The high power target for LENOS Project at Laboratori Nazionali di Legnaro of INFN-LNL

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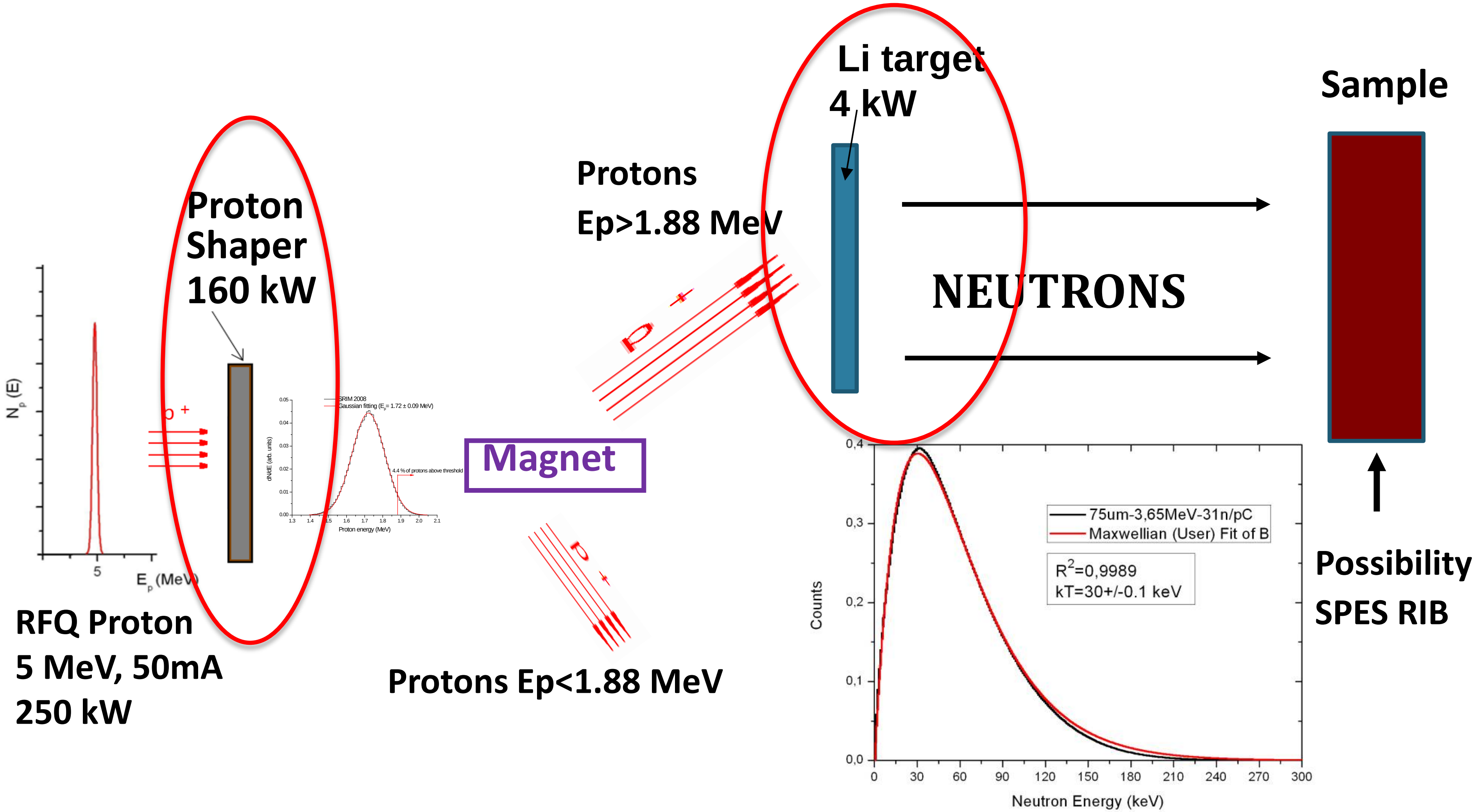
What would be LENOS?

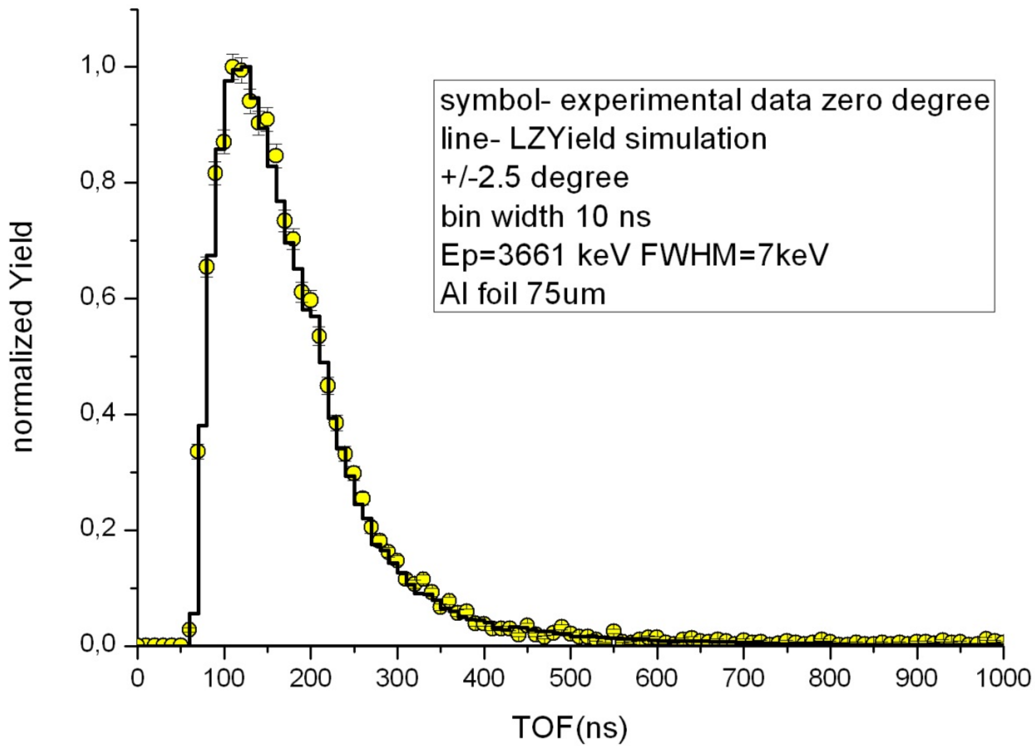
- Neutron facility (irradiation, ? TOF ?)
- It is based on a method for the production of different neutron spectra
  - Nuclear Astrophysics.
  - Validation of Evaluated Data for energy and non-energy applications.
  - Medical physics applications.
  - Radiation damage tests (SEE)
  - Material science physics (neutron imaging)

