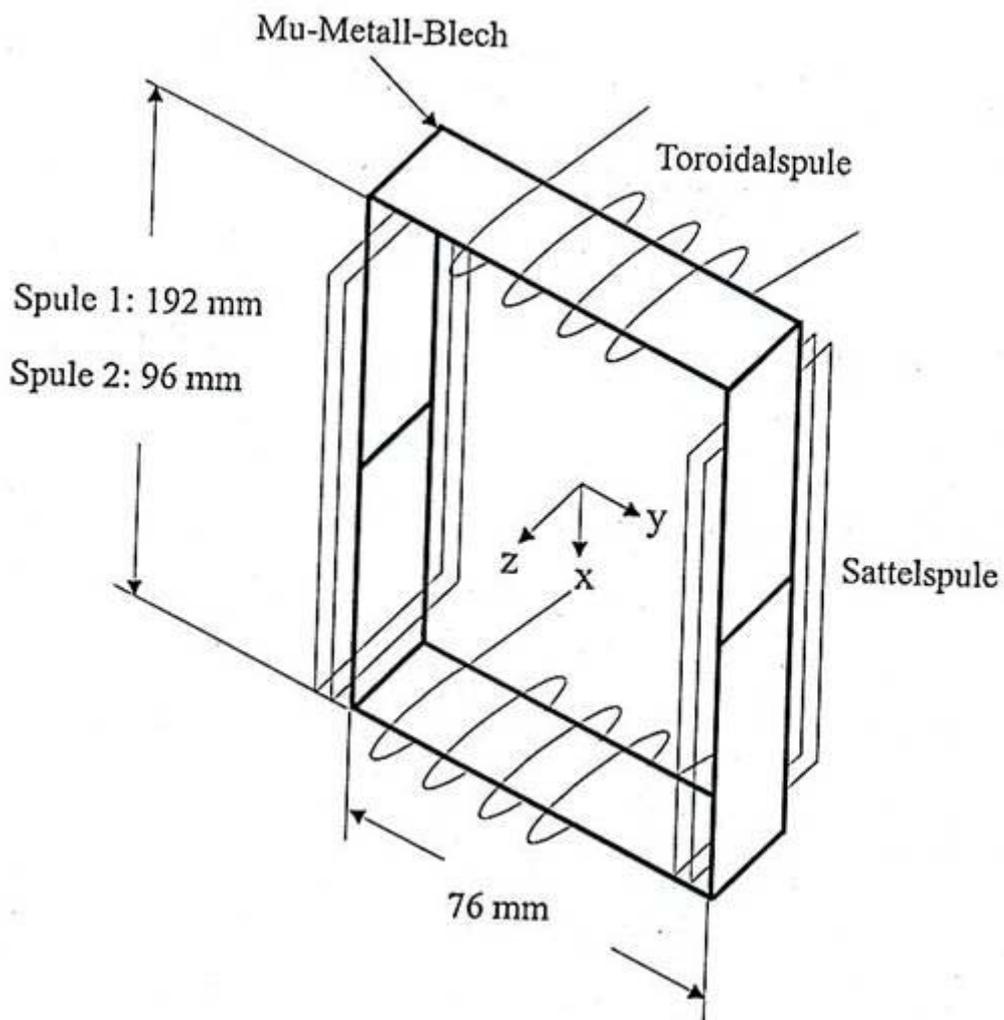


Abbildung 5.7: Ablenkspule

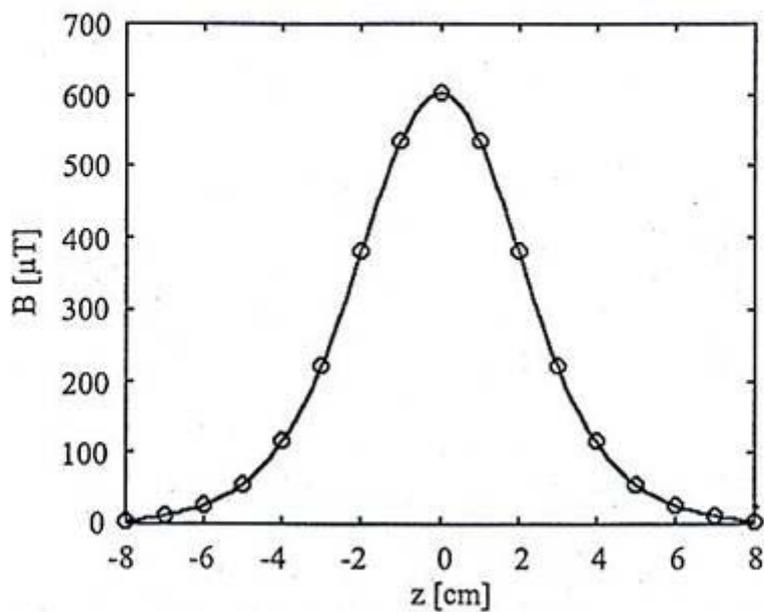
