Axial symmetric open magnetic traps with depressed transversal losses of plasmas

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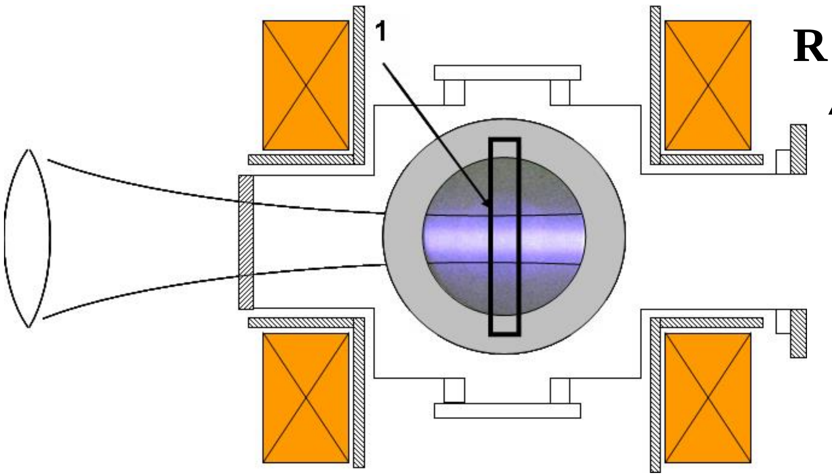
Outline

- Introduction
- Cusp
- Systems with shear flow control
- Non-paraxial systems

Experimental investigations of plasma MHD stabilization in open mirror trap of the ECR ion source



1 – projection of the streak camera slit

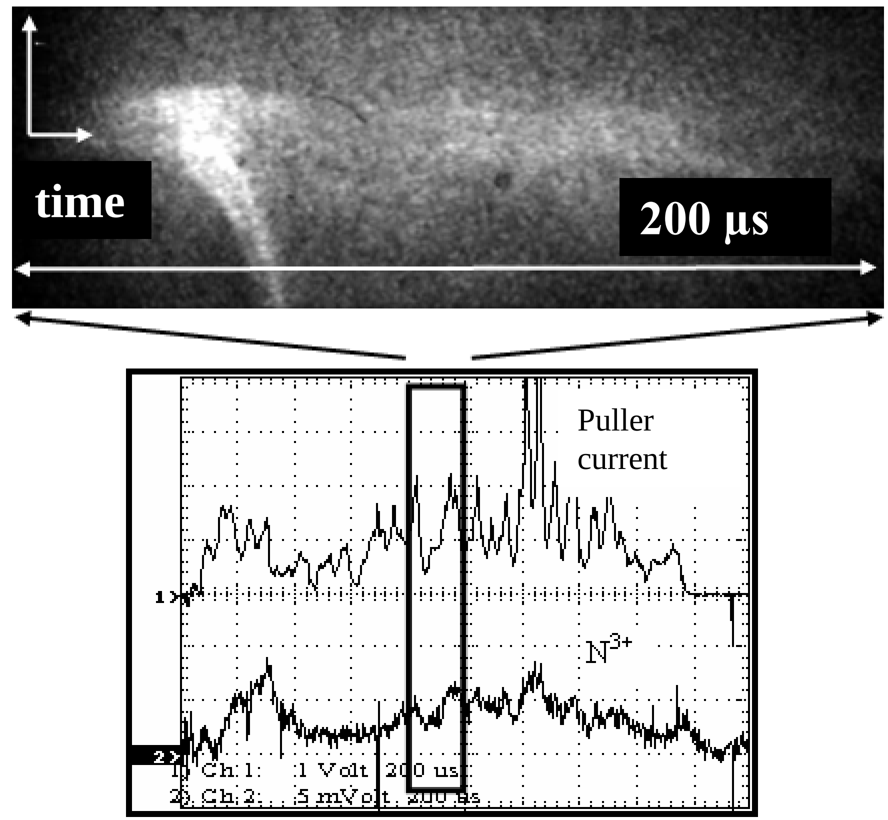


Image from streak-camera (positive image, time goes from left to right, the duration of the entire scan is 200 µs), obtained at the same time with the puller current waveform and N^{3+} ions . Rectangle on the waveforms corresponds to the duration of streak-camera scan.

Theoretical model

• plasma convection in axisymmetric or effectively symmetrized shearless magnetic systems;

• magnetic field can be presented as:

$$\mathbf{B} = [\nabla\psi \times \nabla\varphi] \; ; \qquad \psi = \int_0^r r\,B_z\,dr \; ,$$

• stability of flute-like mode :

$$U'(\psi)\left(p'(\psi) + \gamma p U'/U\right) > 0 \, ,$$

$$S \equiv p\,U^{\gamma} = \text{const} \, ;$$

$$U = \int_{-}^{+} dl/B \, ;$$

Marginally stable (MS) profile

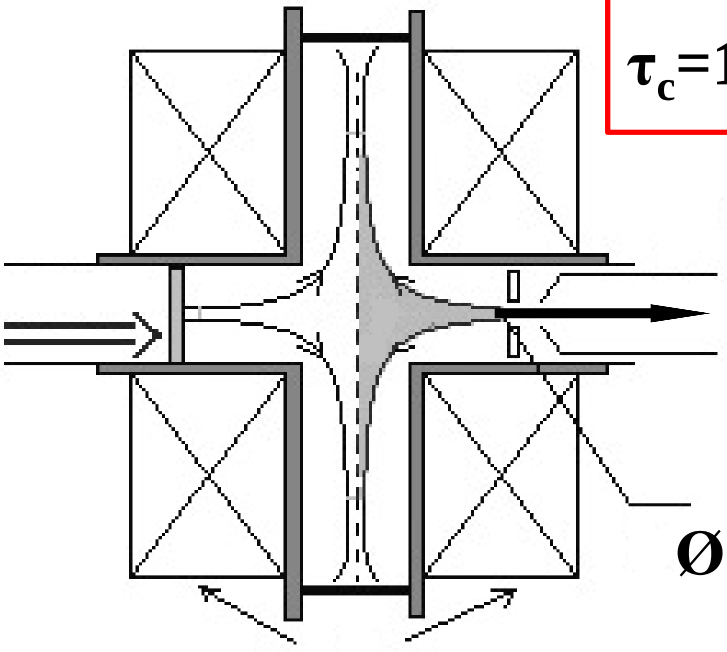
$U' < 0$ - sufficient condition for the reasonable density profiles **BUT not required**

MHD stabilization: Cusp-type magnetic configuration

L_{eff}=30 cm

SMIS 37 setup

MW 100 kW @ 37.5 GHz



Ion beam

Ø 1mm

Magnetic trap

Quasi gas dynamic confinement regime

$\tau_c = 1/\nu_{ei} << \tau_g = L_{eff}/V_s$

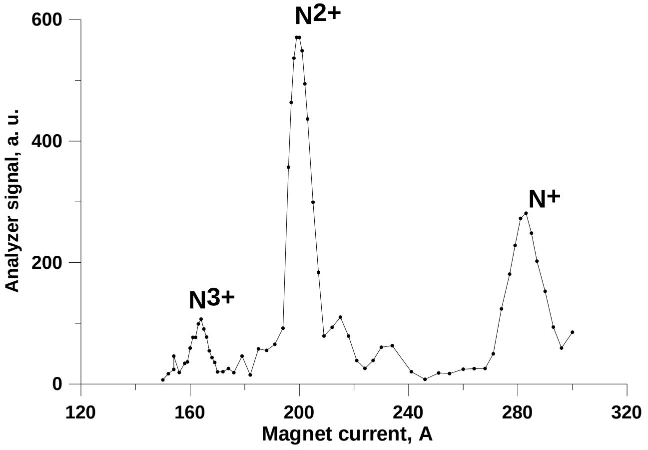
$N_e = 10^{13}$ cm^{-3}

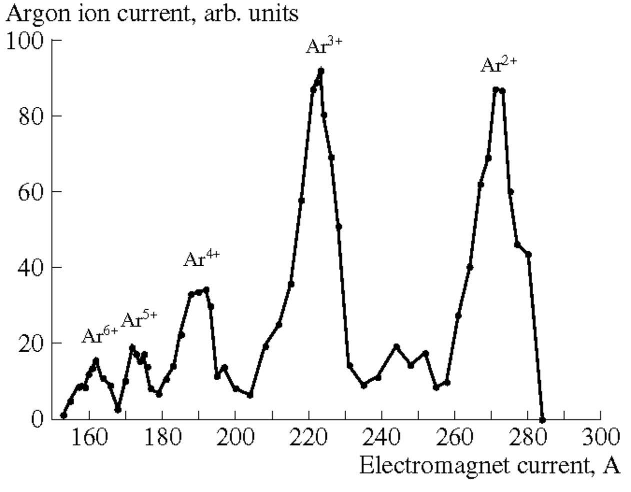
T_e=50 – 100 eV

$\tau_g \approx 10 \mu s$

$N_e \tau_g \approx 10^8 [cm^{-3} s]$

MHD stabilization: Cusp-type magnetic configuration

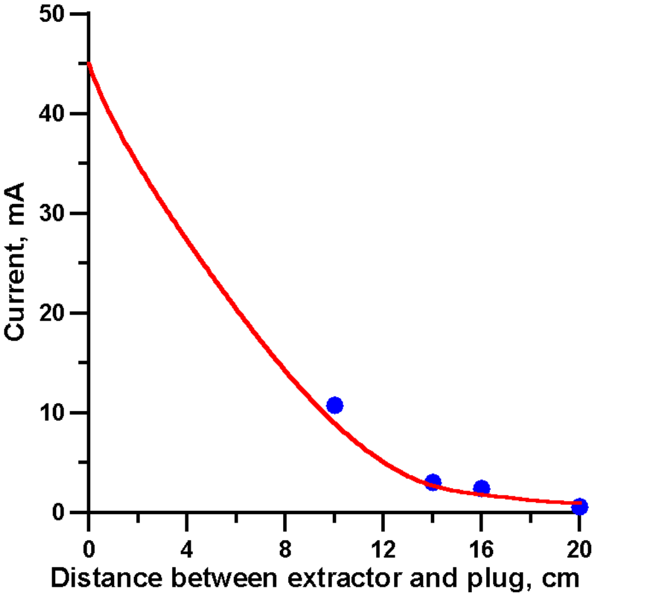




$$\tau_g \approx 10 \mu s$$

$$n\tau \approx 10^8$$

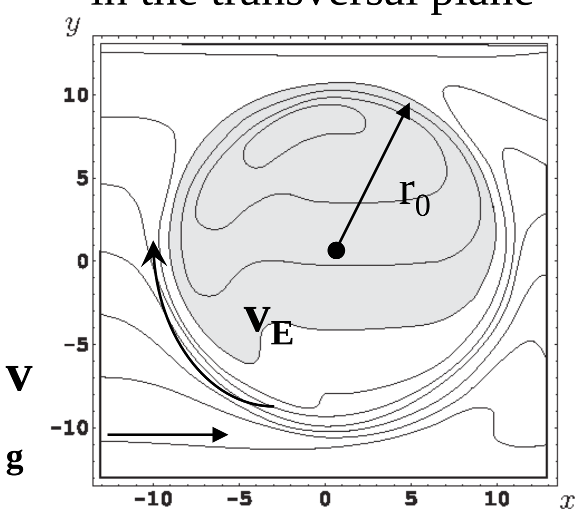
N: <Z>=2
Ag: <Z>=3.5



Losses trough the axial slit is too high!

