ECRIS-2014
THE 21ST INTERNATIONAL WORKSHOP ON ECR ION SOURCES
NIZHNY NOVGOROD, RUSSIA, 24-28 AUGUST 2014

High Current Proton and Deuteron Beams for Accelerators and Neutron Generators

V.A. Skalyga[1], I.V. Izotov[1], S.V. Golubev[1], A.V. Sidorov[1], S.V. Razin[1],
O. Tarvainen[2], H. Koivisto[2], T. Kalvas[2]
A.V. Maslennikova[3], A.V. Strelkov[4]
email: skalyga.vadim@gmail.com

[1]*Institute of Applied Physics, RAS, 46 Ul`yanova st., 603950 Nizhny Novgorod, Russia*
[2]*University of Jyvaskyla, Department of Physics, P.O. Box 35 (YFL), 40500 Jyväskylä, Finland*
[3]*Nizhny Novgorod State Medical Academy, 10/1 Minina Sq., 603005, Nizhny Novgorod, Russia*
[4]*Joint institute for Nuclear Research, 141980, Moscow region, Dubna, Russia*

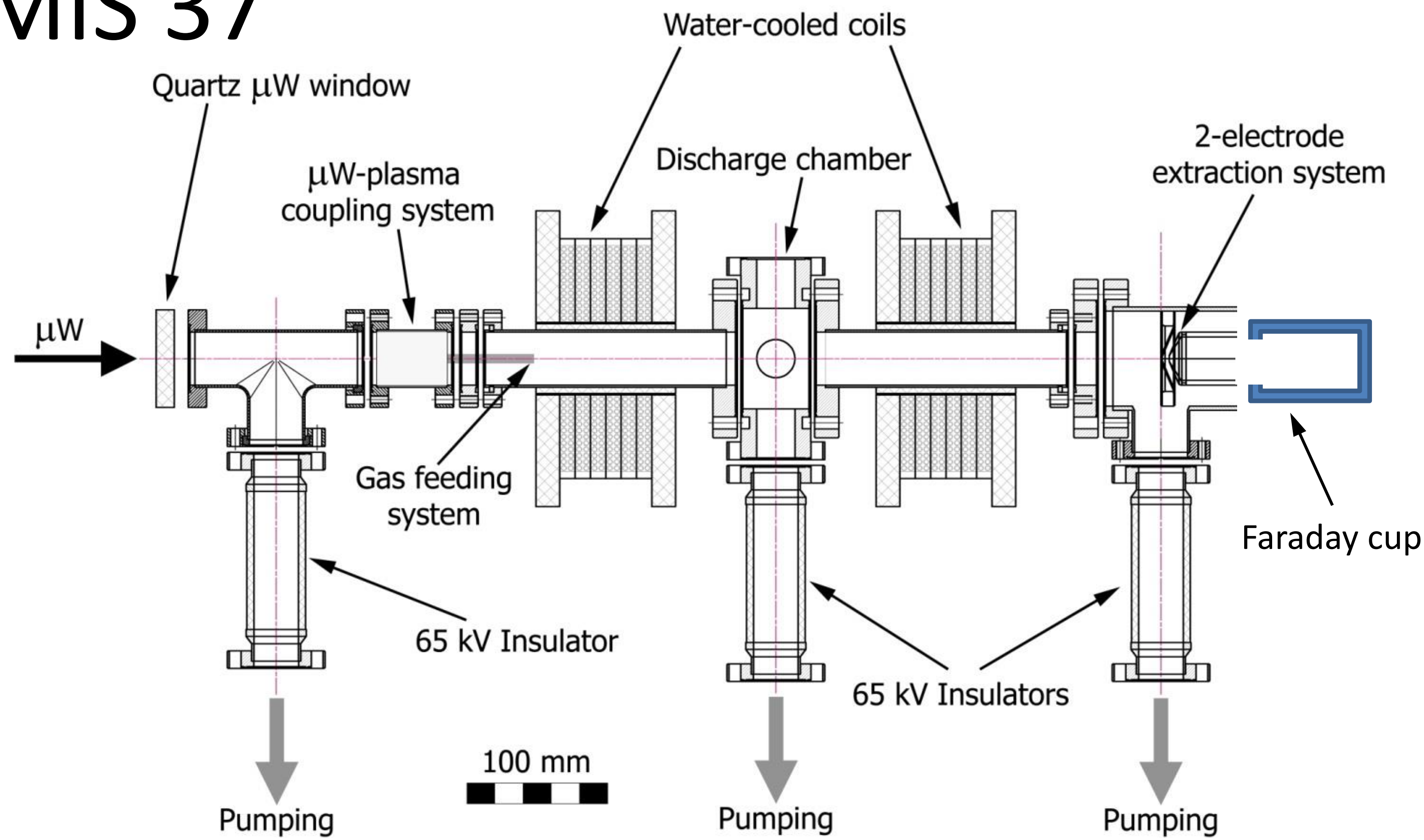
Institute of Applied Physics of the Russian Academy of Sciences

