LEgnaro NeutrOn Source

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, [8] International Nuclear Safety Center, KieV- Ukraine

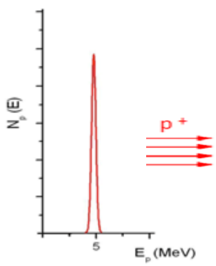
Overview

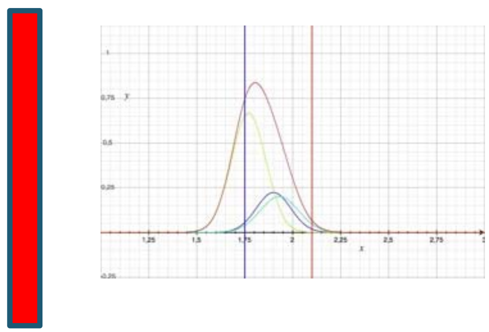
LENOS:

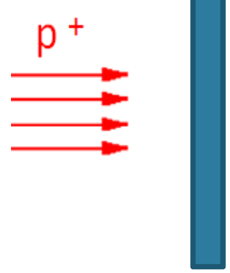
- The new method
- Scientific motivations
- The LENOS project
  - Proton energy shaper
  - Lithium target
- Outlook
- Conclusions

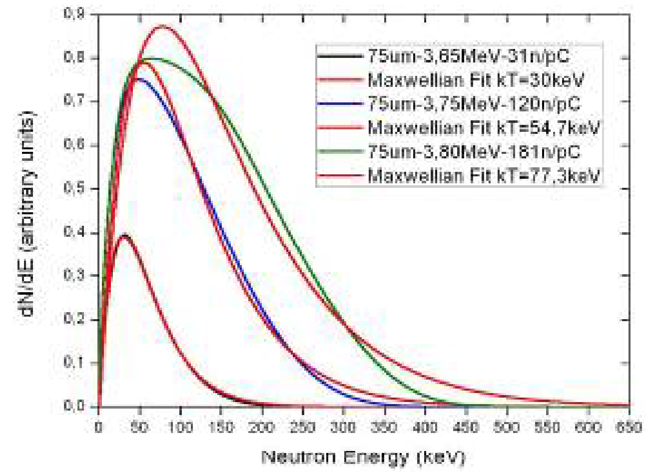
The new method

Proton energy shaper









Monochromatic proton beam

Neutron production target

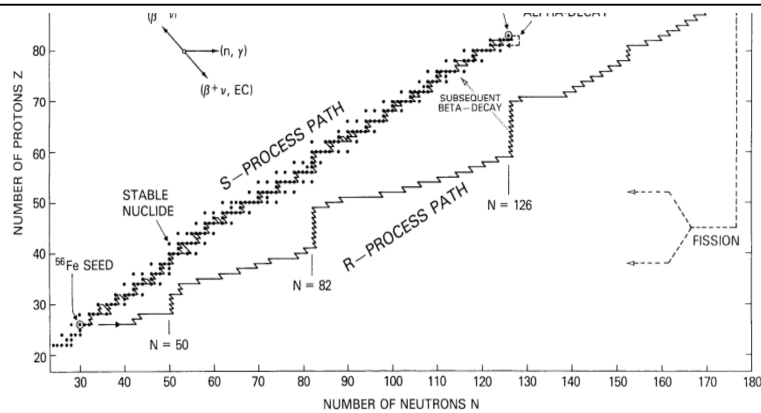
Desired sample integrated neutron energy spectra

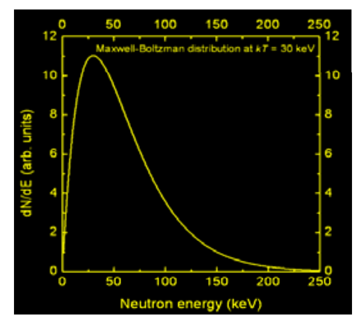
The method is very versatile: using the degree of freedom of beam type and energy, target material and angle integration, a large variety of desired neutron spectra can be obtained.

We are focused on the simulation of a setup for the production of **Maxwell Boltzmann neutron spectra**(MBNS) at different stellar temperature using the ^{7}Li(p,n) reaction near treshold

Scientific motivations: Astrophysics

Nucleosynthesis of elements beyond Fe (B=8.8 MeV/A) are mainly produced in stars by successive neutron captures and β-decays. Stellar neutron distribution is Maxwell-Boltzmann. Depending on the stellar site and evolutionary state the most important stellar temperatures are kT=8, 30 and 90keV.





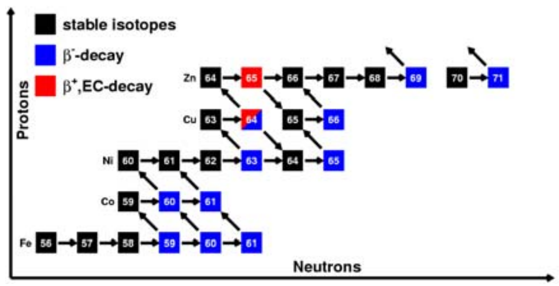
$$\frac{dN_A(t)}{dt} = N_{A-1}(t)\cdot n_n(t)\langle\sigma\cdot v\rangle_{A-1} - N_A(t)\cdot n_n(t)\langle\sigma\cdot v\rangle_A - \lambda_\beta(t)N_A(t)$$

$$MACS \equiv \langle\sigma_v\rangle = \frac{\langle\sigma\cdot v\rangle_A}{v_T}$$

→ **MACS (Maxwellian Averaged Cross Section) is the quantity needed**

Scientific motivations: Astrophysics

s-process



Branching points are unstable (SPES RIB) and can be used to determine the environment inside the stars (density, neutron flux and temperature).

r-process

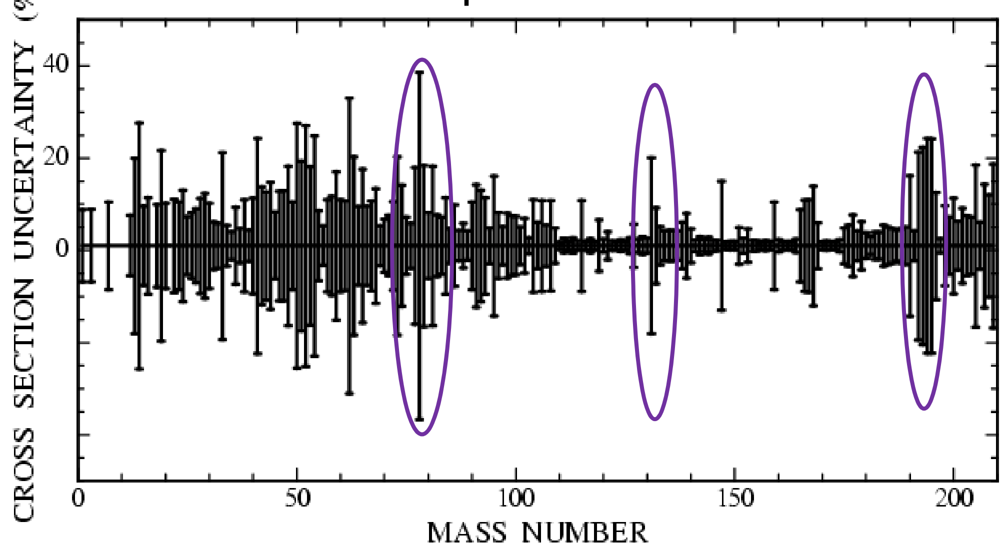
- Short time scale.
- High neutron density: 10^{20} cm^{-3} .
- related to explosive scenarios.

