Nuclear Physics Institute (NPI)
Center of Accelerators and Nuclear Analytical Methods (CANAM)
Řež

Workshop on TALYS/TENDL developments
13-15 November 2017, Prague

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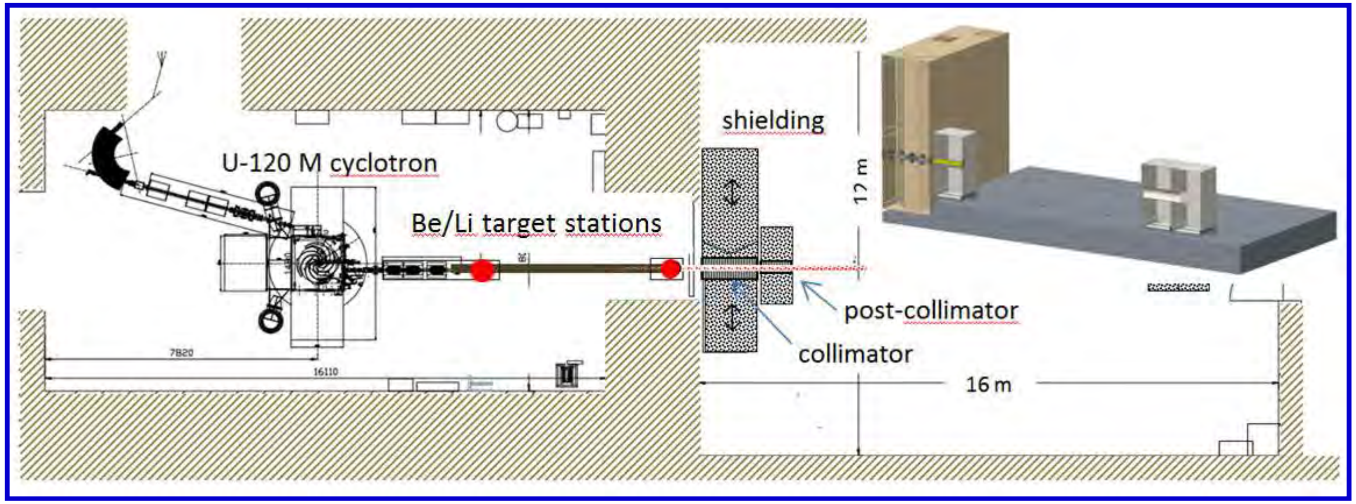
Projected fast neutron facilities on CANAM-NPI cyclotrons

NPI neutron generators – status

- Proton beam (≤ 36 MeV, 15 μA) from U-120M cyclotron on Be/Li targets of NG target stations provides white-spectrum and quasi-monoenergetic neutrons (≤ 34 MeV) with flux up to $1x10^{11}$ and $2x10^{9}$ $n/cm^{2}/s$ at sample positions. They are utilized to
  - □ neutron cross-section measurements by activation technique and
  - □ neutron irradiation tests of microelectronic components

- Natural time structure of proton beam and collimated neutron beam from p+Be/Li(thin target) generator serves to nTOF-spectrometry measurements. Due to low bunch interval ~ 50 ns, energy selection 15 to 35 MeV only is at disposal.

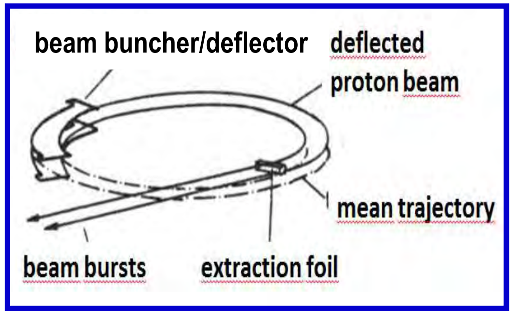


- The energy range and flux of NPI neutron generators are complementary to other European fast neutron facilities (TSL Uppsala and CRC Louvain-la-Neuve)

New projects

1. To extend energy selection in TOF neutron spectrometry

a novel multi-orbital beam bunching and extraction
on U-120M cyclotron is under investigation aiming
to enlarge beam-bunch interval up to 1000 ns range
and to achieve the beam-time structure with T/ΔT ≥ 100
without loss of beam intensity.



2. For recently commissioned **proton cyclotron TR-24**

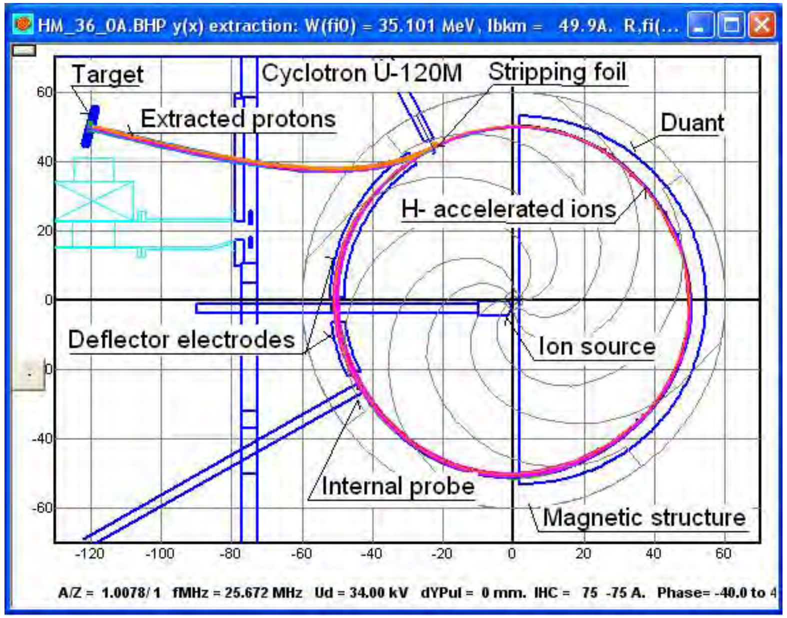
the neutron generator based on interaction
of 24 MeV / 300 μA proton beam with Be target
is developed.
Static target with submerged-jet cooling technique
is under investigation
to handle 7kW power dissipation in the target
and to achieve neutron flux density ≥ 10^{12} n/cm^2/s
at sample position - order improvement comparing to U-120M
The flux and energy range (≤ 22 MeV) are suitable
to allow the measurements of small reaction CS and
to carried out irradiation tests of ITER components.

