THE STATUS OF THE DOUBLE POLARIZED DD-FUSION EXPERIMENT

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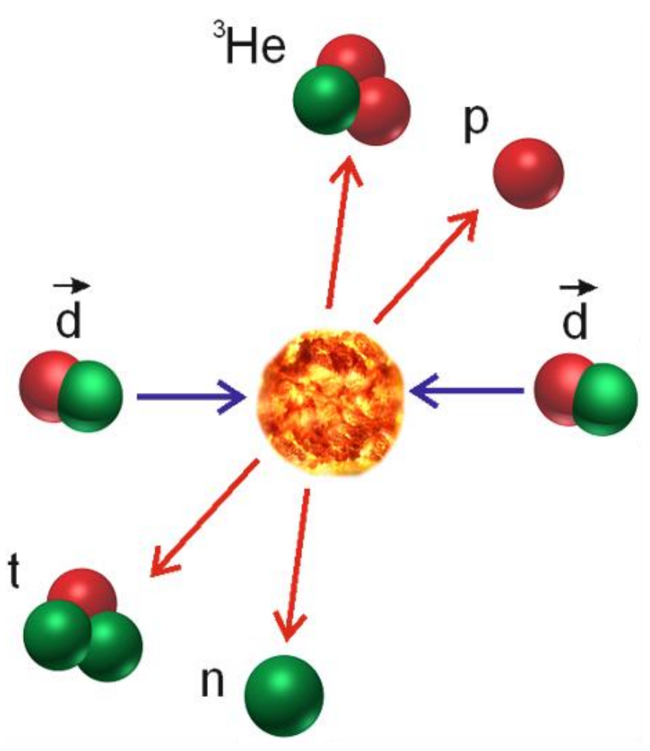
Motivation

The $^2H(d,p)\,^3H$ and $^2H(d,n)\,^3He$ fusion reactions at low energies are relevant in pure and applied physics. These reactions took place in the first minutes during the Big Bang nucleosynthesis and occur in the early phases of stellar burning. Active discussion [1] is being made to encourage scientists in research in the field.

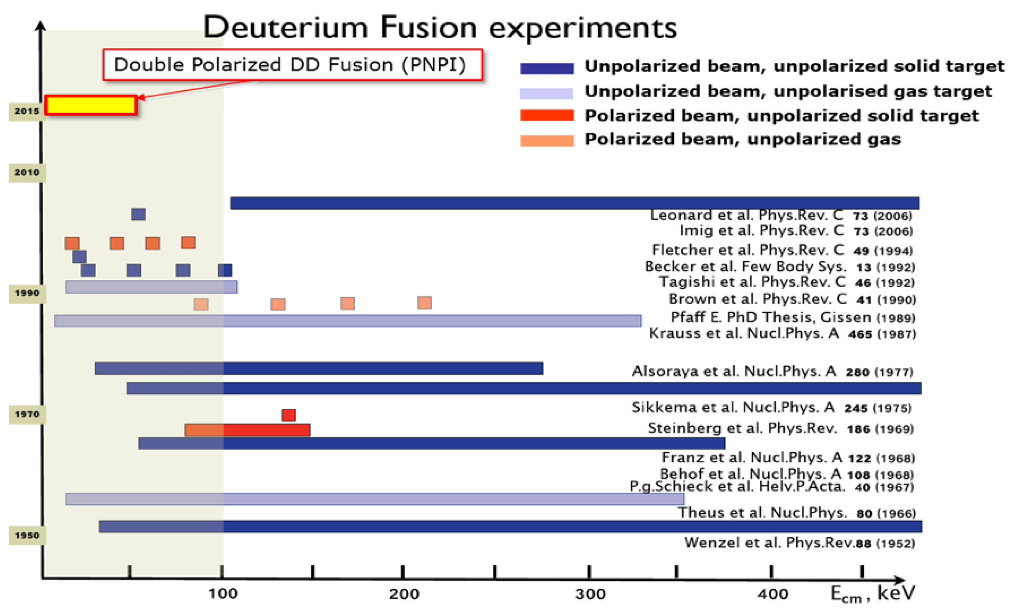
The low-energy regime (tens to hundreds of keV) typical for nucleosynthesis and fusion plasmas is challenging to probe because of exponentially decreasing in the reactions cross section and therefore lowering counting rates. However due to sreening effects of electrons and polarizing reactants [2] fusion reaction rates can be increased significantly.