Waiting point

THE PROBLEM

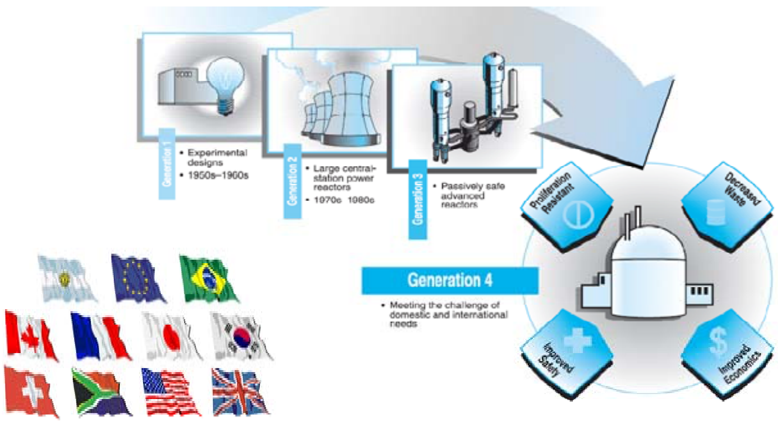
- The uncertainties in the MACS of several stable and most of the unstable isotopes are higher than the requested accuracy.
- Required uncertainties for s-process: **3-5**%

Week s-process



Scientific motivations:
Nuclear data for energy applications

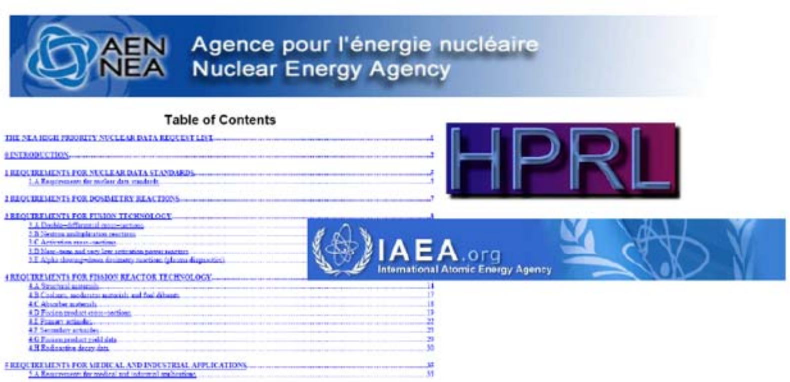
Nuclear data needs



Some actinides for AFC and Gen-IV:

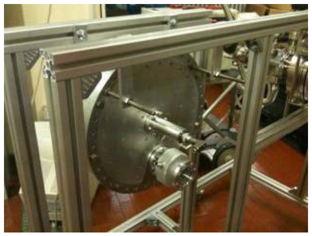
Pu-239 fission in 1 keV – 1 MeV
Pu-241 fission in 1 keV – 1 MeV
U-238 capture in 2 – 200 keV
Am-243 capture in fast and thermal energy range
Am-241fission in fast energy range

NNDC

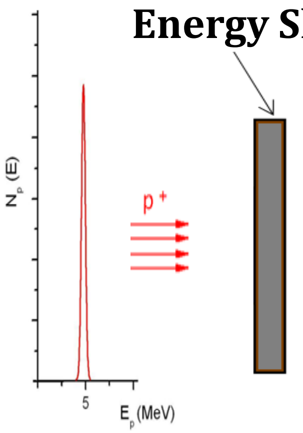


- Large discrepancies between data bases (ENDF,JENDL,JEFF,BRONDL) for many already measured isotopes.
- No measurements for some important isotopes (mainly radioactive)

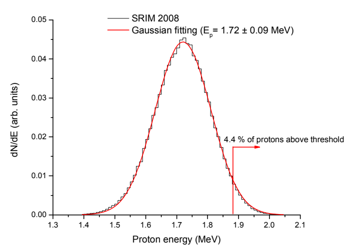
The LENOS project: layout



Energy Shaper



RFQ Proton
5 MeV, 50mA 250 kW
(see Fagotti's talk)

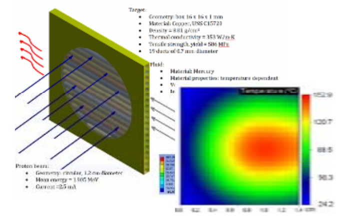


Protons
Ep>1.88 MeV

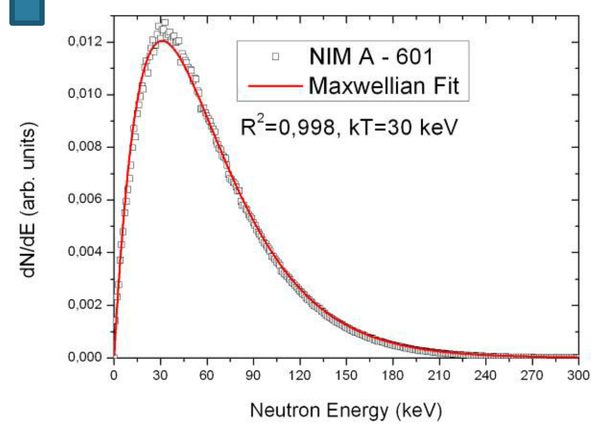
Magnet

Protons Ep<1.88 MeV
Other line or beam dump

Li target
4 kW



NEUTRONS



Sample

Possibility
SPES RIB
(see Prete's
Talk)

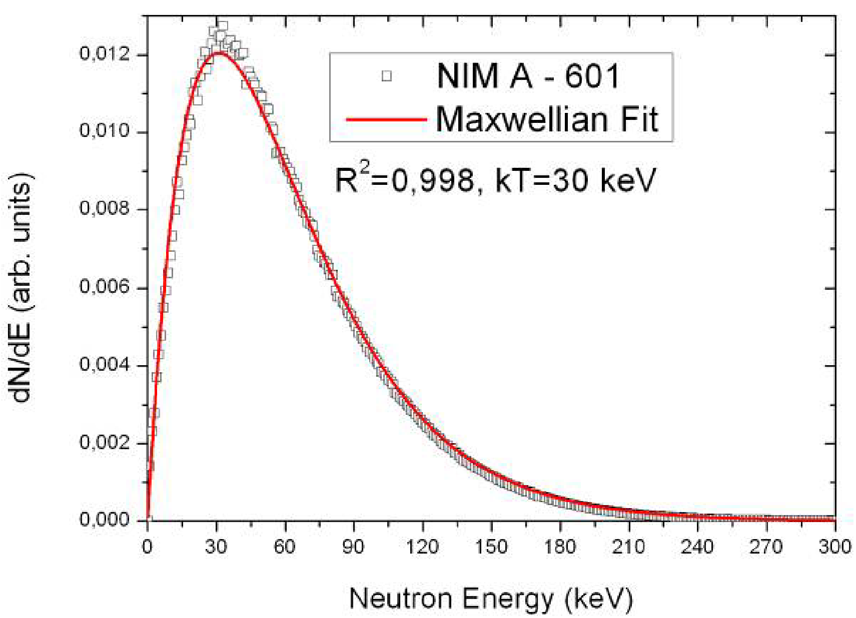
Neutron Flux = $5 \cdot 10^{10}$ n/(s·cm^2)

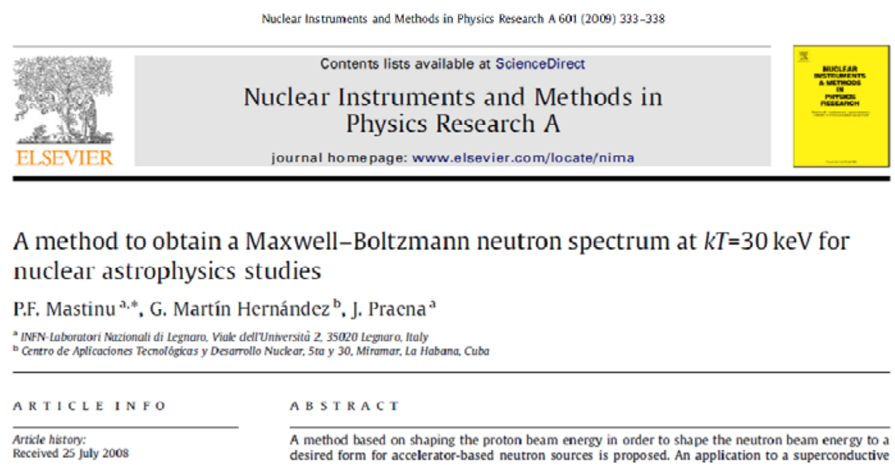
The LENOS project: simulation procedure

✓ We used SRIM-2008 for energy loss calculations of protons through the energy shaper materials. Results checked with **Measurements**.