TR 24 – Advanced Cyclotron System Inc. (Canada)

Bunching system on the U-120M cyclotron for TOF facility

Basic idea:

- „deflection-bunching“ TOF method on the internal cyclotron beam (Karlsruhe cyclotron, 1980)
- **unique adaptation and connection with** the negative-ion cyclotron U-120M
- internal deflector deflects last orbits from 48 to 50 cm simultaneously bellow the cyclotron median plane
- negative ions hit the extraction carbon foil
- bunch of protons after stripping is directed to the external Be target



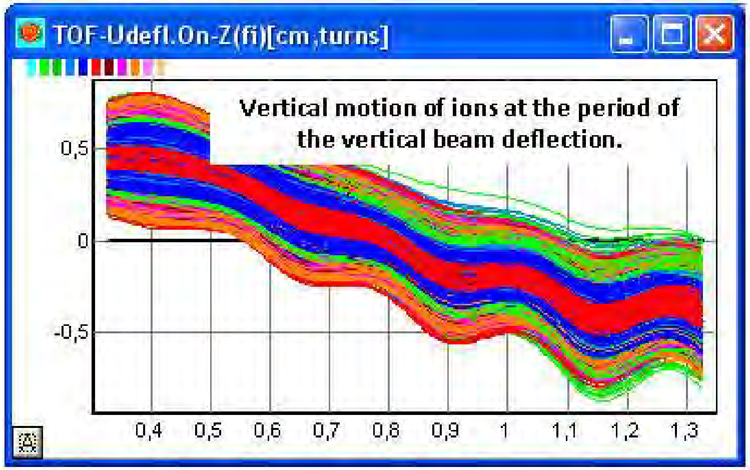
Main advantages:

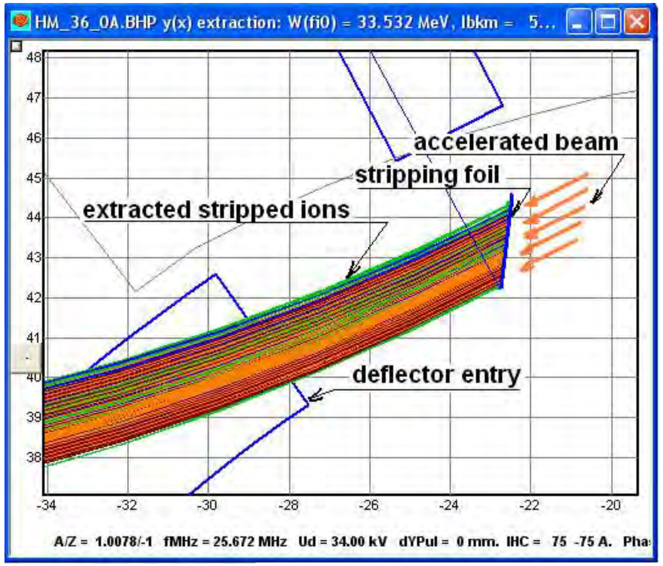
- requested extension of repetition interval (≥1000 ns) between individual bunches (5ns FWHM)
- due to orbit cumulation on the final radii – no lose of the mean extracted ion beam current (to reach the same parameters i.e. to get rid of selected bunches can result in decrease of extracted beam intensity by two orders)
- theoretically 100% of extraction efficiency, no reduction of extracted ion beam current

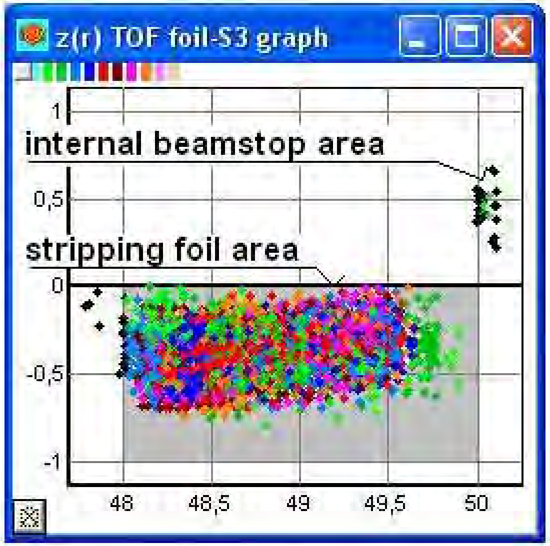
Results of simulations

Optimal setup:

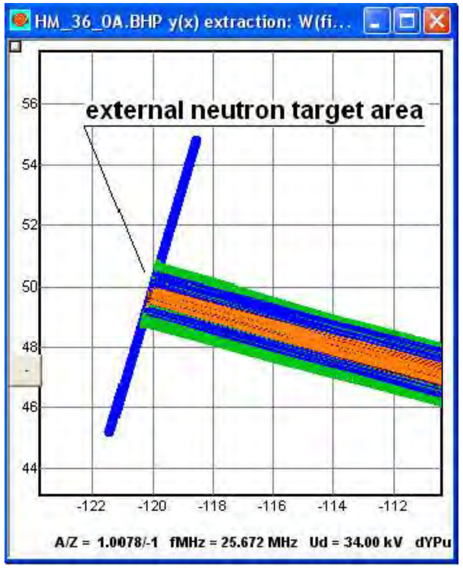
■ Range of extracted ions radius	48.0 – 50.0 cm
■ Radius of internal beam-stop at probe S3	50.00 cm
■ HV deflector pulse amplitude	- 10.0 kV
■ Vertical position of the stripping foil upper edge	0.0 mm
■ Shift of the magnetic field medial plane	+ 4.5 mm
■ Deflector gap	20 mm
■ Extracted beam pulse width – FWHM	4.99 ns
■ Repetion period of accelerated beam bunches	38.95 ns
■ Repetion period of extracted beam bunches	1012.80 ns
■ Pulse duration to the repetition period relation	1 : 203