Conditions of the “vortex” creation

View of the plasma core
in the transversal plane



$\otimes \vec{B}$

$\mathbf{v_g}$ **-** velocity transversal flow caused by flute instability

If $v_E >> v_g$ then the closed streamlines appears and the existence of the vortex like structures is possible

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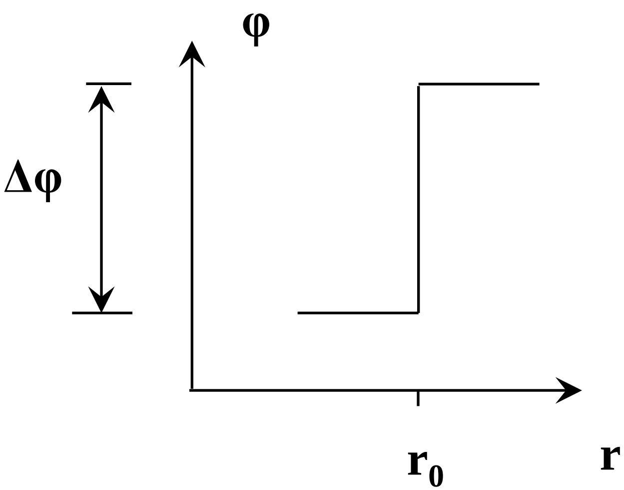

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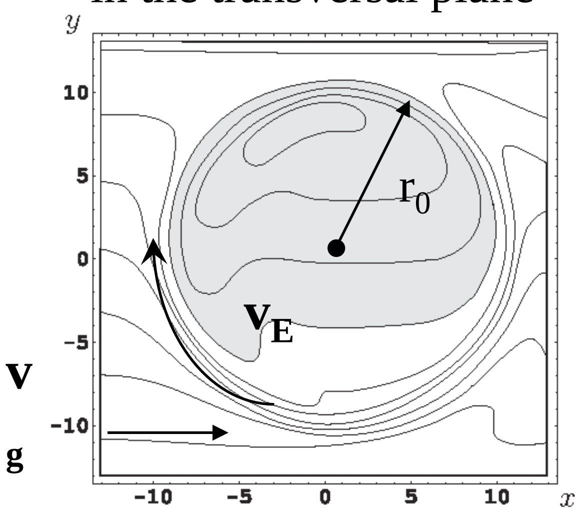

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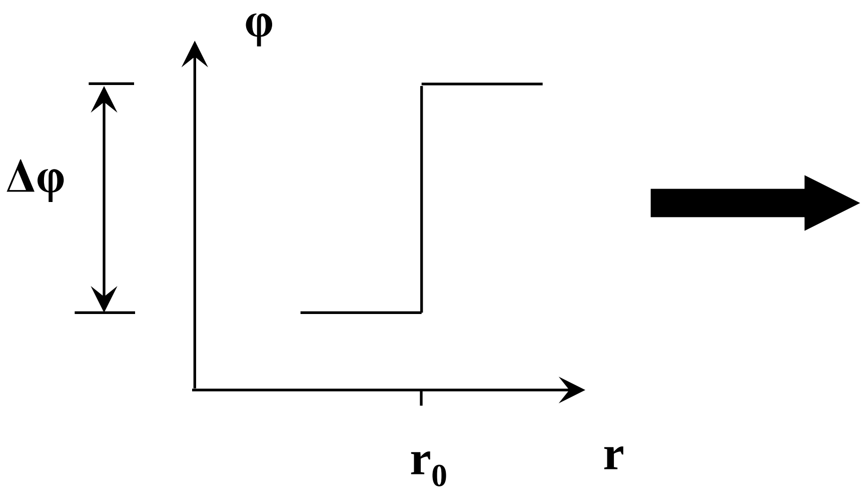

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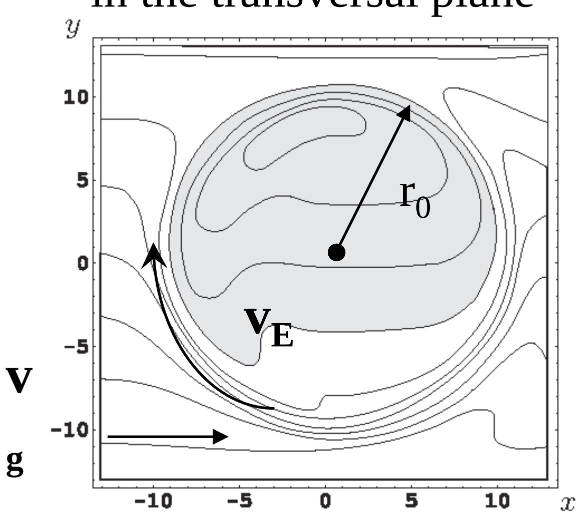

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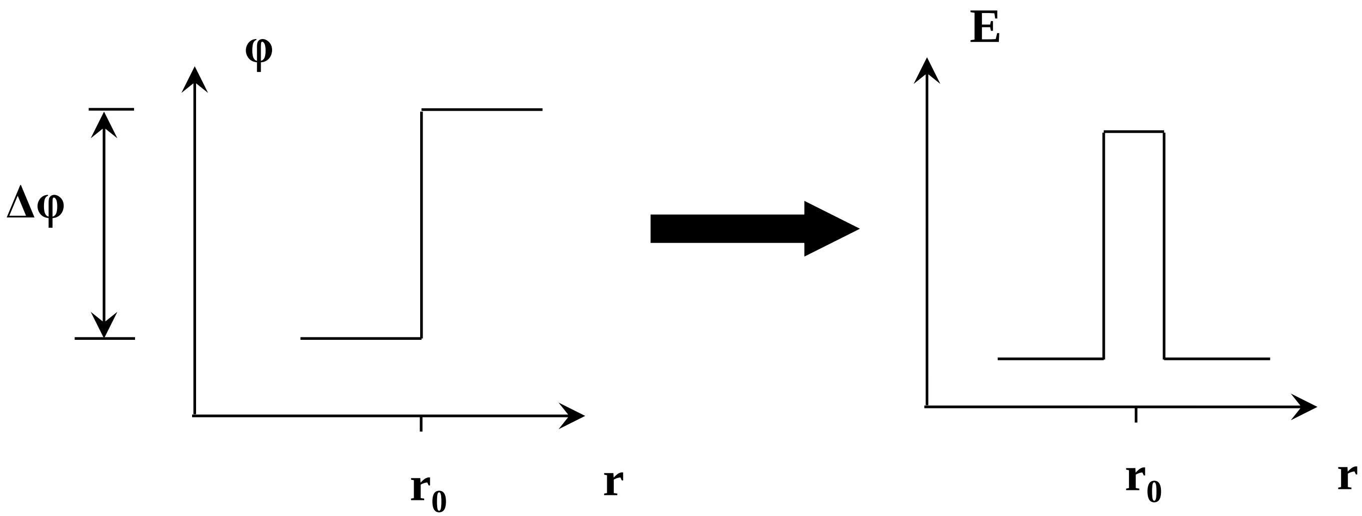

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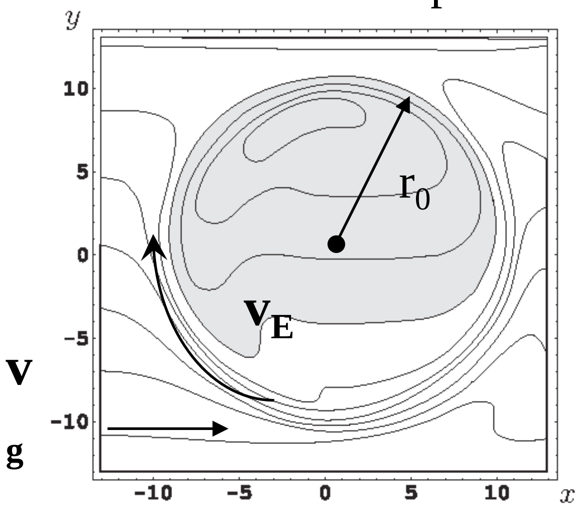

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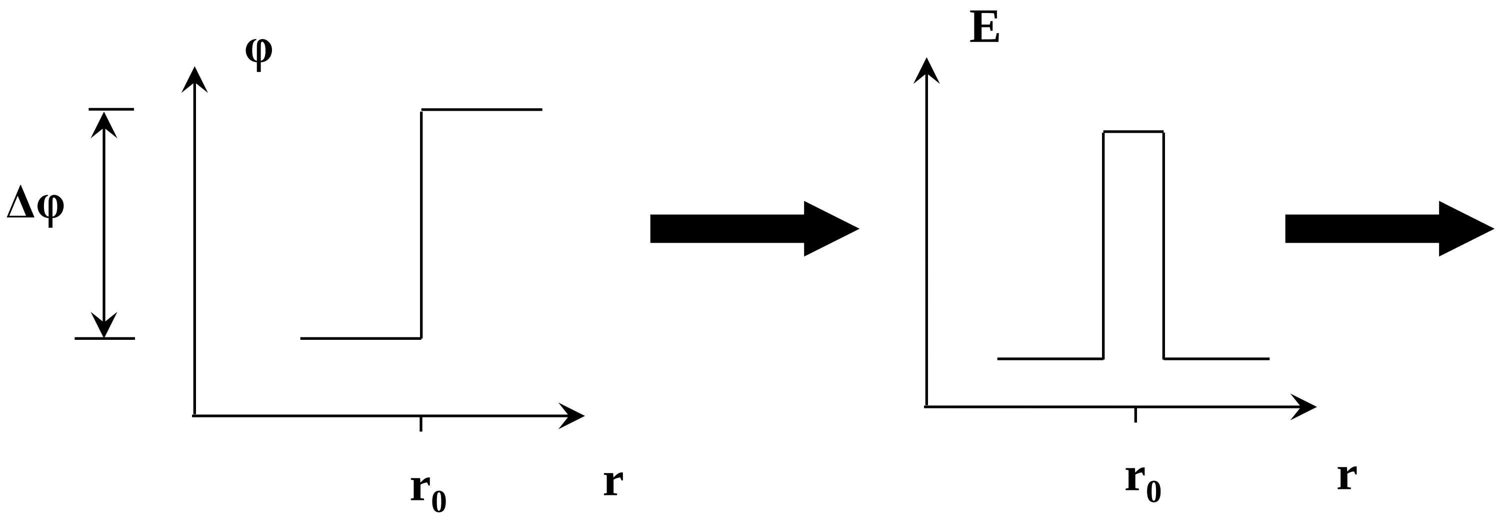