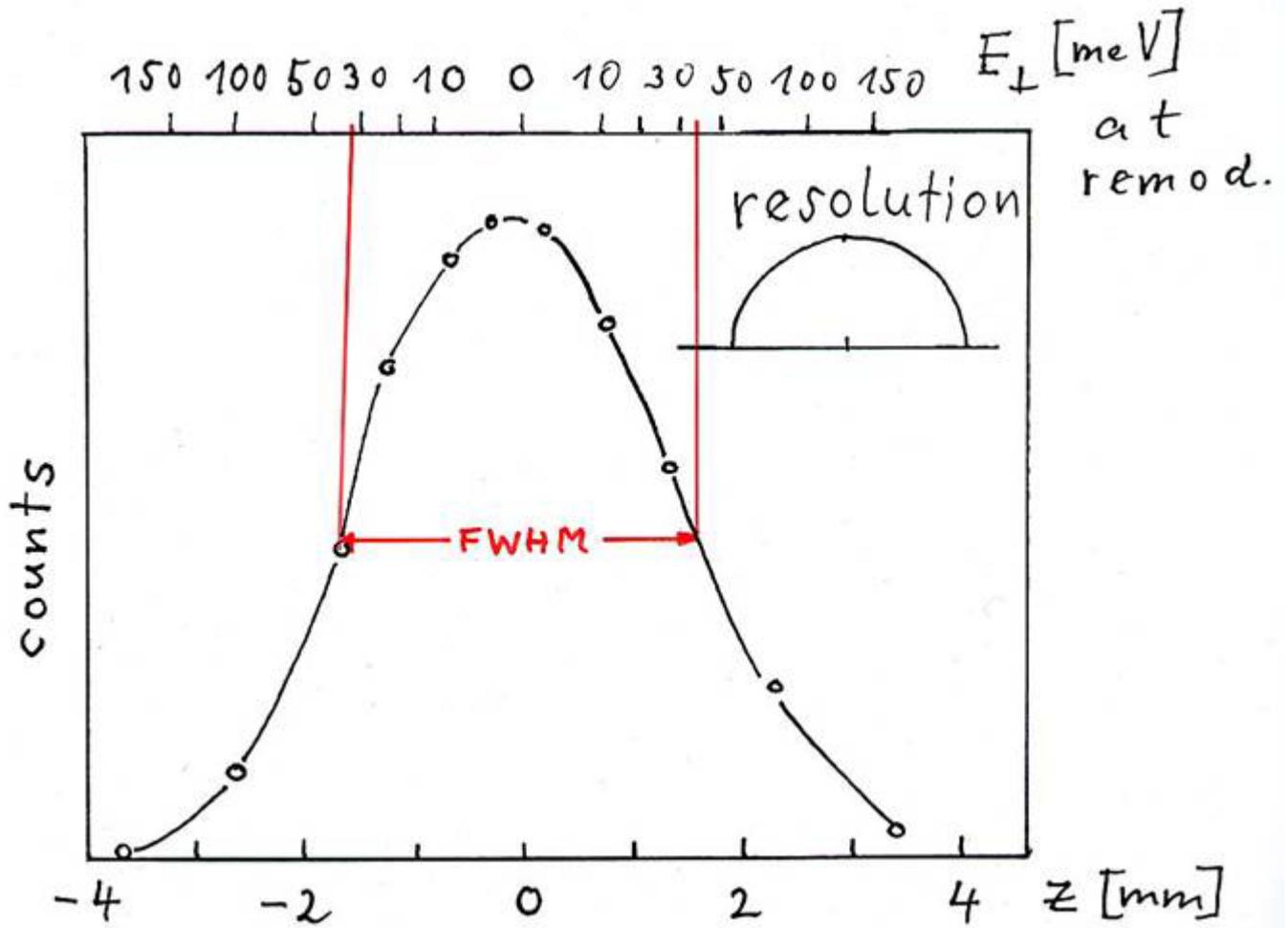
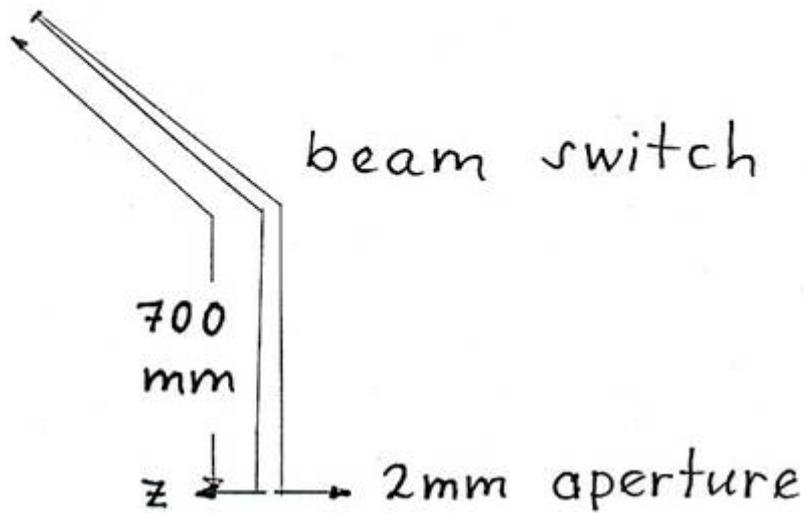