Stripping foil and beamstop area



External Be target

Main properties of optimally extracted beam

Beam energy:

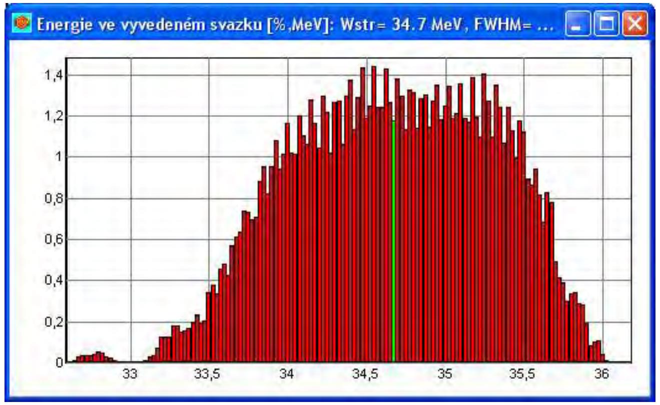
- Average energy 34.7 MeV
- RMS dispersion 0.632 MeV
- FWHM dispersion 1.960 MeV

Beam size:

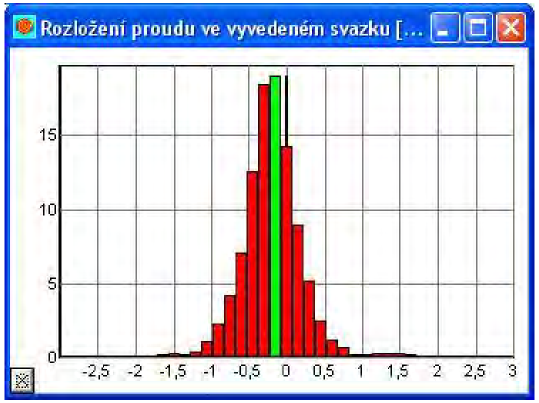
- full horizontal size 34.0 mm
- full vertical size 26.7 mm

Beam RMS emittance for 95%

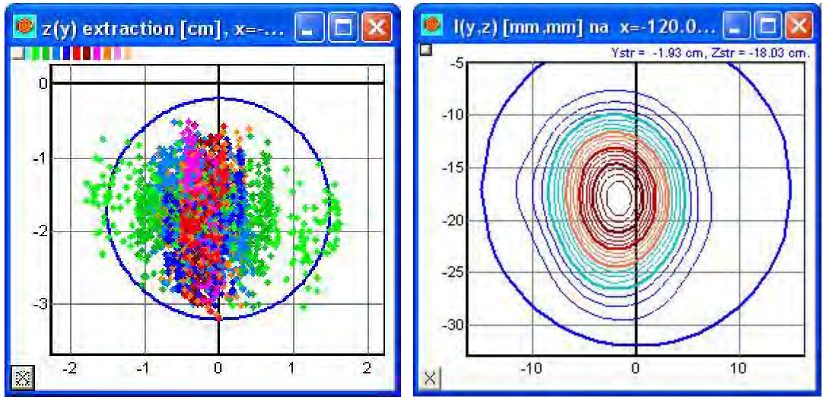
- horizontal 502 mm.mrad
- vertical 44 mm.mrad