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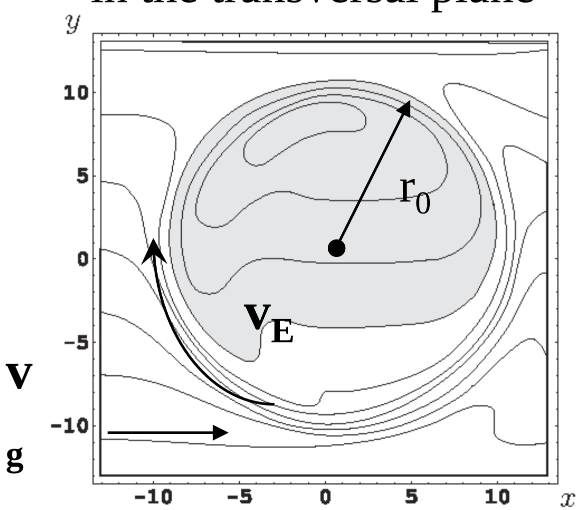

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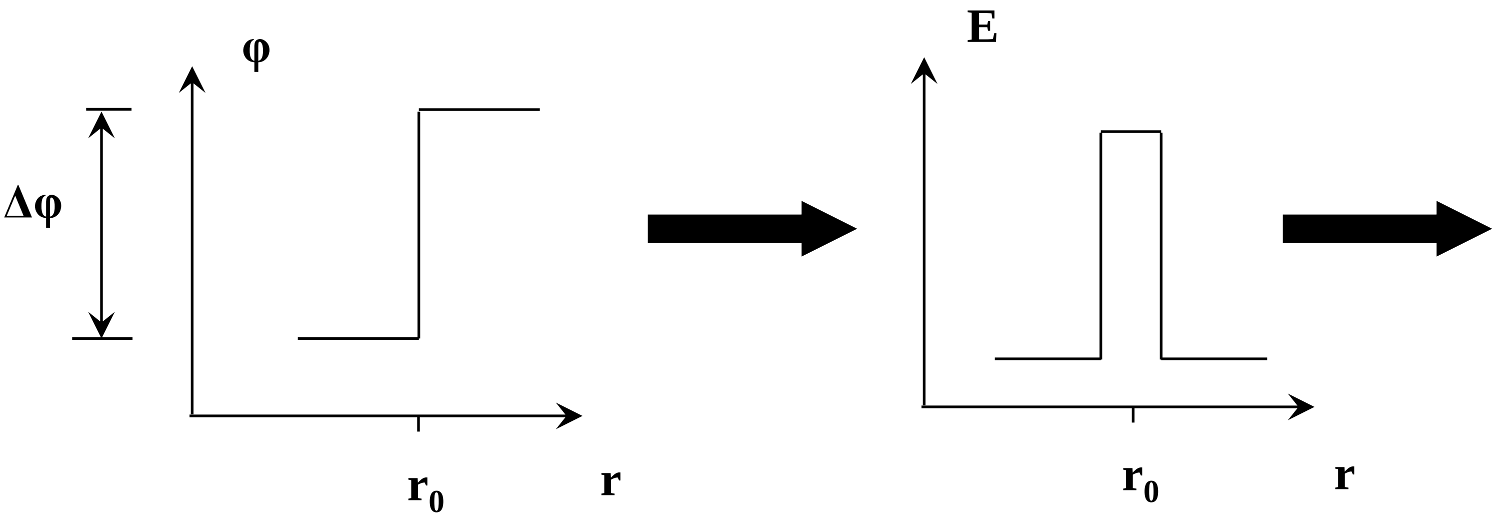
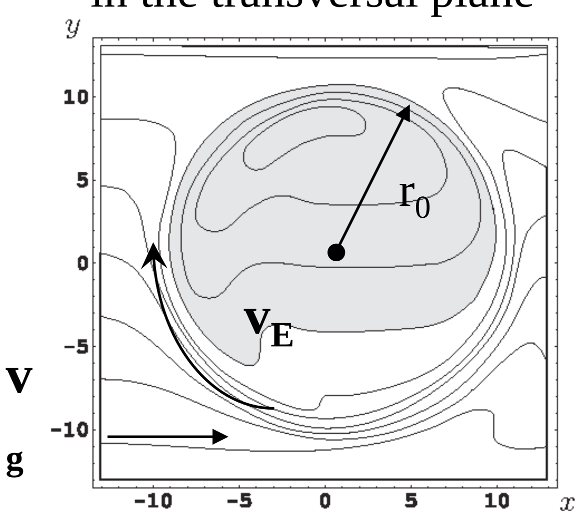


$v_E = c\cdot(E\times B)/B^2$
velocity of the rotation

View of the plasma core in the transversal plane



$\otimes \vec{B}$

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The threshold of the vortex confinement: analytical estimations

$$\frac{e\Delta\varphi}{T_e} \geq 10\sqrt{\frac{T_e M}{Z}}\frac{\kappa c}{eBL}$$

According to the SMIS 37 parameters
(L=30 cm, B=0.5 T, κ=6, Te=100 eV) one can get:

$$\frac{e\Delta\varphi}{T_e} \geq 0.45\sqrt{\frac{A}{Z}}$$

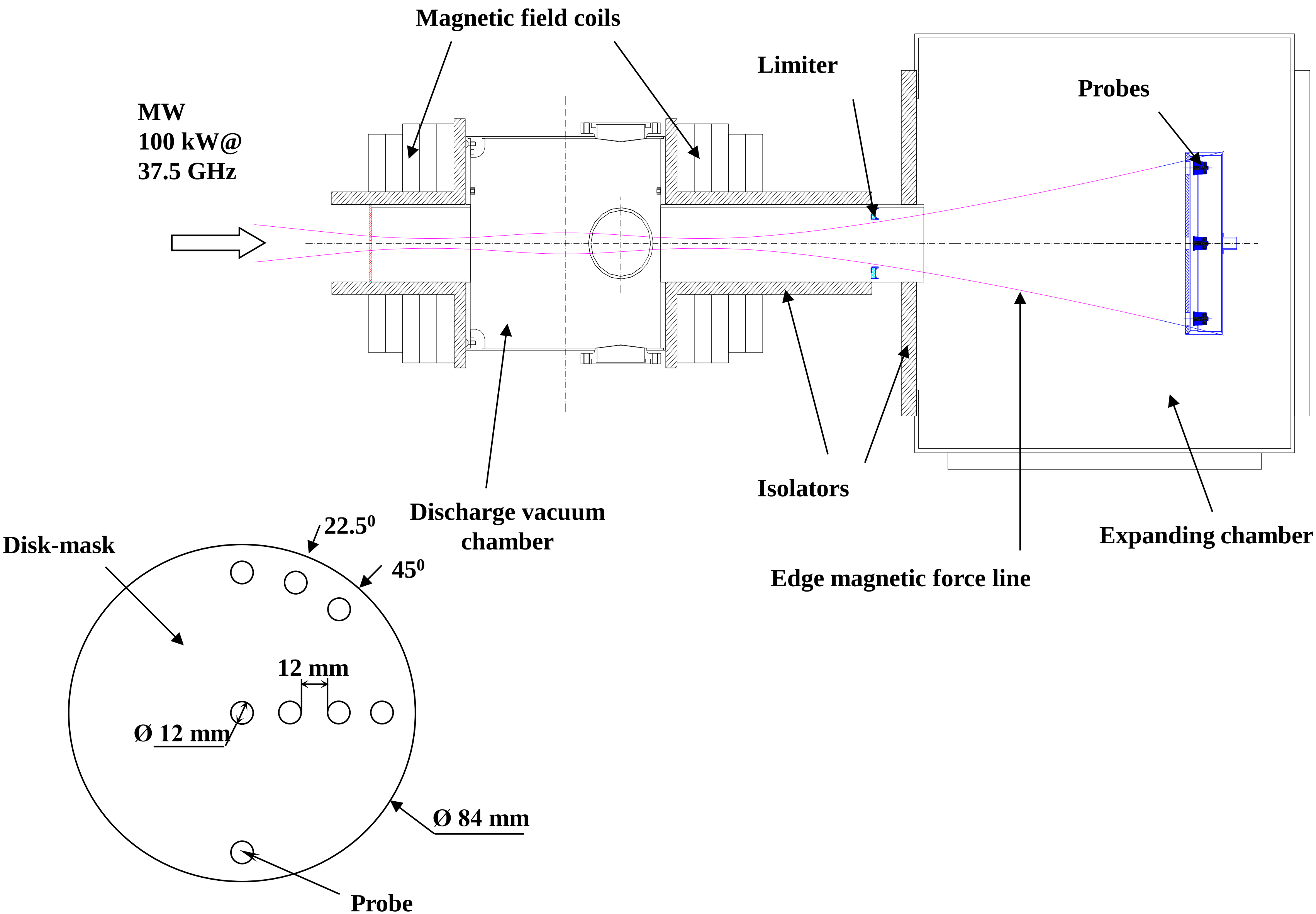
For the helium and nitrogen ions:

$$e\Delta\varphi \geq 1.2T_e$$

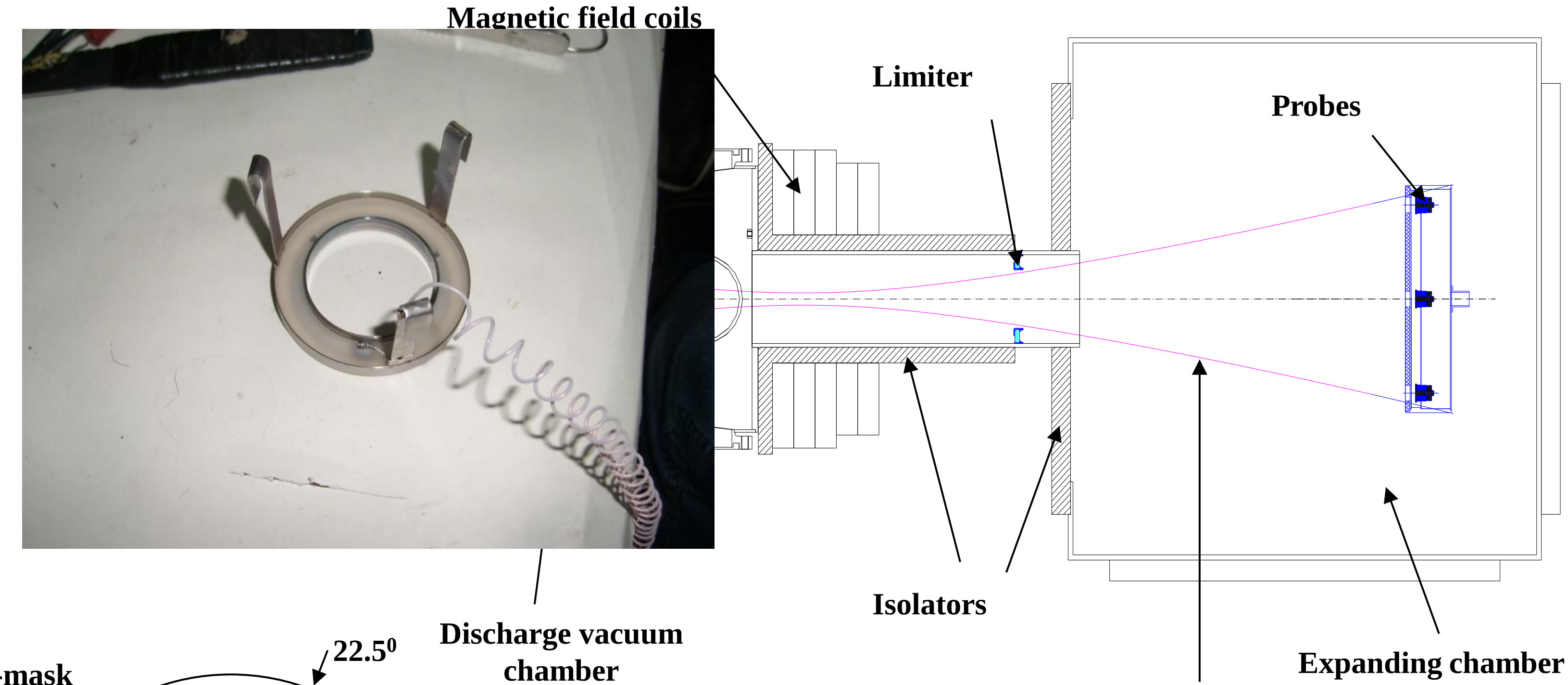
So, the value of the limiter
Voltage has to be in order of
100 V according to the estimations

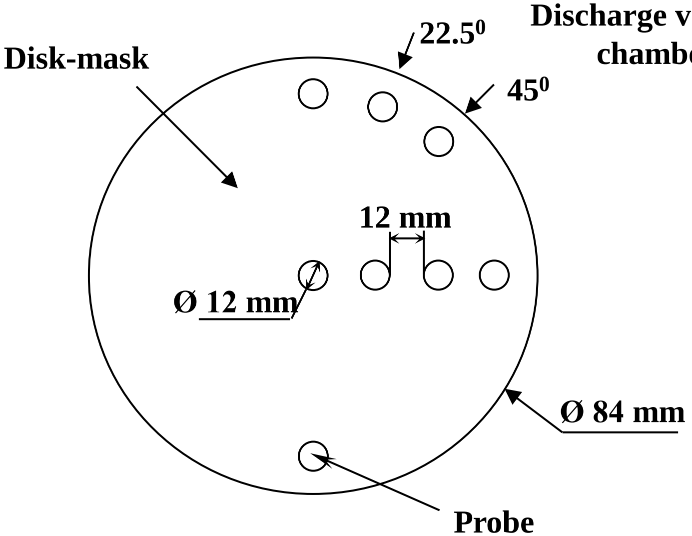
Beklemishev, A. D. Shear Flow Effects in Open Traps. Theory of Fusion Plasmas, AIP Conference Proceedings.
V. 1069. P. 14 – 25 (2008)

Scheme of the experiments (SMIS 37)



Scheme of the experiments (SMIS 37)





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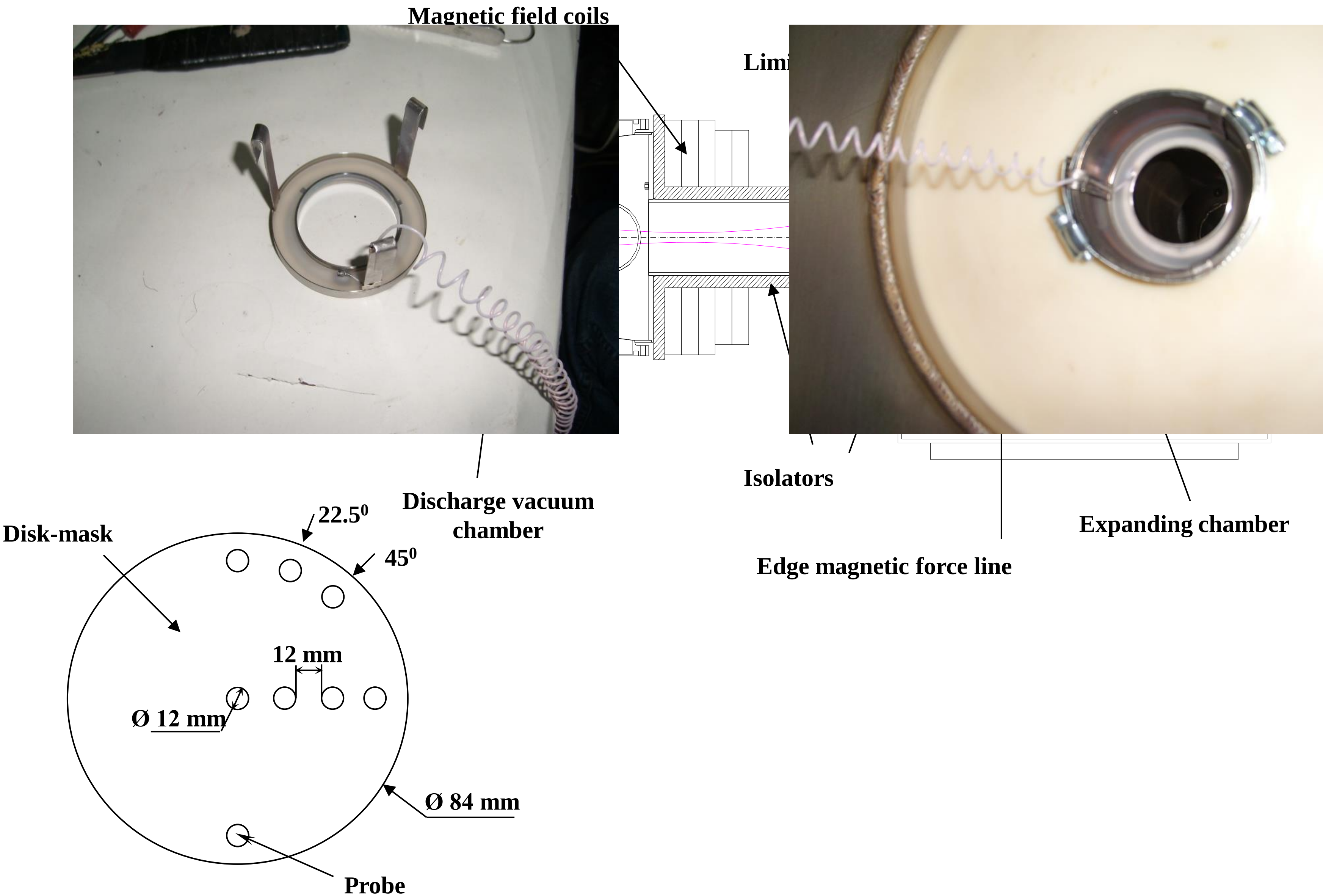