Abbildung 5.9: Magnetische Induktion der Spule 2, \circ gemessene Werte

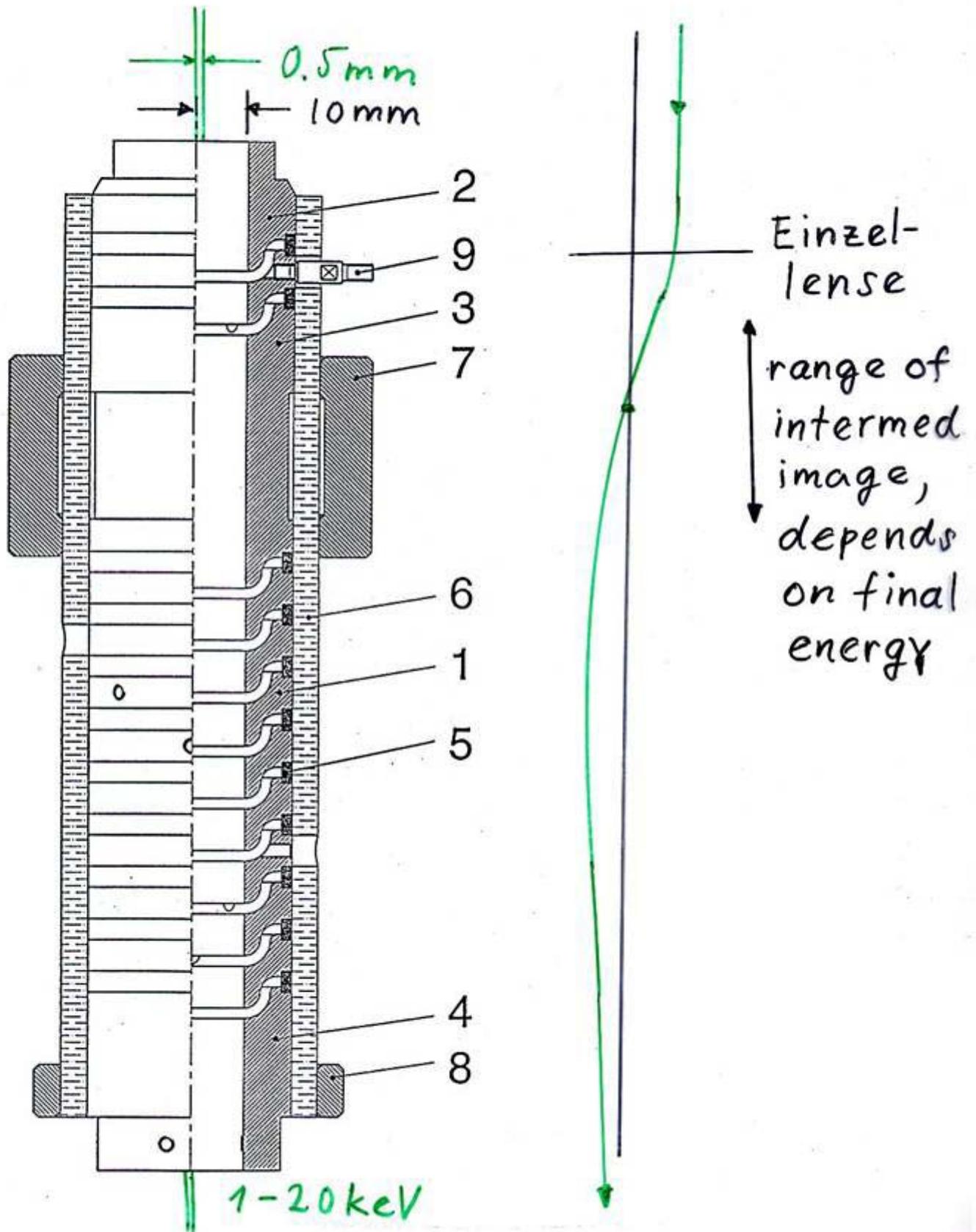
The remoderated beam

~ 2000 e^+/s at 150 MBq ^{22}Na

remod.