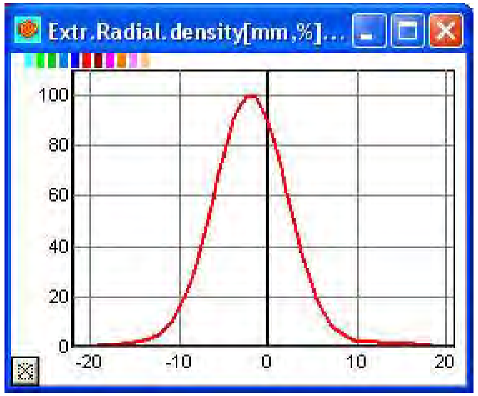
Extracted beam energy distribution



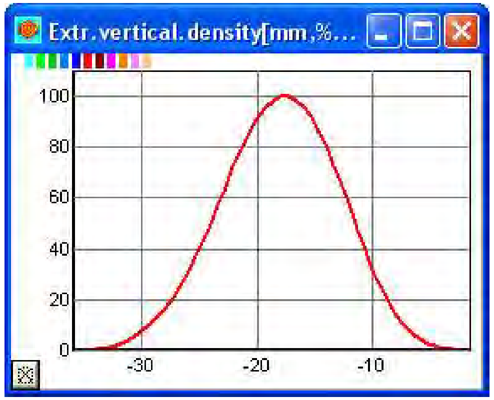
Beam current density distribution



Extracted beam cross-section at the TOF target

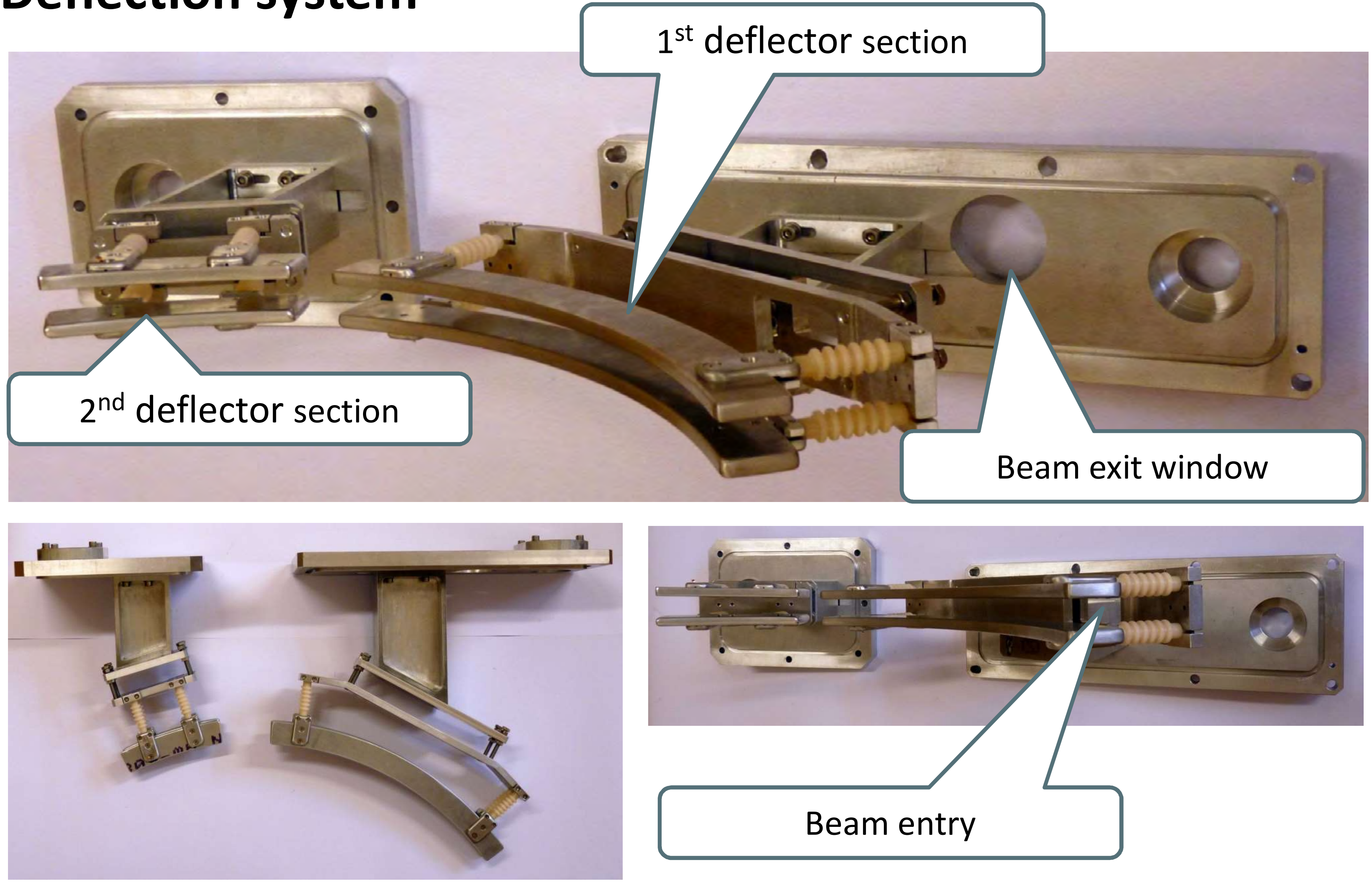


Horizontal beam curent density distribution



Vertical beam curent density distribution

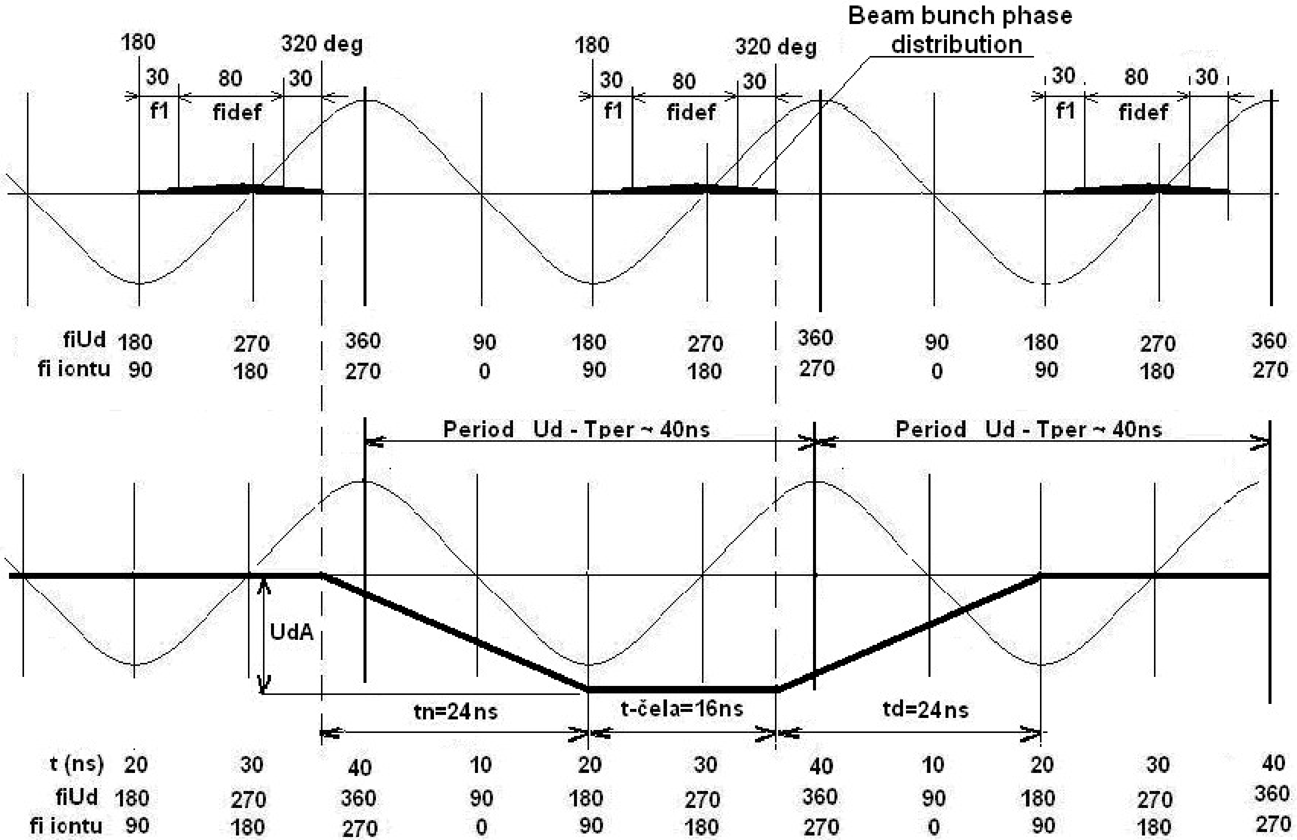
Deflection system



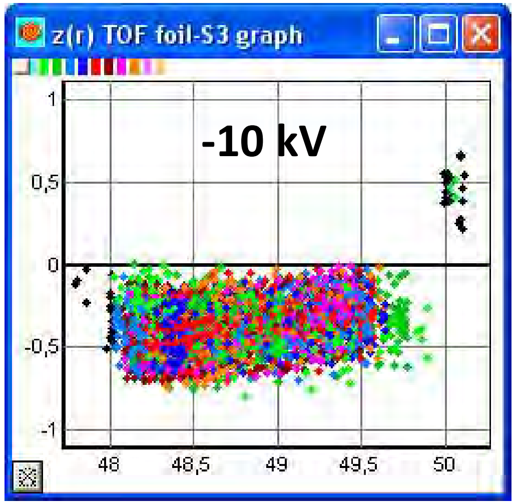
High voltage pulsed power supply

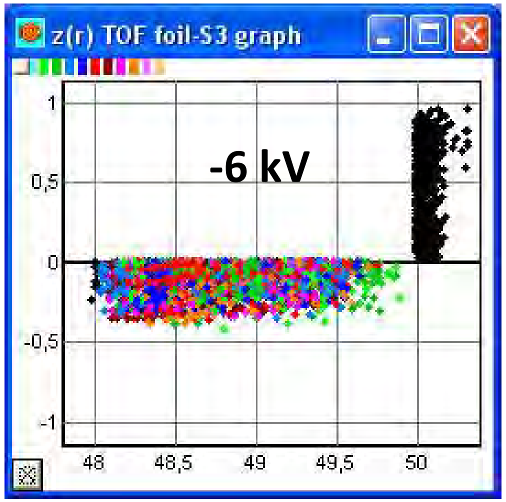
Parameters

- ■ Trapezoidal pulse deflection voltage, amplitude **-10kV**
- ■ Time structure: front edge 24ns/amplitude 16ns/back edge 24ns
- ■ Repetition frequency 1MHz
- ■ Average power 13kW