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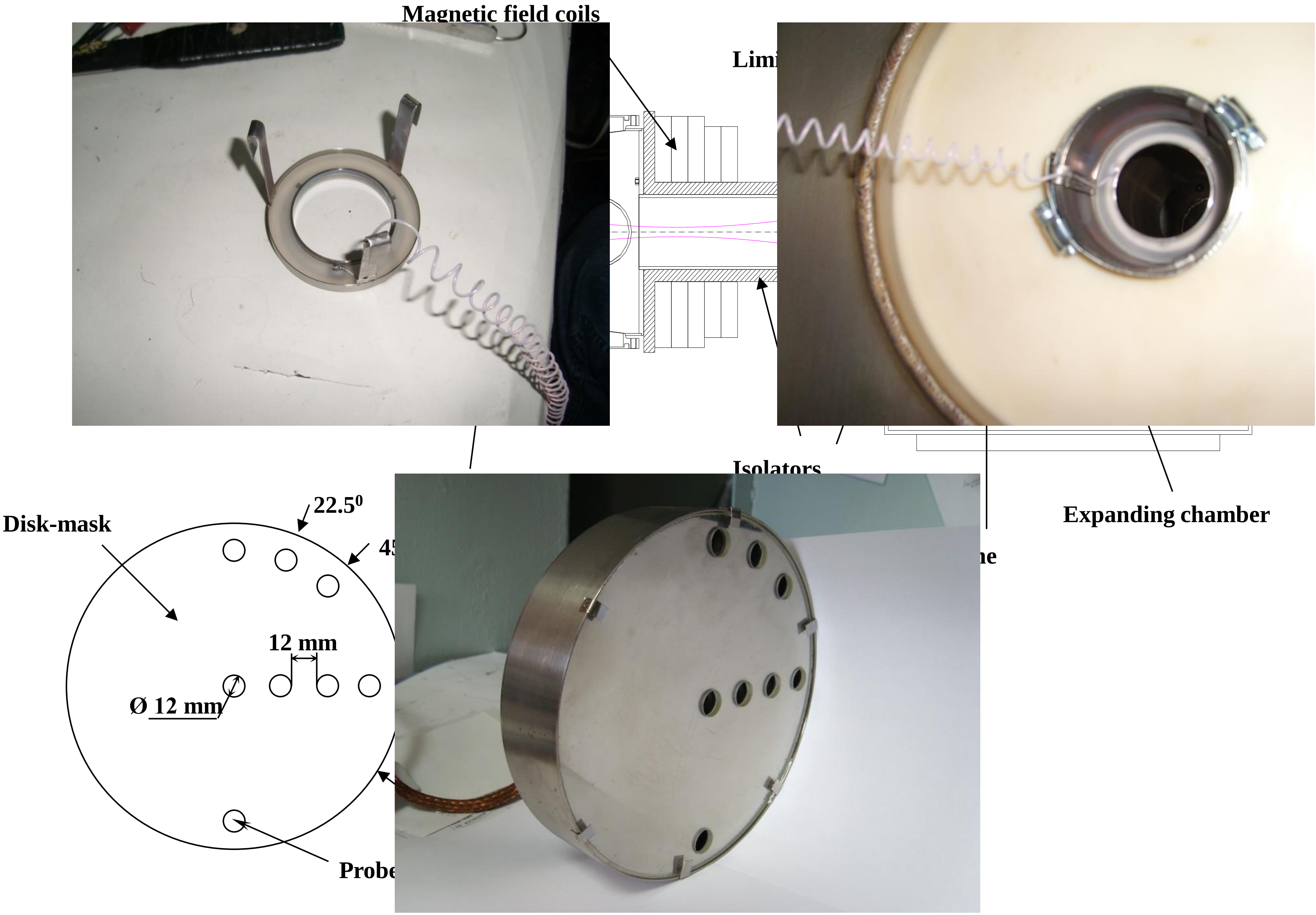
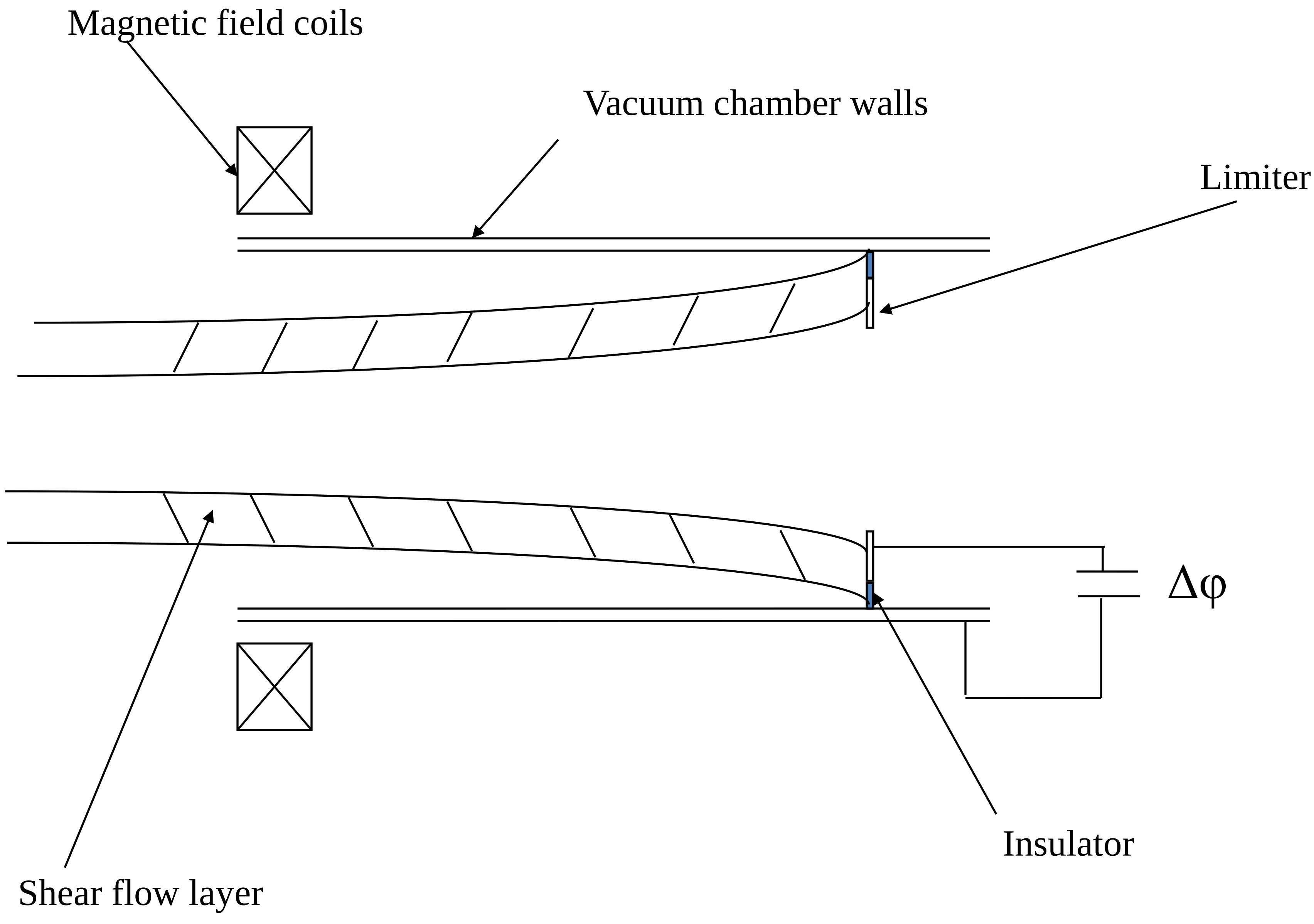
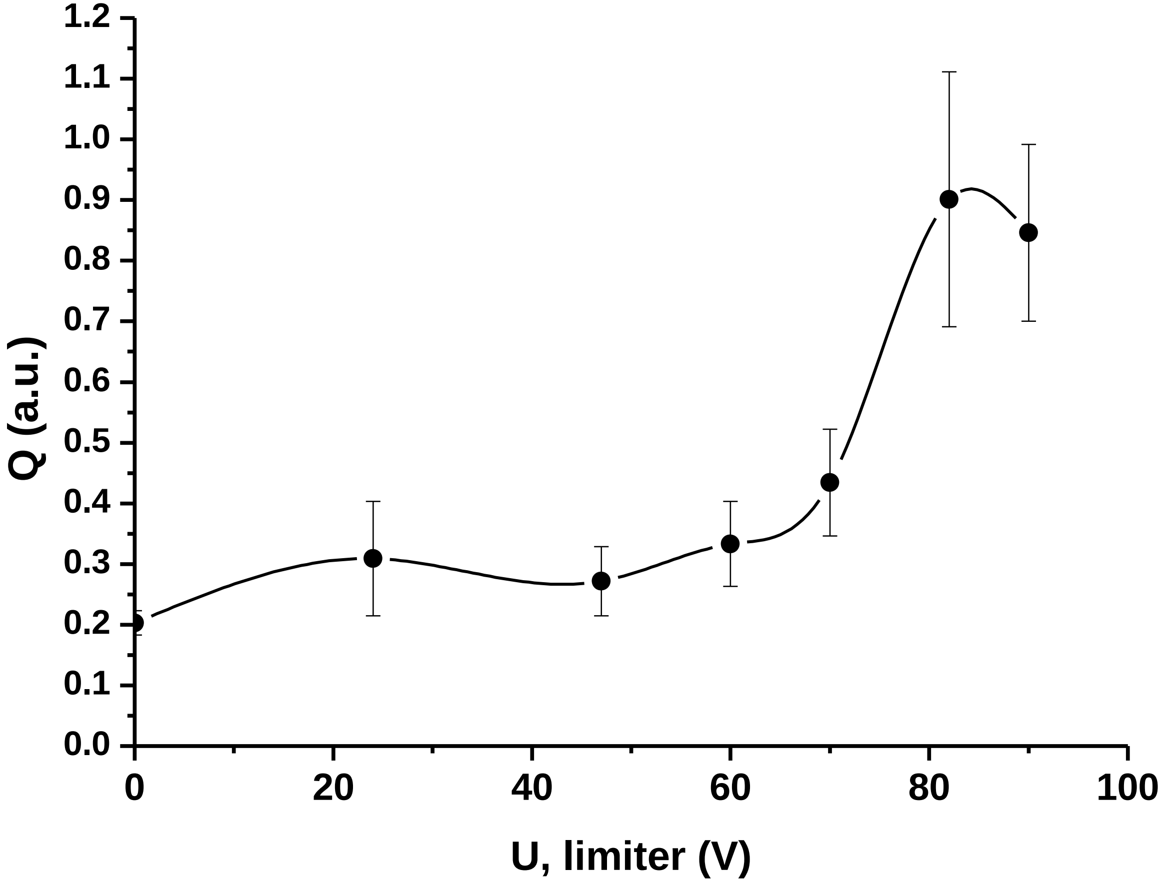


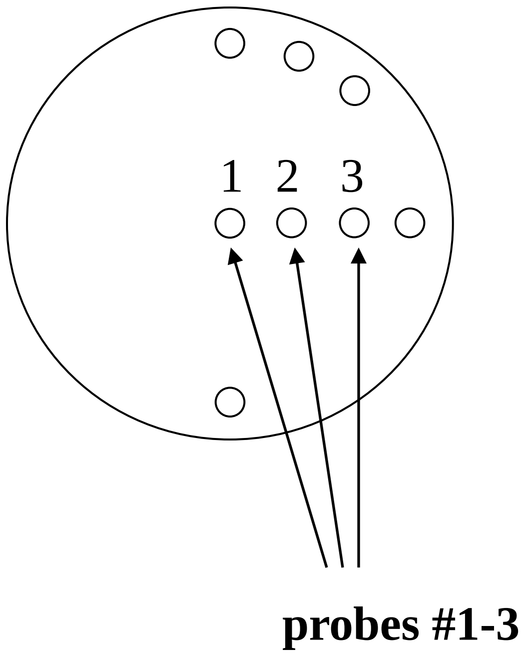
Scheme of the experiments (shear flow drive)