✓ We developed a code (LZYield) based on the NIM B 152 (1999) that generates the differential neutron yield of ^{7}Li(p,n).

✓ MCNPX is used for the transport of neutrons with angular and energy yield of LZYield.





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A method to obtain a Maxwell–Boltzmann neutron spectrum at kT=30 keV for nuclear astrophysics studies

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ABSTRACT

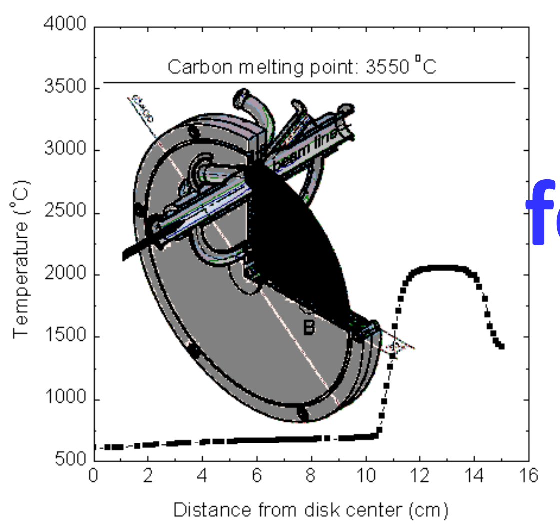
A method based on shaping the proton beam energy in order to shape the neutron beam energy to a desired form for accelerator-based neutron sources is proposed. An application to a superconductive

The LENOS project: Proton energy Shaper

We decided to shape the proton beam by using the energy straggling and stopping power of charged 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.



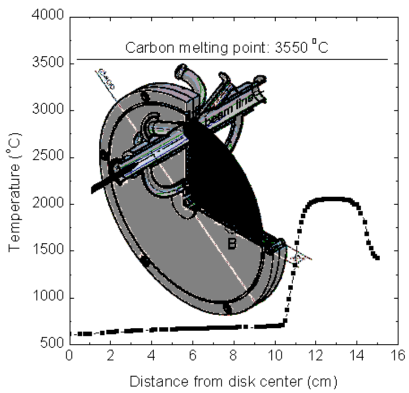
→ GRAPHITE foil is a forced choice for LENOS

For lower power we use a monolayer Aluminium foil.

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

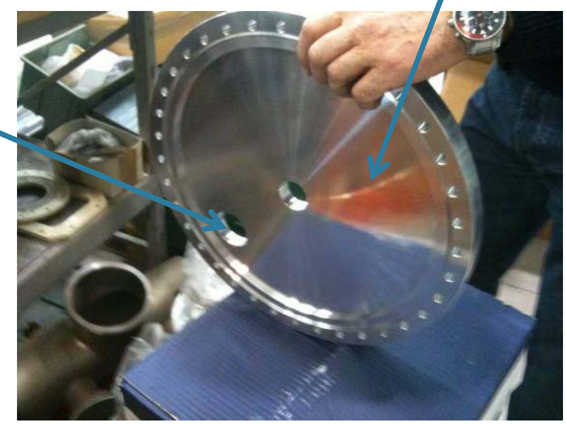
The LENOS project: Proton energy Shaper

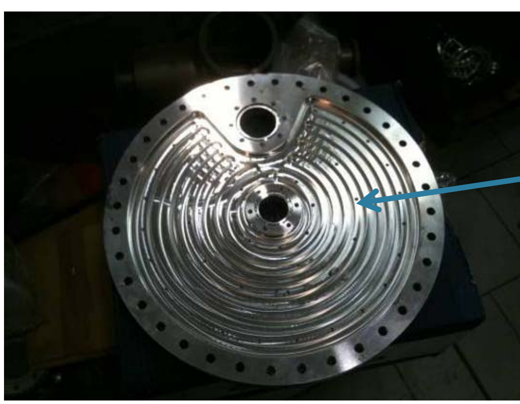
Graphite disk 70 μm thickness. Power to be dissipated about 50 kW, Mainly by radiation. Working temperature <2000° C
Construction material Al Ergal alloy



