R&D effort for the design of the Multi Megawatt Target Station of EURISOL

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On behalf of the EURISOL-DS Collaboration
Task#2 (leaded by Yacine Kadi, CERN)

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EURISOL-DS Project Contract no. 515768 RIDS

Presentation outline

I. **The EURISOL Project**

II. The MMW spallation target design

   1. The baseline design with window
   2. The innovative windowless design

III. Conclusion

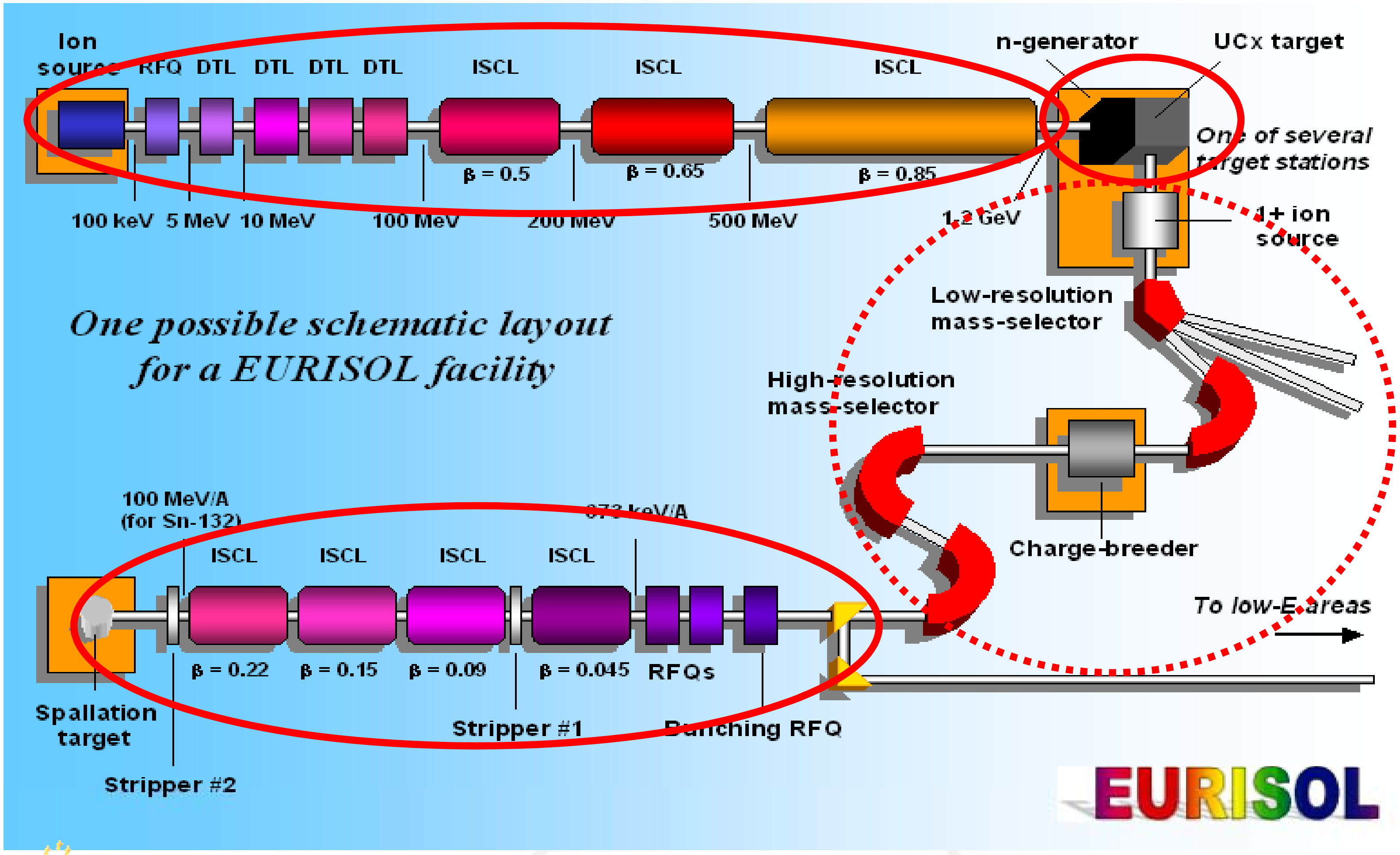
The Aim of EURISOL

- The EURISOL program aims at the construction beyond the year 2012, of the ‘3rd generation’ European Isotope Separation On-Line (ISOL) Radioactive Ion Beam (RIB) facility
- It will extend and amplify the existing work presently being carried out at the 1st generation RIB facilities in Europe and other parts of the world
- The EURISOL facility will play a complementary role to the recently approved SPIRAL-II and the FAIR project at GSI Darmstadt, Germany, the European ‘2nd generation’ ISOL and In-Flight RIB facilities

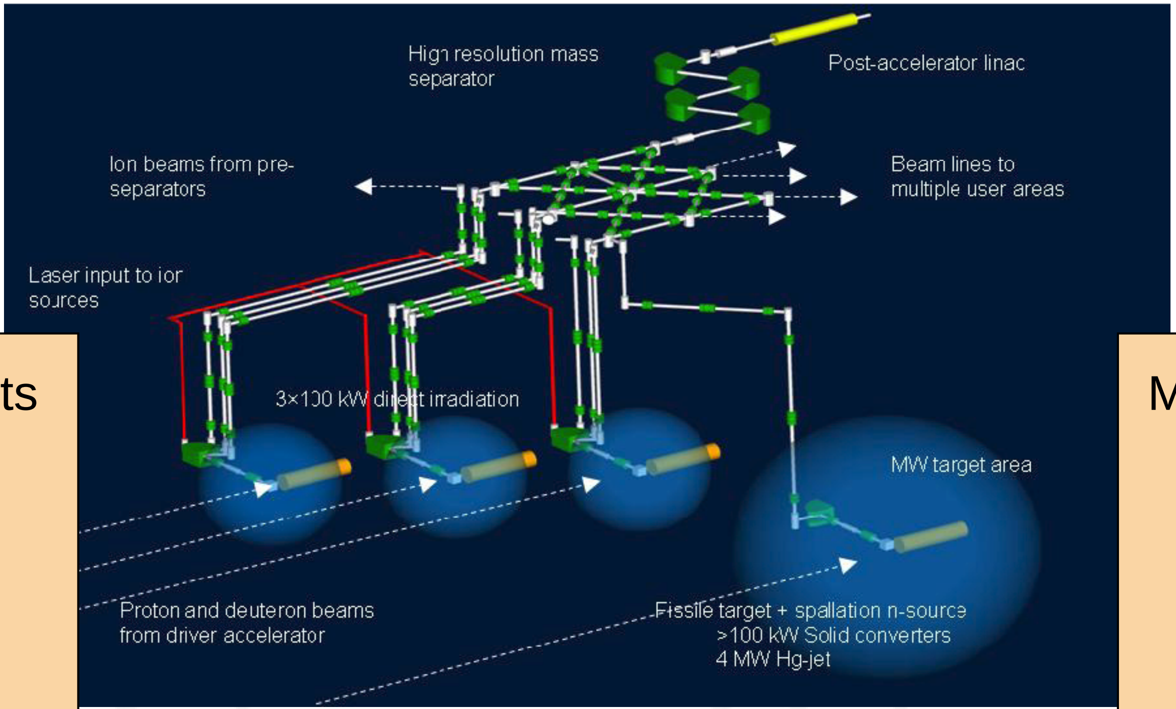
EURISOL Roadmap

- Phase 1: Preliminary Design Study of EURISOL (2000 - 2003), the ‘next-generation’ European ISOL Radioactive Ion Beam (RIB) facility => enhance RIB yields (vs. 1999 data) by factors of 2 to 4 orders of magnitude (FP5)
- Phase 2: Design Study (2005 - 2009) address the main technological challenges leading to a full engineering design (FP6)
- Phase 3: **Full Engineering Design** (3y)
- Phase 4: **Construction** of the facility (> 2012)