Results of simulations for various HV amplitude

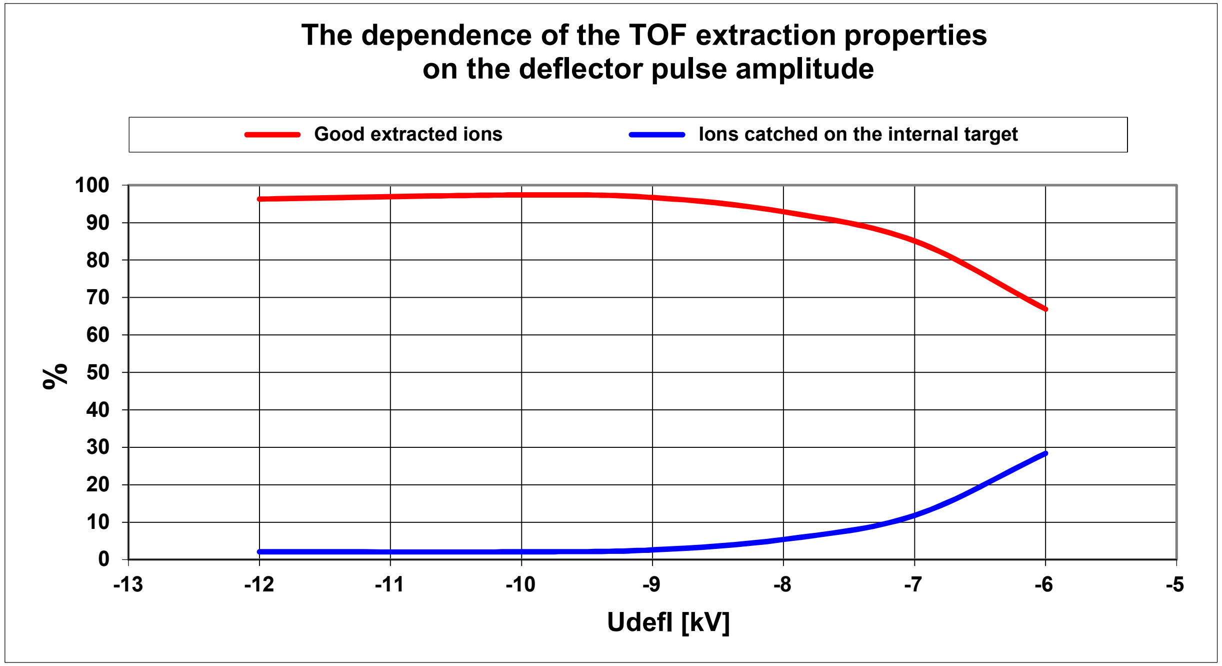




The number of acceleration periods = 26

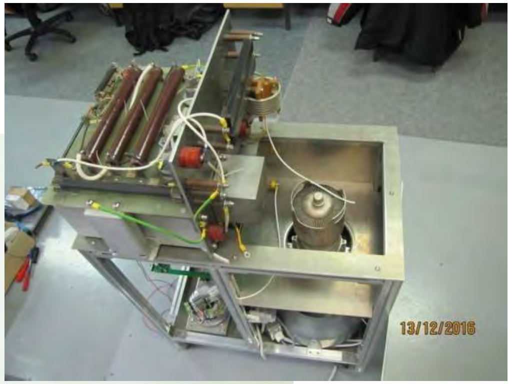
The interval between pulses = 1.013 μs

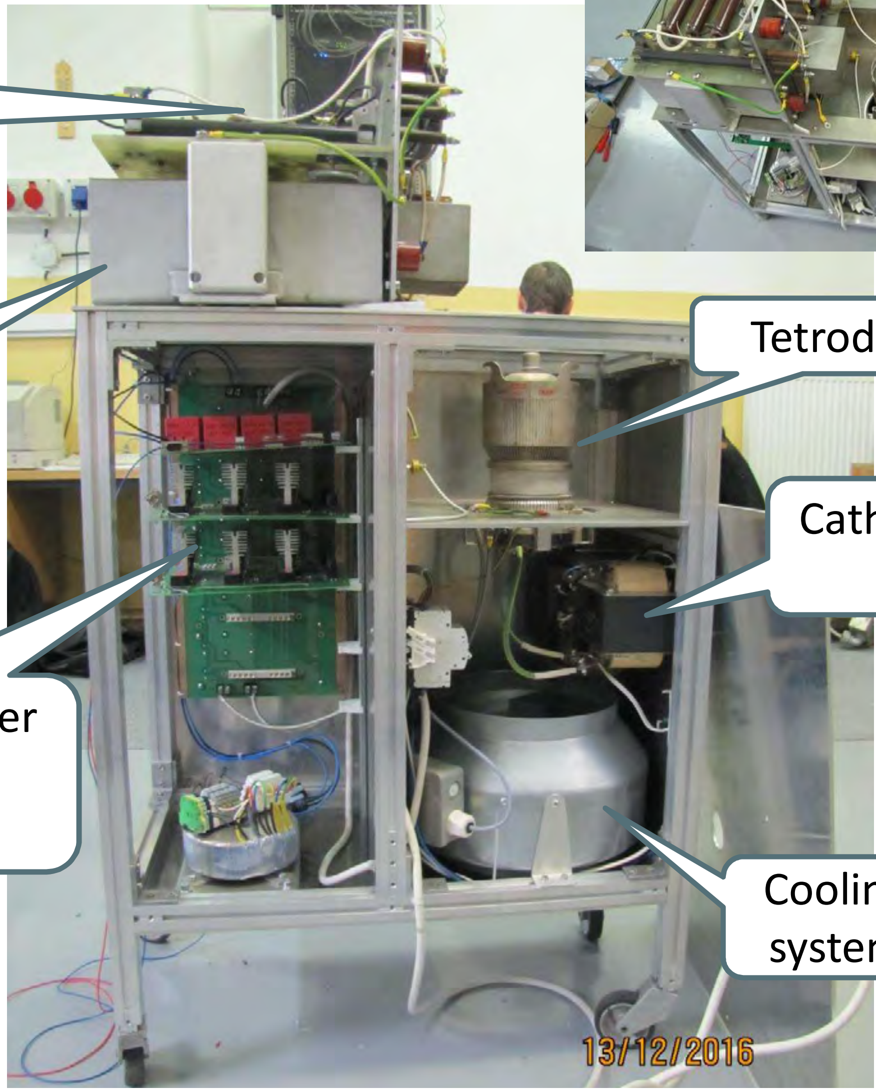
Udef kV	LOST	Bad0	Frame	GOOD	Broth	S3-upper	behind	Sum S3	Eff
-12	1.2	0	0.3	96.3	0	1	1.1	2.1	96.3
-10	0.1	0	0.4	97.4	0	1	1.1	2.1	97.4
-9	0.2	0	0.4	96.7	0.1	1.5	1.1	2.6	96.7
-8	1.1	0	0.3	92.9	0.2	4.3	1.1	5.4	92.9
-7	2.3	0	0.3	85.1	0.5	10.7	1.1	11.8	85.1
-6	3.6	0	0.2	66.9	0.9	27.2	1.2	28.4	66.9



Prototype of HV pulsed PS

Bunching system on U-120M





Future steps:

■ test of deflection system with low level pulsed signal with required time parameters

■ completion of electronic design and implementation of the high voltage high power pulsed power supply

■ completion of simulations of negative ion extraction with stripping foil method –parameters of the stripper

■ construction, manufacture and implementation of the stripper

High power neutron generator on TR-24 cyclotron

- TR-24 cyclotron provides proton beam with variable energies up to 24 MeV and 0.3 mA beam current on external target.

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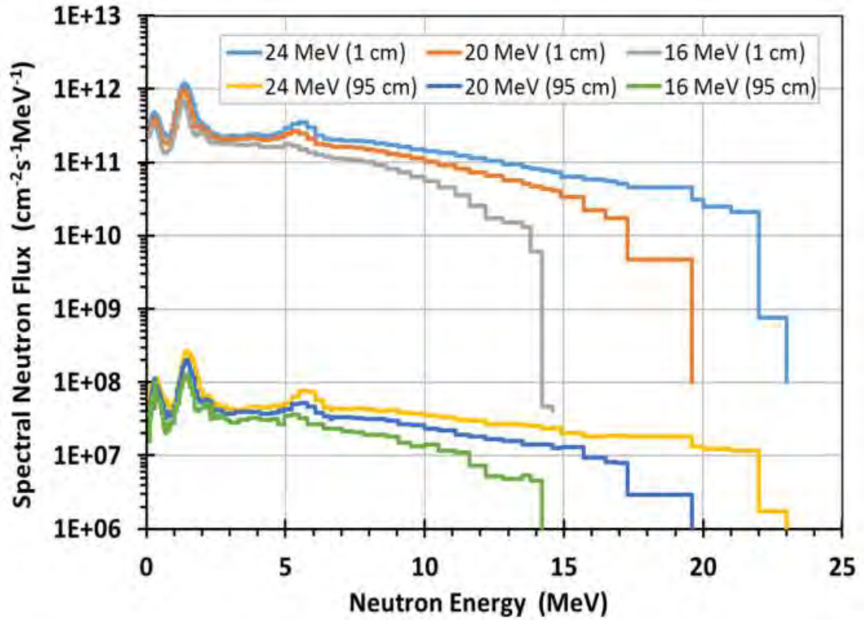
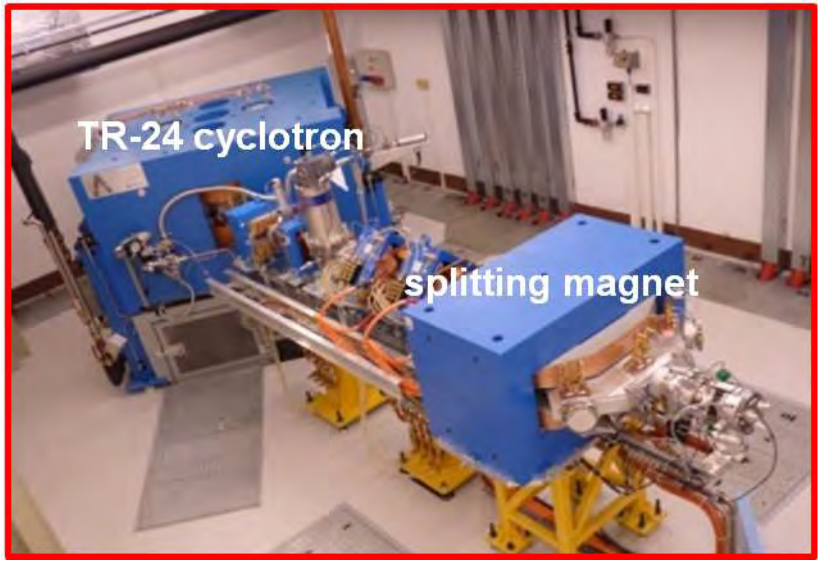