Internal part

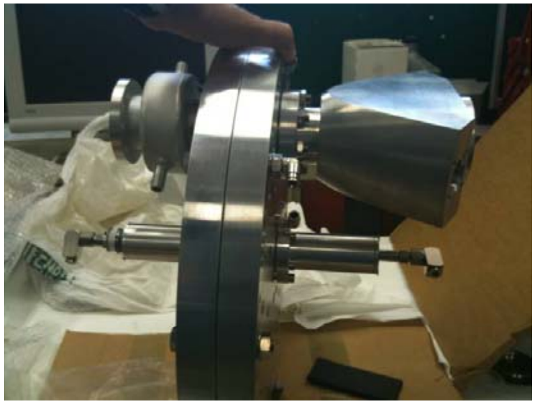
Beam entrance

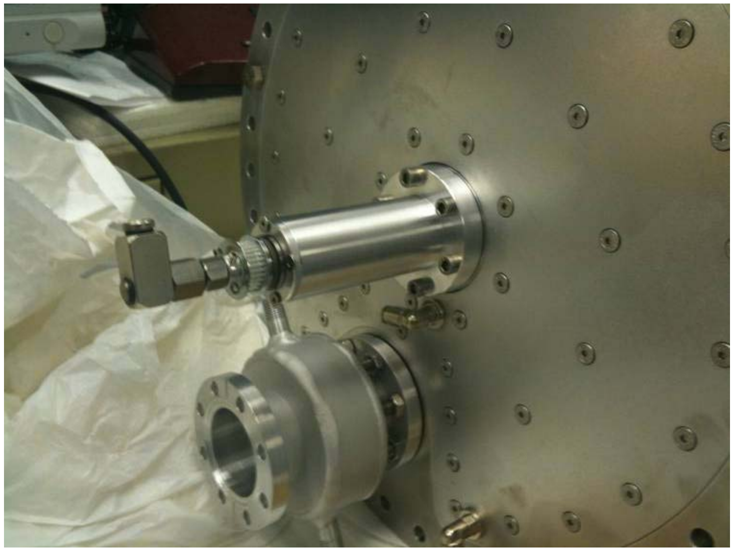


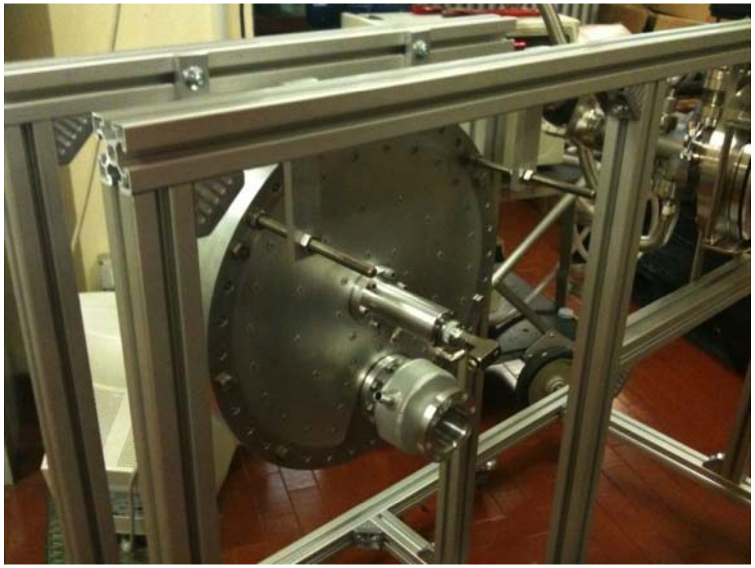


Water cooled serpentine

The LENOS project: Proton energy Shaper







Prototype almost completed

LENOS project: Lithium target

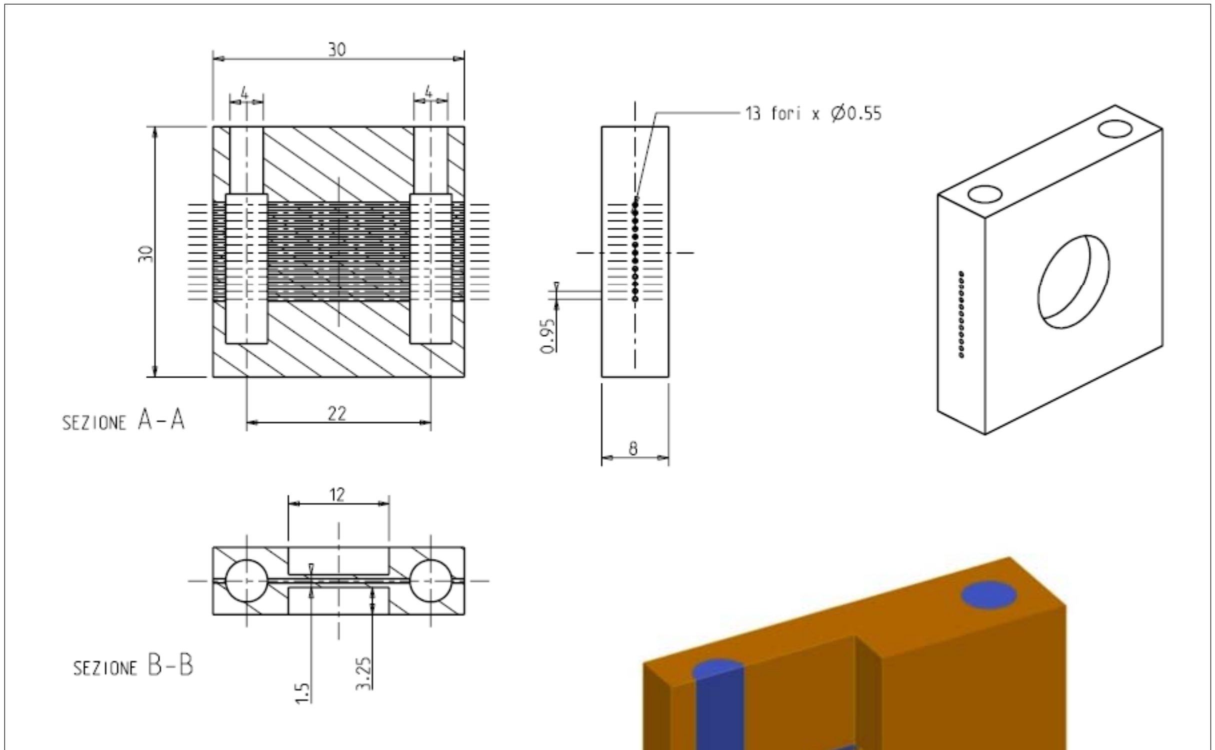
In order to dissipate so high specific power (about 3 kW/cm^2) a new generation of heat cooling devices have to be implemented and developed.

The target must satisfy some constraints:

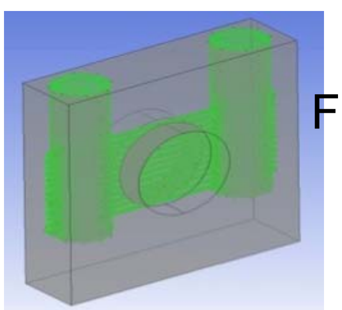
- Low mass (to avoid neutron backscattering and reduce activation)
- Small thickness, in order to maximize the neutron flux (keeping the measuring sample in touch with the neutron producing surface) and reduce neutron spectra perturbation
- Low cost and easy to manufacture procedure, in order to replace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

Microchannels + liquid metal cooling medium

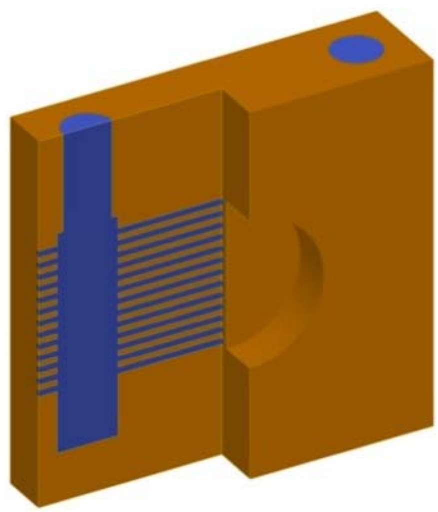
LENOS project: Lithium target Design



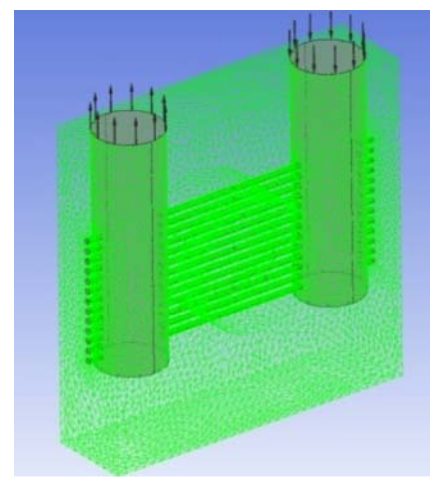
Cu Backing:
13 micro channels
14 mm long
0.45 mm diameter
0.95 mm spacing
0.5 wall thickness
6.4 mm in-out diam tube



Fluid domain



Solid domain



LENOS project: Lithium target

WATER		
parameters	description	value
cp [J/kg K]	fluid specific heat	4181,7
λFl [W/m K]	fluid thermal conductivity	0,6069
λCu [W/m K]	target thermal conductivity	401
ν [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
Tav,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
Ts [ºC]		77,30937992
Tbeam [ºC]	temperature on beam surface	124,6909261
Tin [ºC]	fluid inlet temperature	20
Q [m^3/s]	fluid volumetric flow	4,63287E-05
Tus [ºC]	fluid outlet temperature	25,17728529
	lithium thickness [m]	0,00004
Ts(Li) [ºC]		126,7787516
λLi [W/m K]	gold thermal conductivity	84,7

GALINSTAN		
parameters	description	value
cp [J/kg K]	fluid specific heat	365
λFl [W/m K]	fluid thermal conductivity	36
λCu [W/m K]	target thermal conductivity	401
ν [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	15
Re	Reynolds number	23753,28054
Nu	Nusselt number	8,85821701
α [W/m^2 K]	convection coefficient	579810,5679
Tav,fl [ºC]	fluid average temperature	50
n	number of microchannels	13
q [W/m^2]	beam specific thermal power	19231222,29
q [W/cm^2]	beam specific thermal power	3846,244458
q [W/]	beam thermal power on target	4350
Ts [ºC]		83,16811275
Tbeam [ºC]	temperature on beam surface	117,338302
Tin [ºC]	fluid inlet temperature	20
Q [m^3/s]	fluid volumetric flow	4,63287E-05
Tus [ºC]	fluid outlet temperature	60,42821788
	lithium thickness [m]	0,00004
Ts(Li) [ºC]		126,4203432
λLi [W/m K]	gold thermal conductivity	84,7

Different GaInSn eutectic alloys are commercially available with different thermophysical propierties

TABLE I. Summary of the thermophysical properties of liquid metals used in heat transfer applications and water for comparison. Experiments conducted as part of this study utilized a commercially available $Ga^{61}In^{25}Sn^{13}Zn^{1}$ alloy. The limited thermophysical property data for this alloy available to the authors includes a melting point of 8 °C and a density of 6500 kg/m³ (Ref. 15).