EURISOL facility layout



EURISOL Target Stations



100 kW direct targets

RIB production:
- Spallation-evaporation
- Main: P-rich
  (10 to 15 elements
  below target material)
- Residues: N-rich
  (A few elements
  below target material)

Target materials:
- Oxides
- Carbides
- Metal foils
- Liquid metals

MMW converter target

RIB production:
- Fission
- N-rich
- Wide range
  Z = 10 to Z = 60

Target material:
- U (baseline)
- Th

Converter:
- Hg

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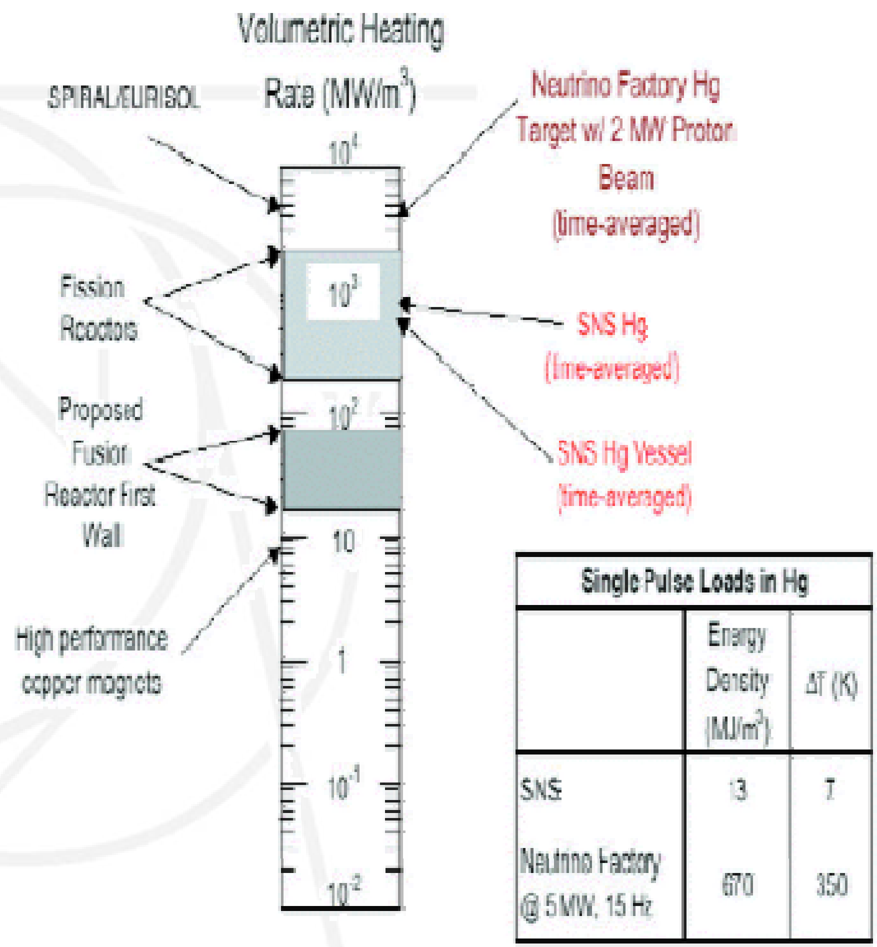
EURISOL-DS Target Challenges

EURISOL shall deliver RIB's 3 orders of magnitude higher intensity than in presently operating facilities.

Increase the intensity of the beam driver by the same order of magnitude

High-Power issues

- Thermal management
  - Target melting
  - Target vaporization
  - Thermal shock
  - Beam-induced pressure waves
  - Material properties
- Radiation / Safety
  - Radiation protection
  - Radioactivity inventory
  - Remote handling



Single Pulse Loads in Hg

	Energy Density (MJ/m^3)	ΔT (K)
SNS	13	7
Neutrino Factory @ 5 MW, 15 Hz	670	350

Liquid metal Target

- Remove heat from reaction zone by moving the target material
- No radiation damage in target material
- Low specific decay heat due to large target mass
- No need for decay heat removal in reaction zone

- Good arguments but....
- .....need to be proven at these Powers!

The Choice of Hg as a Target

- Mercury has the highest density of all heavy liquid metals and hence produces the brightest neutron source
- Mercury is liquid at room temperature and hence needs no auxiliary heating
- Mercury produces practically no alpha-emitters with any sizable life time
- Hg purification
- Hg disposal in the form of a stable solid amalgam

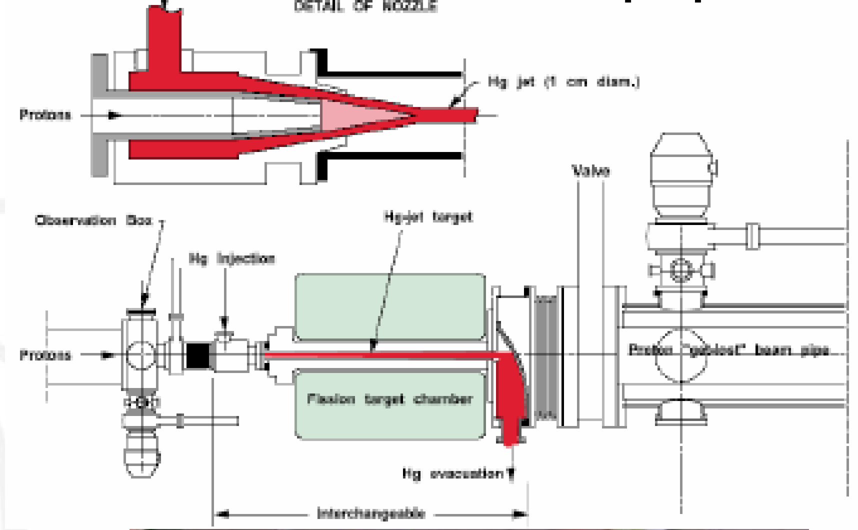
→ LBE (Lead Bismuth Eutectic) might be an other option