Total charge registered by probes #1-3, Helium

Magnetic field at the plug: 1.7 T





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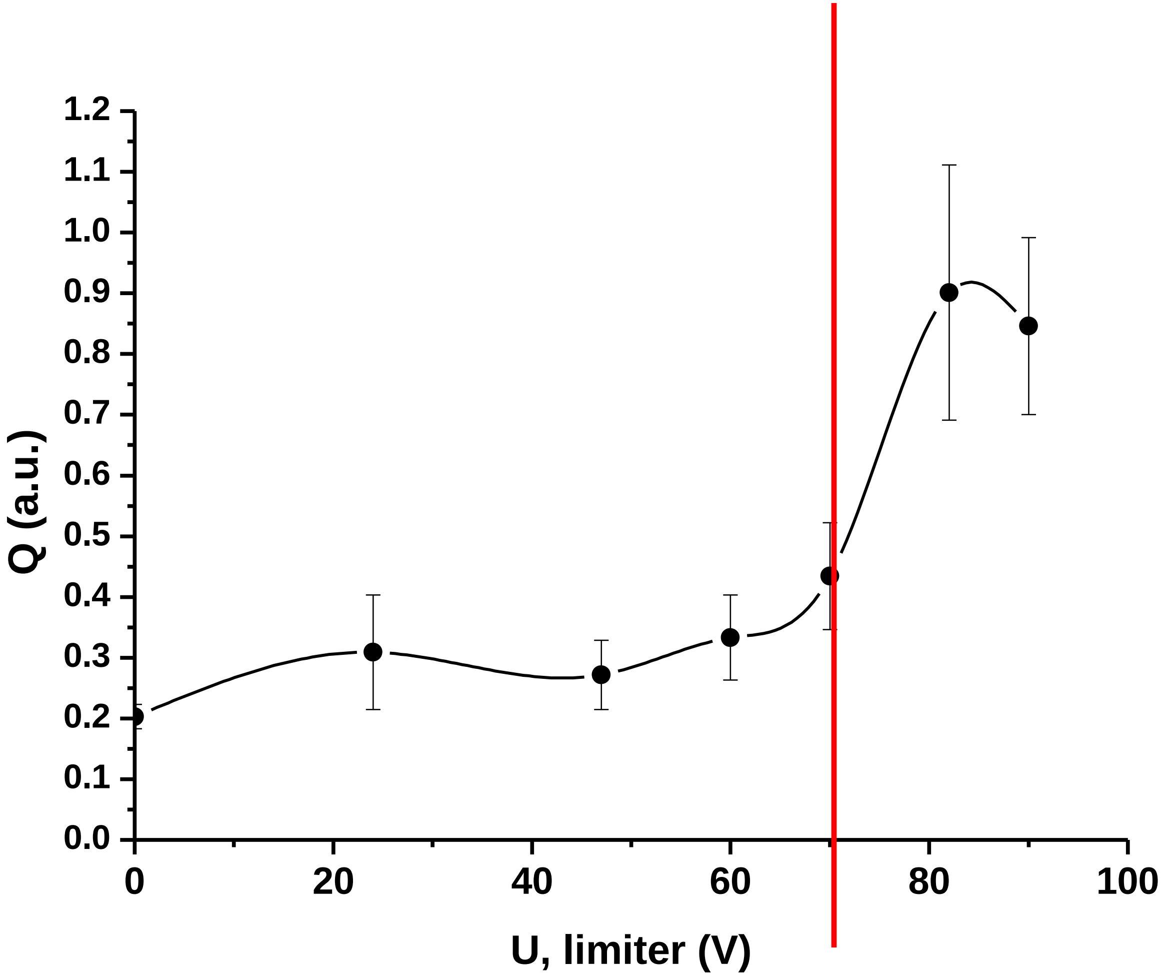
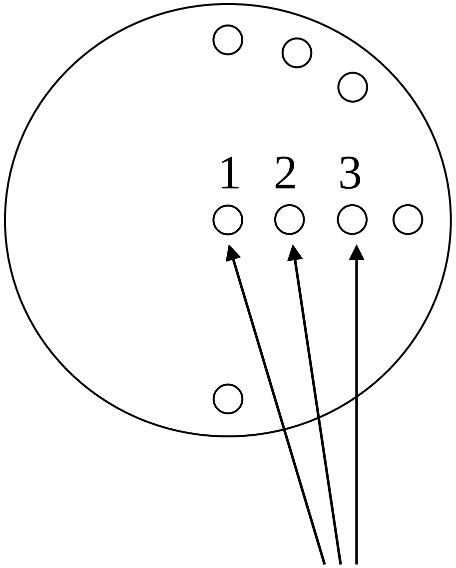
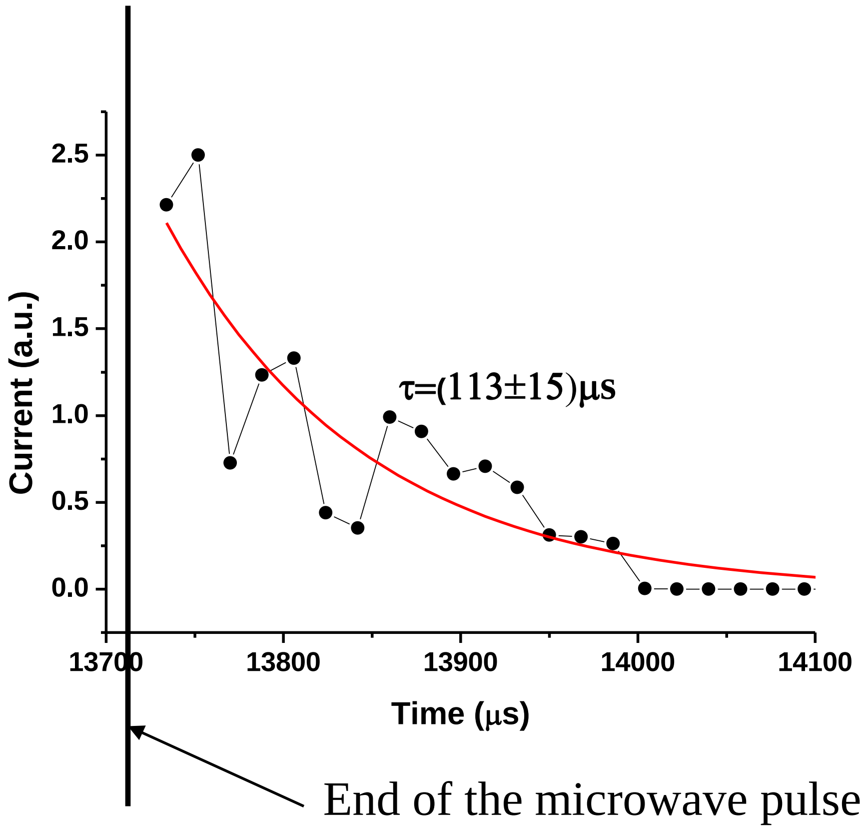