The dd fusion is the reliable source of thermonuclear energy and tritium fuel for future reactors [3] without an external tritium source. Handling of neutron production and the by-products emission direction can be achieved by polarizing deuterium in specific ways [2].

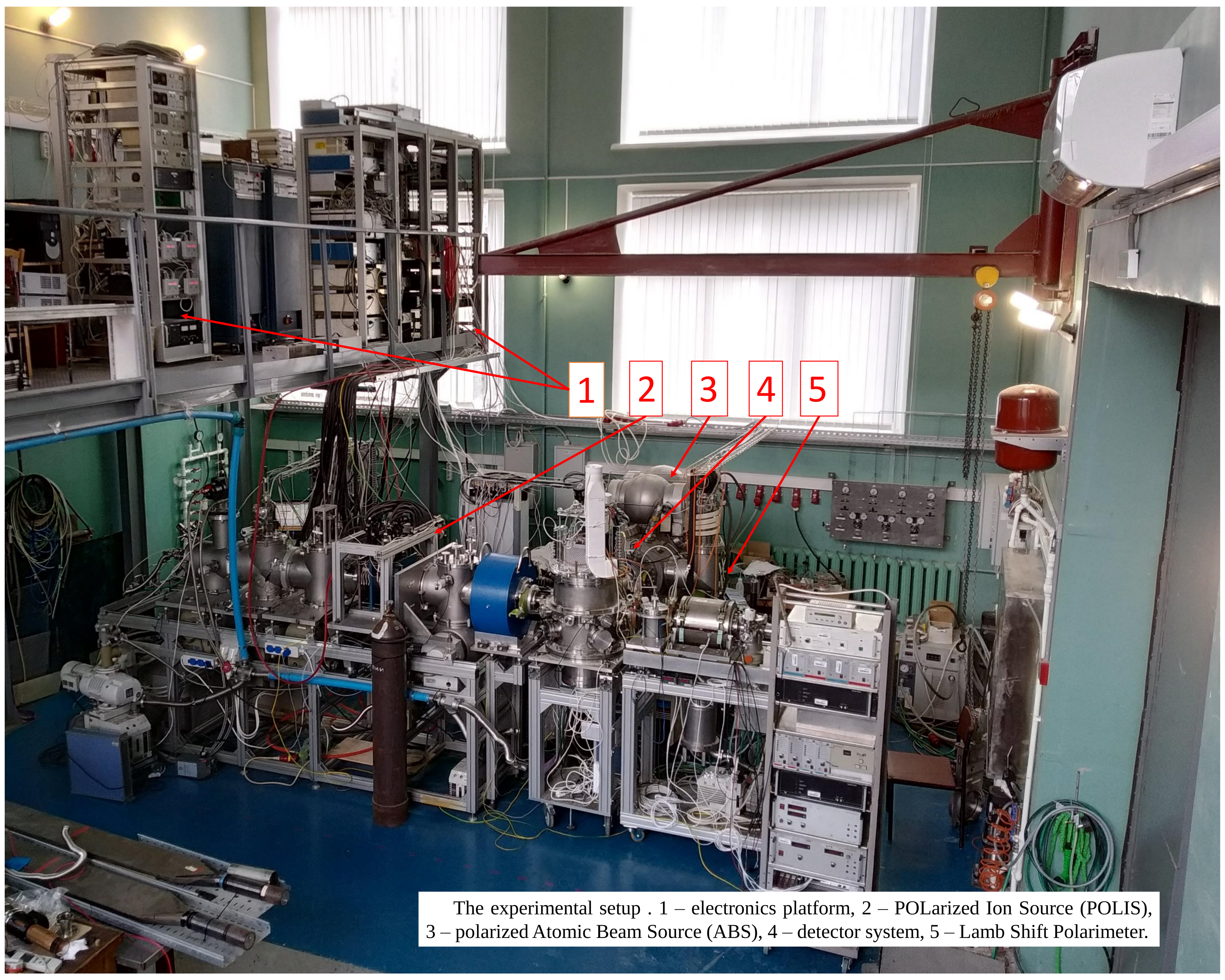


The experiment aims to study fusion reactions of $^2H(d,p)\,^3H$ and $^2H(d,n)\,^3He$ with the beam energy at 10-100 keV and various spin combinations. Fusion byproducts are detected by using the 4π detector system with 51% filling based on 560 silicon pin-diodes to measure its energy.