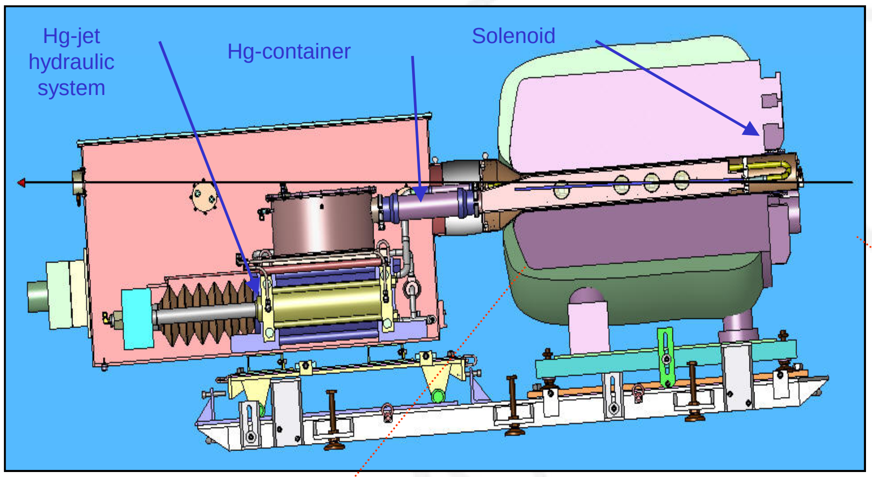
Target initial design

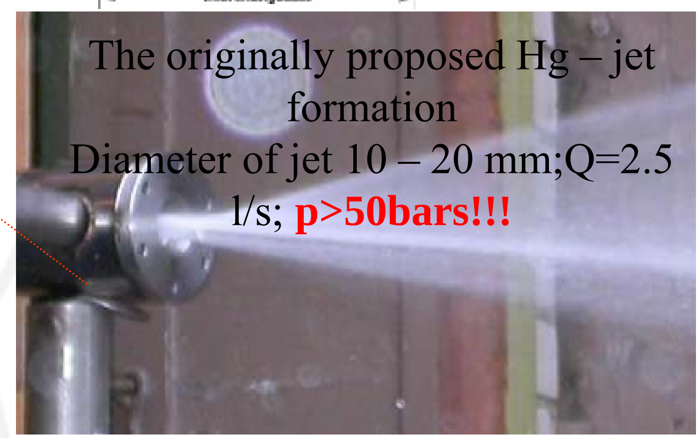
*A **proof-of-principle test of a target station** suitable for a ν-Factory or μ- Collider source*

*PS extracted proton beam of 14(24)-GeV, incident on a **free mercury jet** target located inside a **15-T capture solenoid magnet**.*

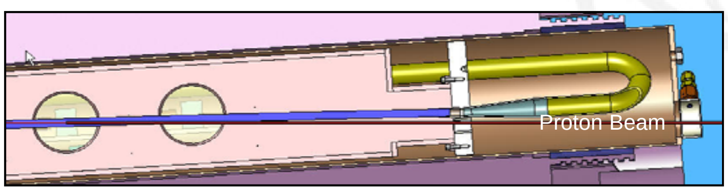
Initial RTD proposal







The originally proposed Hg – jet formation
Diameter of jet 10 – 20 mm;Q=2.5 l/s; **p>50bars!!!**



Target initial design

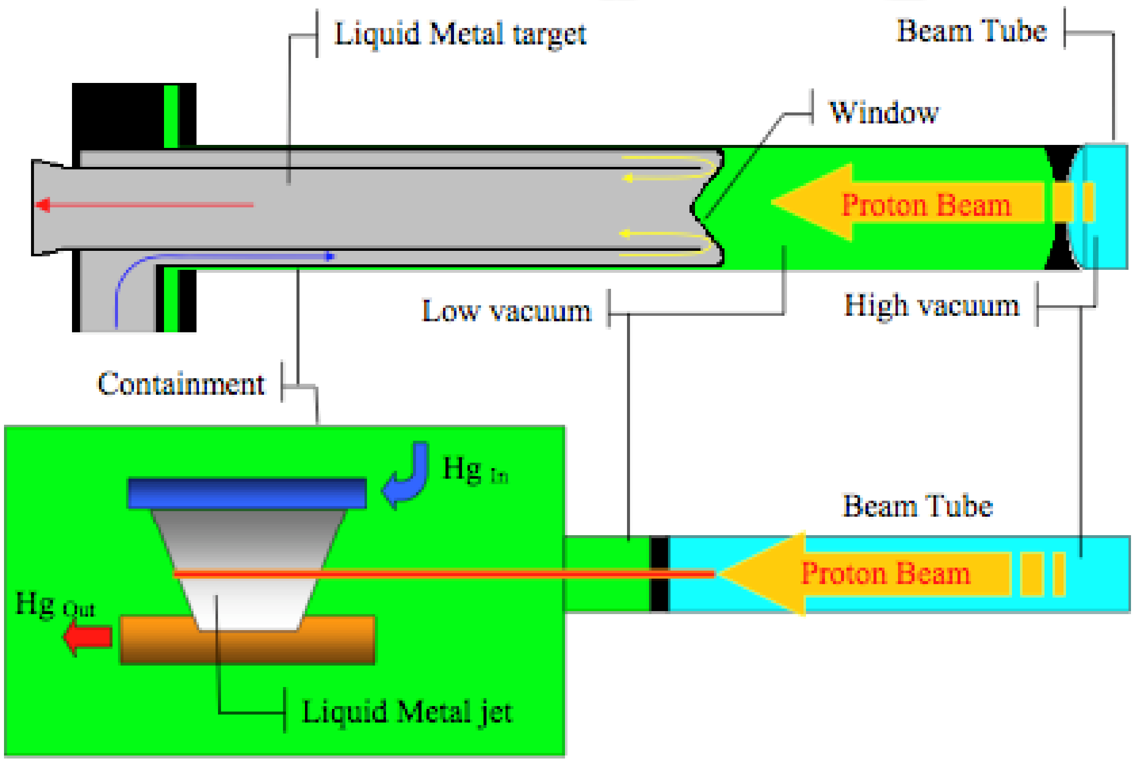
Initial RTD proposal:

- Complexity and reliability issue
- Need of an active beam dump
- Small beam size inducing high Power density
- High leakage of particles (Shielding issue, Thermal load on nearby structures)
- Need of a solenoid 15T (cryogenics, compromising the use of fission target close to neutron source)

Multi-MW Liquid Hg Target

New proposal: 2 designs

Compact Hg-loop with beam widow and Confined transverse film windowless



	Beam diameter		Units
Gaussian beam geometry	15 mm	25 mm	
Beam power	4		MW (continuous)
Beam particle energy	1		GeV
Beam current	4		mA
Beam escapes	$2x10^8$		primary/cm^2/s/ MW of beam
Estimated peak temperature in the liquid	261	180	°C
Estimated peak temperature in the window	260	258	°C
Maximum velocity	6		m/s
Maximum loss of pressure	5		bar
Peak power density in the Mercury	1.8	0.8	kW/cm^3/MW of beam
Peak power density in the window	0.9	0.3	kW/cm^3/MW of beam
Beam power deposition in the Mercury	2.3	2.3	MW/cm^3/MW of beam
Estimated Stress level in the window	<140	<110	MPa