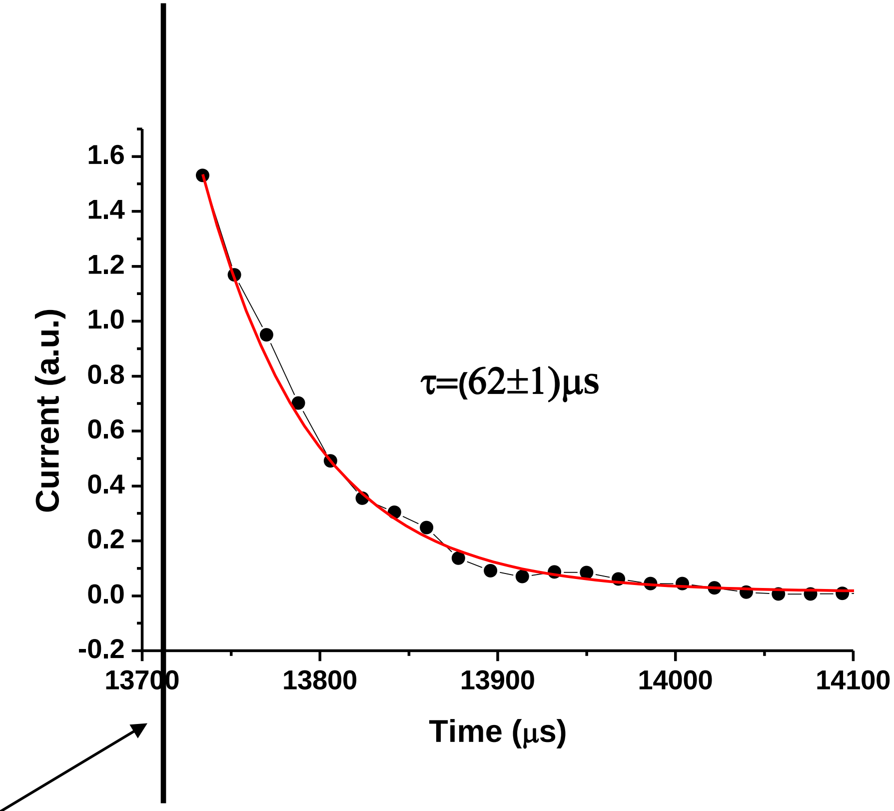
probes #1-3

"Decay" experiment: microwave pulse-length 400μs

Limiter voltage U_{lim}=150 V



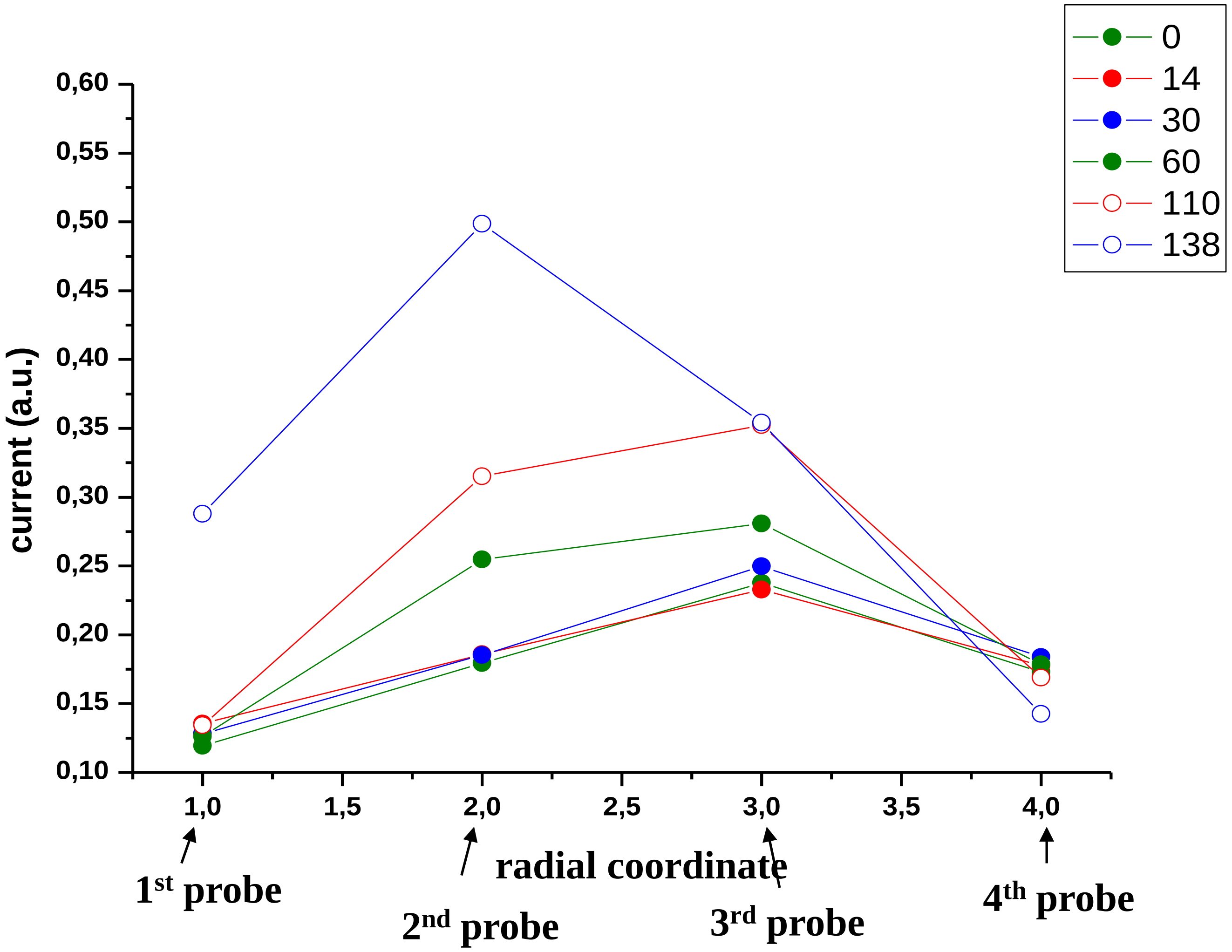
Limiter voltage U_{lim}=0 V



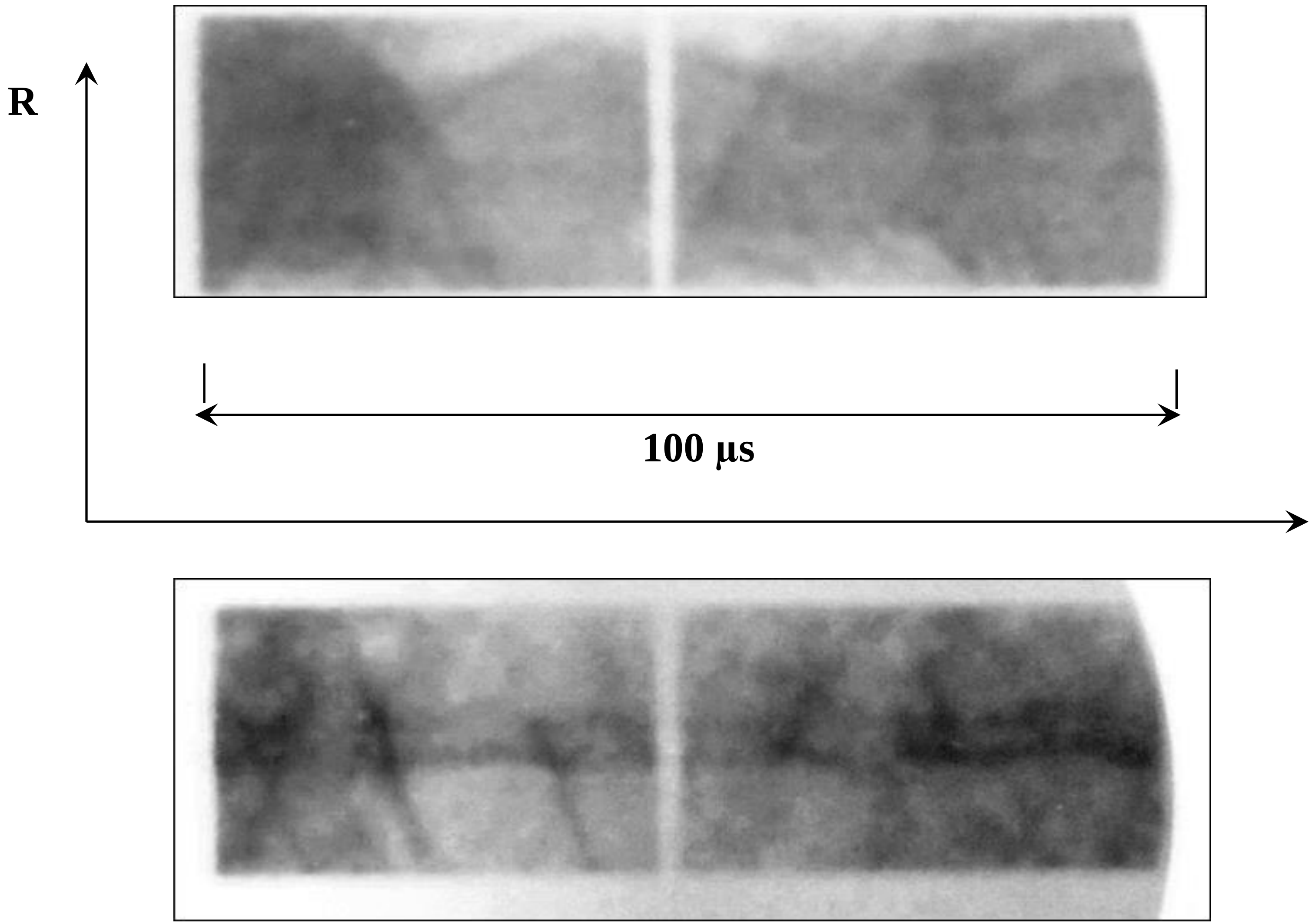
End of the microwave pulse

Ion saturation current on the center probe (#1)

Results of the recent experiments: ion current density profiles, B=1.7 T



Results of the experiments with streak camera: photos, B=1.7 T



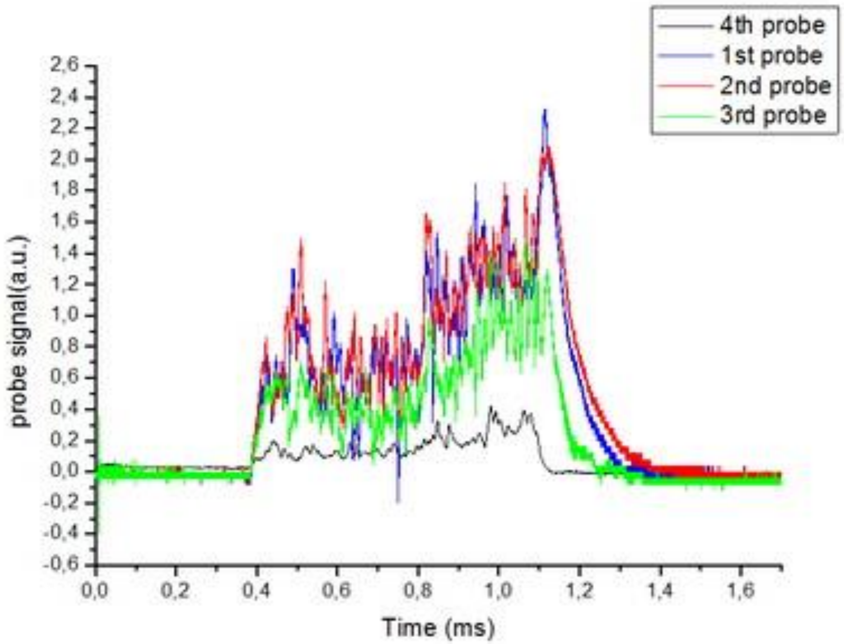
Limiter potential 0 V

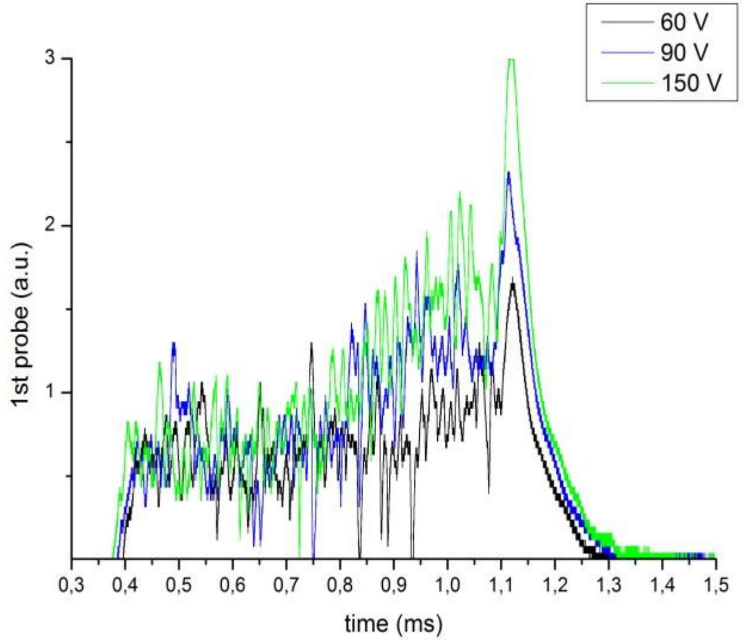
time

Limiter potential 120 V

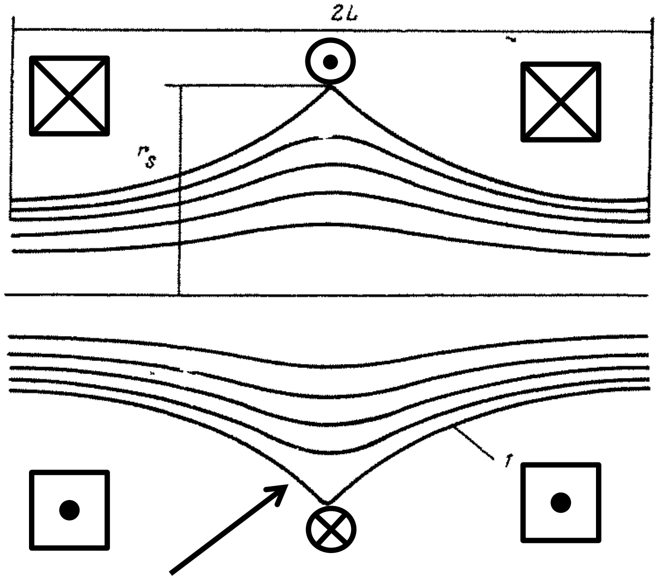
75 GHz plasma heating

- Total current increase with the shift of limiter potential
- Shift of the plasma density profile maximum
- Bias of the plasma potential in radial direction with no external potential on limiter





