

Study of the axial distribution of DD reaction intensity in the GDT experiments

A.V.Anikeev, P.A.Bagryansky, A.A.Ivanov, A.N.Karpushov,
V.N.Kornilov*, A.A.Lizunov, V.V.Maximov

Budker Institute of Nuclear Physics, 630090 Novosibirsk, Russia

**Novosibirsk State University, 630090 Novosibirsk, Russia*

Introduction

The Gas-Dynamic Trap (GDT) is a long axisymmetric mirror confinement system with the high mirror ratio [1,2]. The plasma confined in the GDT is of two-component. One component is a collisional warm "background" plasma with the ion and electron temperatures of about 100 eV and density of $(3-5) \cdot 10^{13} \text{ cm}^{-3}$. For this component the ion mean free path of scattering into the loss cone is less than mirror-to-mirror distance that suggests the gas-dynamic regime of confinement. The oblique Neutral Beams (NB) injection creates the second plasma component that is fast ions with energies of 2-17 keV and the density up to 10^{13} cm^{-3} . For this component the ion mean free path of scattering into the loss cone is much greater than mirror-to mirror distance. Consequently the regime of confinement is appeared to be mirror for this component.

The main objective of the GDT experiments is the studying of the basic physical phenomena underlying the project of a 14 MeV neutron source for the irradiation testing of the fusion materials [3]. Quite narrow angular distribution function of the fast ions and thus picked near the ion turning points axial profile of the fusion reactions intensity are the distinguishing features of the projecting neutron source.

Kinetic of fast ion relaxation and scattering have been studied in detail experimentally using the special diagnostic set to measure local energy and angular distribution functions of fast ions [4]. The main conclusions of the experiments mentioned were as follows:

- ➔ fast ion relaxation and scattering are basically determined by two-body Coulomb collisions;
- ➔ microinstabilities which could cause significant additional scattering of fast ions and anomalous losses into the loss cone and also anomalous cross-field transport of the fast ions have not yet been observed in GDT experiments in high- β regime.

These conclusions concerned confinement of the fast ion population are the key points of the results of experimental feasibility study of the neutron source based on the Gas-Dynamic Trap. Thus, it was very important to carry out special experiments to corroborate additionally these basic conclusions.

To see fulfilled this additional confirmation special experiments with deuterium neutral beam injection to measure distributions of 2.45 MeV neutrons and 3.02 MeV protons radiation intensity along the plasma column have been carried out.

Detector of the DD reaction products

To detect the products of the DD synthesis special counters based on an organic scintillator combined with a photo multiplier tube (PMT) have been developed (see Fig.1). Counters were located closely to the plasma column inside of the vacuum vessel to decrease the influence of scattered neutrons and to improve the spatial resolution of measurements.

The intensity of the scattered neutron flux was evaluated through MCNP [5] neutron

transport calculations. The heaviest parts of the GDT facility and the longitudinal distributed DD neutron source were taken into account. The main result of the estimates is that scattered background has intensity that is comparable (besides 40% in the midplane of the GDT) to the direct neutron flux.

Using the PMT of the "fine mesh" type (HAMAMATSU H2611) allowed us to apply photo multiplier tube in a strong magnetic field up to 1.5 T. Entrance window of the counter was covered by 20 μm aluminum foil to reject the flux of the other products of DD reaction: 0.8 MeV α -particles and 1 MeV tritons. The movable stainless steel shield transparent to neutrons and not transparent to protons allowed us to separate proton and neutron fluxes. Special collimator have been used to increase the spatial resolution of the measurements in the regimes of proton detection.

The light flashes caused by particles in the scintillator were detected by PMT. Current pulses from the anode of the PMT were amplified by a preamplifier and then recorded by the high-speed digitizer. Single pulse duration was about 45 ns, digitizing speed – 200Msample/s. Figure 2 demonstrates typical amplitude distributions of recorded pulses during detection of the protons together with neutrons – "a" and neutrons – "b". The analysis of the amplitude distribution allowed us to avoid the influence of the noise and to separate counts of detected protons and neutrons (see Fig. 2 "b", "c").

Experimental results

Detailed measurements of the axial distribution of the DD reaction intensity have been carried out in two regimes of the GDT operation:

1. deuterium neutral beams were injected into hydrogen warm plasma;
2. deuterium neutral beams were injected into deuterium warm plasma.

Figure 3 presents the longitudinal profile of the 3.02 MeV proton emission intensity

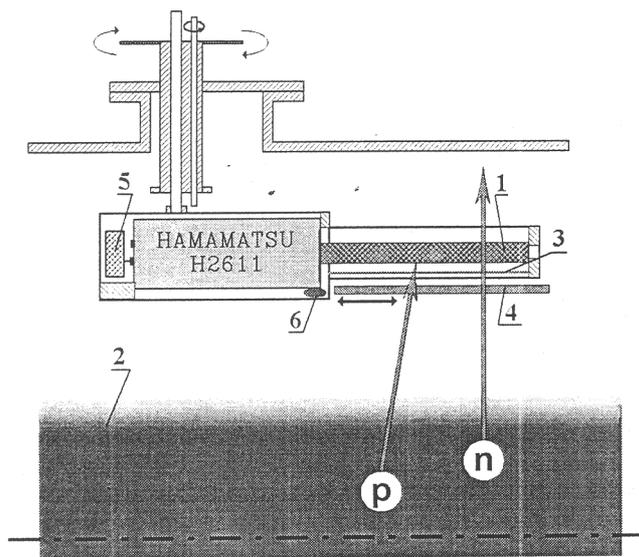


Fig. 1 Layout of the counter: 1–plastic scintillator; 2–plasma; 3–Al foil; 4–movable shield; 5–preamplifier; 6–light diode.