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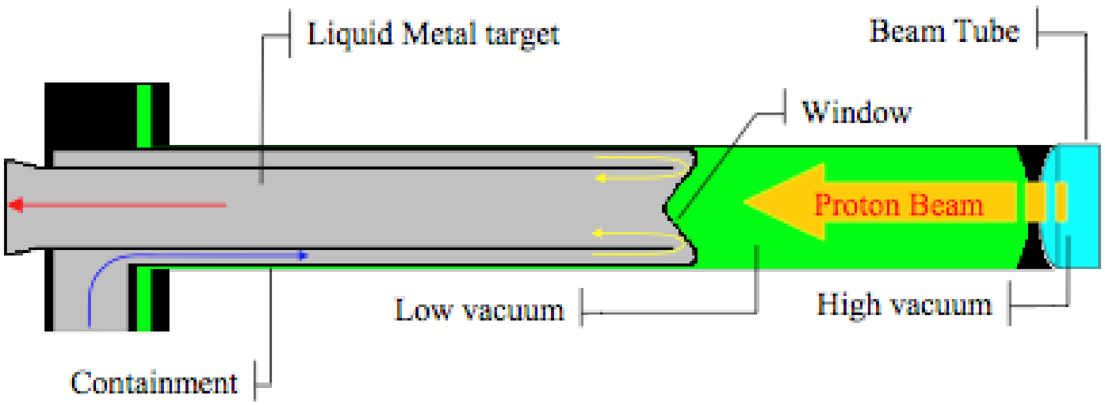
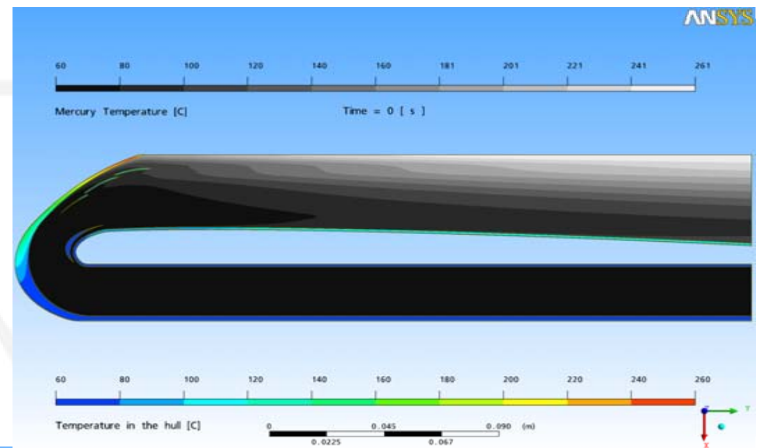
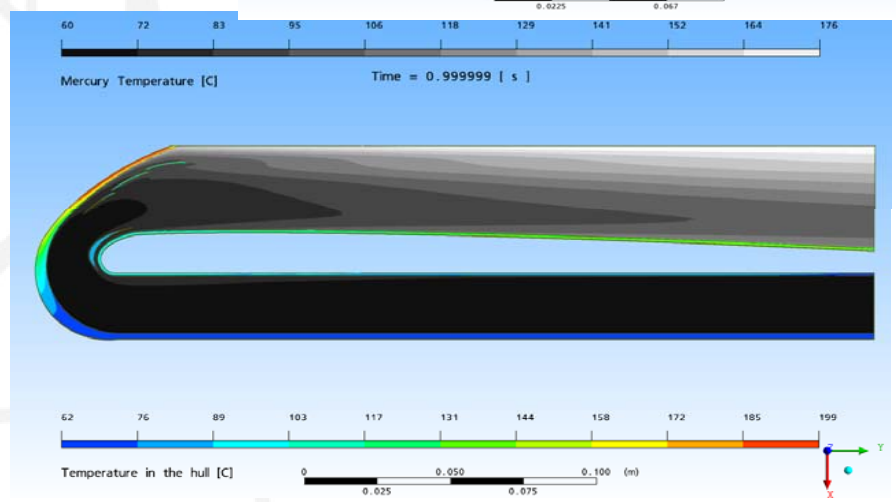
2D CFD & Structural Analysis

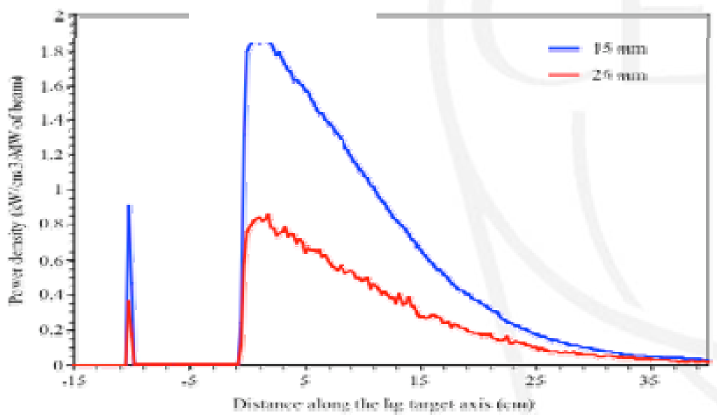
The CGS (Coaxial Guided Stream) design

Ref K. Samec et al. (PSI)