Divertor (DS) stabilization in mirrors



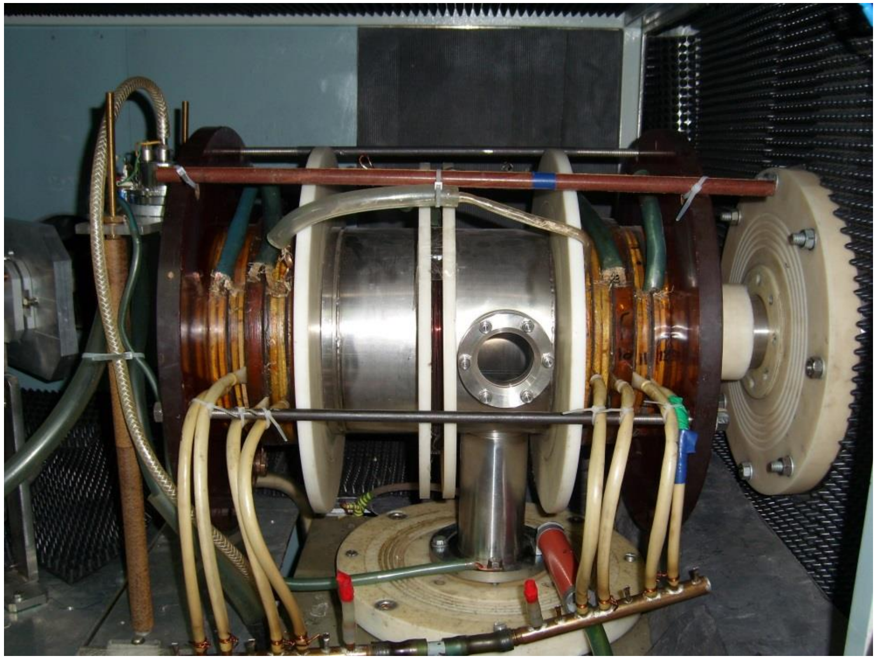
Contrary to min B principle realization of DS is based on maintenance of the MS pressure profile $p \sim U^{-\gamma}$

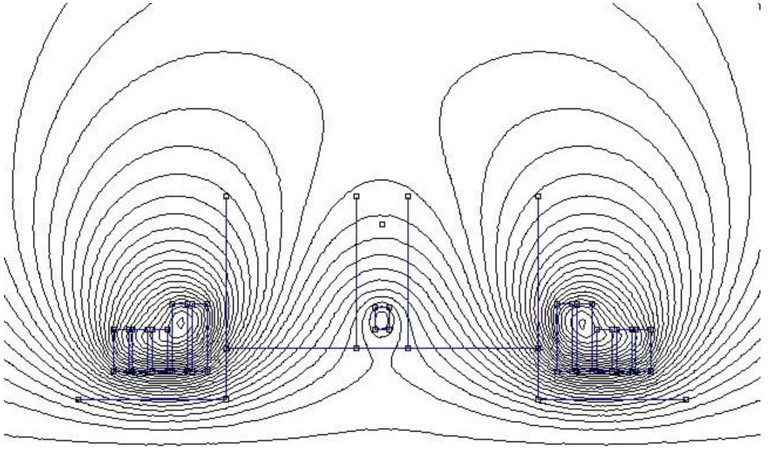
Plasma compressibility is the main stabilizing effect in the nonparaxial magnetic field with “unfavorable” curvature. Under influence of this effect sufficiently gradually decreasing pressure profiles become stable for all interchange flute-like modes.
$grad(B)/B > grad(p)/p$

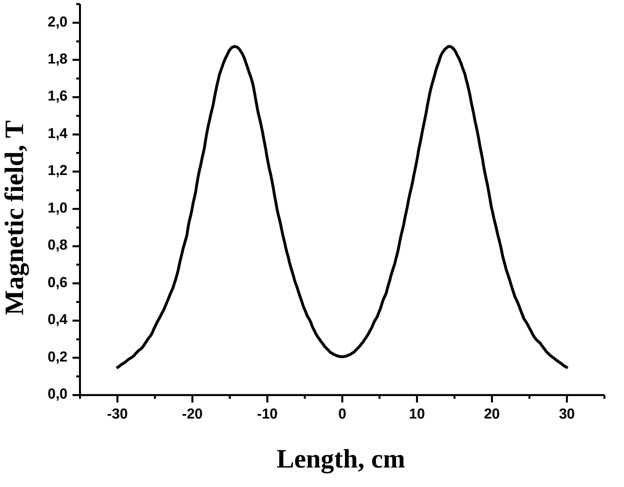
Optimal divertor
$r_s \sim L$

Presence of the divertor-like separtrix with magnetic field nulls essentially enhances the effect of compressibility and leads to existance of MS pressure profiles with the vanishing pressure value at separatrix $p(\psi_s)=0$

Divertor magnetic system

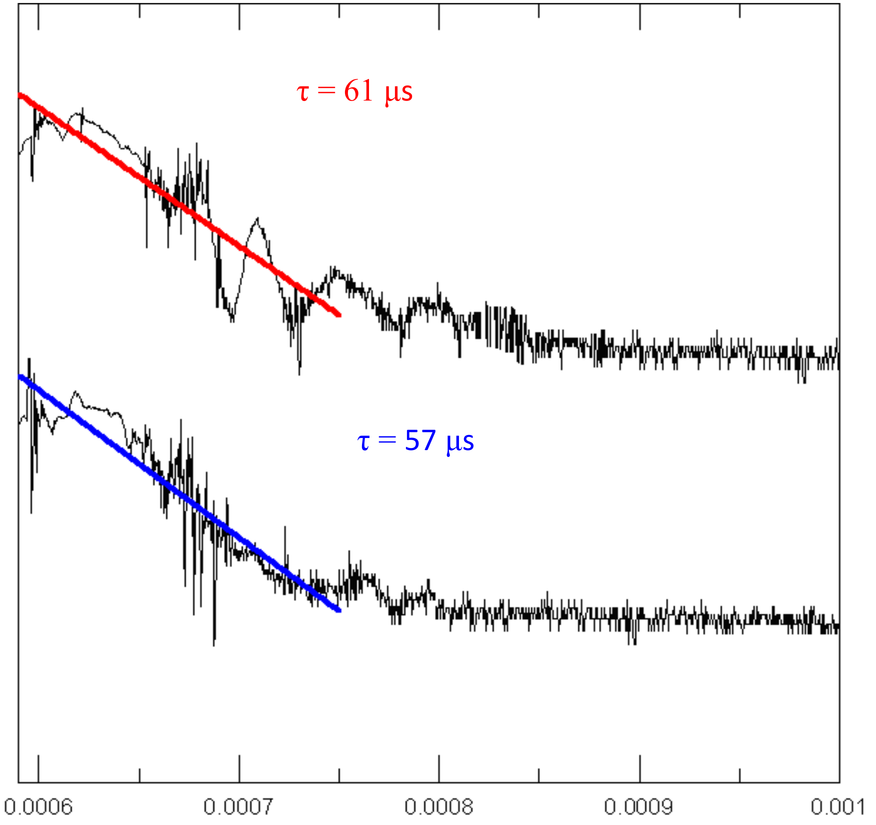


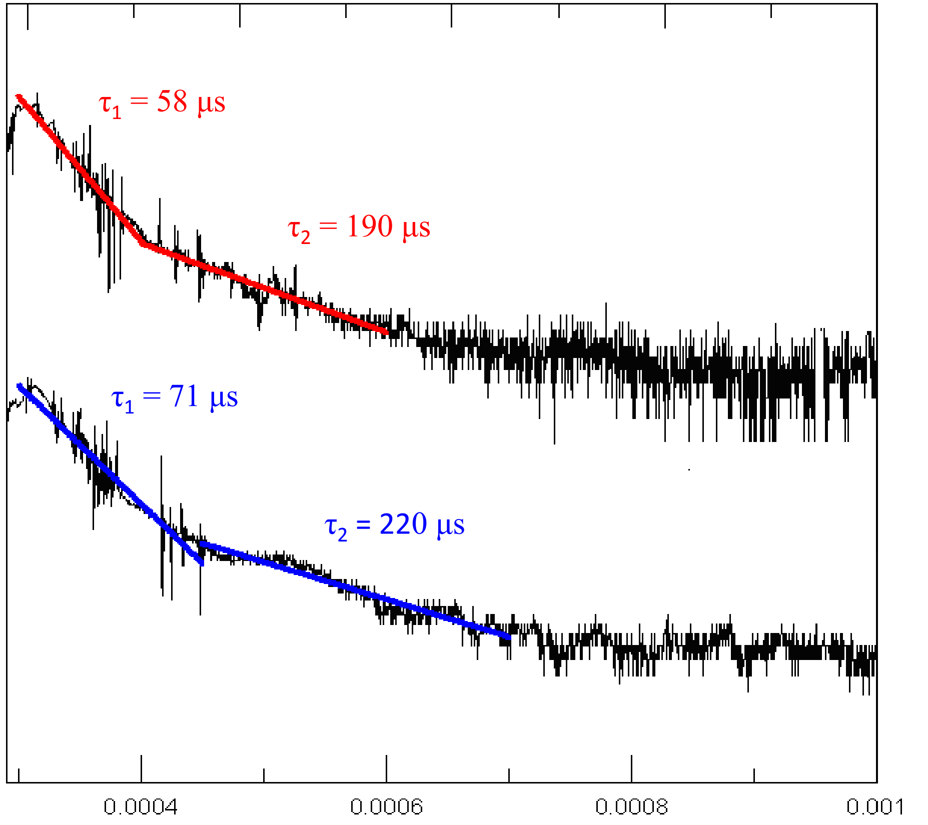




Coils current – 1.4 kA

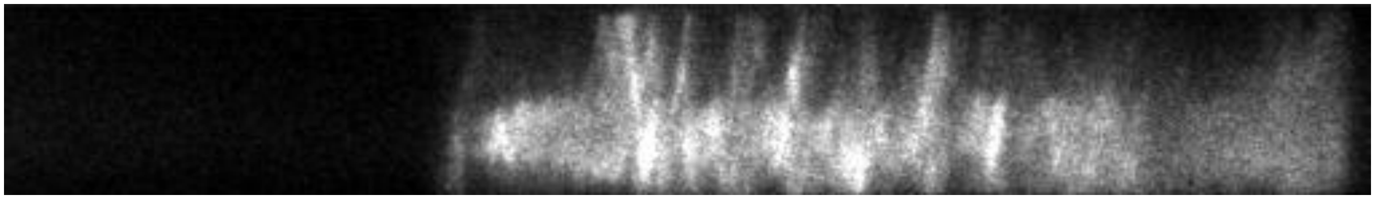
Plasma confinement in open magnetic trap with divertor





Plasma decay. Waveforms of the probe ion currents in semilog scale. The forms start from the end of MW pulse. Left side – trap w/o divertor. right – with divertor.

Plasma confinement in open magnetic trap with divertor



a.)

b.)

a – trap w/o divertor, b – with divertor

Thank you for your attention!