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MEASUREMENTS OF THE SLOSHING ION PARAMETERS IN THE GDT EXPERIMENT

Budker INP 95-109

NOVOSIBIRSK

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ABSTRACT

The results of the measurements of energy and angular distribution of the sloshing ions in the GDT experiment are presented. The experimental data are discussed in comparison with predictions of the model which includes classical processes of the angular scattering and energy losses of the fast ions in the bulk plasma.

1. Introduction

The GDT experiment [1] is an open axisymmetric trap with a two component plasma. In the trap after its filling with a warm target plasma the second plasma component - a population of the fast sloshing ions is generated as a result of injection of powerful hydrogen neutral beams. About 30% of injected atoms are transformed into fast ions due to charge exchange on the target plasma ions and are captured into the trap. The magnetic field of the device increases from the center to the mirrors, therefore motion of the ions takes place between two reflection regions, which are located in the increasing field. As the ions approach the turning points, their longitudinal velocity reduces and the density increases. A simple estimation shows, that the relative density peak is a function of the injection angle and the angular spread of the ions: $n_{max}/n_0 \simeq 1/\sin\Theta_0 \cdot (2\mathrm{ctg}\Theta_0/\Delta\Theta_0)^{1/2}$, where Θ_0 and $\Delta\Theta_0$ are the injection angle and the angular spread of ions in the midplane, respectively.

A subject of the report is the following: what is the dominant interaction mechanism of the fast ion population with the target plasma in the GDT? Is it determined only by the Coulomb collisions or by some additional non-classical processes? That is a basic question for open traps with two component plasma. It is expected that in a neutron source, based on the GDT concept [2], the fast ion density peaks, located in the reflection regions, will be narrow and high. Just these located zones will produce the maximum neutron yield. On the other hand, the effect of the fast ion density peaking can be used for the provision of the MHD-stability of two-component plasma in the open traps [3]. For this purpose it is necessary to form the favourable curvature of the magnetic field lines in the reflection region of ions, where their pressure is high.

Thus we can see, that the experimental study of the angular scattering and energy losses of the sloshing ions is a key point in the development of the GDT-based neutron source.

2. Experimental conditions and diagnostics

Experiments were performed on the GDT device [1]. A sectional view of the GDT central cell is presented on the Fig.1.