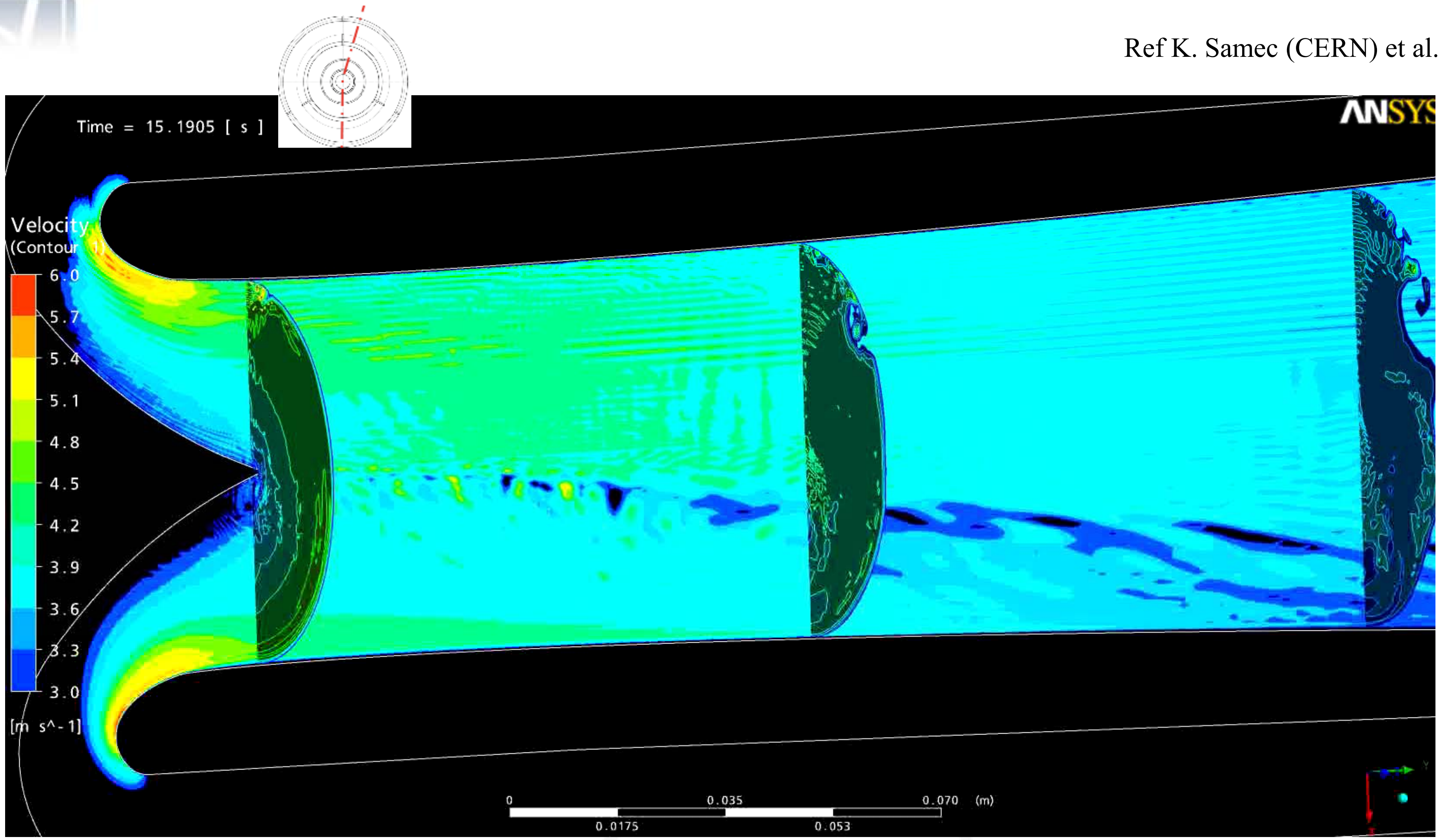




Power density distribution for the considered beam widths, along the beam axis and around the window

3D CFD & Structural Analysis

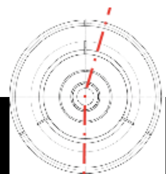
Ref K. Samec (CERN) et al.

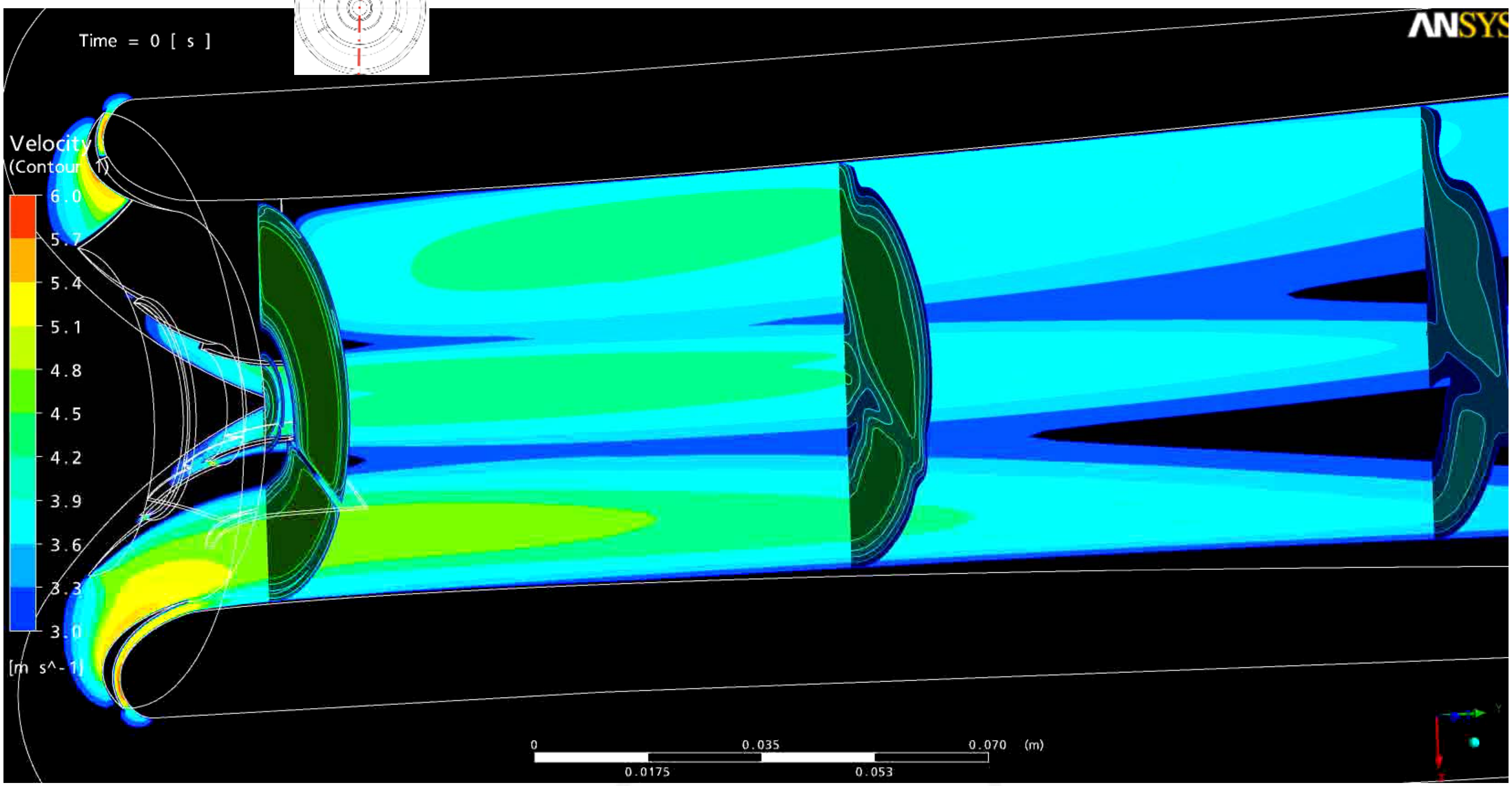


3D CFD & Structural Analysis

EURISOL Design Study

Ref K. Samec (CERN) et al.