We plan to measure different spin-correlation parameters such as assymetry, vector and tensor analyzing powers, spin-correlation coefficients, polarization transfer coefficients, and also differential and total cross sections of the reactions at given energy range.

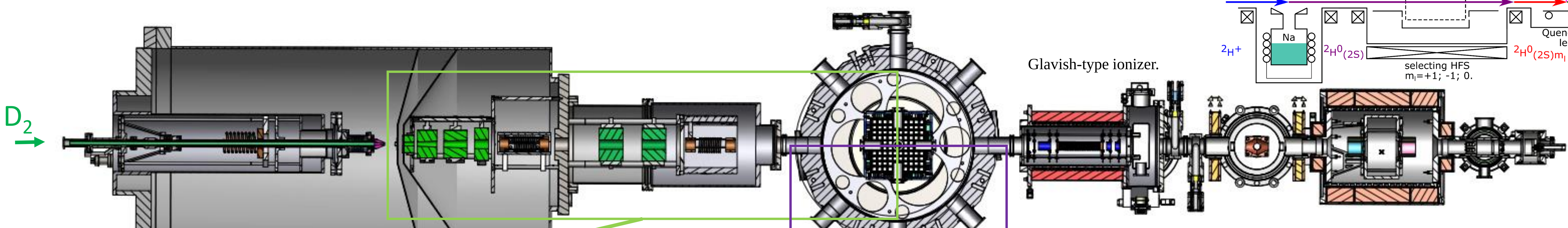


The world's first colliding-beam experiment with both polarized beams PolFusion [4] has been started in PNPI, Gatchina, in collaboration with Forschungszentrum Juelich and INFN University of Ferrara.

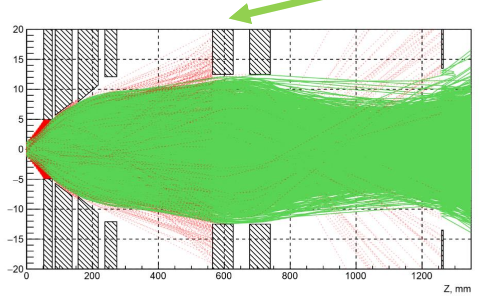


The experimental setup . 1 – electronics platform, 2 – POLarized Ion Source (POLIS), 3 – polarized Atomic Beam Source (ABS), 4 – detector system, 5 – Lamb Shift Polarimeter.

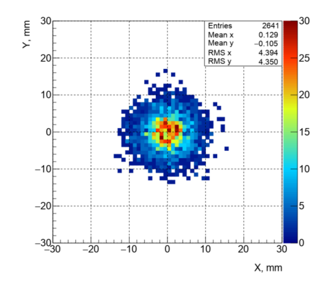
Polarized atomic beam source



Polarized deuterium atoms of the Ferrara ABS beam collide with polarized deuterons of the POLIS in the center of the 4π detector system. It delivers a beam of deuterium atoms of requested nuclear vector or tensor polarization and energies of about 0.1 eV. The intensity of the beam of $4\cdot10^{16}$ atoms/s, achieved at the IUCF [5], is sufficient for the measurements of the fusion reaction with low cross-section.



Simulating of deuterium atoms trajectories [6] passing through the spin-separation system of the Ferrara ABS.

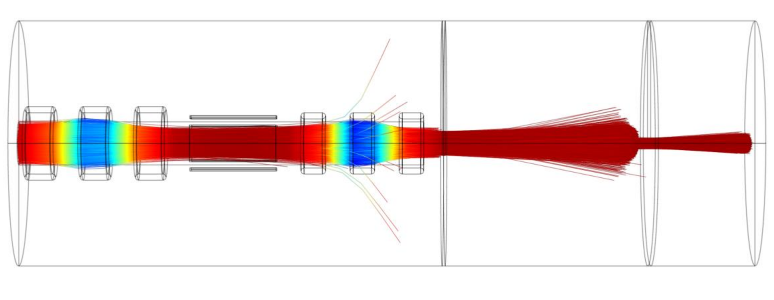


The beam profile of the Ferrara ABS. The initial number of particles emitting from the nozzle is 10^6.