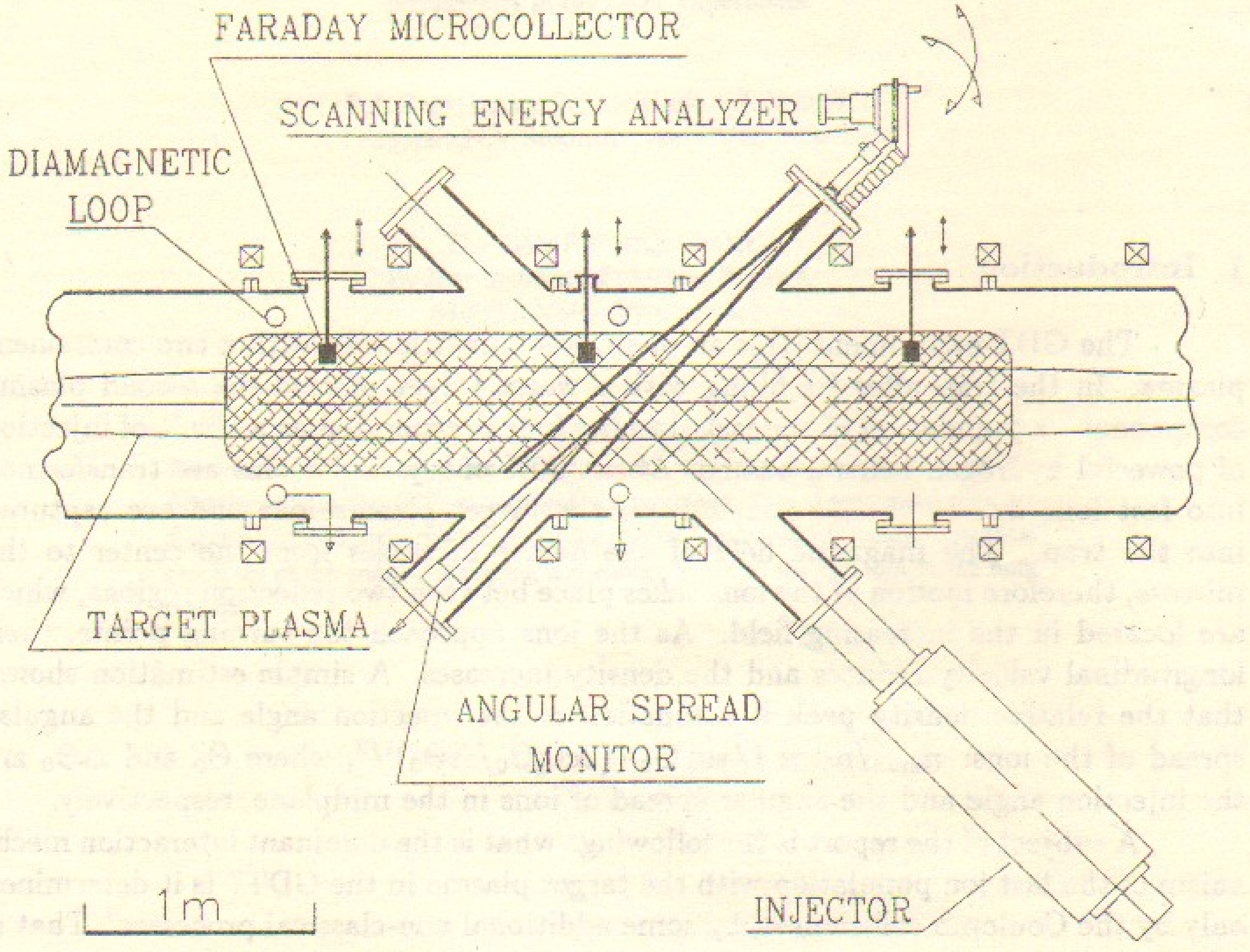


Fig.1. Part of the GDT central cell and location of the diagnostics

Parameters of the sloshing ions have been measured at following conditions.

Target plasma parameters

Plasma density	$n \simeq 5 \cdot 10^{13} cm^{-3}$
Initial electron temperature	$T_e \simeq 3-5\ eV$
Diameter in the centre	$2a \simeq 30\ cm$

Injection parameters

Energy of particles	$E_0 \simeq 15\ keV$
Equivalent current	$I_0 \simeq 250\ A$
Pulse duration	$\tau = 1\ ms$
Captured power	$P \simeq 1\ MW$
Energy of fast ions population	$W \simeq 160\ J$
Maximum plasma temperature	$T_e = 45\ eV$