Main accelerator



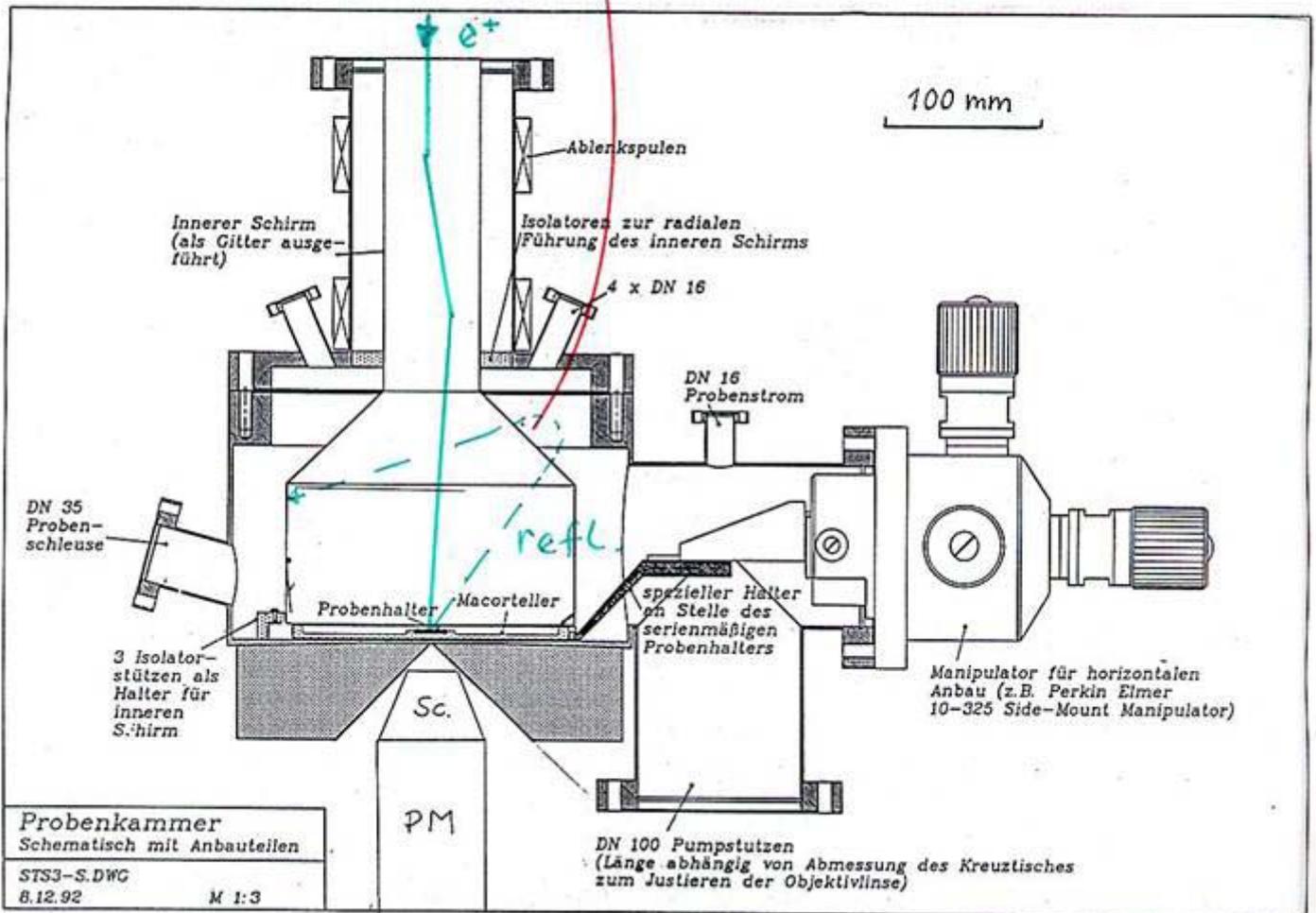
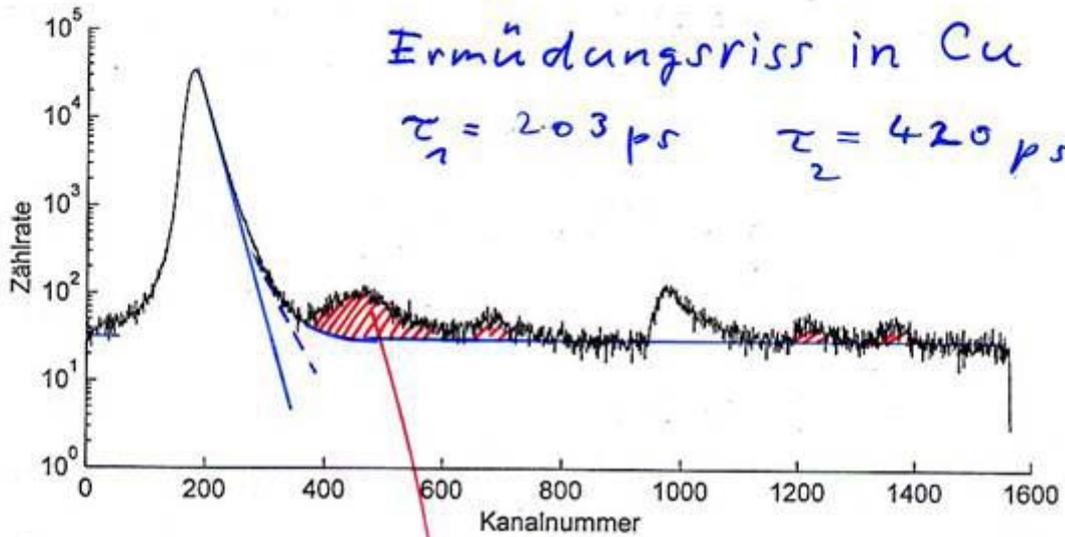
Section of the main accelerator. (1-4) several lens elements, (5) Macor insulator rings, (6) Macor tube, (7,8) clamp rings, (9) connector pins.