JYVÄSKYLÄN YLIOPISTO
UNIVERSITY OF JYVÄSKYLÄ

Outline

- SMIS 37 ion source
- H+ & D+ beams production at SMIS 37
- Neutron generators
- Neutron production at SMIS 37
- Perspectives and plans

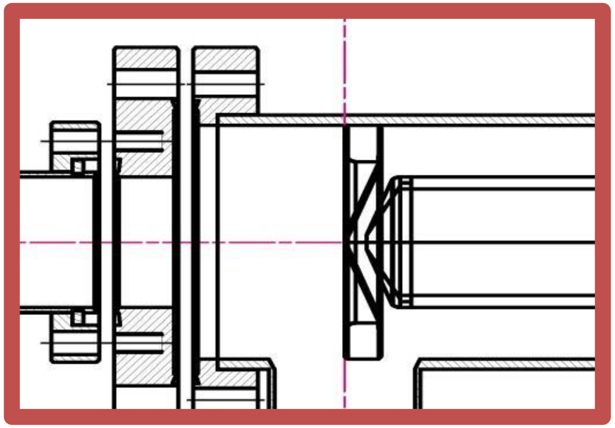
SMIS 37

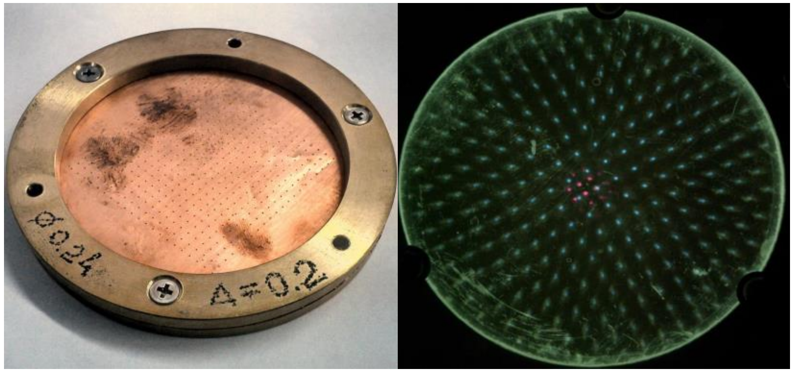


Gyrotron 37 GHz, 10-80 kW, 1ms/1Hz. Gasdynamic plasma confinement

- ✓ High plasma density >$2*10^{13}$ cm^{-3}
- ✓ High collision rate -> Low plasma lifetime ~ tens of μs
- ✓ Plasma flux at the mirror point >10 A/cm^2
- ✓ T_e ~ 20-300 eV -> close to 100% ionization
- ✓ T_i ~ 1-5 eV + extraction in the area of low magnetic field -> excellent emittance