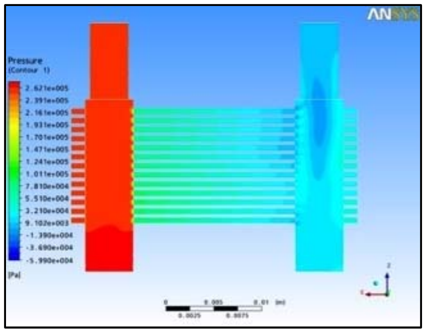
	Hg[a]	$Ga^{68}In^{20}Sn^{12}$ [a]	$Na^{27}K^{78}$ [a]	SnPbInBi[a]	Water[a]
Density (kg/m³)	13 564.0[c]	6363.2[c]	868.2[c]	9230[e]	998.0[g]
Melting point (°C)	−38.87	10.5	−11	58	0
Heat capacity (J/kg/K)	139.068[c]	365.813[c]	982.1[c]	209[e]	4181[g]
Kinematic viscosity (10^{-6} m²/s)	0.114 8[c]	0.348 09[c]	1.05[c]	4.04[e]	0.960[g]
Electrical conductivity (S/μm)	1.044 52[c]	3.307 37[c]	2.878[c]	1.28[e]	5.5×10^{-12}
Thermal conductivity (W/m/K)	8.716 9[c]	39[d]	21.8[c]	10[d]	0.606[g]
Prandtl Number ()[f]	0.024 8	0.020 8	0.0411	0.7793	6.62

- Calculations shows that ~1-3,5 kW/cm² could be dissipated. T_{Li}<152 °C. Melting point of Lithium is 182°C.
- Li (30μm) on a backing of Cu (1.5mm).
- Microchannels, GALINSTAN (**gal**lium, **in**dium **e stan**num $Ga_{68}In_{21}Sn_{11}$), alloy at T=15 °C

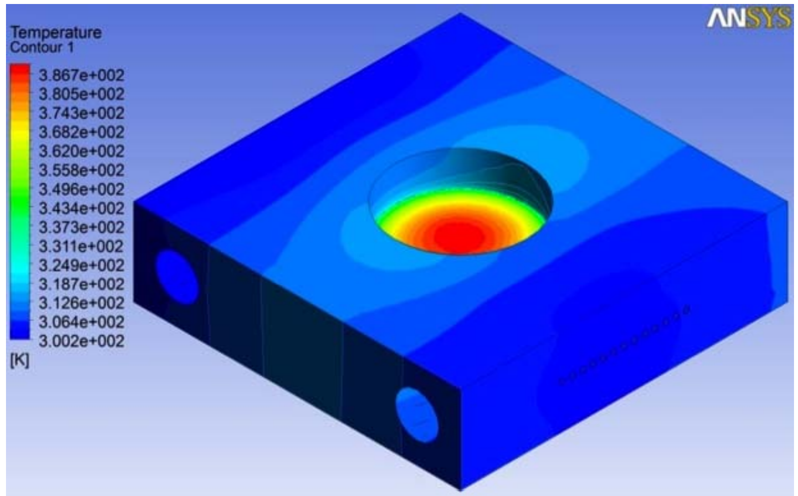
LENOS project: Lithium target ANSYS results

Water cooled

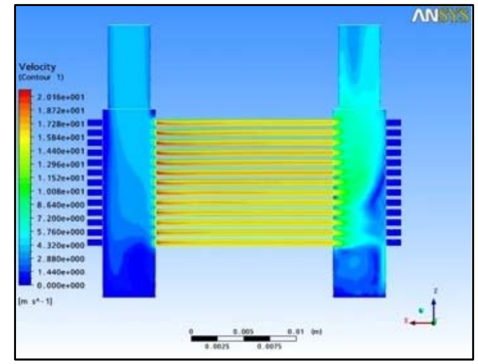
Pressure



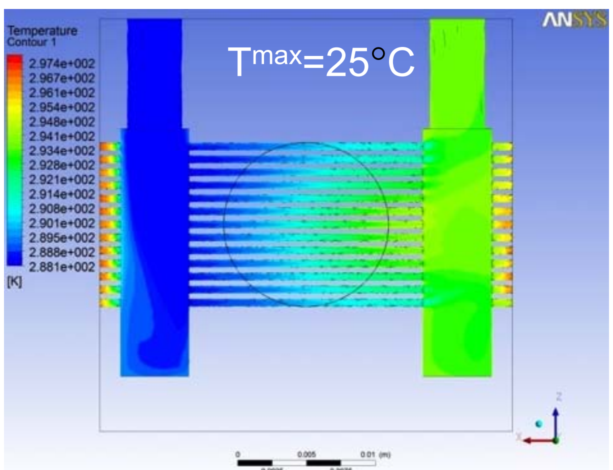
P^{in}=2.7 bar
ΔP=2.7 bar



Velocity



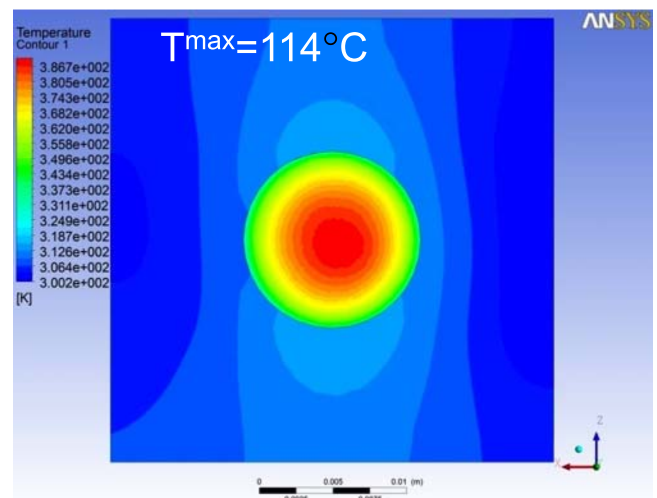
μ-channel fluid velocity =15m/s



Temperature

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

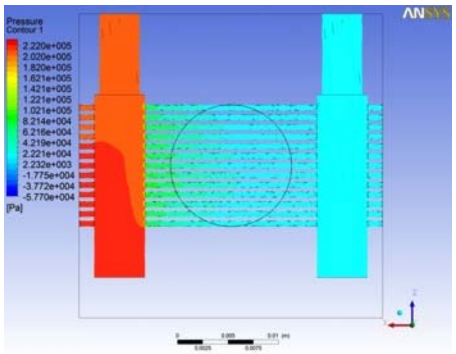
Melting point Li = 182°C



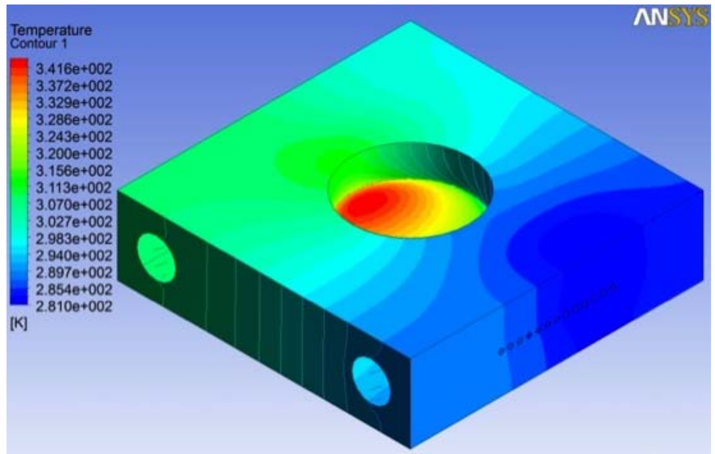
LENOS project: Lithium target ANSYS results