$E_{impl.} = 16 \text{ keV}$

Ermüdungsriss in Cu

$\tau_1 = 203 \text{ ps}$

$\tau_2 = 420 \text{ ps}$



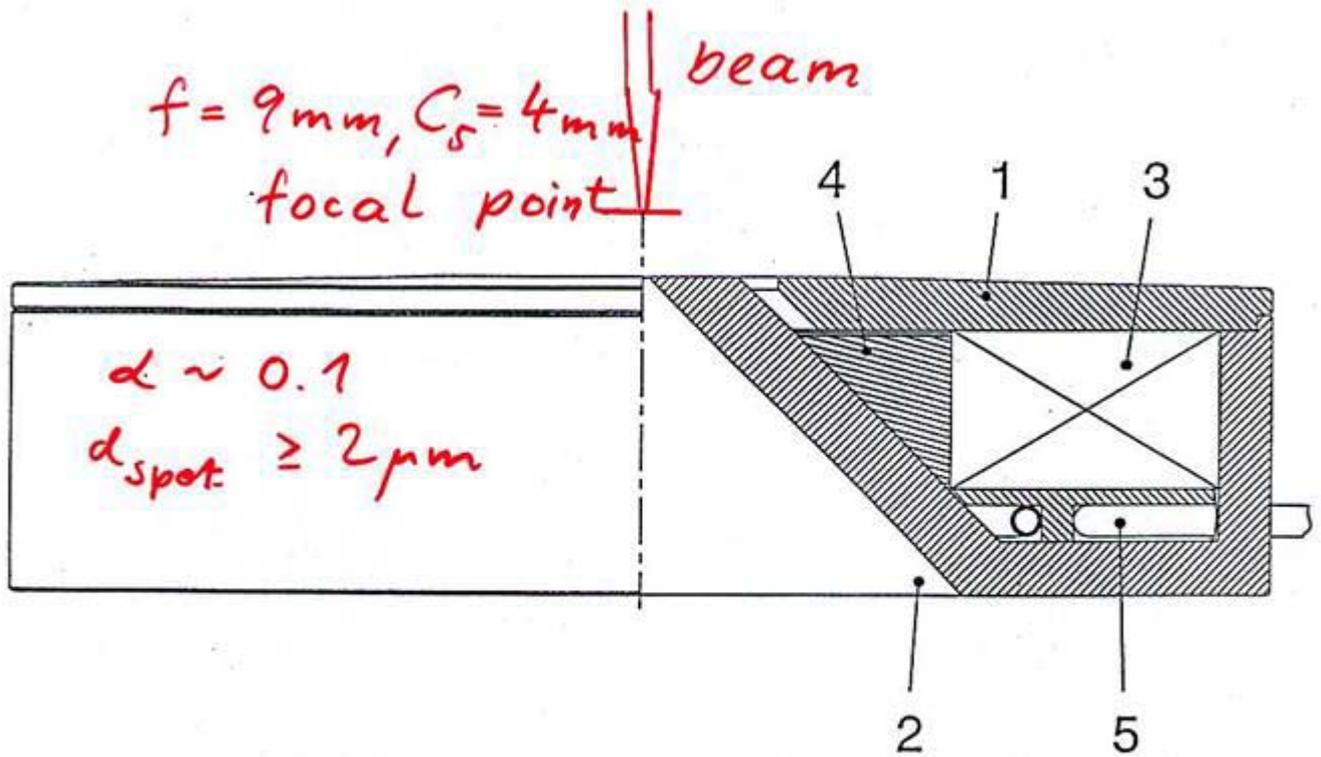


Fig. 11 : Half section of the probe forming lens. (1) top plate, (2) assembly of pole shoe body and central cone, (3) coil, (4) centring ring, (5) water cooling. The outer diameter of the lens amounts to 240 mm.