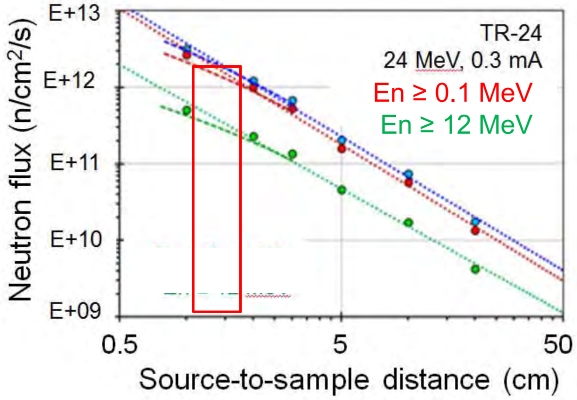


- Source of white-spectrum neutrons with variable energies ≤ 22 MeV and flux up to **5×10^{12} n/s/sr** could be built on TR-24 utilizing p+Be(thick target) source reaction.

- Target station with open area at forward direction is assumed to provide the irradiation at unlimited arrangement of associated hardware. The station would include remotely controlled manipulation technique with- and parking for- the irradiated components.

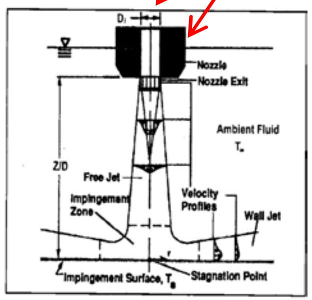
Neutron flux, target mode and cooling

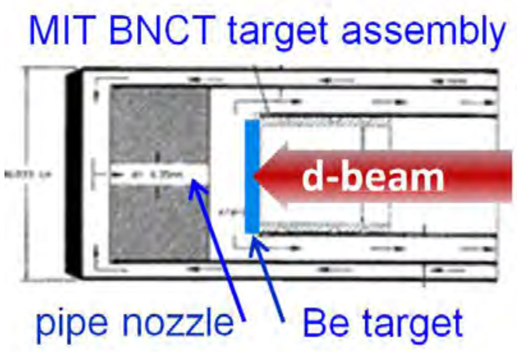
- Point-like mode of accelerator-based n-source causes strong $1/r^2$ dependence of the flux density on source-to-sample distance (r). Consequently,
- the **static type** of **Be target** and optimized arrangement of cooling are considered to reach minimum s-to-s distance and maximum neutron flux (10^{12} n/s/cm^2 at r ≤ 2cm)



- Proton beam (24 MeV, 0.3 mA) will deliver up to 7.2 kW heat power to the target (beryllium disk, t 3 mm, d 40 mm active area). The beam spot (Gaussian FWHM ≤ 12 mm) will cause the **heat density** ranging up to 4 kW/cm^2.

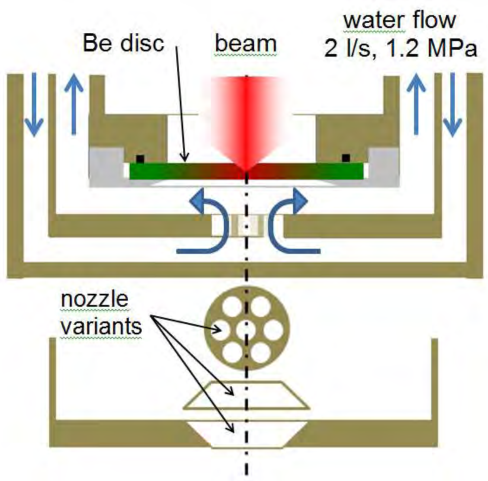
- The use of submerged impinging jets as a most effective enhanced heat transfer is proven widely in electronic devices and industrial processes.

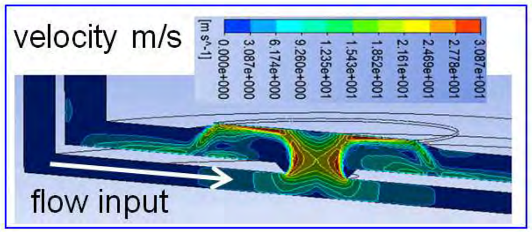


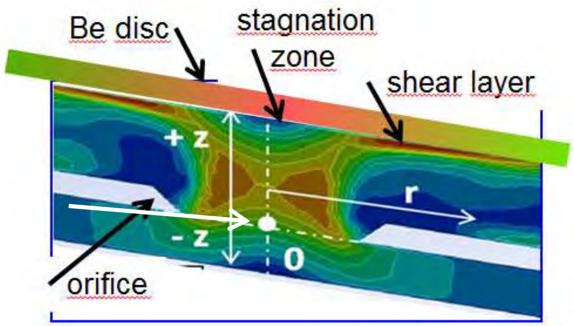


- Using submerged impingement pipe-nozzle jet a cooling of target at 1-6 kW/cm^2 heat load was investigated at **MIT BNCT neutron facility** *[Massachusetts Institute of Technology, 2003].* However, long pipe-nozzle of cooling assembly derogates the advantage of high flux intesity at short s-to-s distances.