SnInGa alloy cooled

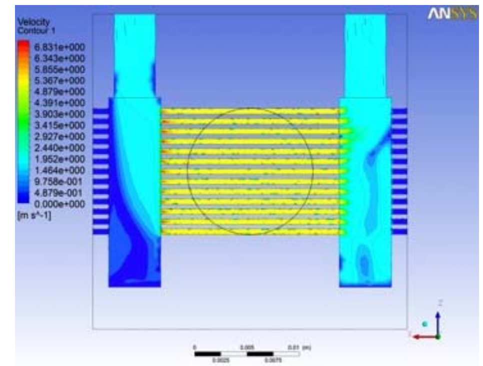
Pressure



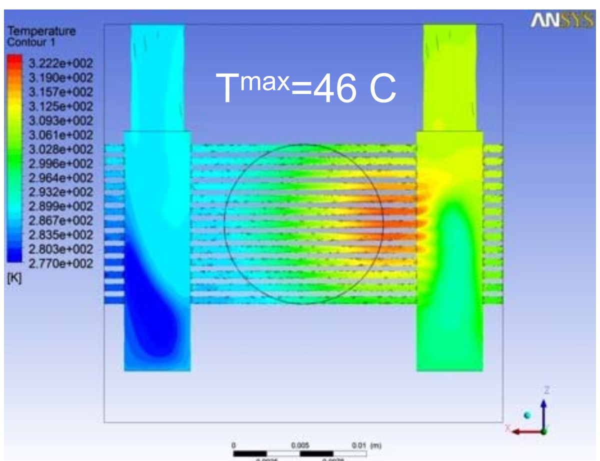
P^{in}=2.5bar
ΔP=2.5 bar



Velocity



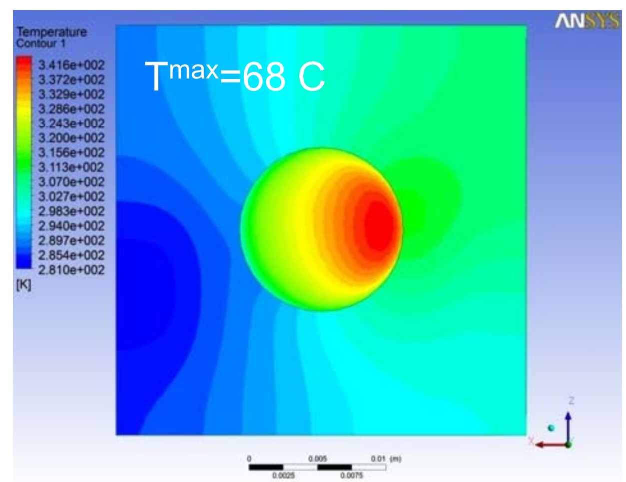
μ-channel fluid velocity =5 m/s



Temperature

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

Melting point Li = 182°C



LENOS project: Lithium target

Good agreement for water, less for liquid metal

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
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$T_{av,n}$ [ºC]	fluid average temperature	23
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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

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parameters	description	value
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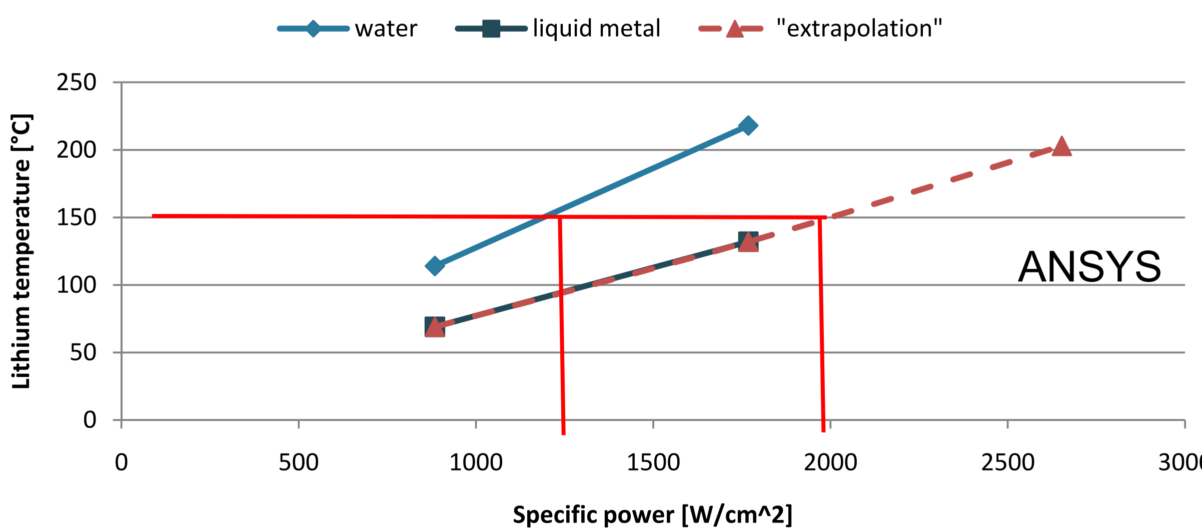
λ_{Cu} [W/m K]	target thermal conductivity	401
v [Pa s]	fluid viscosity dinamic	0,00221
ρ [kg/m^3]	fluid density	6363
d [m]	diameter of the microchannels	0,00055
Pr	Prandtl number	0,022406944
v [m/s]	velocity in the microchannels	5
Re	Reynolds number	7917,760181
Nu	Nusselt number	7,305505188
α [W/m^2 K]	convection coefficient	478178,5214
$T_{av,n}$ [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	1,34429E-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

With liquid metal a factor of 2 improvemen expected



LENOS project: Lithium target tests

Copper backing has been successfully manufactured at LNL

TIG test: measured power transfer: <u>3.4 kW</u>
Not reached the Indium melting point

Preliminary Tests done depositing a thin Indium layer instead of Lithium.
Melting point of Indium 157°C.
Thermal conductivity of Indium is 81.6 W/(m·K).
Thermal conductivity of Lithium is 84.7 W/(m·K).