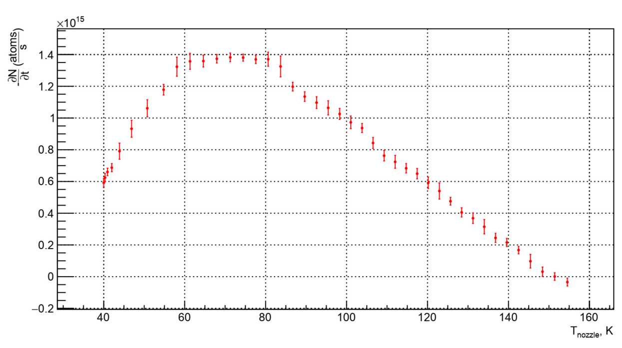
Polarized ion source (POLIS)

The POLIS is capable of producing an ion beam of 20 μA with energy up to 100 keV. The variety of polarization states can be achieved using a combination of one weak-field (WF) and two strong field (SFI, SFII) radio-frequency transition units.

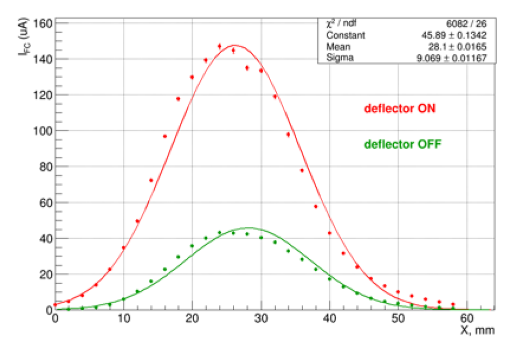
The gas jet formation system consists of a nozzle, skimmer, colimator, cooling and temperature stabilization subsystems including heat interception, thermal bridge, cryo-generator, heater, and a temperature sensor.



The new focusing system consists of two einzel lenses and the deflector.

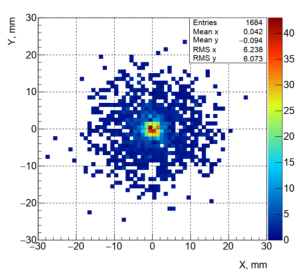


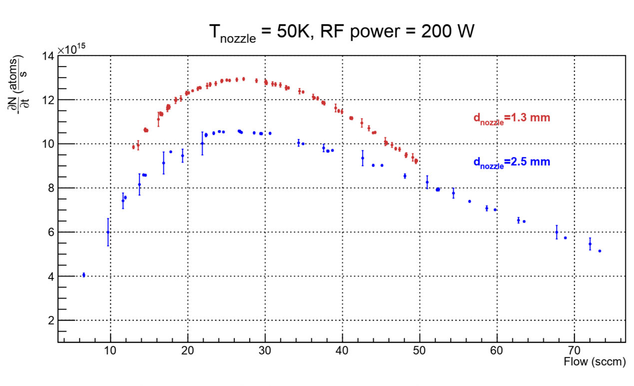
Dependence of the atomic beam intensity on the nozzle temperature, as measured at the outlet of the focusing system.



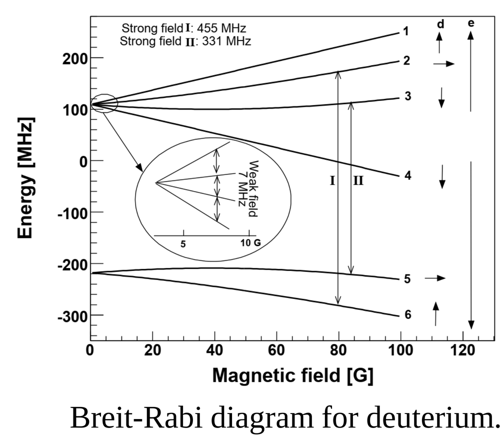
The ion beam profile is measured in the center of the detector system.