Beam extraction

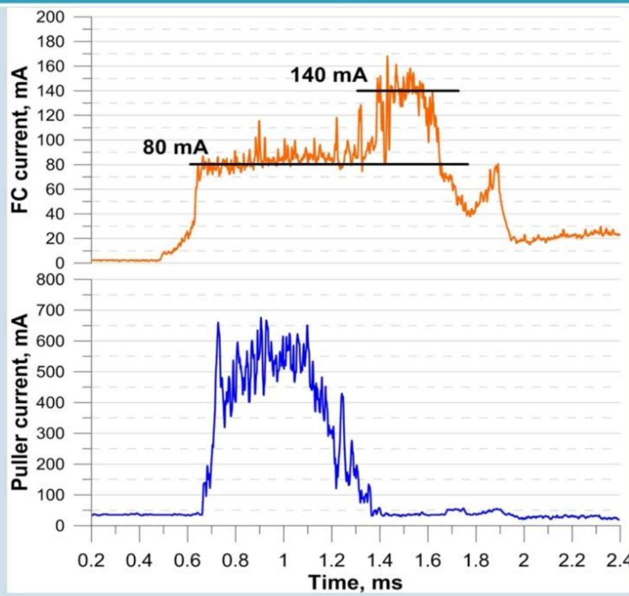


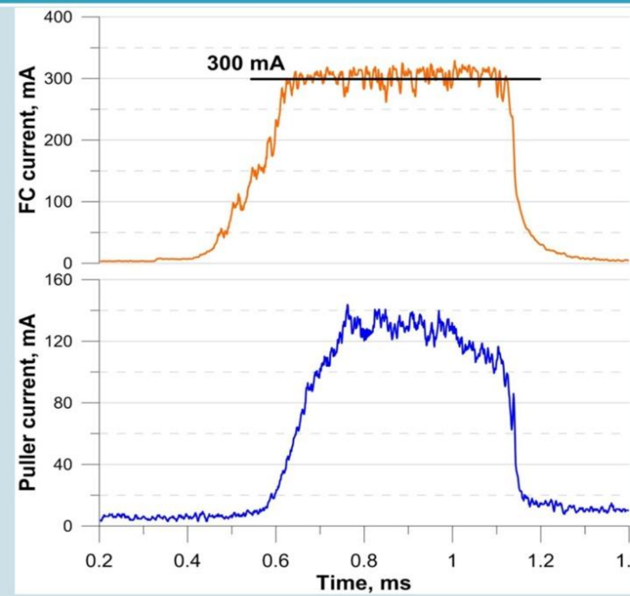


Plasma electrode aperture diameter from 5 to 10 mm

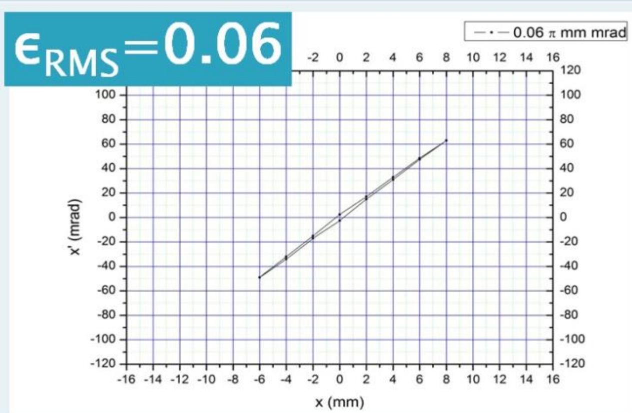
Beam current measurements

5 mm, H^+	7 mm, H^+

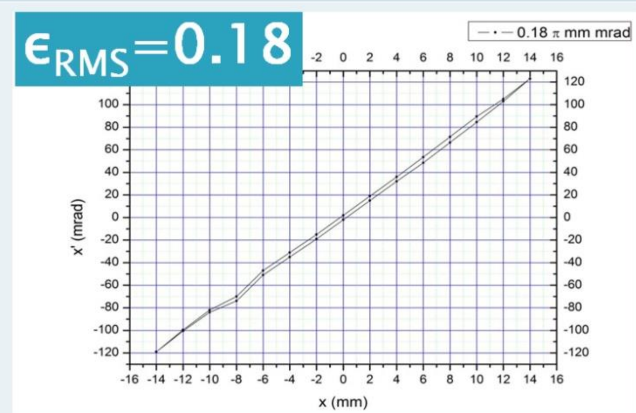




$\epsilon_{RMS}=0.06$

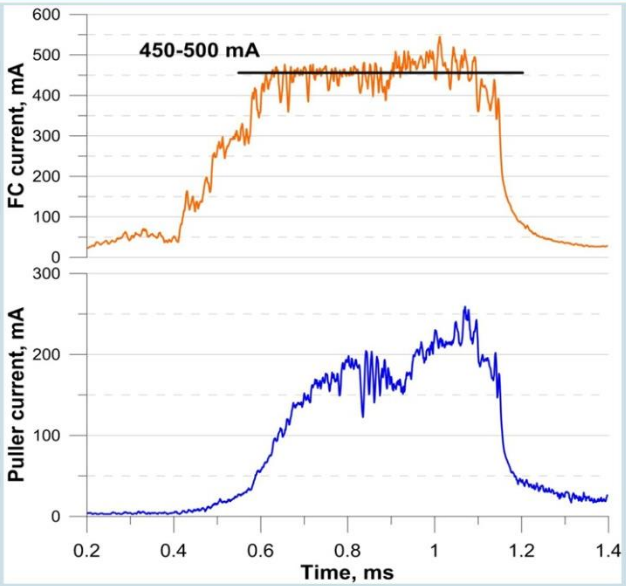