3D CFD & Structural Analysis

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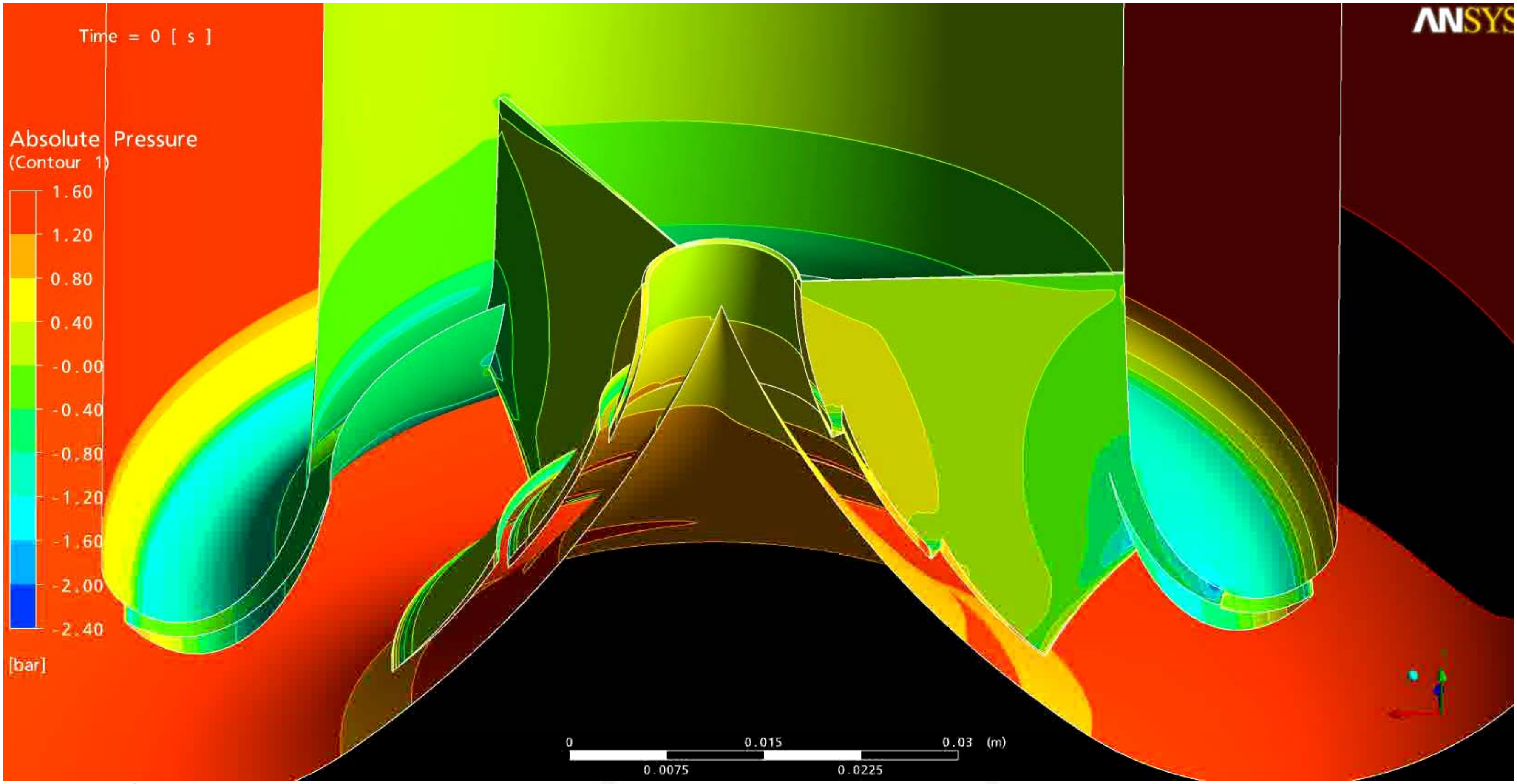

3D CFD & Structural Analysis

Ref K. Samec (CERN) et al.

3D Model – Main results

Broadly same results as in 2D:

- stable flow, no oscillations or large recirculation zones.
- cavitation at around P = -2.5 bar.
- Total pressure loss of P = 0.6 bar.

Coaxial Guided Stream design (CGS)

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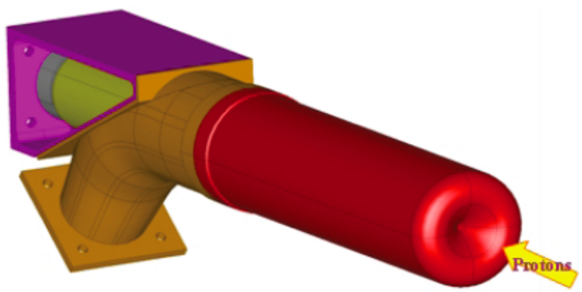
Basic performances of the target

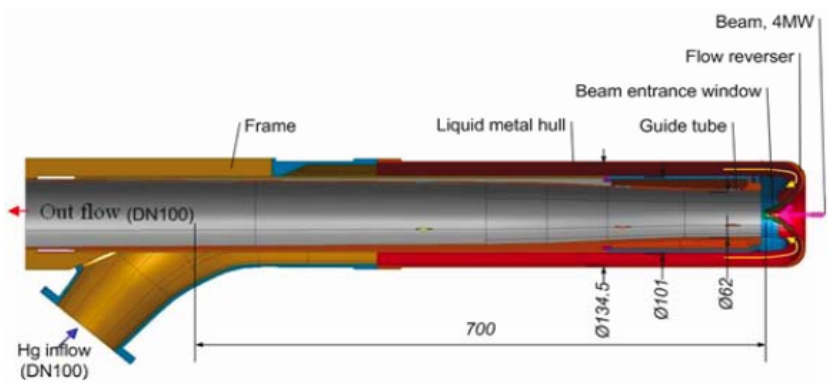
TM-34-07-05 K.Samec /Design of the EURISOL converter target. – PSI 2007

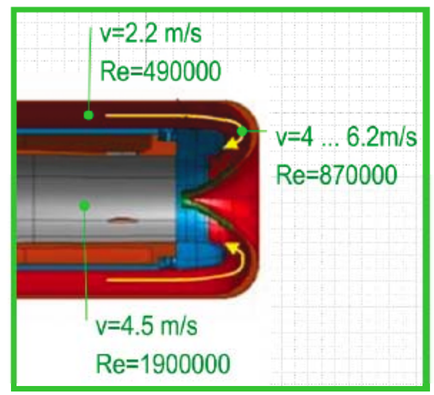


4MW thermal power

Parameter	symbol	value	unit
Liquid compound	Hg	13.5	kg/l
Flow rate	ϕ	172	kg/s
Entrance temperature	T_{in}	< 60	C
Exit temperature	T_{out}	< 180 > 150	C
Pressure drop	ΔP	< 5	Bar
Static pressure	P_0	< 5	Bar

Ab.13 l/s

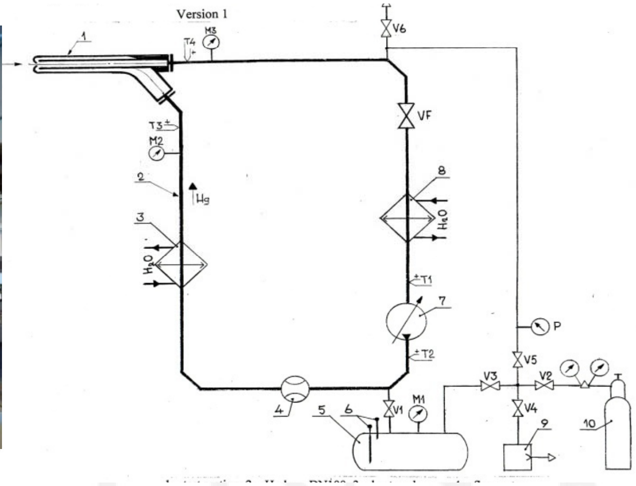




Paul Scherrer Institut • 5232 Villigen PSI

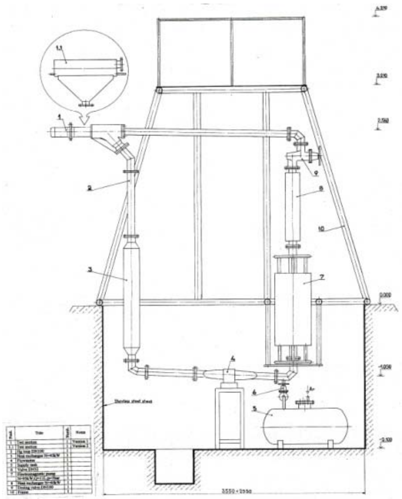
PSI. EURISOL converter target. Hg test preparation. Technical meeting. PSI February 7 2008 DS34

Liquid Hg Loop for tests of target mock-ups and other components



Existing Hg – loop in Institute of Physics) parameters of EMP p=4 bars; Q~12l/s

1 – test section; 2 – Hg loop DN100; 3 – heat exchanger; 4 – flowmeter;
5 – supply tank; 6 –level meter; 7 – electromagnetic pump; 8 – heat exchanger;
9 – vacuum pump; 10 – argon vessel; M1…M3 – pressure meter; P – vacuum gauge; T1…T4 – thermocouple; V1…V6 – valve; VF – dosing valve;