Center of the ECR ionizer

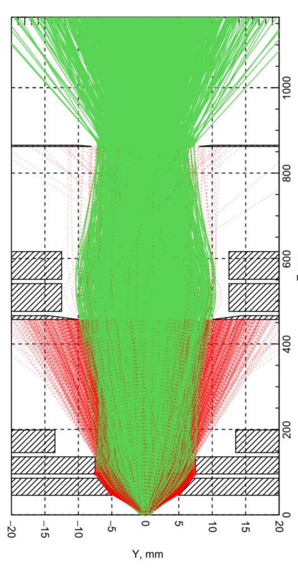




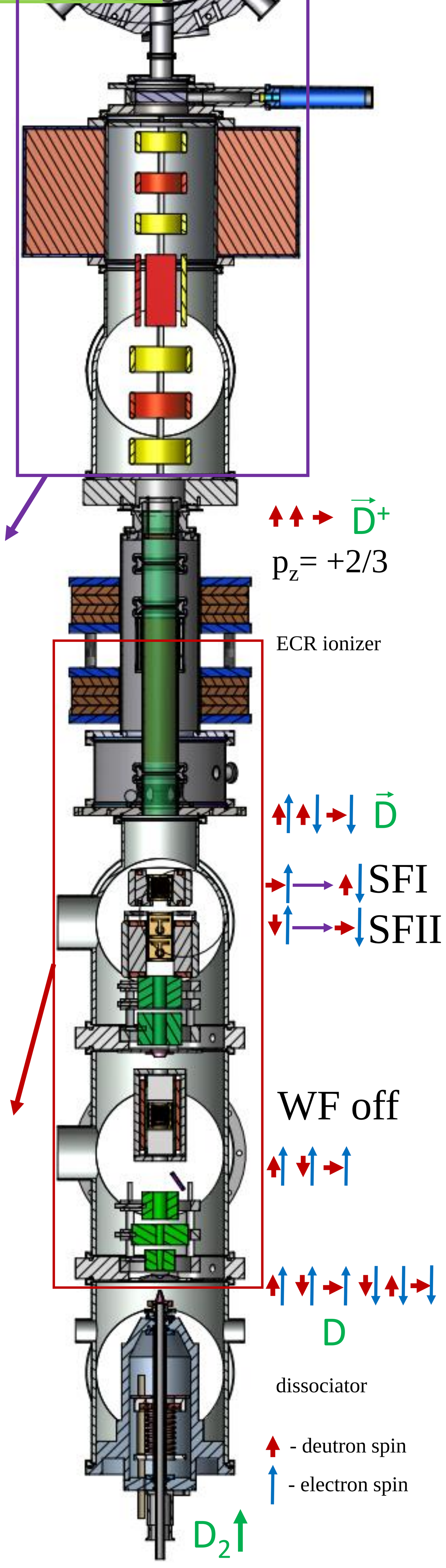
Dependence of the atomic beam intensity on the gas flow temperature, as measured in the center of the ECR ionizer.



Breit-Rabi diagram for deuterium.

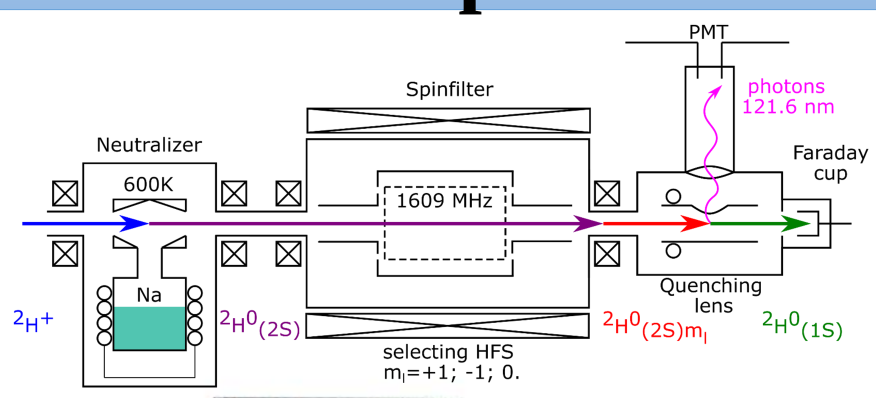


Simulating of deuterium atoms trajectories [6] passing through the spin-separation system of the POLIS.



As a result of the improvements made we managed to achieve the atomic beam intensity at the level of $1.3\cdot10^{16}$ $^{\text{atoms}}/_{s}$ by using the nozzle with an output diameter of 1.3 mm cooled to 65 K and powering the dissociator with 200 W.