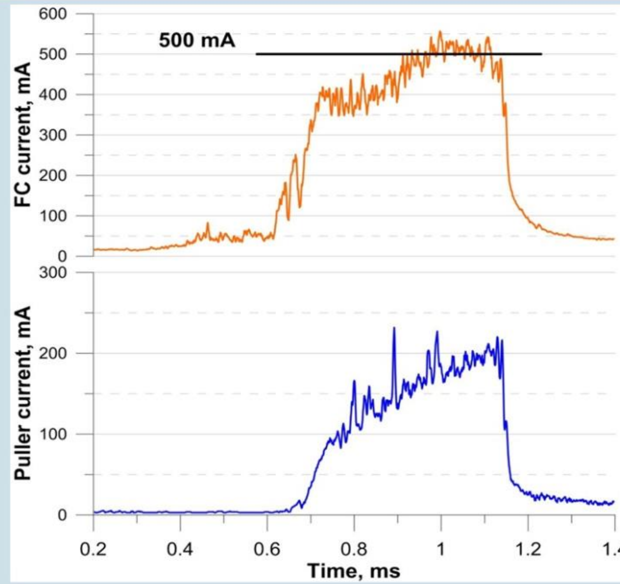
$\epsilon_{RMS}=0.18$



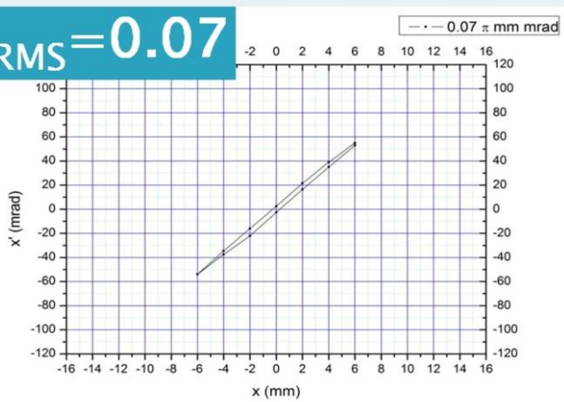
Beam current measurements

10 mm, H^+	10 mm, D^+

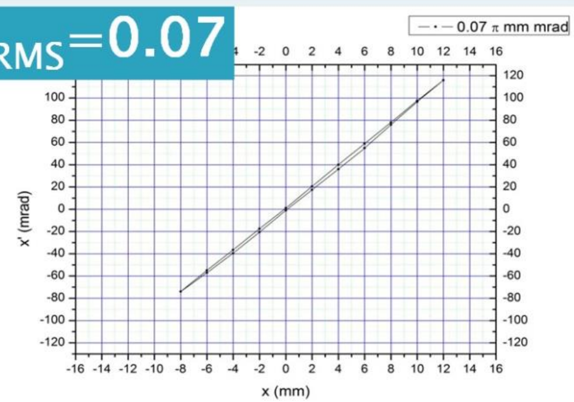




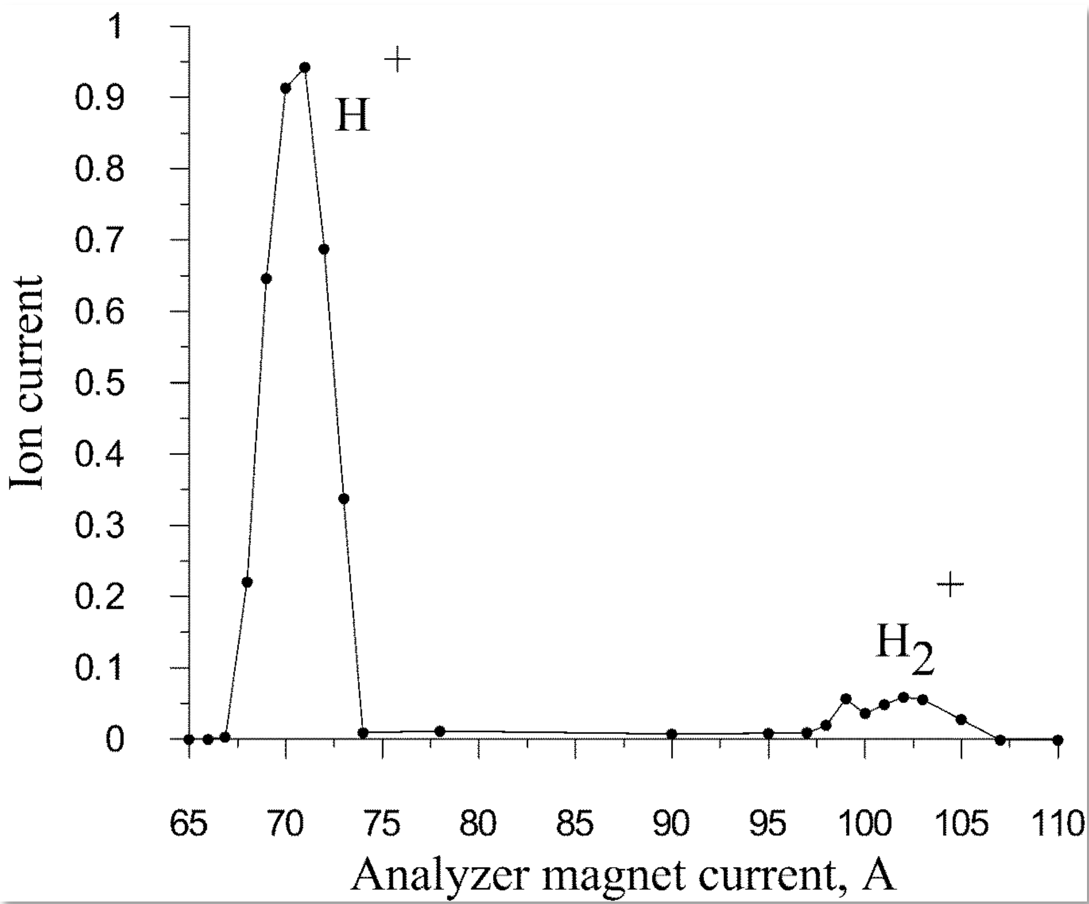
$\epsilon_{RMS}=0.07$



$\epsilon_{RMS}=0.07$



Ion spectrum (Hydrogen, Deuterium)