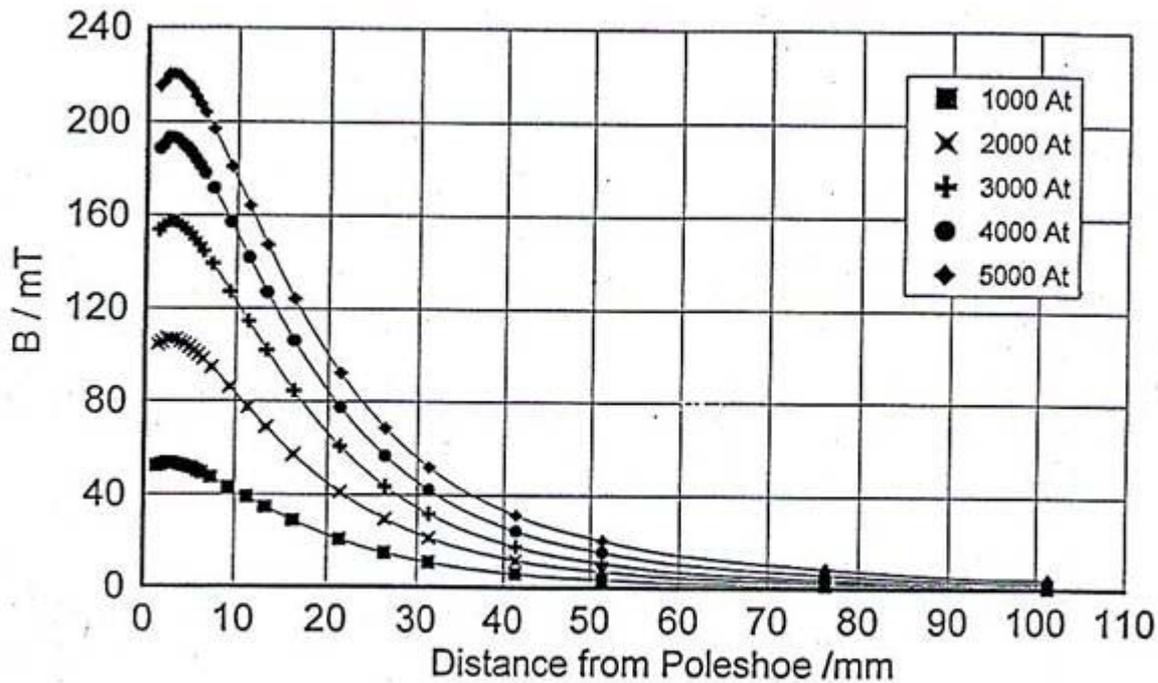
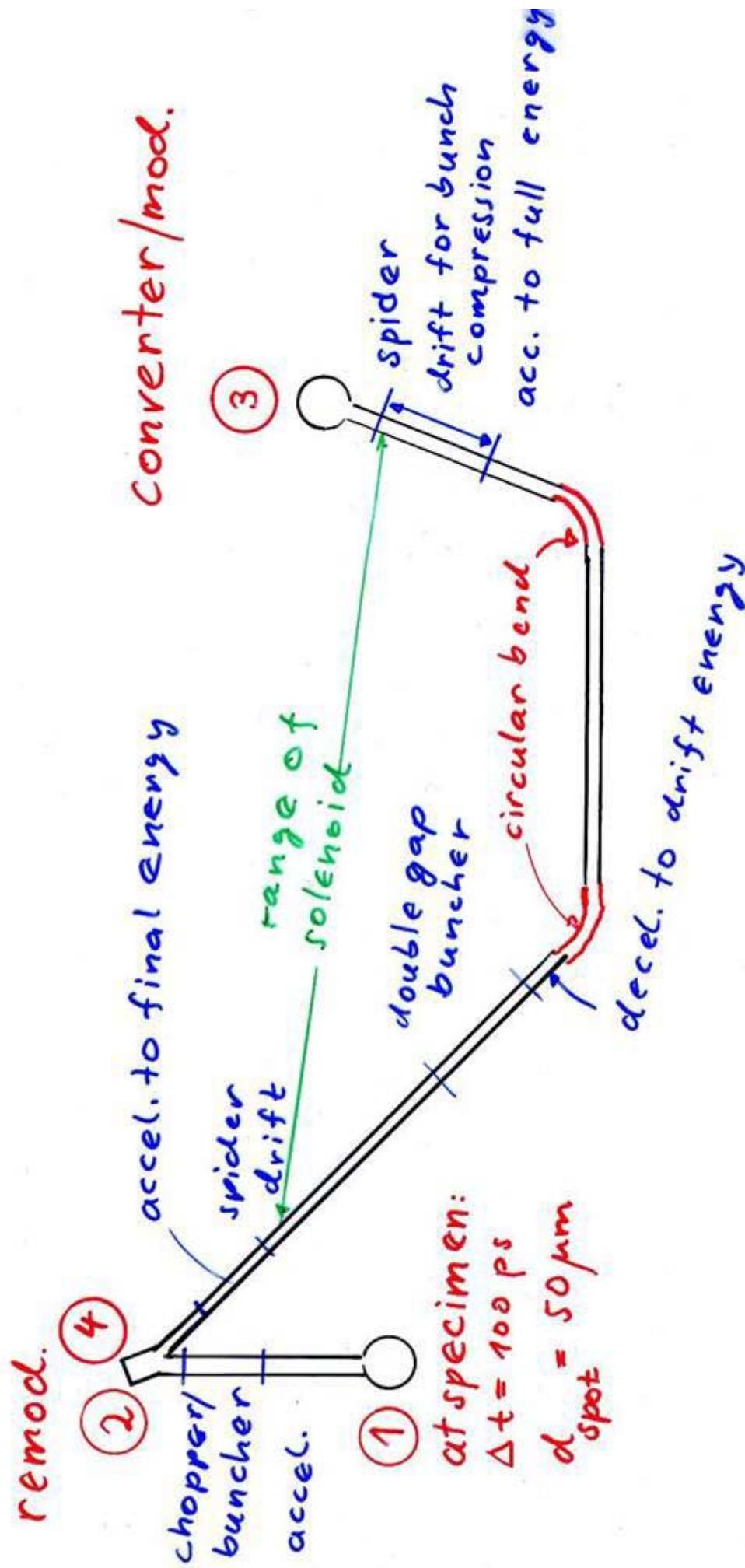


Fig. 12 : Measured axial magnetic field of the probe forming lens for different excitations (At = Ampere turns).