Lamb shift polarimeter

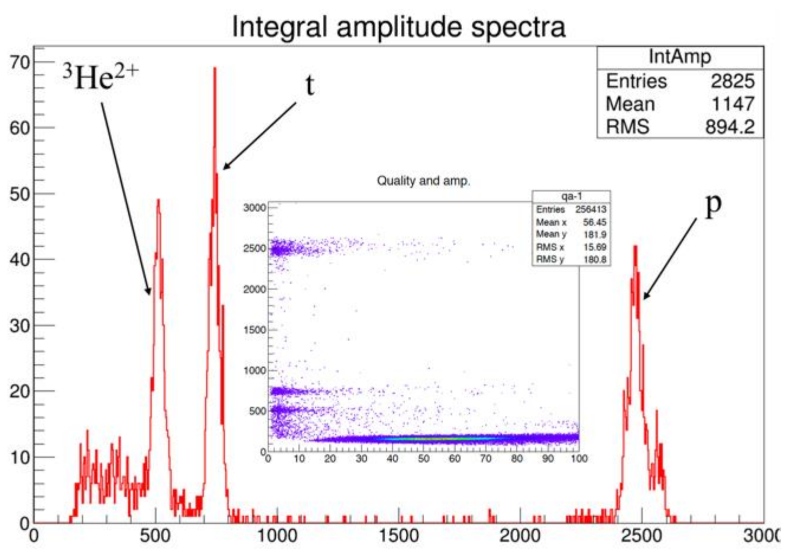


The Lamb-Shift Polarimeter measures directly the spin substate distribution of a deuteron beam from which the polarization can be obtained with an absolute precision better than 1% within a few seconds [7].

Results

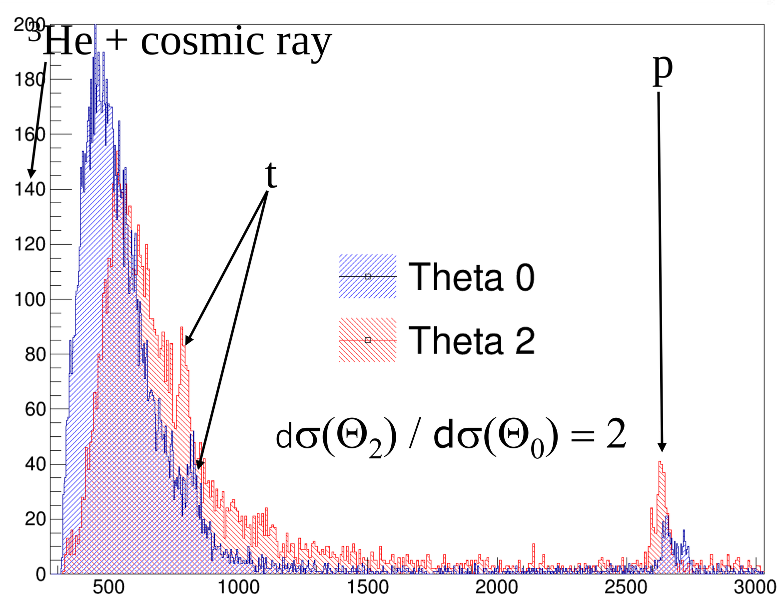
Two test-runs were carried out with the test system including the 4π detector system and the POLIS in 2015 and 2019 on different targets.

The amplitude spectra obtained show three distinct peaks of the deuterium fusion products, namely 0.8 MeV $^3He^{2+}$, 1 MeV triton, and 3 MeV protons (neutrons are not detected in this experiment). Typical count rates do not exceed 120 events per hour for 30 keV ions. Therefore background and noise should be minimized to distinguish these rare events.



In the test-run of 2015 the foil of deuterated polymethylmetacrylate was used as a target. The reaction products energy was measured by eight silicon detectors that surrounded the collision area.

The target was exposed to the ion beam of 10 μA with 15 keV energy.



Results of the test-run in 2019 with heavy water vapor (D_2O) as a target (~ 10^{18} $^{\text{atoms}}/_{s}$). POLIS provided the ion beam of 10 μA with 10 keV energy. The 4 π detector system had 22 silicon detectors on front, bottom and top planes.

Θ_0(8 pin-diodes) bottom plane

Θ_2(4 pin-diodes) front plane

References

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