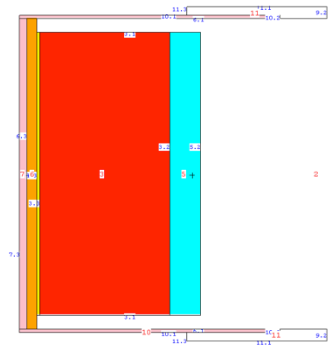
Sketch of SPES/LENOS Layout

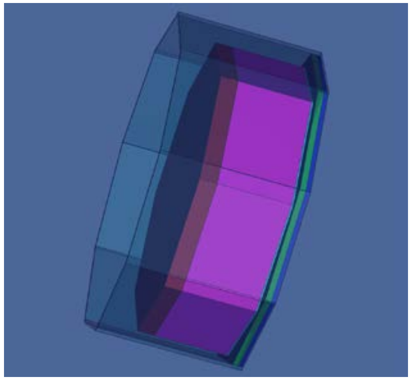


Expected Neutron Flux = $5\cdot10^{10}$ n/s·cm²

Validation of the proposed method: 0^{o} time spectra.

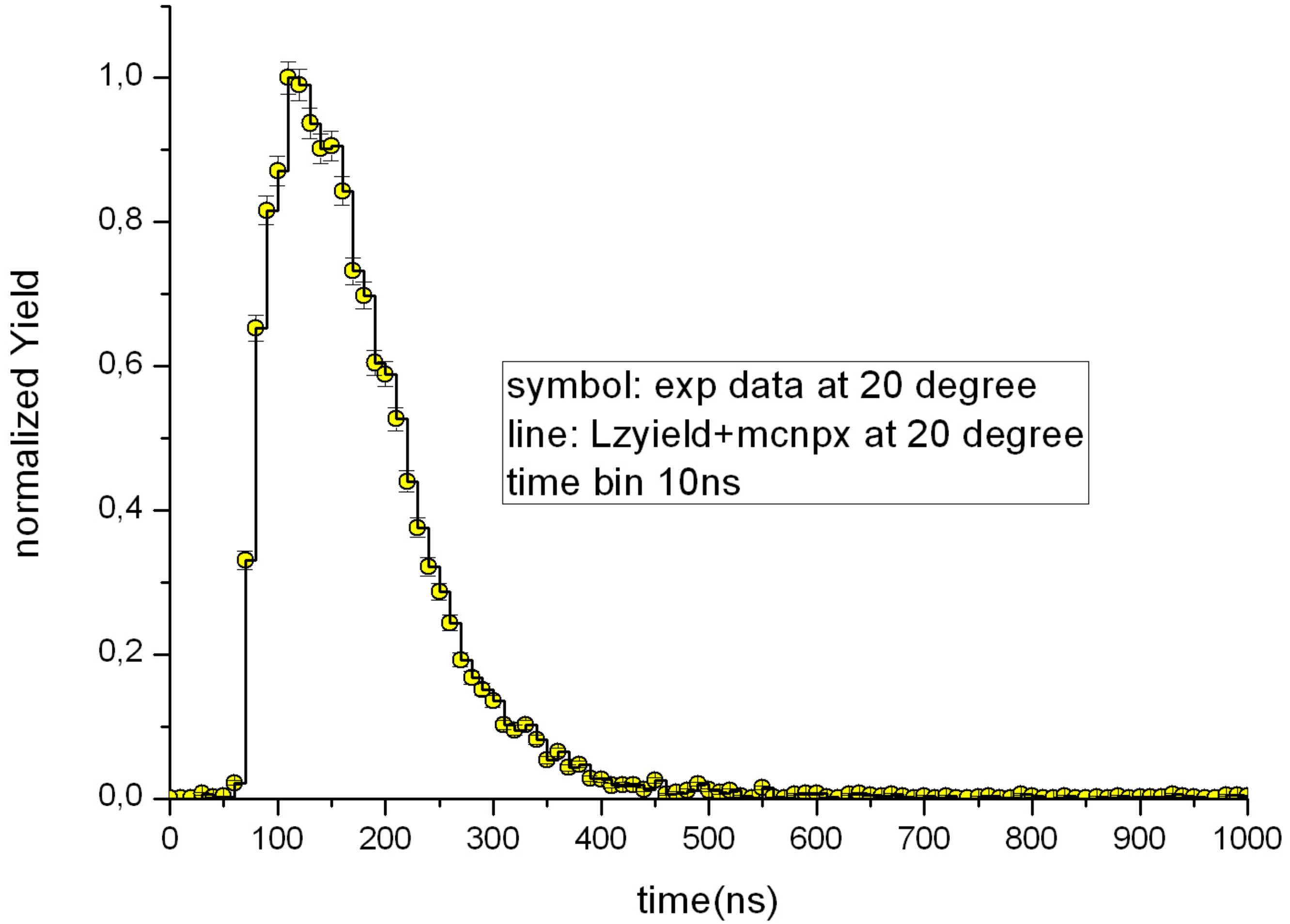






Neutron spectra has been measured at CN accelerator (BELINA facility) using 3.66 MeV protons inpinging on 75 μm thickness Al layer. LZYield predictions and MCNPX transport with detailed geometry of the setup.

Experimental data: 20^0 time spectra.

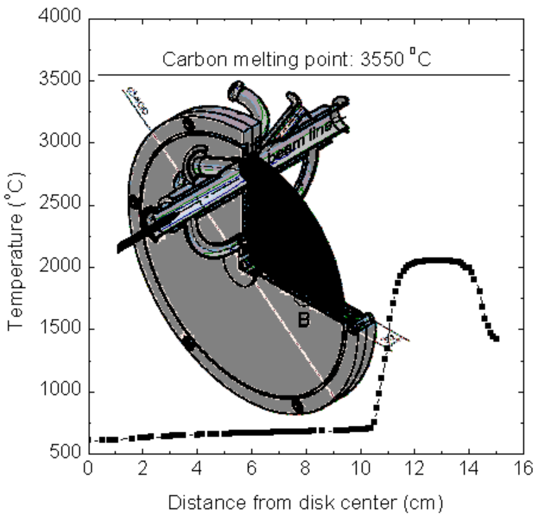


Yellow points are our experimental data at 20^0.
Black line is the simulated neutron spectra with our code LZYield+ transport (MCNPX)

SPES/LENOS Layout: Energy Shaper

. We decide to shape the proton beam by using the energy straggling and stopping power of charge particles when interact with a thin foil of material. General method: **multilayer energy shaper.**

LENOS foil material requirements :
Low atomic number and low density, high melting point, high emissivity, high thermal conductivity, high tensile strength.