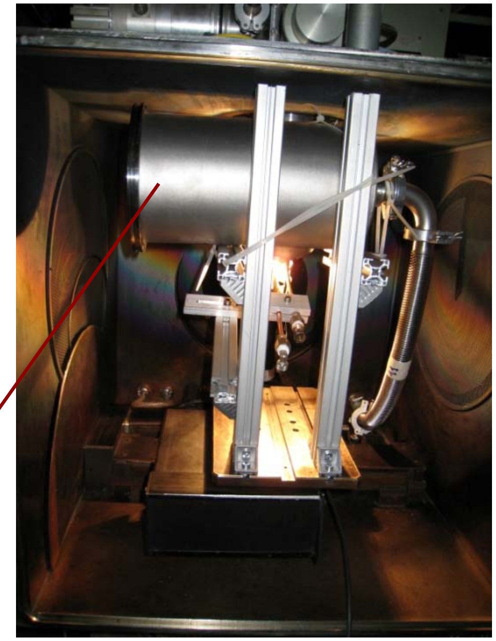
Heat spot

Oxyd-acethilene test:
Measured power transfer =1.5 kW
Not reached the Indium melting point

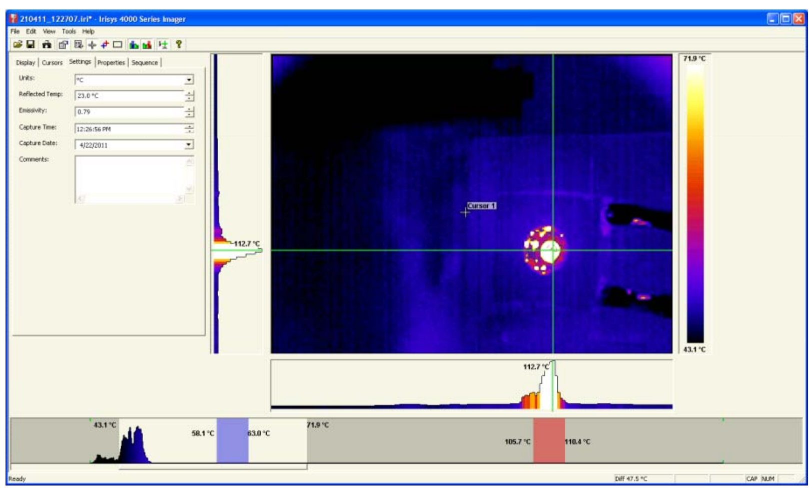
Lithium target testing

Target (copper backing) was irradiated by electron beam in 10^{-4} mbar
Idea of the test is verification of sustainability and reliability of cooling system