H^+, D^+ > 94 %
H_2^+, D_2^+ < 6 %

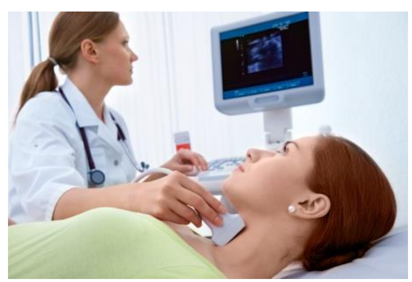
Beam extraction summary

Extraction system	Faraday cup current, mA	Normalized rms emittance, π·mm·mrad	Extraction voltage, kV
d = 5 mm	80-140	0.06	45
d = 7 mm	300	0.18	45
d = 10 mm	500	0.07	45

H^+, D^+ > 94 %

H_2^+, D_2^+ < 6 %

Medicine

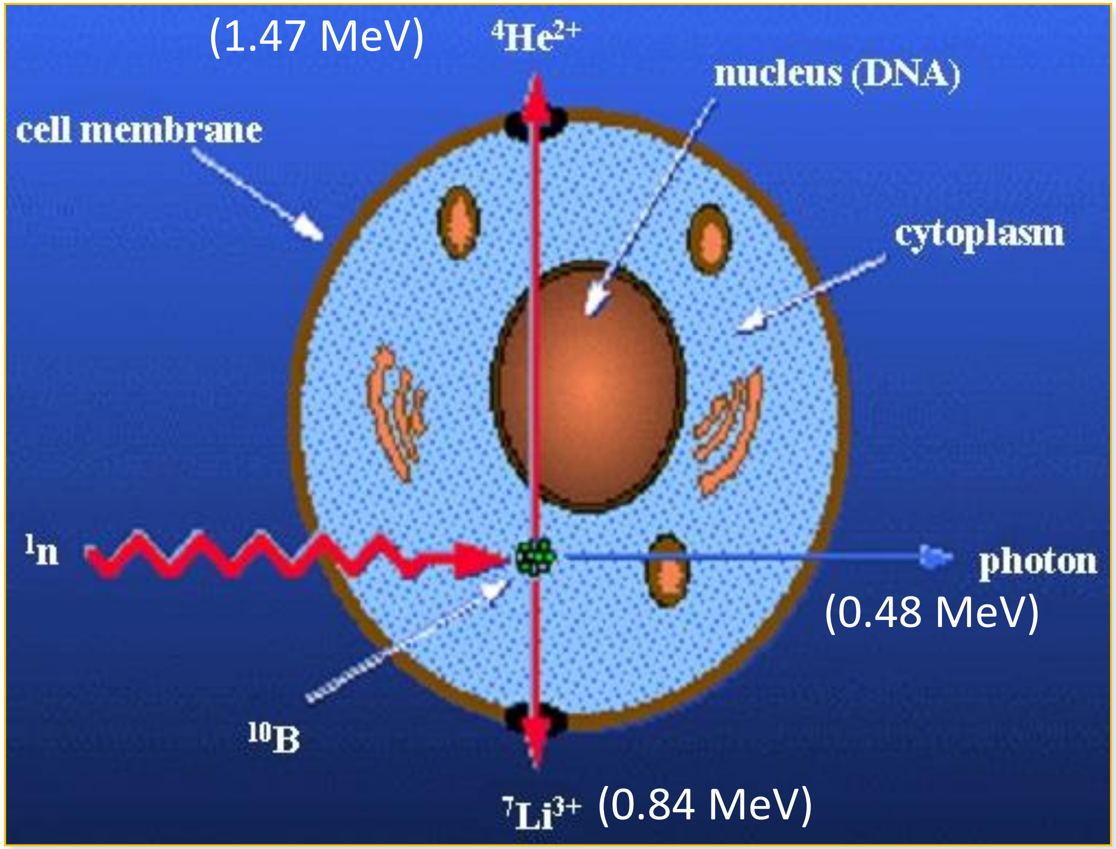


- Neutron radiography
- Neutron spectroscopy
- Neutron brachytherapy
- **Boron-neutron capture therapy (BNCT)**

BNCT principle

- α-particle free pass is close to the cell dimensions:
  $^{4}He^{2+}$ (9 μm)
  $^{7}Li^{3+}$ (6 μm)

- Ionization led to double-strand break of DNA prevented further cell division



$^{10}B + n_{th} \rightarrow {}^{11}B^{*} \rightarrow {}^{7}Li$ (0.84 MeV) + α (1.47MeV) + γ (0.48 MeV) (94 %)