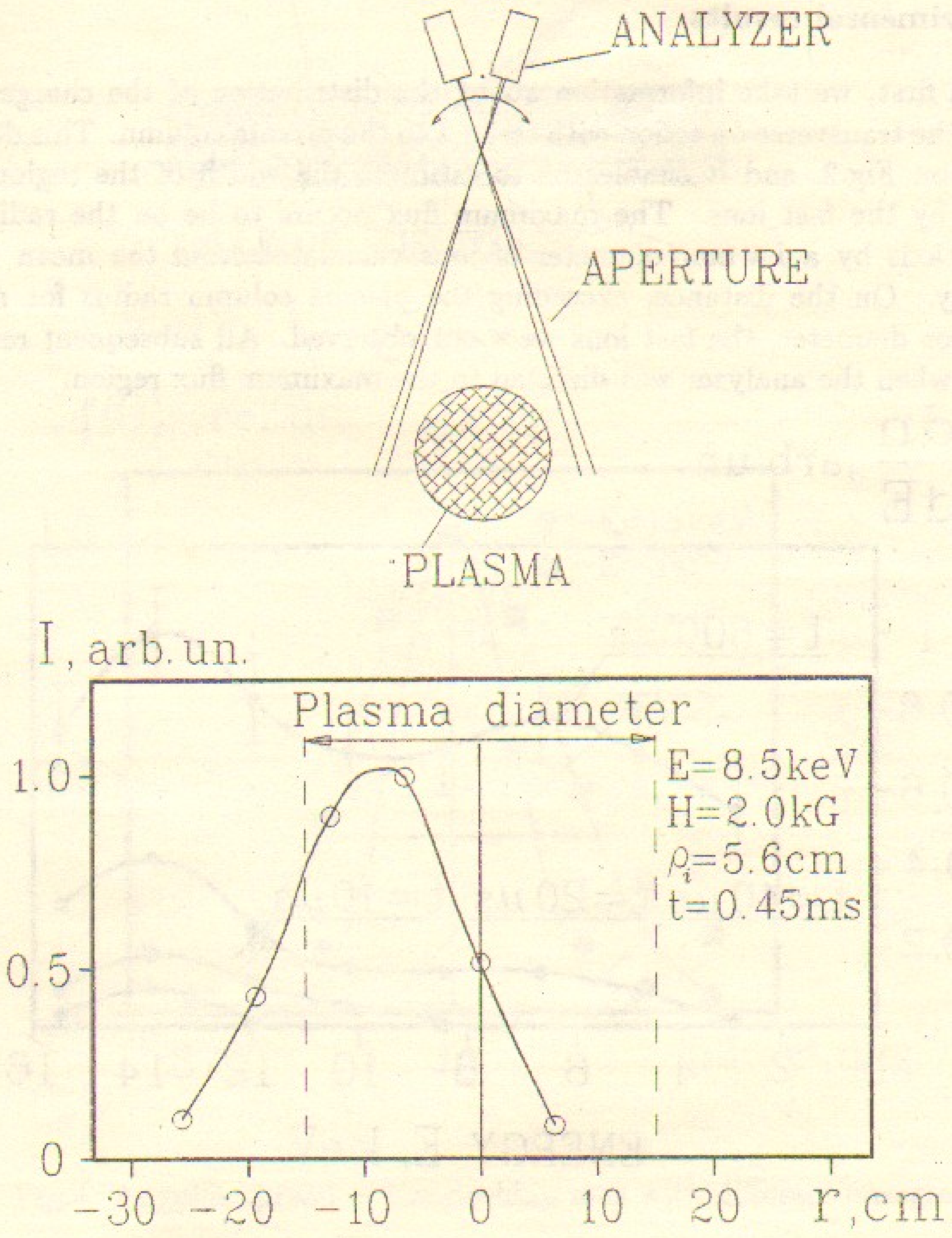


Fig.2. Radial dependence of charge exchange outflux.

For measurements we have used the following diagnostics, which were located as it is shown on Fig.1. The main diagnostics are based on the analysis of charge exchange atoms emitted by the plasma. We used two charge exchange analyzers. The first one has a small angular aperture and allows to measure the energy distribution functions and angular spread of the sloshing ions in the central cell of the GDT [4]. The second analyzer with stripping foils has no energy resolution and was used as a monitor of the angular spread of the charge exchange atoms emitted from the plasma. We used also diamagnetic loops for measurements of the fast ions pressure as well as the target plasma [5]. Faraday microcollectors were located in different points of the ion cloud, and they measured the local current density of the ions [6].

3. Experimental results

At first, we take information about the distribution of the charge exchange atoms in the transverse direction with respect to the plasma column. This dependence is shown on Fig.2, and it enables us to estimate the width of the region which is occupied by the fast ions. The maximum flux occurs to be on the radius shifted from the axis by a Larmor diameter of ions calculated from the mean transverse ion energy. On the distance, exceeding the plasma column radius for more than the Larmor diameter, the fast ions were not observed. All subsequent results were obtained when the analyzer was directed to the maximum flux region.