I=0-74 A V=60 kV
P=ηV·I =0-4.4 kW

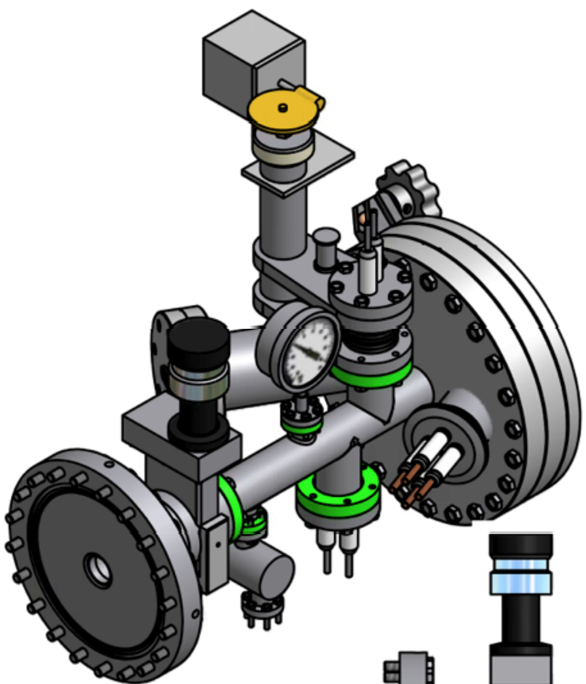


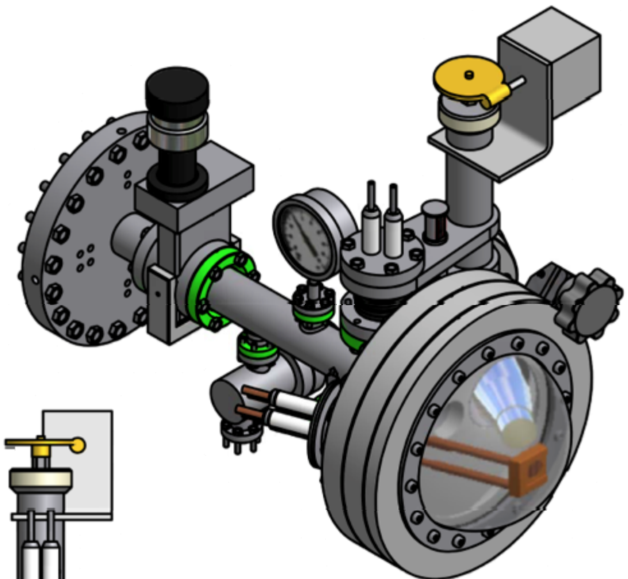
Temperature mapped with thermocamera

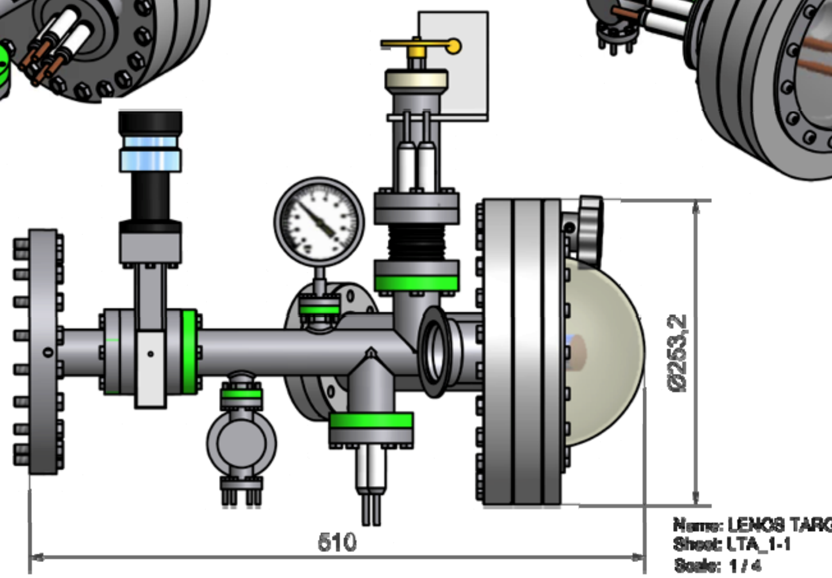


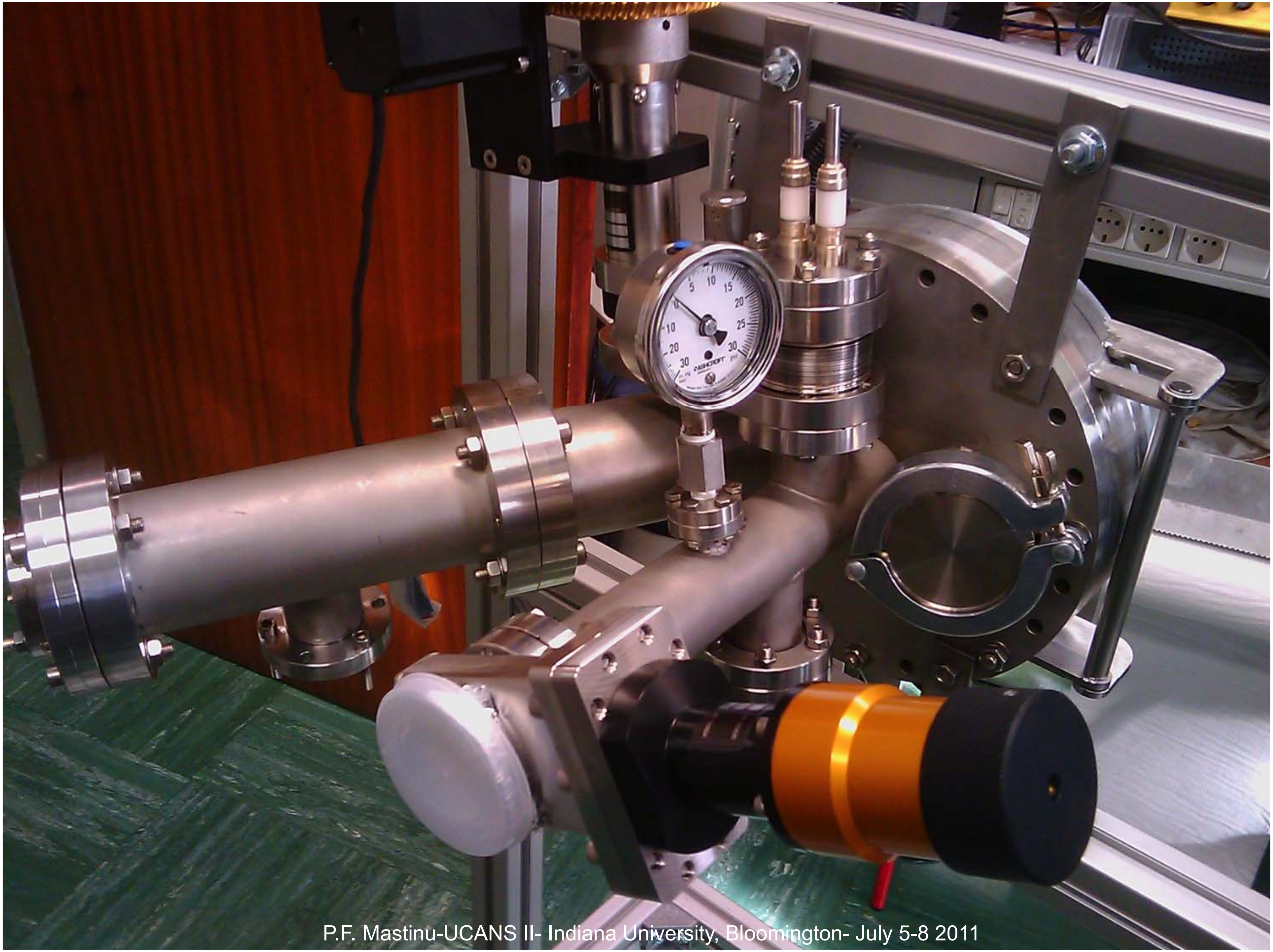
Analysis is ongoing…

LENOS project: Lithium Target Assembly





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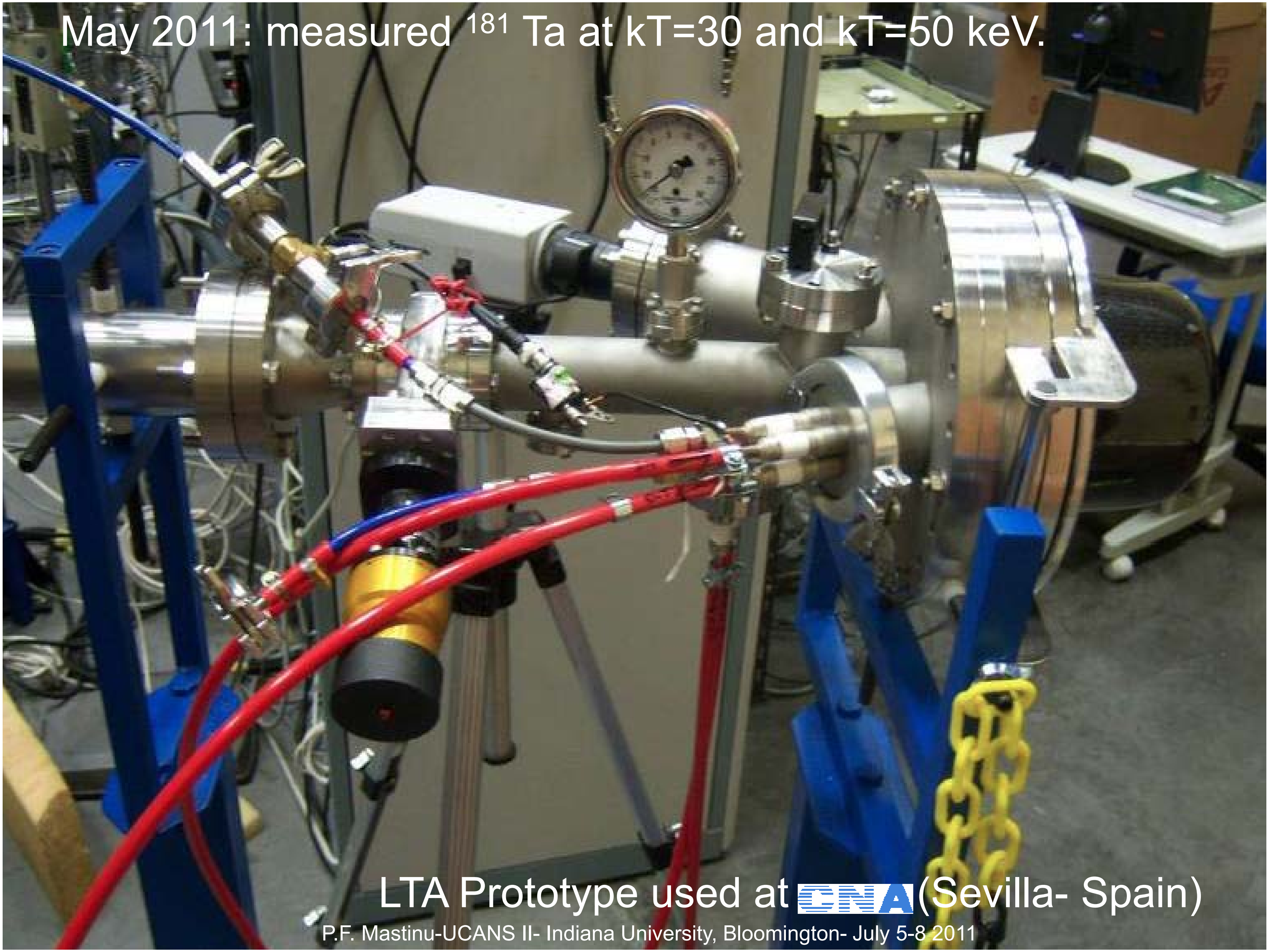
May 2011: measured ^{181}Ta at kT=30 and kT=50 keV.



LTA Prototype used at CNA (Sevilla- Spain)

Outlook

- Experimental validation of the method and the procedures
  - Already approved experiment at IRMM_VdG whithin EUFRAT. Scheduled for February 2012
- In the meanwhile, MACS measurements at existing facilities (LNL and CNA)
  - Measurements of standards
  - Measurement at 30 keV for comparison
  - Measurements at kT up to 50 keV in the same set-up
    (never measured before)
- MACS of Ta is already measured at CNA at 30 and 50 keV, other are coming

Conclusions

LENOS:

- The LENOS method has to be validated : already approved experiment at IRMM Feb-12
- Energy shaper is almost constructed: need to be tested
- Cooper backing for Lithium target is constructed: preliminary tests already done ($P_{dissipated}$> 3 kW/cm^2). Other are ongoing
- There are significant discrepancies between analytical calculations, FEM calculations and preliminary tests. More detailed experimental measurements and calculations are required
- Erosion/corrosion effect to be studied: planned end of the year with water
- Radiation damage effects must be experimentally investigated: suitable facility is needed
- Thermal tests with RF heather (planned after summer at ENEA-Brasimone)
- Liquid metal cooling system: implementation on 2012
- We are open to any collaboration on all aspects of the project