Liquid Hg Loop at IPUL

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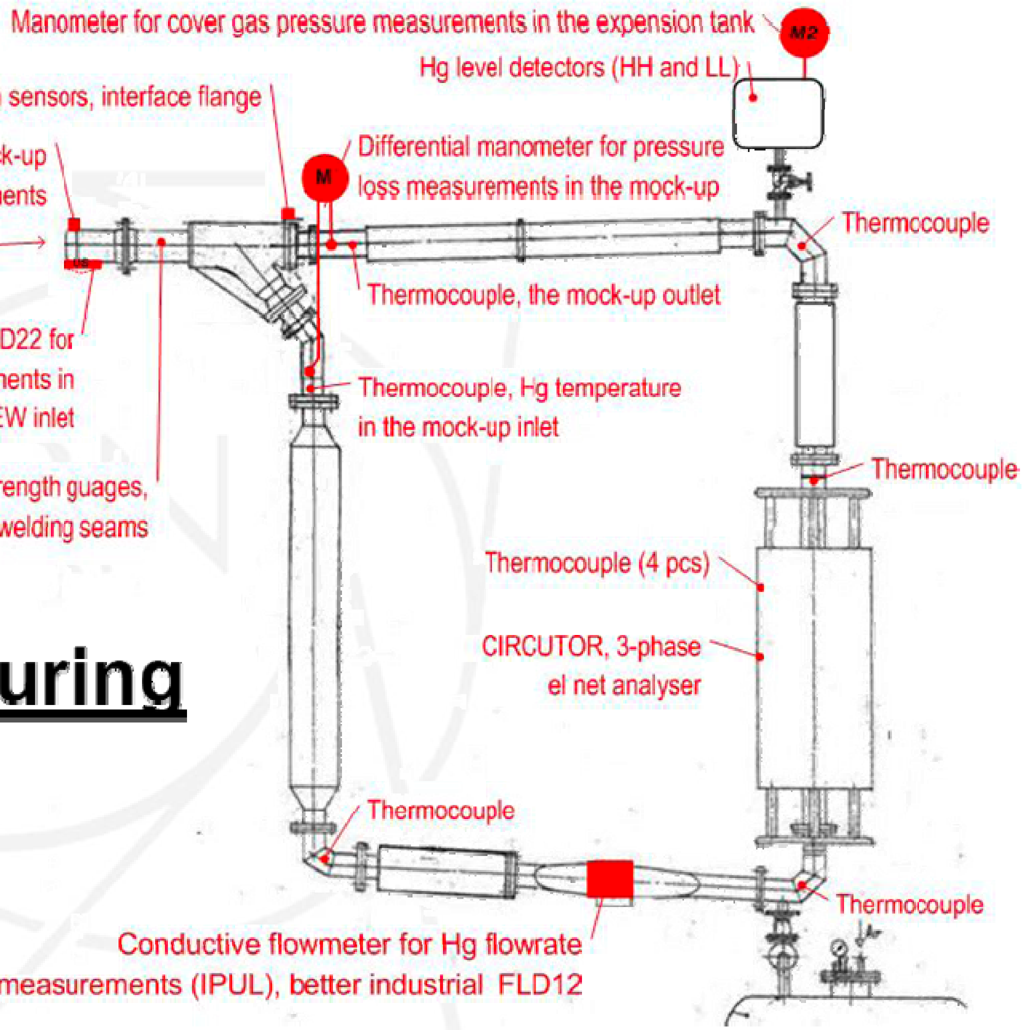

METEX 1. Measuring system

CERN

EURISOL Design Study

Experimental Program

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Mercury Target Experiment

Sergejs Dementjevs (PSI) et al.

METEX 1:

Hydraulic Hg test of the mock-up with the purpose to check workability and regime of the target operation under close to nominal Hg flowrate: pressure loss, vibrations, cavitations, velocity distribution in the BEW inlet; stress in the welding seams: **session 1** - without the blades; **session 2** - with the blades

METEX 2.1:

Record and analysis of "cavitations noise" with use of acoustic or/and high frequency pressure sensors in collaboration with the Fachhochschule; preparation ongoing, ab 3 months, 25kCHF

METEX 3 (optional in future):

Measurements of heat transfer coefficients distribution between Hg flow and the BEW shell, PSI, J.Patorski

METEX 2.2 (optional in future):

Hg velocity measurements downstream from the flow reverser:

Doppler anemometry, Dr.S.Eckert (FZK Dresden – Rosendorf); Prof. Y.Takeda (Hokkaido University); MET-FLOW AG, Lausanne

US anemometry, Prof. R.Kazy (Kaunas University)

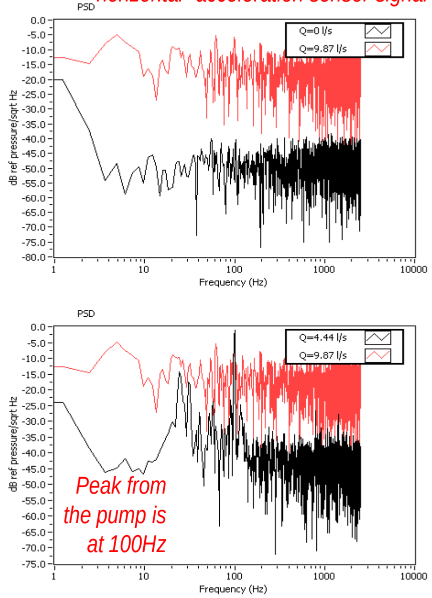
Potential probes for local velocities measurements near a wall, PSI S.Dementjev.

Duration of the experiment preparation 6-8 months, coast 50-100 kCHF

METEX experiment

- 11 L/s reached (~150kg/s)
- Acceptable vibration behaviour of the target

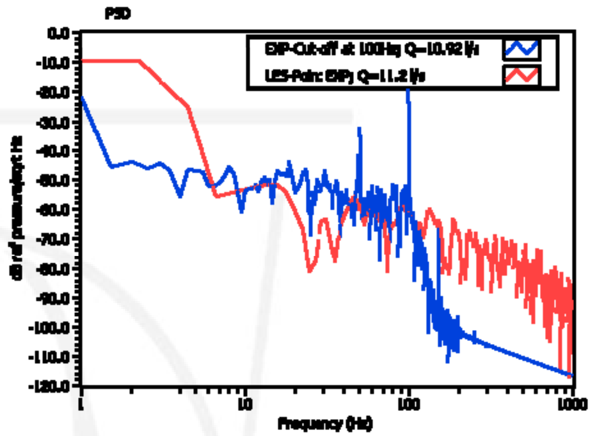
Power Spectral Density of the "horizontal" acceleration sensor signal