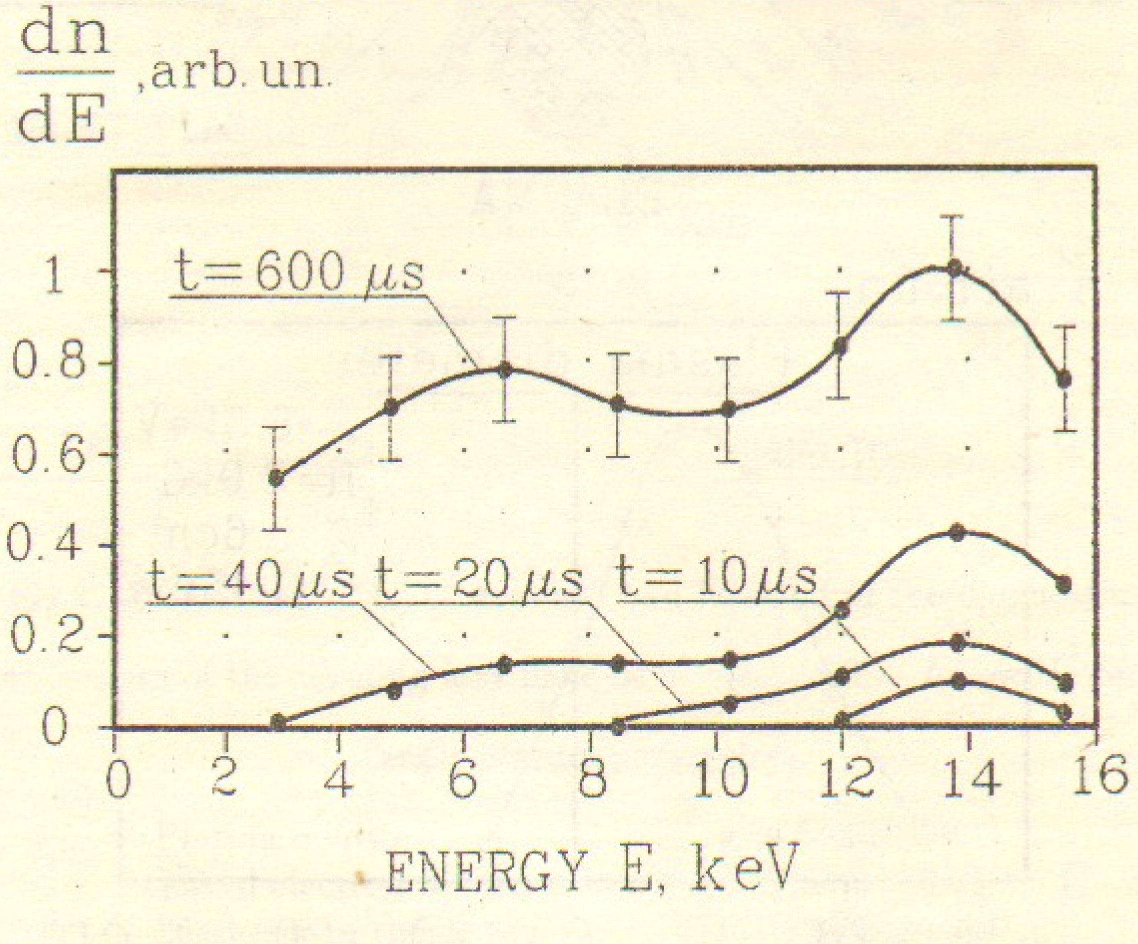
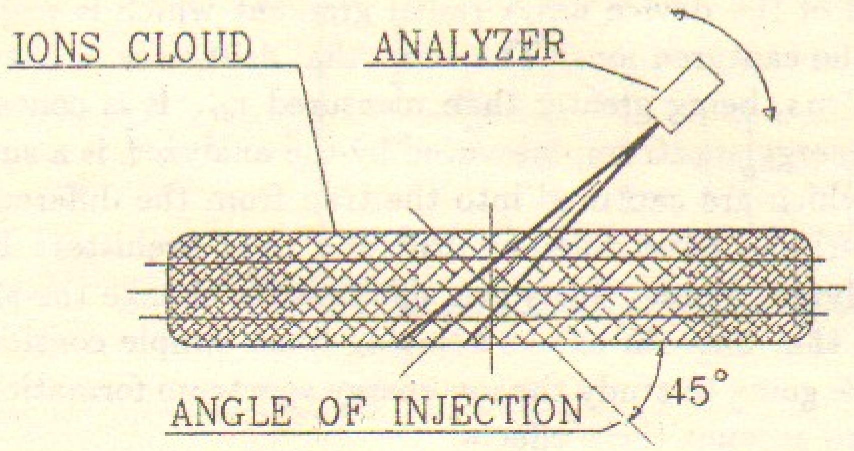


Fig.3. Energy distribution functions of sloshing ions

On Fig.3. the energy distribution functions of the fast ions are presented at different time points after the start of the neutral beam injection. Since the deformations of the ion distribution function at the initial stage of the injection being measured, one can directly and easily estimate the drag time of the ions in the target plasma. It is found that the ion drag time corresponds to the estimated electron drag time. From the measurements of the energy spectra one can determine the mean energy of ions. At quasi-stationary stage of the neutral beam injection pulse, the mean ion energy was estimated to be about 8.5 keV.