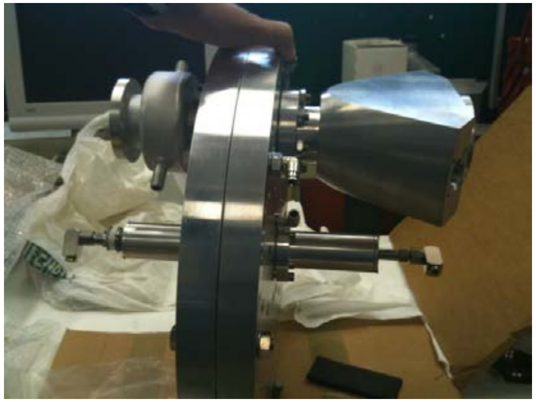


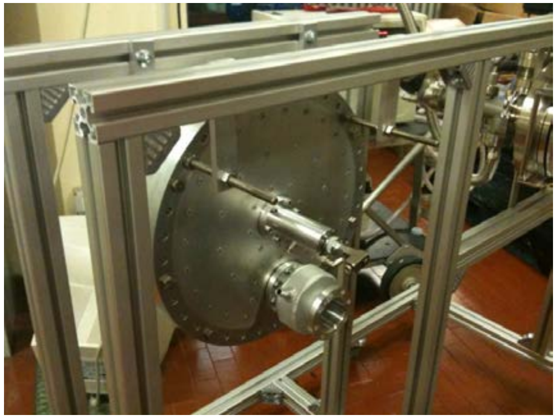
→ **GRAPHITE foil**

For lower power we can use a monolayer Aluminium foil.

P=2x80 kW for 50mA *ANSYS, Inc*

LENOS Layout: Energy Shaper





Starting from this device, the new ANEM rotating target has been constructed (see L. Silvestrin Talk)

LENOS Layout: Lithium target

In order to dissipate so high specific power (about 3 kW/cm^2) a new generation of heat cooling device have to be implemented and developed.

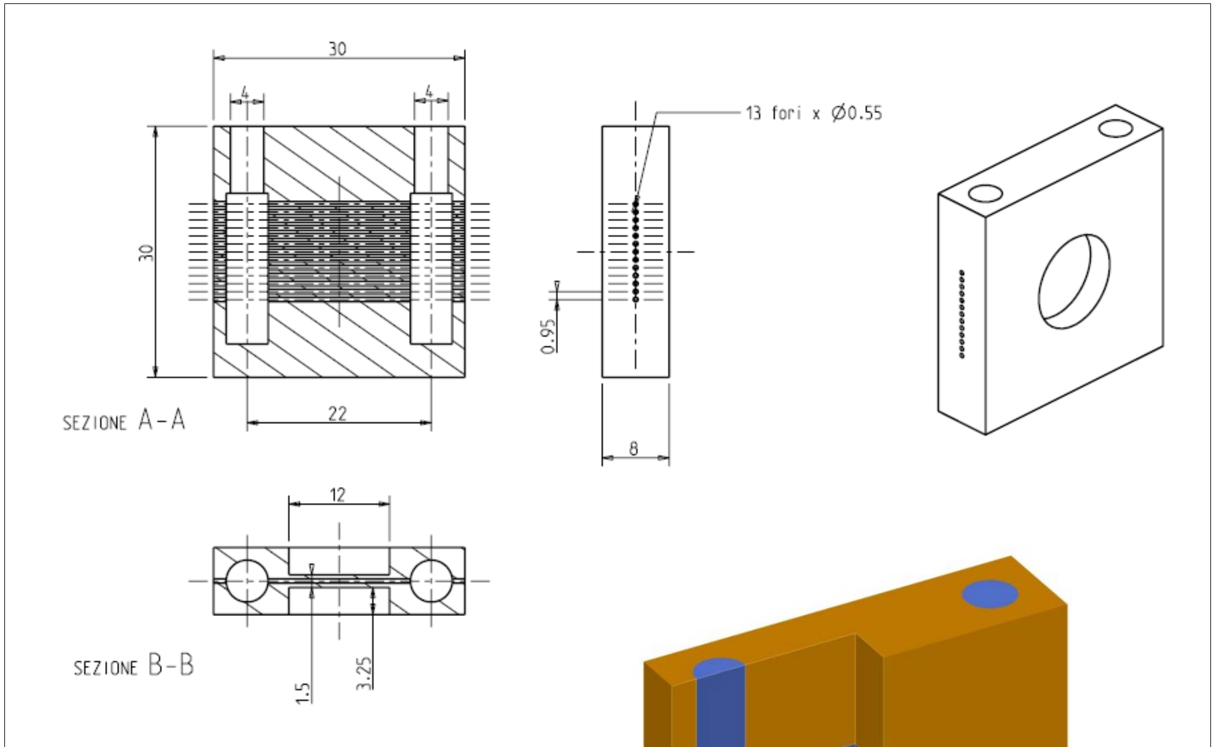
The target must satisfy some constrains:

- Low mass (to avoid neutron backscattering and reduce radioactivity)
- Small thickness, in order to maximize the neutron flux (keeping the measuring sample in touch with the neutron producing surface) and reduce neutron spectra perturbation
- Low cost and easy to fabricate procedure, in order to replace the target often even during a measurements

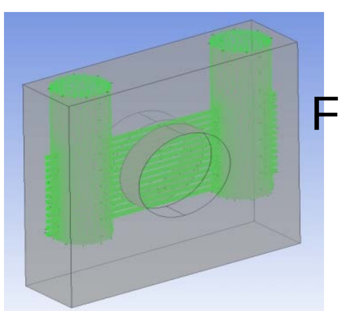
Microchannels + liquid metal cooling medium

This target is suitable for many other applications (BNCT, radio pharmaceutical production, CPU heat sink etc…)