$^{10}B + n_{th} \rightarrow {}^{11}B^{*} \rightarrow {}^{7}Li$ (1.01 MeV) + α (1.78 MeV) (6 %)

Neutron sources for BNCT

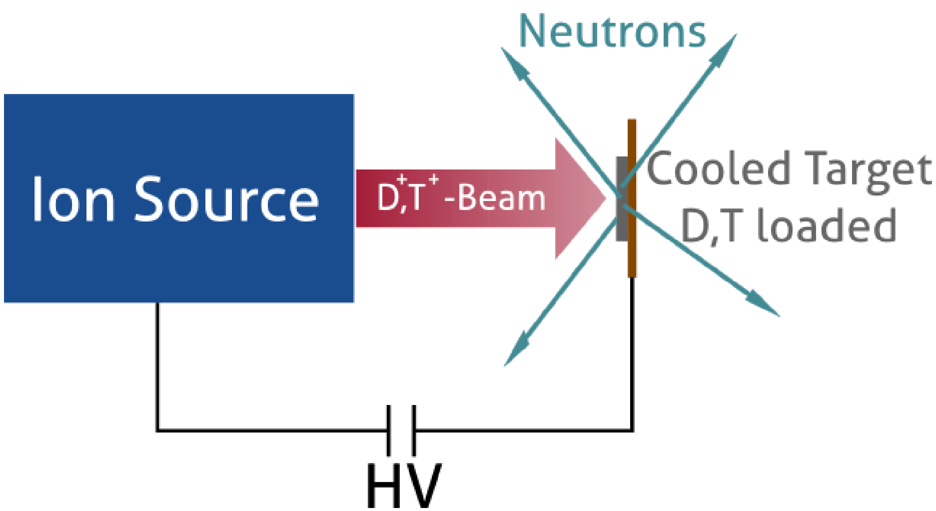
- Nuclear reactors
  - High neutron flux
  - High running cost and complexity
- Accelerators
  - Satisfactory neutron flux
  - Lower cost
  - Safety
- Neutron generators
  - Low neutron flux
  - Small size, low cost
  - Easy to use

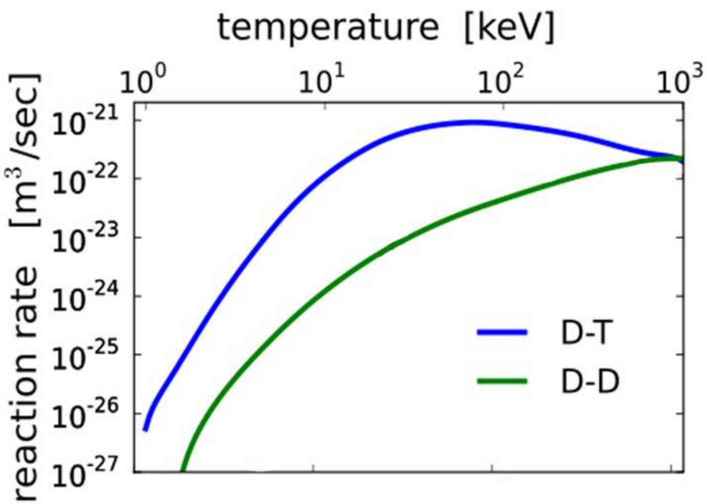
D-D and D-T neutron generators

"Low" energy D+ ion beams:

» D + D --> ^{3}He3 + n   3.26 MeV

» D + T --> ^{4}He3 + n   17.6 MeV

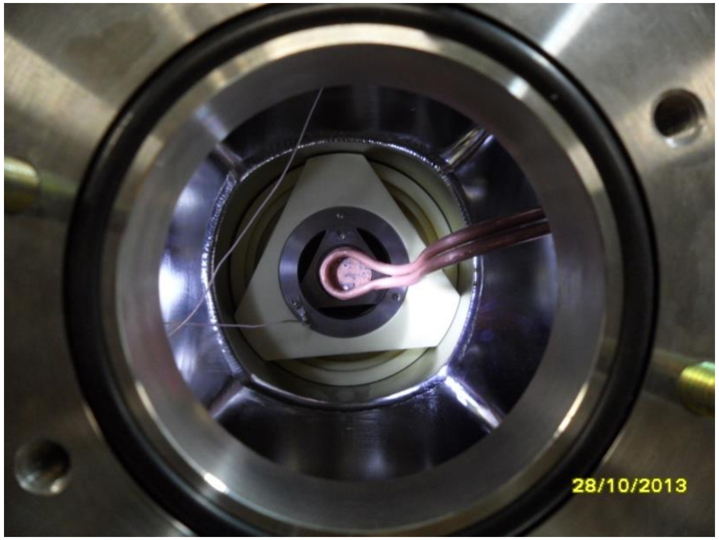




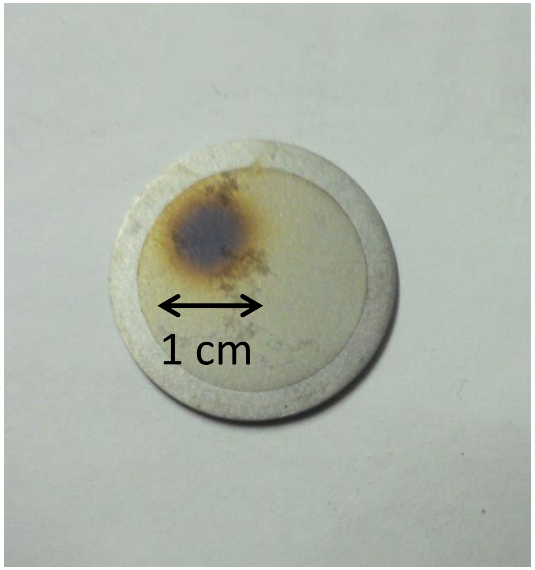
Targets: TiD_2, ZrD_2, ScD_2

Up to 1,8 D atoms per one sorbent atom

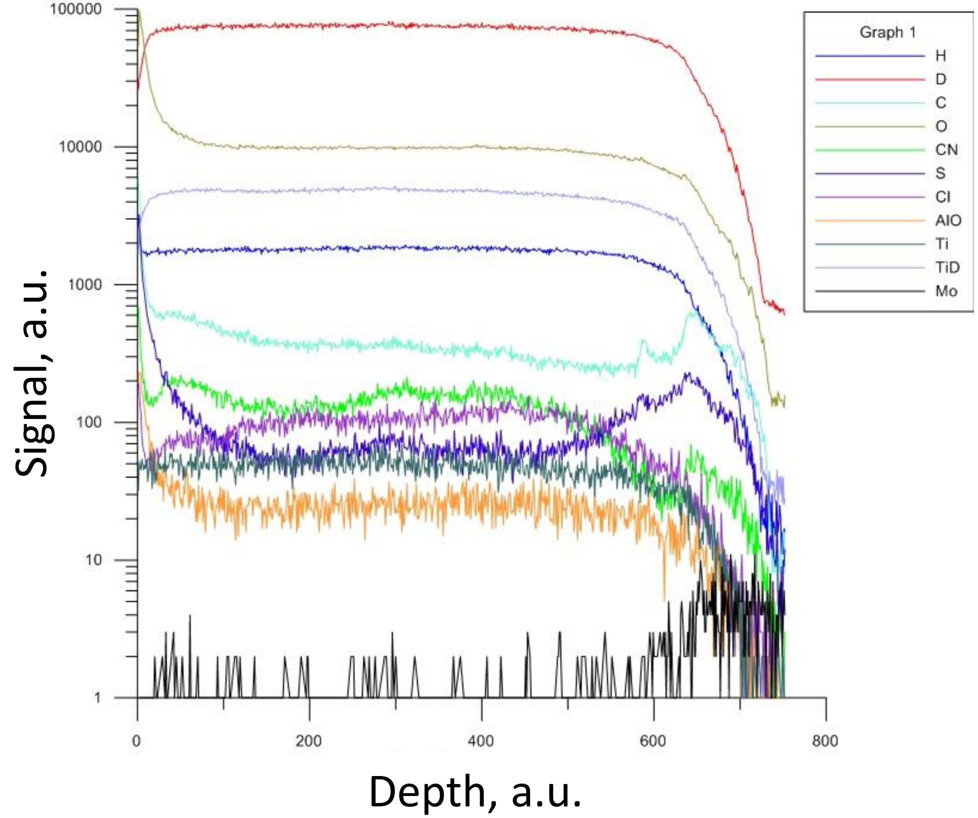
Ice target (D_2O)



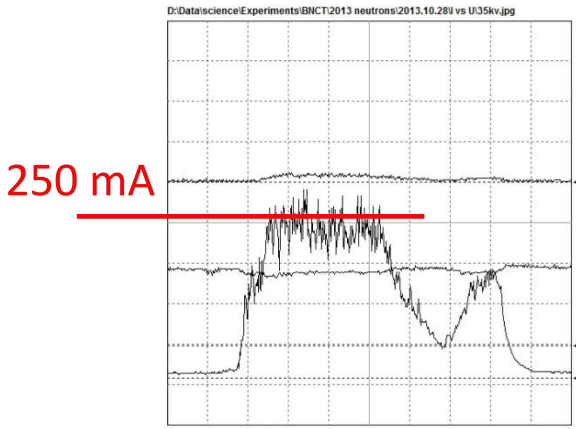
TiD_2 target



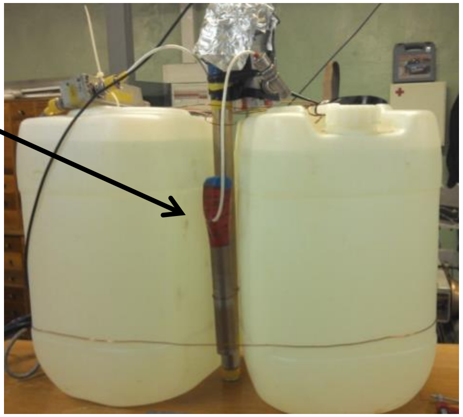
Secondary-Ion Mass Spectrometry (SIMS) of the target