IPOS



EPOS characteristics

① final spot $d = 50 \mu\text{m}$ at $E = 8 \text{ keV}$
 aperture $\alpha_{\text{foc}} = 0.1 \approx C_s < \frac{50 \mu\text{m}}{\alpha_{\text{foc}}^3} = 50 \text{ mm}$
 \approx

② remoderated beam, $\Delta E_{\perp} = 30 \text{ meV}$
 $\approx \alpha_{\text{source}} = \sqrt{\Delta E_{\perp} / E} = 2 \cdot 10^{-3}$

\approx spot diam. at remod.
 $\leq d \cdot \frac{\alpha_{\text{foc}}}{\alpha_{\text{source}}} = 2.5 \text{ mm}$

primary beam at remod. spot:

$\Delta \tau \leq 1 \text{ ns}$, $\Delta E_{\parallel} \leq 100 \text{ eV}$ (chrom. aberr.)

$\approx \Omega_{\text{long}} \leq 100 \text{ ns} \cdot \text{eV}$

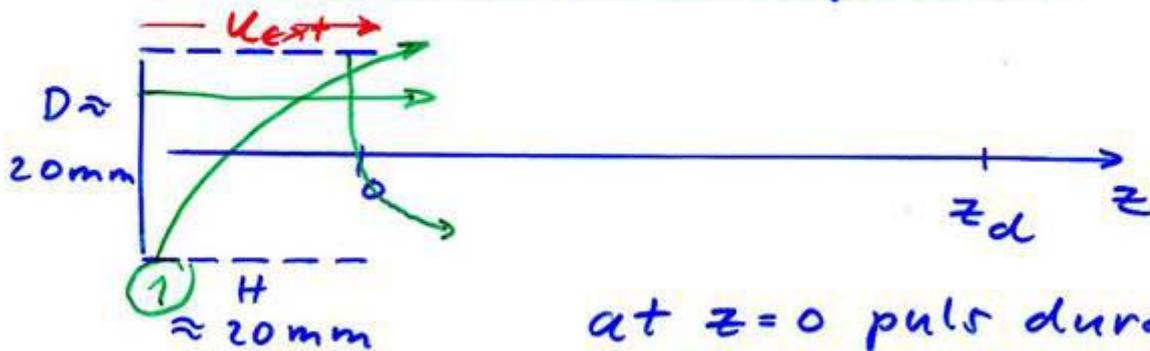
α_{foc} at remod.	$C_s < \frac{d}{\alpha_{\text{foc}}^3}$	$\Omega_{\text{tr}} = d_{\text{foc}}^2 \cdot d \cdot 5 \text{ keV}$
0.15	744 mm	550 mm ² eV
0.30	93 mm	2200 mm ² eV

④ Ω_{long} and Ω_{tr} as delivered by the converter/moderator must not exceed the values above.

EPOS converter/moderator

required: $\Omega_{\text{long}} < 100 \text{ eV ns}$, $\Omega_{\text{tr}} < \frac{2200 \text{ mm}^2 \text{ eV}}{550 \text{ mm}^2 \text{ eV}}$

conventional configuration



at $z=0$ pulse duration
 $= \text{TOF from } (1) \approx 0.3 \frac{H}{\text{mm eV}} \sqrt{U_{\text{ext}}} \text{ ns}$

$\sim \Delta \tau \geq 20 \text{ ns}$

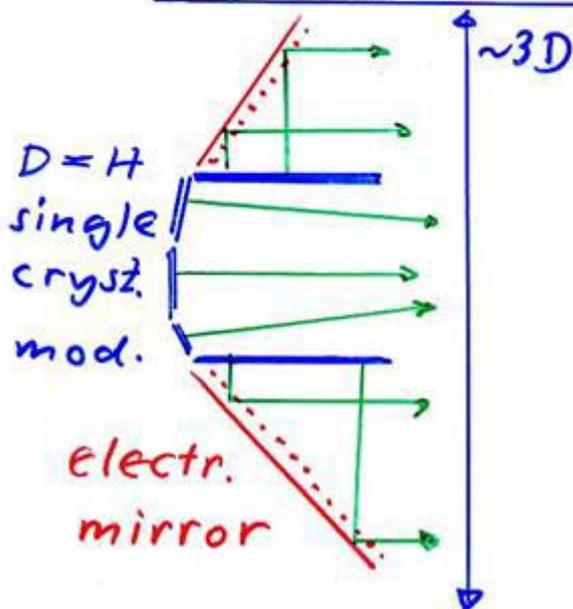
$\Delta E_{\parallel} = eU_{\text{ext}} + W \geq 10 \text{ eV}$

$\Delta E_{\perp} > 2W \approx 6 \text{ eV}$

$\sim \Omega_{\text{long}} \geq 200 \text{ ns} \cdot \text{eV}, \Omega_{\text{tr}} \geq 2400 \text{ mm}^2 \text{ eV}$

Possibly $\Delta \tau$ will shrink at z_d ?