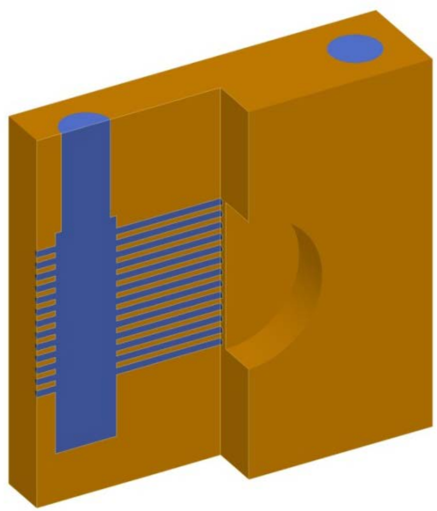
LENOS: Lithium target. First Design



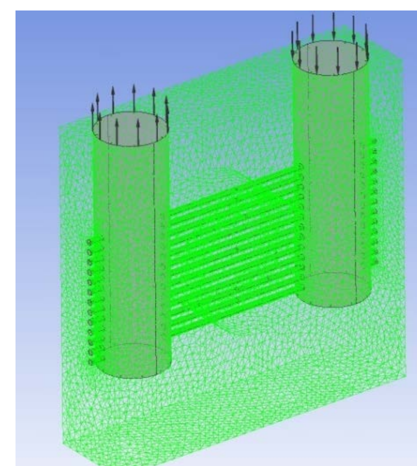
Cu Backing:
13 micro channels
14 mm long
0.45 mm diameter
0.95 mm spacing
0.5 wall thickness
6.4 mm in-out diam tube



Fluid domain



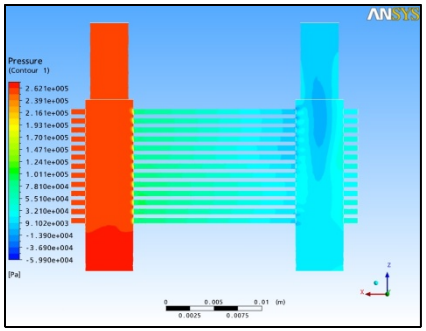
Solid domain



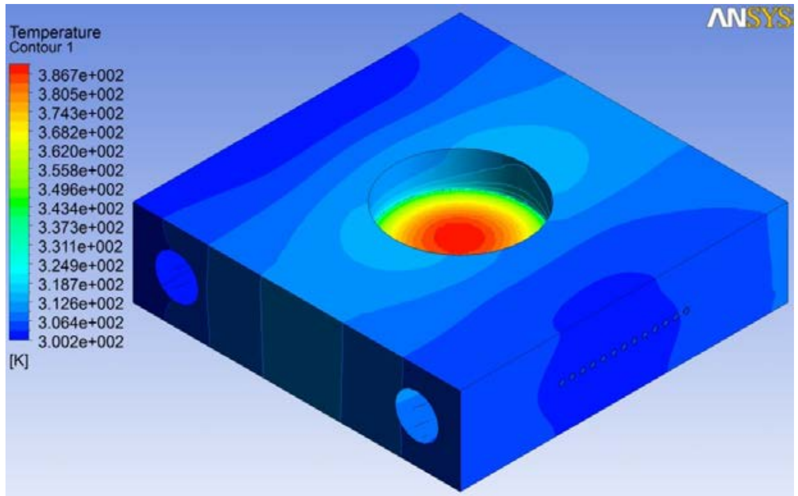
LENOS: Lithium target. ANSYS results

Water cooled

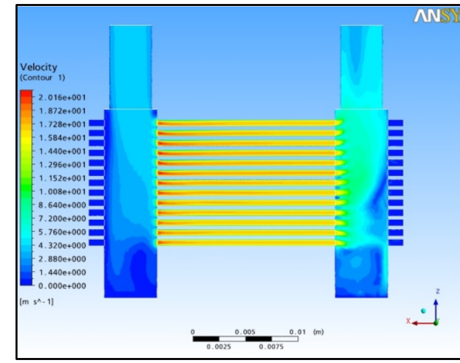
Pressure



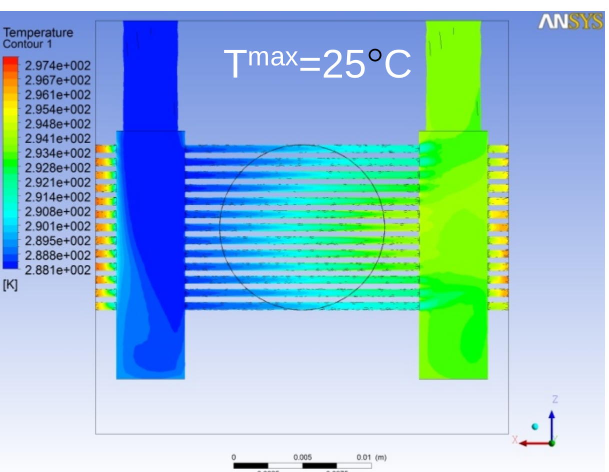
P^{in}=2.7 bar
ΔP=2.7 bar



Velocity



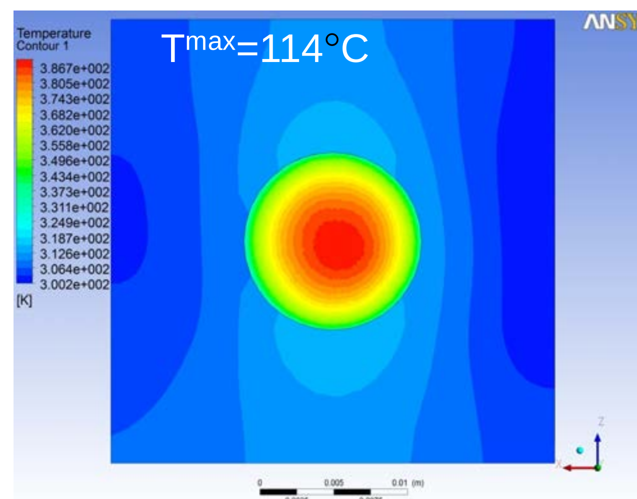
μ-channel fluid velocity =15m/s



Temperature

Li 40 μm
Mass flow=160l/h
Inlet fluid temperature=15° C
Beam Power=1000 W
Flat beam profile