Nozzle selection using simplified structure of the simulated target



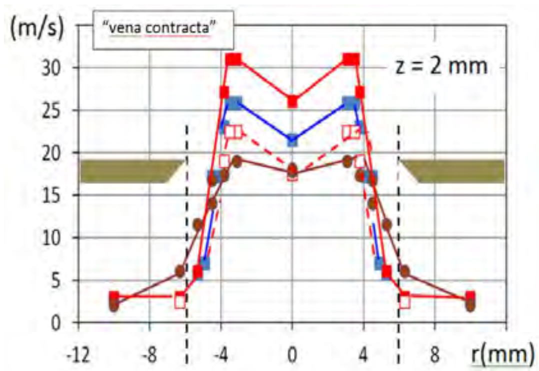


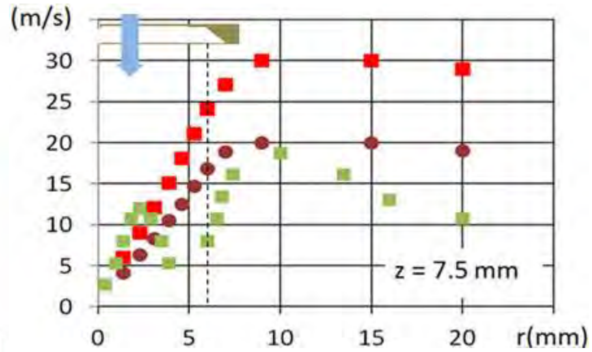


■ To utilize high-flux option at short s-to-s distances
the **orifice-nozzle** jet was selected for target cooling.
Using ANSYS simulation of flow parameters -

- □ the fluid pressure (in stagnation zone)
- □ and the velocity (in jet stream and along shear layer) -

various types of orifice nozzles were compared to pipe mode.

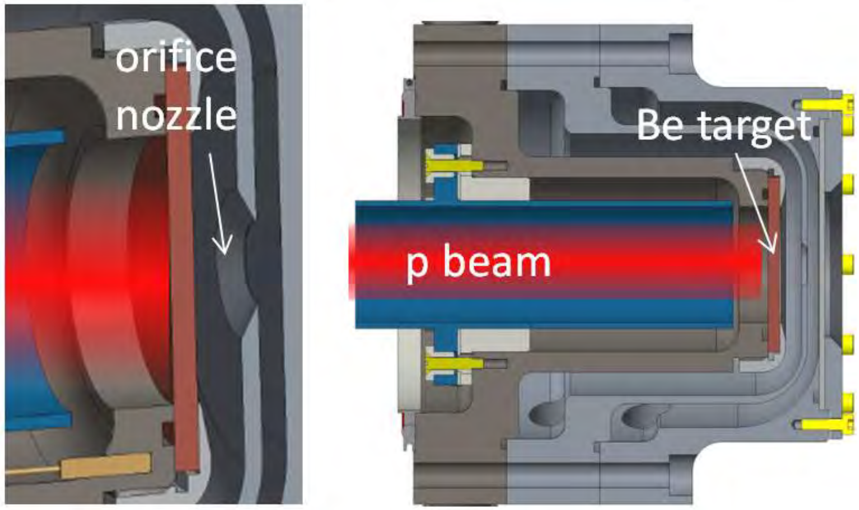




■ Comparing to results for MIT pipe-jet variant, the open orifice have shown comparable and/or better results of simulated parameters under identical input data.

■ The comparison of simulated kinematic parameters to experimental data of MIT indicates q_{max} ~ 5 kW/cm^2 as achievable thermal load of designed source target utilizing open orifice-jet for the cooling arrangement.

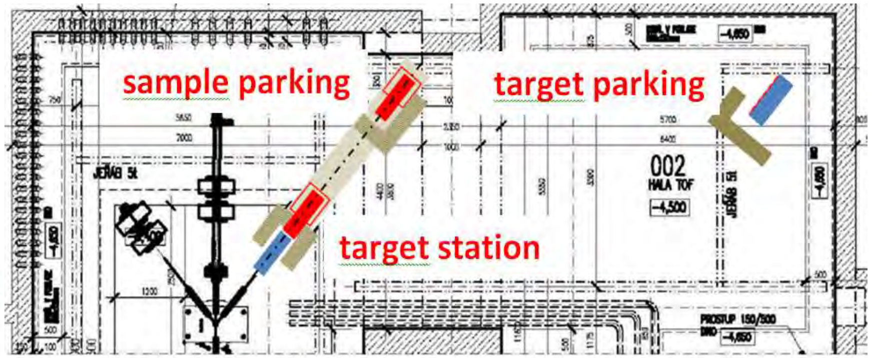
Mock-up of the target



is manufactured

- to tune the construction and cooling system of designed target and
- to measure power dissipation in the target necessary to tune the ANSYS simulations and- in particular – to determine experimentally the CHF (critical heat flux) for designed cooling set up.

- Safety constrains has obliged more complex design including remotely controlled manipulators and parking stations for irradiated components.



- Starting thermal-test experiments on cooling system (Al instead of Be target) at low power of proton beam (2 kW) are foreseen in the next months.

Support of the projets

CANAM, CZ.02.1.01/0.0/0.0/16_003/0001812, OP RDE, MEYS, Czech Republic
CANAM infrastructure LM2015056.
Czech Academy of Sciences (RVO61389005)

Projects realization – by the end of 2019

Thank you for your attention!