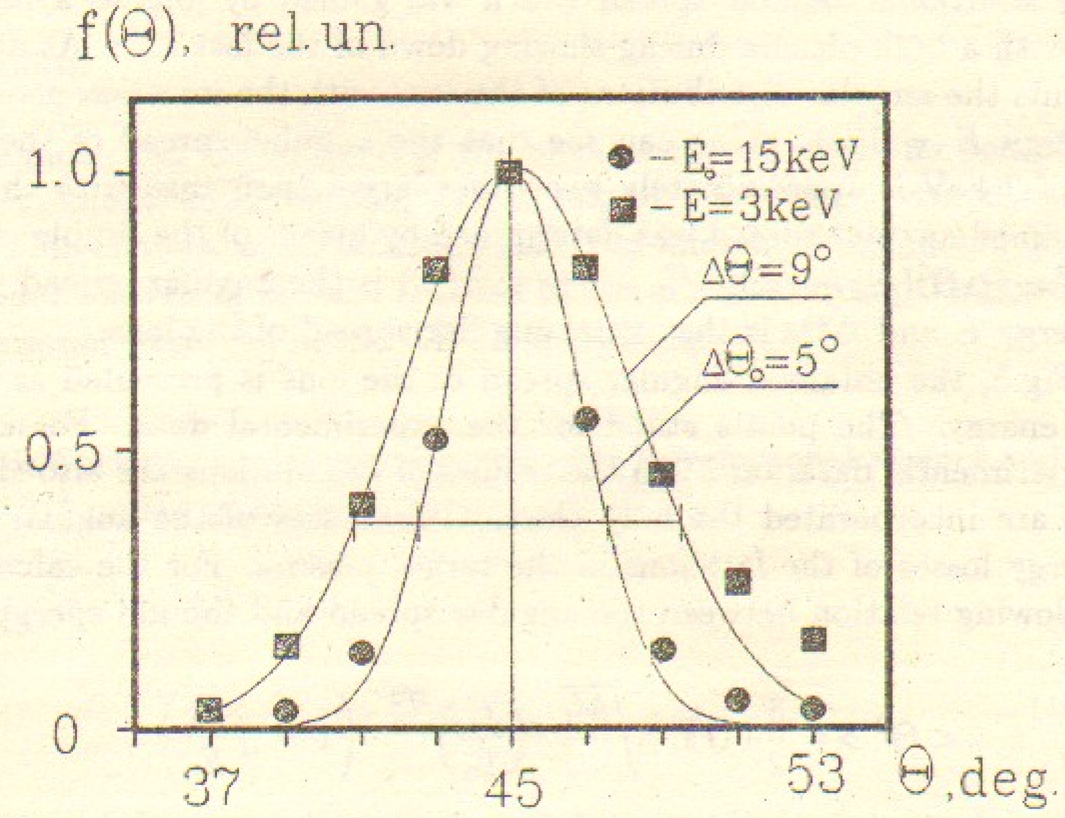


Fig.4. Angular spread of the sloshing ions with different energies

For the azimuthally homogeneous neutral beam injection, the form of the fast ions distribution function can be estimated from the following expression $f(E) \sim E^{\frac{\tau_{dr}}{\tau_{ex}}-1}$ [7]. Under our experimental conditions, electron drag time was $\tau_{dr} \simeq 0.2ms$ and charge exchange time was $\tau_{ex} \simeq 0.4ms$ for the middle of the injection pulse [5]. So, the energy spectrum of the sloshing ions should be approximately the following $f(E) \sim E^{-1/2}$. But the neutral injection in the real GDT experiment is azimuthally inhomogeneous. The injection was performed by six injectors divided into two groups, one opposite to another. In each group the angles between injectors are 30^0. Magnetic field of the device has a radial gradient which is responsible for the azimuthal drift of the captured ions. The azimuthal drift-time of the fast ions is approximately $\tau_{df} \simeq 0.5ms$, being greater than measured τ_{dr}. It is conceivable that in such conditions the energy spectrum, measured by the analyzer, is a superposition of spectra of the ions which are captured into the trap from the different injectors. These groups of the particles have different drift and drag prehistory before their registration by the analyzer. These effects can significantly change the shape of the measured spectra from that one can expect relaying upon simple consideration. In the nearest future we are going to study the ion energy spectrum formation in a more detailed way to take into account these effects.