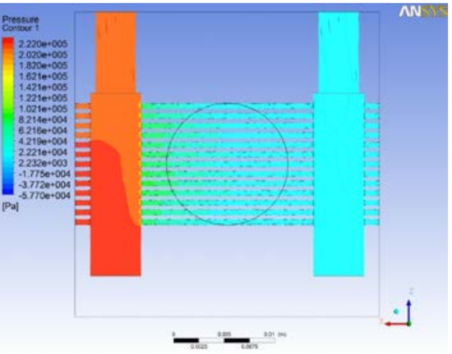
Melting point Li = 182°C



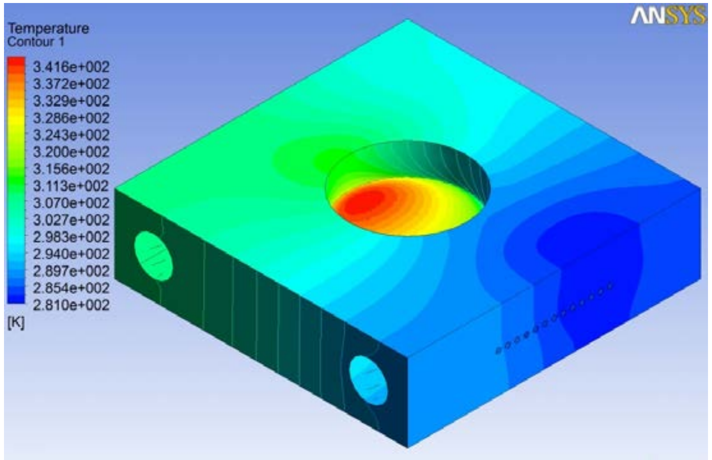
LENOS: Lithium target. ANSYS results

SnInGa alloy cooled

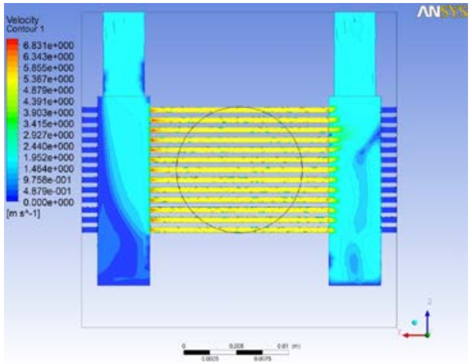
Pressure



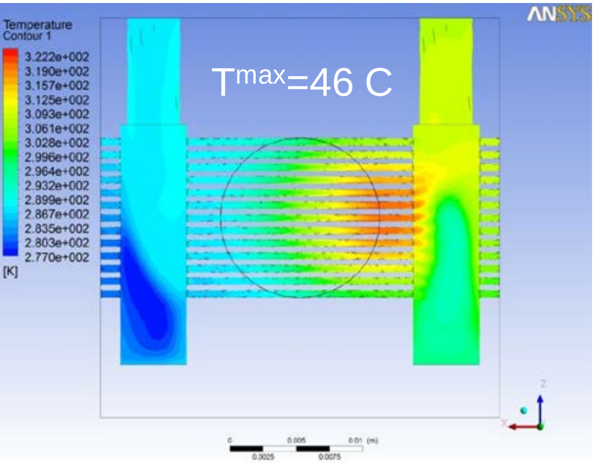
P^{in}=2.5bar
ΔP=2.5 bar



Velocity



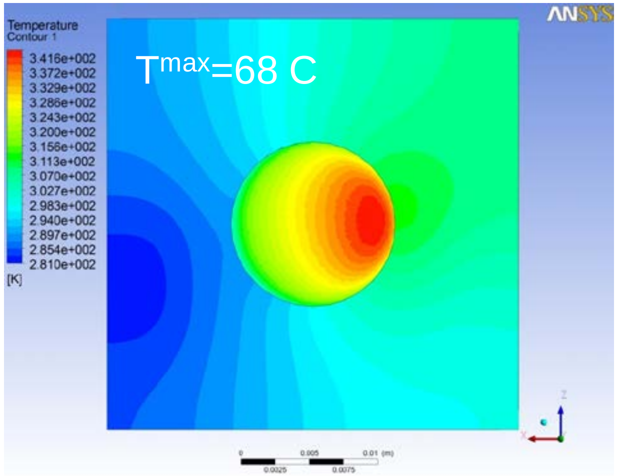
μ-channel fluid velocity =5 m/s



Temperature

Li 40 μm
Mass flow=55 l/h
Inlet fluid temperature=15° C
beam Power=1000 W
Flat beam profile

Melting point Li = 182°C



LENOS: Lithium target. Fluid Comparison

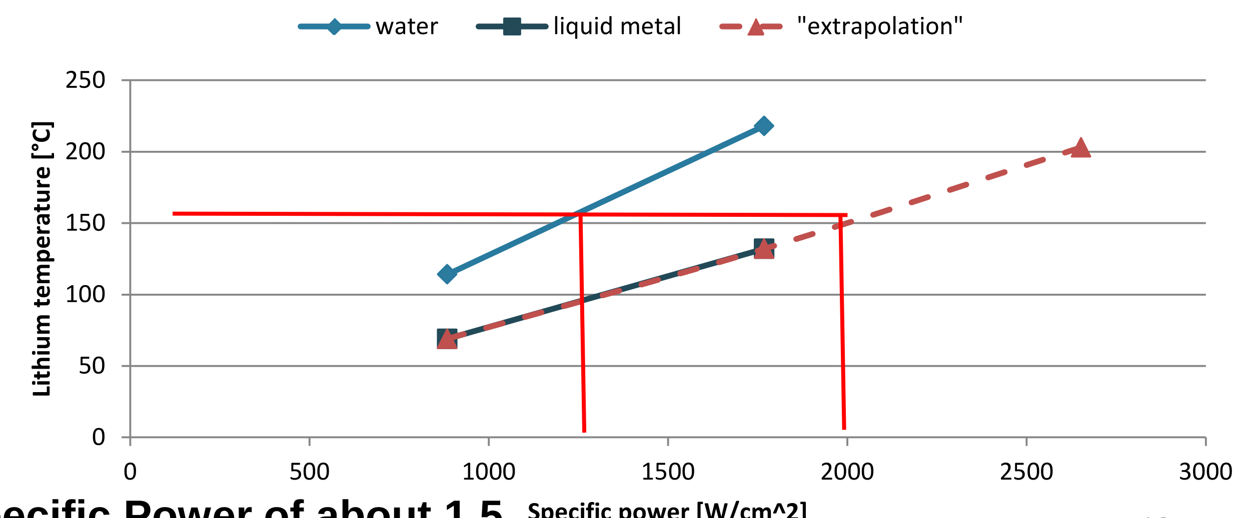
Analytical

WATER		
parameters	description	value
c_p [J/kg K]	fluid specific heat	4181,7
λ_{Fl} [W/m K]	fluid thermal conductivity	0,6069
λ_{Cu} [W/m K]	target thermal conductivity	401
v [Pa s]	fluid viscosity dinamic	0,0008899
ρ [kg/m^3]	fluid density	997
d [m]	diameter of the microchannels	0,00055
Pr	Prandtl number	6,131644142
v [m/s]	velocity in the microchannels	15
Re	Reynolds number	9242,89246
Nu	Nusselt number	73,77145321
α [W/m^2 K]	convection coefficient	81403,44537
$T_{av,fl}$ [ºC]	fluid average temperature	23
n	number of microchannels	13
q [W/m^2]	beam specific thermal power	4420970,641
q [W/cm^2]	beam specific thermal power	884,1941283
q [W]	beam thermal power on target	1000
T_s [ºC]		77,30937992
T_{beam} [ºC]	temperature on beam surface	124,6909261
T_{in} [ºC]	fluid inlet temperature	20
Q [m^3/s]	fluid volumetric flow	4,63287E-05
T_{us} [ºC]	fluid outlet temperature	25,17728529
	lithium thickness [m]	0,00004
$T_{s(Li)}$ [ºC]		126,7787516
λ_{Li} [W/m K]	gold thermal conductivity	84,7