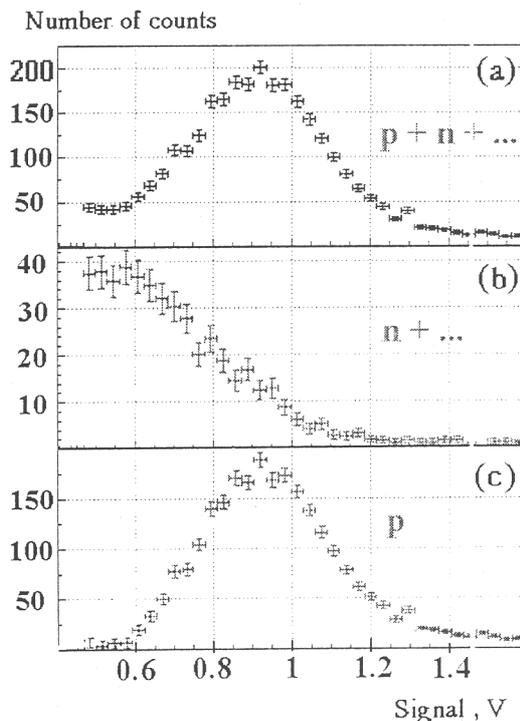


Fig 2. Amplitude distributions: a) protons+neutrons; b) neutrons; c) protons

i.e. number of protons emitted by 1 cm length of the plasma column. The data were obtained in the regime (1). The simulated profile of the DD reaction intensity is also presented in Fig.3. The simulations were carried out by two steps:

- ➔ Monte-Carlo code FIT [6] based on the theory of Coulomb collisions have been used to simulate energy and angular distribution functions of fast ions D^+ . As input parameters for the calculations the following data from the experiments were used: configuration of the magnetic field, time evolution of the electron temperature and density radial profiles of the target plasma, time evolution of the neutral beam parameters;
- ➔ simulated distributions were used to calculate the local intensity of DD reaction.

A reasonable agreement between experimental data and results of simulations allowed to conclude that, within the measurement accuracy, two-body Coulomb collisions determine the kinetic of angular scattering of the fast ions.

Axial profiles of proton emission intensity obtained in the regimes (1) and (2) are presented in Fig.4. The ratio between emission intensities in the turning point of fast ions and in the midplane in regime (2) is much less than in regime (1). This result could be explained taking into account the following circumstances:

- ➔ DD reactions between fast D^+ ions and D^+ ions of the "background" plasma play an essential role;
- ➔ the angular scattering rate in DD collisions is greater than the scattering rate in deuteron-proton collisions.

Conclusions

On the basis of the results presented above we can draw the conclusions as follows:

1. diagnostic to measure the absolute value of proton and neutron flux have been developed;
2. axial profile of DD reactions intensity have been measured in high- β regime of the GDT operation;

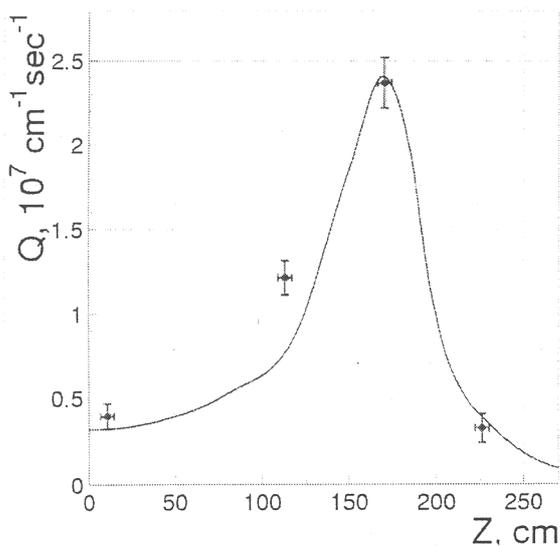


Fig. 3 Axial profile of proton emission intensity measured by the collimated detector in the regime (1) of GDT operation (points with error bars) and simulated profile (curve)

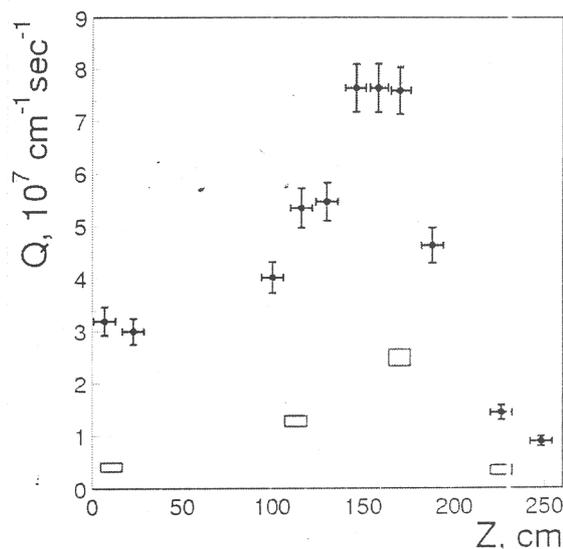


Fig. 4 Axial profiles of proton emission intensity obtained in the regimes (2) (points with error bars) and (1) (rectangles)

3. reasonable agreement between the experimentally measured DD reaction intensity and results of simulations allowed to conclude that, within the measurement accuracy, two body Coulomb collisions determine the kinetic of angular scattering of fast ions.

Acknowledgments

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