innovative configuration



$\Delta E_{\perp} \approx \Delta E_{\parallel} \approx 0.1 \text{ eV}$

$E_{\parallel} \approx W = 3 \text{ eV}$

$\sim \Delta \tau < 2 \text{ ns}$

$\Omega_{\text{tr}} = 400 \text{ mm}^2 \text{ eV}$

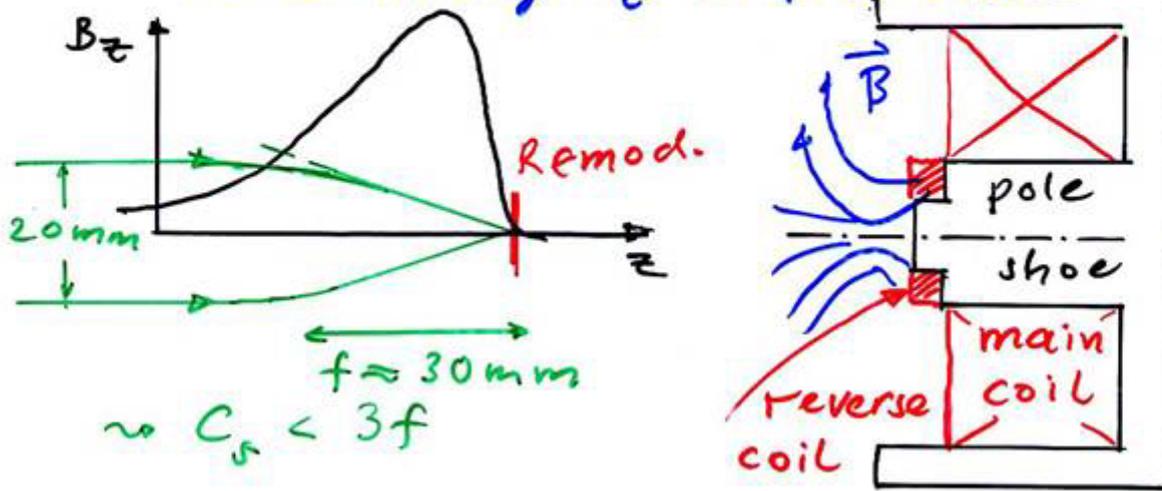
$\Omega_{\text{long}} = 0.2 \text{ ns eV}$

EPOS remoderation unit

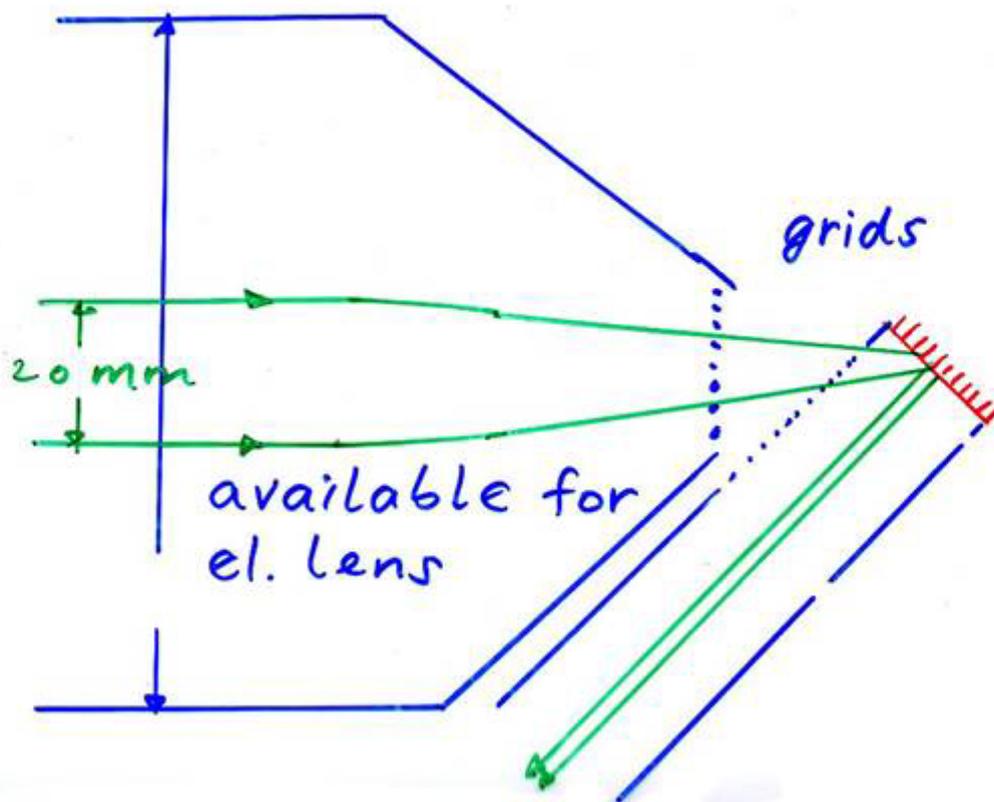
a) magnetic lens (if $\alpha = 0.3$ required)

problem: B_z at remod. $\ll 10\text{G}$ \approx rapidly

decreasing B_z at pole shoe



b) electrostatic lens, $\alpha = 0.15$ sufficient
 $f \approx 70\text{mm}$



Conclusions

	SPM	EPOS (estimate G.K.)
Ω_{tr} [mm ² eV] at 1 st moderator	0.12	400 - 2200
at remoder.	$1.2 \cdot 10^{-5}$	0.19
final spot size exper.	$> 2 \mu\text{m}$	—
theor.	$\sim 1 \mu\text{m}$	$50 \mu\text{m}$

- EPOS ambitious, no principal problems
- the intended performance is close to the limit \leadsto
careful consideration of the entire,
interdependent chain
converter/moderator to final
spot is crucial for success!