GALINSTAN		
parameters	description	value
c_p [J/kg K]	fluid specific heat	365
λ_{Fl} [W/m K]	fluid thermal conductivity	36
λ_{Cu} [W/m K]	target thermal conductivity	401
v [Pa s]	fluid viscosity dinamic	0,00221
ρ [kg/m^3]	fluid density	6363
d [m]	diameter of the microchannels	0,00055
Pr	Prandtl number	0,022406944
v [m/s]	velocity in the microchannels	5
Re	Reynolds number	7917,760181
Nu	Nusselt number	7,305505188
α [W/m^2 K]	convection coefficient	478178,5214
$T_{av,fl}$ [ºC]	fluid average temperature	80
n	number of microchannels	13
q [W/m^2]	beam specific thermal power	11052426,6
q [W/cm^2]	beam specific thermal power	2210,485321
q [W/]	beam thermal power on target	2500
T_s [ºC]		103,113599
T_{beam} [ºC]	temperature on beam surface	122,7516388
T_{in} [ºC]	fluid inlet temperature	20
Q [m^3/s]	fluid volumetric flow	1,54429E-05
T_{us} [ºC]	fluid outlet temperature	89,70382393
	lithium thickness [m]	0,00004
$T_{s(Li)}$ [ºC]		127,9712027
λ_{Li} [W/m K]	gold thermal conductivity	84,7

ANSYS and Analitycal calculations: Good agreement for water, less for liquid metal

ANSYS



Expected a gain in term of specific Power of about 1.5

LENOS: Lithium target

The target has been successfully manufactured at LNL

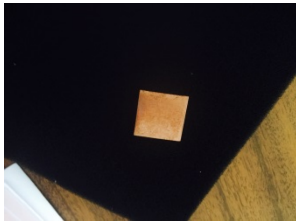
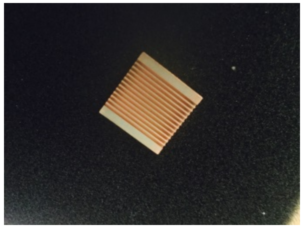
Micro-channels produced with electro-erosion drilling machine.

This production method limits too much the sizes, shapes and the use of other materials

The new version of the μ-channels target

Micro-channels are produced trough micro-tubes

- Grooves are produced in the target backing (one or both faces)

- Micro-tubes are inserted in the grooves

- Interference is produced in order to have a full thermal contact

tubes:
- 0.6 mm internal diameter
- 0.8 mm external diameter

Copper substrate 1.2 mm thickness, 2x2 cm
Wall thickness tube distance 0.5 mm
Number of tubes: 13

INFN international patent APPLICATION n. PCT/IB2014/067156

Improvements and developments

With this new method of production we have no more limitations on channels length, geometry (flat, curved etc..), and use of different materials (both for substrate and tubes)

First improvement under test: replace the copper substrate with diamond one

Thermal conductivity:

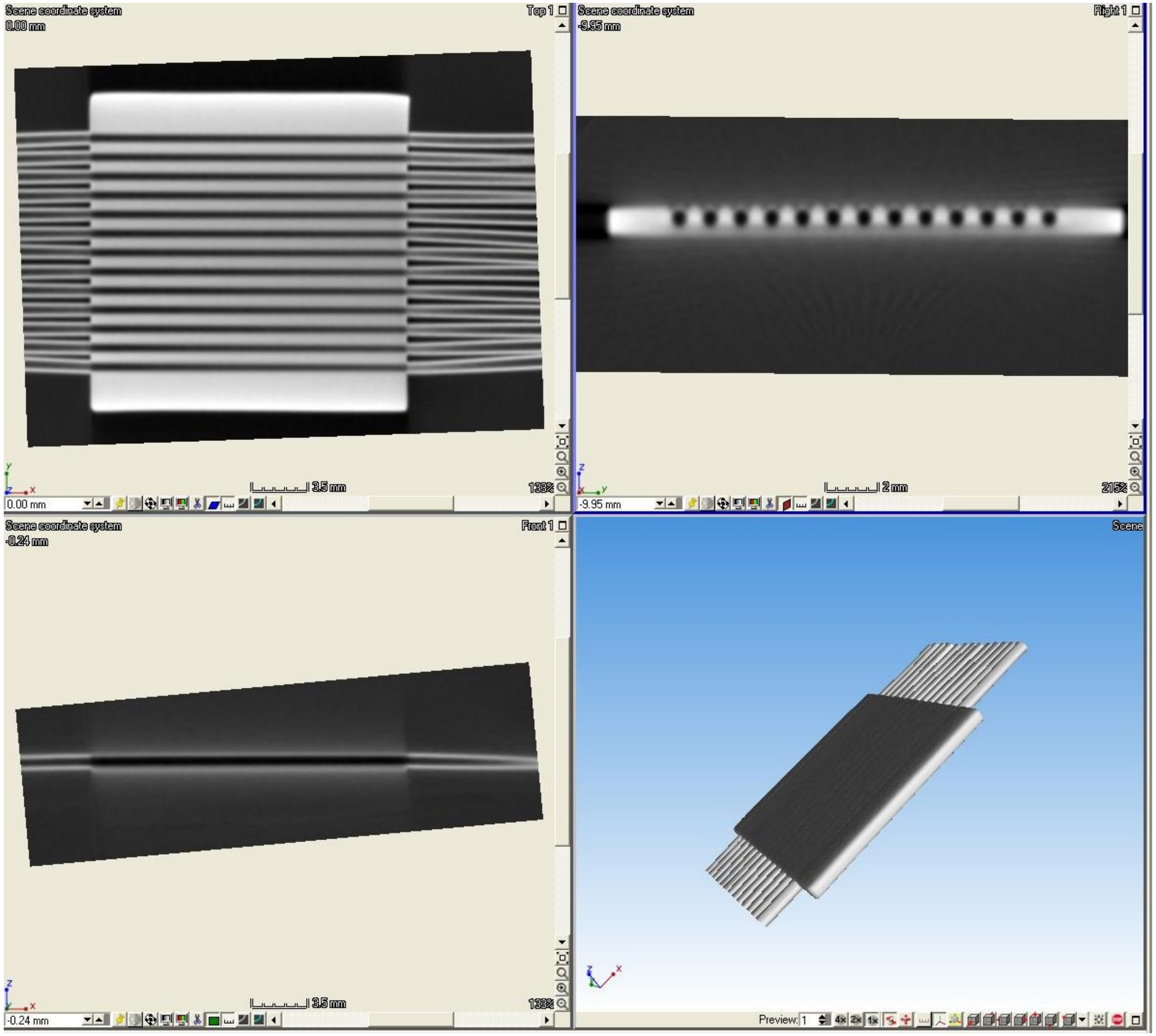
- Cu=390 W/m K
- Diamond (thermal grade) >8000 W/mK