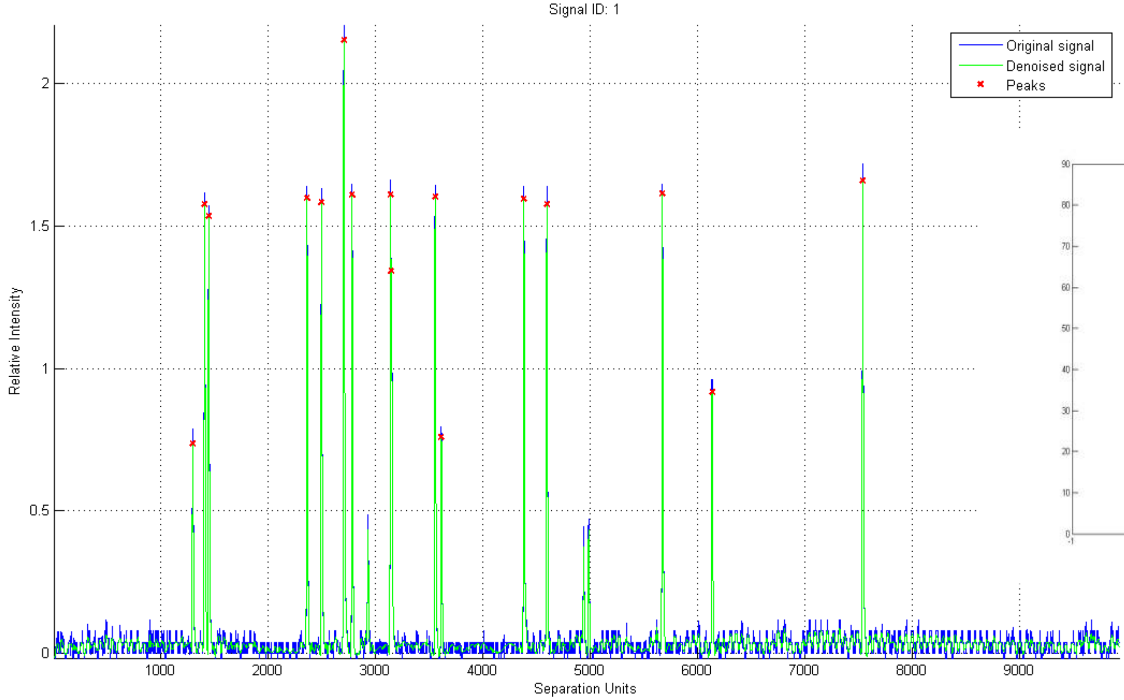


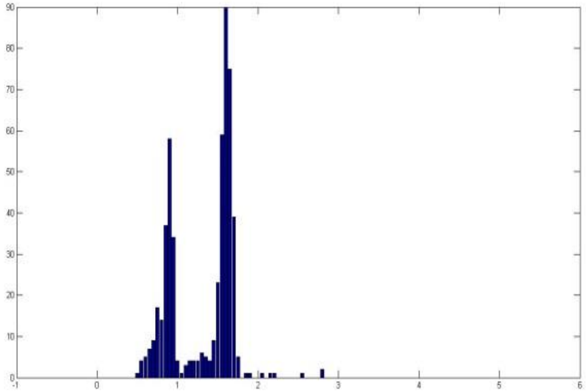
Neutron flux measurements



Two ^3He proportional counters were used in experiments







Results (45 keV beam energy)

Target	Neutron flux per 1 mA of D+ beam at 45 keV	Total neutron flux (300 mA of D+)
TiD_2	$2 \cdot 10^6$	$6 \cdot 10^8$
D_2O	$3 \cdot 10^6$	10^9

Estimations

10^8 Neutrons per second for 1 mA D^+ at beam energy 100-120 keV

↓

Beam current: 500 – 1000 mA

↓

Expected neutron flux:
$5 \cdot 10^{10} - 1 \cdot 10^{11}$ s^{-1} ($5 \cdot 10^{12} - 1 \cdot 10^{13}$ s^{-1} T-target)

↓

Expected neutron flux density: > 10^{10} $s^{-1} \cdot cm^{-2}$

Future plans

- H^+ & D^+ beam at 100 keV
- High quality target
- Bigger target
- CW D+ beam production (24 GHz, 10 kW)
- Design of target cooling

Many thanks for your attention!