The ion distribution functions were measured under different orientation of the analyzer with respect to the injection angle. Thus in the experiments we can measure the additional angular spread which was gained by ions as a result of the interaction with a bulk plasma during slowing down of the fast ions. As an example, Fig.4. presents the angular distributions of the ions with the injection energy E_0 and with an energy $E = 3keV$. One can see that the angular spread of the ions with the energy of 3 keV is approximately two times larger than that with the injection energy. Obtained angular spread was determined by means of the simple relationship $< \Delta\Theta^2 >^{1/2} = (\Delta\Theta^2(E) - \Delta\Theta_0^2)^{1/2}$, where $\Delta\Theta(E)$ is the angular spread of the ions with the energy E and $\Delta\Theta_0$ is the initial angular spread of the ions.

On Fig.5, the obtained angular spread of the ions is presented as a function of the ions energy. The points stand for the experimental data. For comparison with the experimental data, on Fig.5 the results of calculations are also shown. The calculations are incorporated the only classical processes of the angular scattering and the energy losses of the fast ions in the target plasma. For the calculations we used the following relation between the angular spread and the ion energy, obtained [7]:

$$< \Theta^2 >= \frac{3}{2} \cdot \sqrt{\pi} \cdot \sqrt{\frac{M_i}{m_e}} \cdot \left(\frac{T_e}{E_i}\right)^{3/2} \cdot \left(1 - \sqrt{\frac{E_i}{E_0}}\right) ,$$

where T_e is the electron temperature and E_0 is the initial energy of the particles. The results, shown on Fig.5, refer to the time point corresponding to a half-time of the injection pulse when the bulk plasma electron temperature was 20 eV.

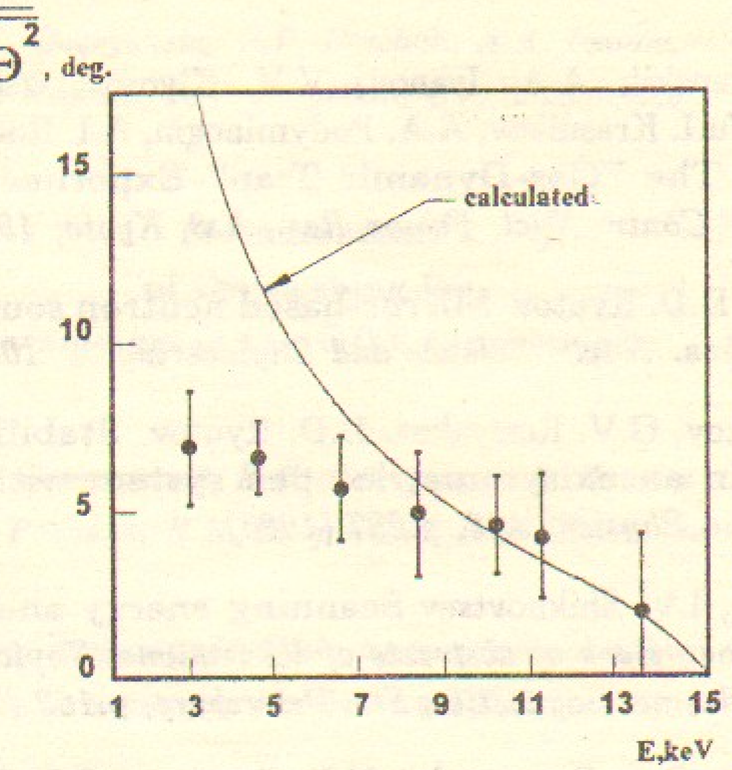


Fig.5. Angular spread of fast ions vs. energy.

4. Conclusion

The measured dependence of the angular spread as a function of the energy of ions is explained quite well by their Coulomb interaction with the bulk plasma particles. This enables us to conclude that the microinstabilites which could cause the additional scattering of ions, trapped in the plasma during the powerful neutral injection, are not observed in the GDT experiments.

*This work was supported in part by the International Science and Technology Center (ISTC) under grant #050-94.

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Budker INP 95-109

Ответственный за выпуск С.Г. Попов
Работа поступила 27.12 1995 г.

Сдано в набор 27.12 1995 г.
Подписано в печать 28.12 1995 г.
Формат бумаги 60×90 1/16 Объем 0,7 печ.л., 0,6 уч.-изд.л.
Тираж 80 экз. Бесплатно. Заказ N 109

Обработано на IBM PC и отпечатано на
ротапринте ГНЦ РФ “ИЯФ им. Г.И. Будкера СО РАН”,
Новосибирск, 630090, пр. академика Лаврентьева, 11.