PCD machinable with electro erosion !!

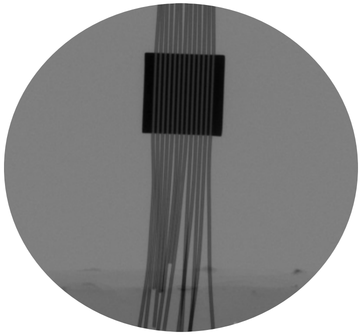
Tubes can be made of different materials for different applications (steel for corrosive fluids, Nb for liquid metals, etc…)

Tomography

Interference between tubes and grooves is fundamental:



Certified an almost perfect contact (no defect at the 1 µm level precision)



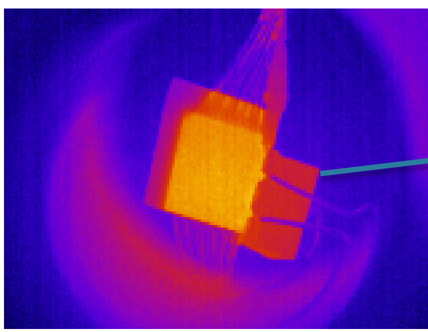
Target : beam tests at Birminghamm University

In July 2014 the target has been tested at Birmingham University.

2.8 MeV proton beam, with different current and beam spot has been used

- Delivered beam power has been measured by measuring the mass flow and difference of temperature at inlet and outlet

Surface temperature has been measured by thermo camera (IRISYS model 4000)

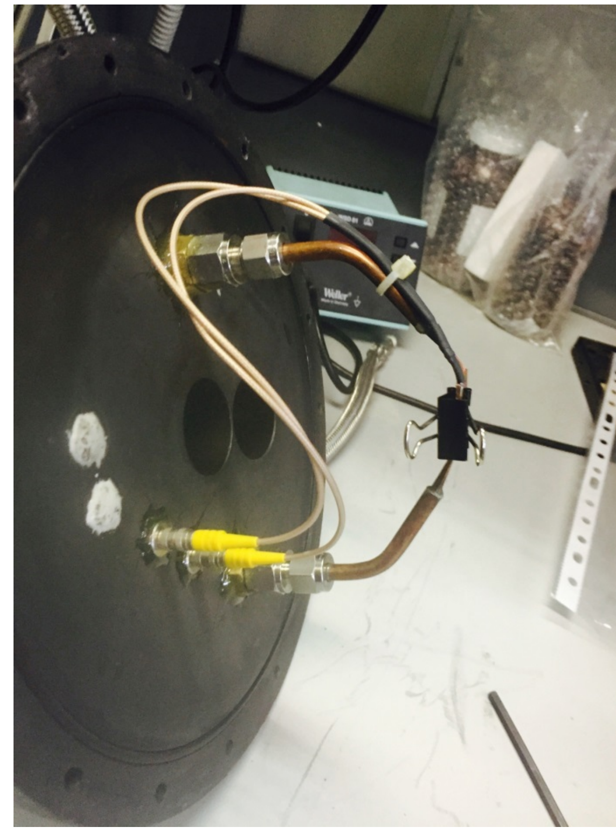


Thermocouple has been used for cross check

- Inserite foto lta chiuso

Target has been accommodated in a Carbon fibre chamber (emissivity close to 1)

- Thermo camera has been calibrated in a dedicated experiment:
  - An heat bath has been used to warm up the water (at 40,50 and 70 ^{o}C)



- Reflected temperature has been measure for each point with Lambert reflect meter
- Real emissivity is calculated assuming the previously calculated reflected temperature, by tuning e in order to reproduce the fixed target temperature
- The 3 points (40,50 and 70 ^{o}C) agree well with 30.7 ^{o}C reflected temperature and 0.21 emissivity

Target : beam tests at Birminghamm University

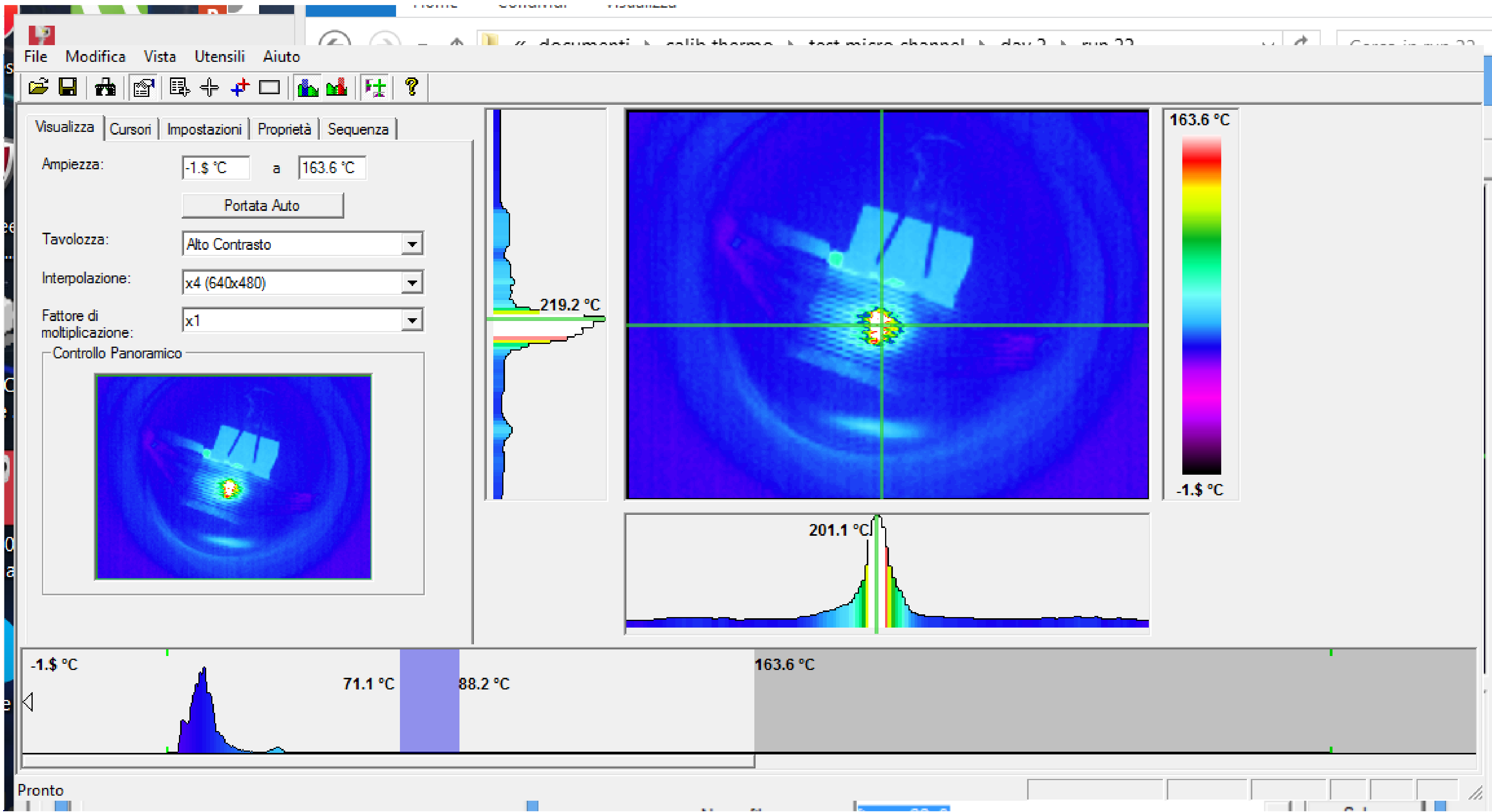
Mass flow: 2.94 l/min

T^{in}_{water}=13.0 °C

250<P<1360 W

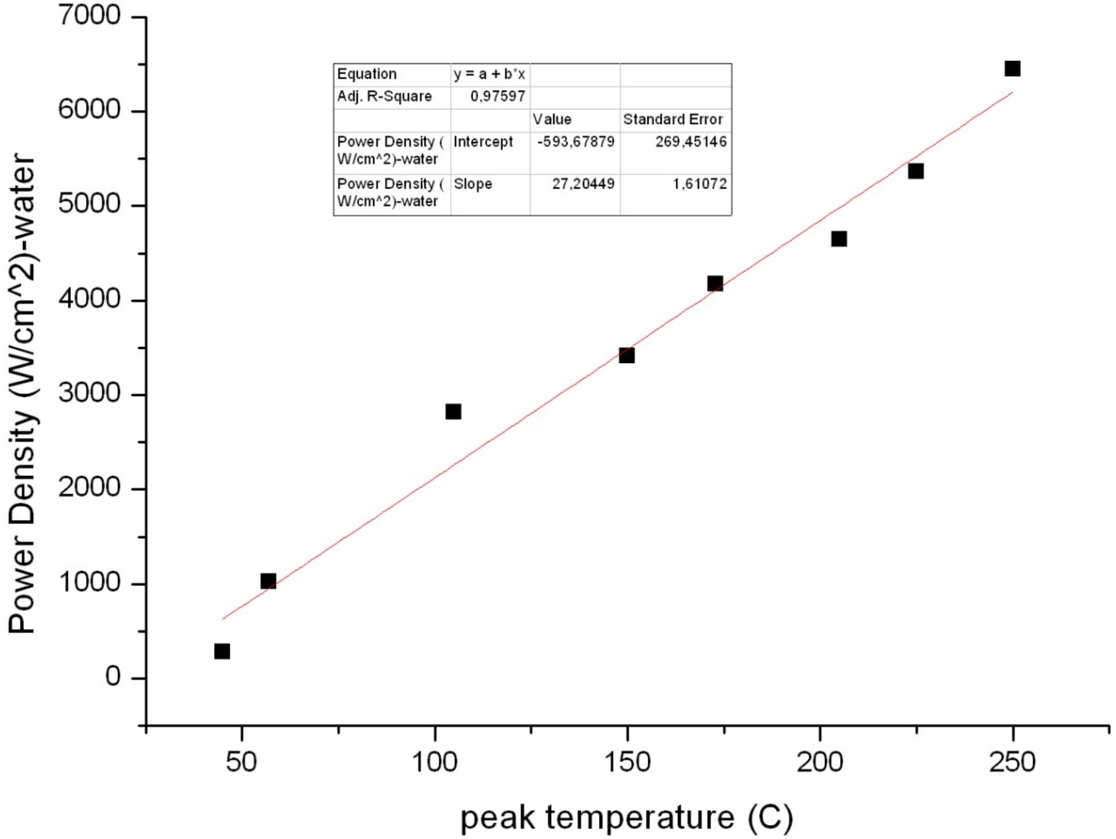
Conservative beam spot diameter calculations (FWHM)

0.064<beam spot area<0.2 cm^2



Experimental results

Range of 2.8 MeV protons on copper is 30.73 um



The used target was not optimized. Much better performances obtainable

3,5 kW/cm^2 dissipated with a peak temperature of 150 ^{o}C

P_V=1 Mw/cm^3

More appropriate:

P_s=27 w/cm^2 K

SUMMARY AND CONCLUSIONS

- A micro-channel target has been developed, constructed and tested.
- A non optimized version of a bare target shows to be able to dissipate a specific power of 3.5 kW/cm^2 keeping the peak surface temperature below 150 ^oC (Li target application)
- Next step will be the validation of the target with metal Lithium layer
- Applications under study cover a wide range of applications: SPES beam dump (50 kW), radioisotope production, BNCT
- It is a deposited INFN international patent n. **PCT/IB2014/067156**
- Other improvement using different materials for tubes and backing are planned

THANK YOU FOR YOUR ATTENTION