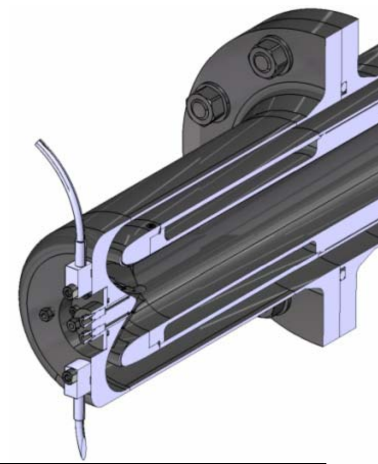


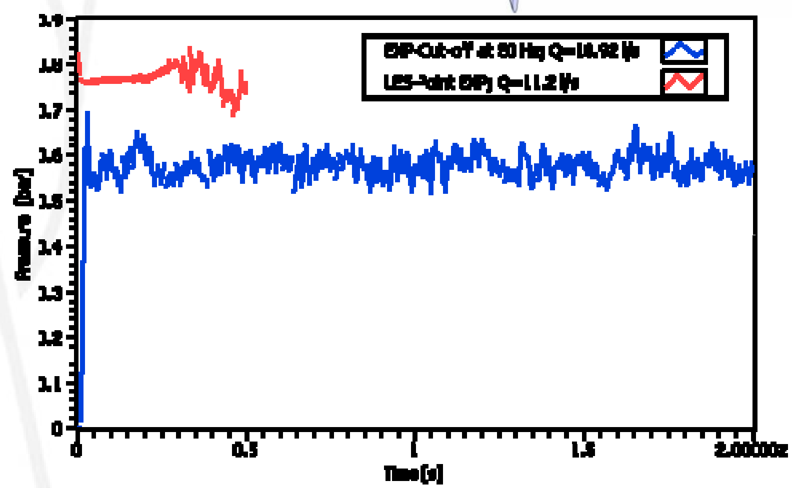
Acceleration sensors fixed on the BEW mock-up

To be published:
Rade Milenkovich (PSI) et al.
Laure blumenfeld (CEA Saclay / CERN)

Pressure sensor at the window



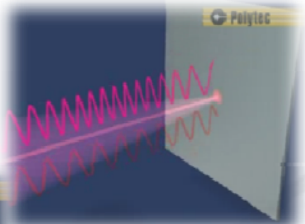


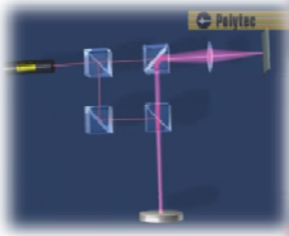


Cyril. Kharoua@esss.se / Workshop on Applications of High Intensity Proton Accelerators October 19-21, 2009 Fermi National Accelerator Laboratory, Batavia, IL, USA

Cavitation detection

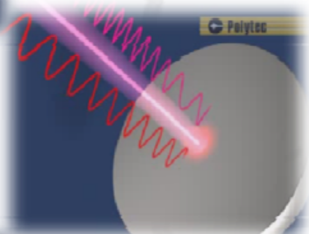
The incident Laser signal is reflected by the surface of the vibrating object

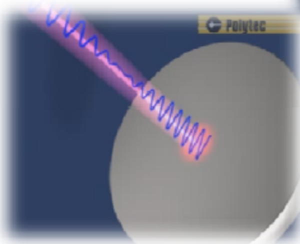




The signal is then compared through the interferometer

Though the Doppler phenomena the velocity vibration is determined



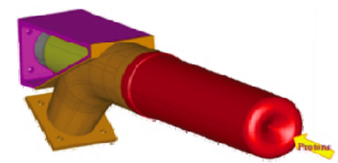


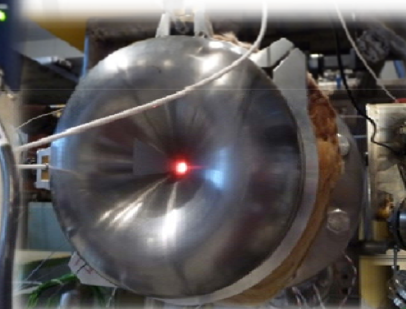
The output signal is then recorded in the time space.

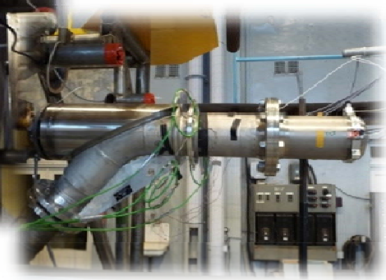
Signal

Laser Doppler Vibrometers operate on the Doppler principle, measuring back-scattered laser light from a vibrating structure, to determine its vibrational velocity and displacement.

During the METEX experiment the LDV was used to measured the velocity of the wall at the window of the CGS (Coaxial Guided Stream) target design.
The objective was to detect the occurrences of cavitations.



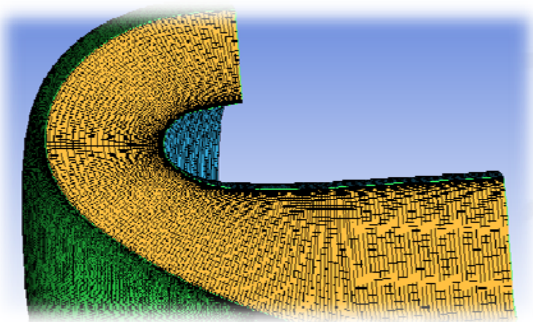




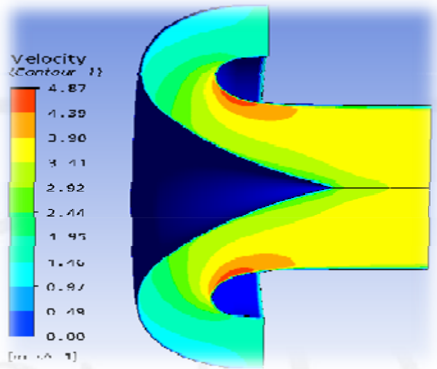
To be published:
Cyril Kharoua (CERN) et al.

Cavitation detection

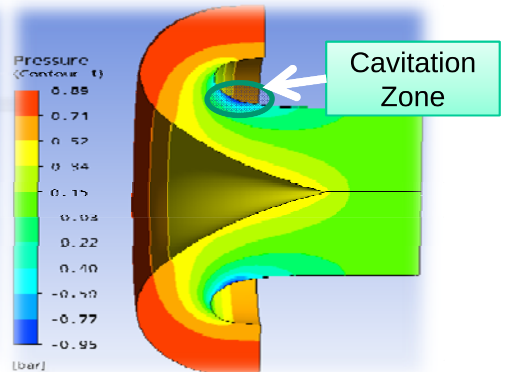
CFD simulation and prediction of cavitations zone



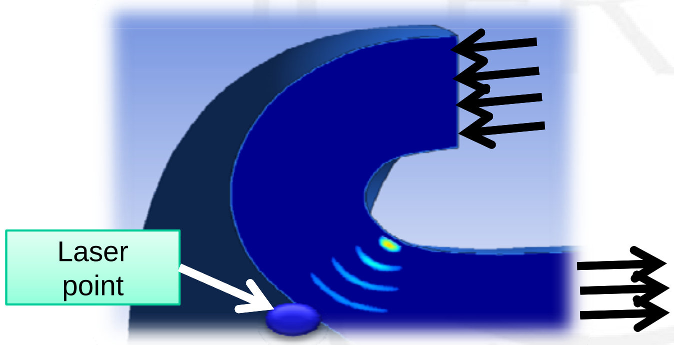
CFD Model



Velocity Distribution



Pressure Distribution



Cavitation Bubble implosion and pressure wave propagation

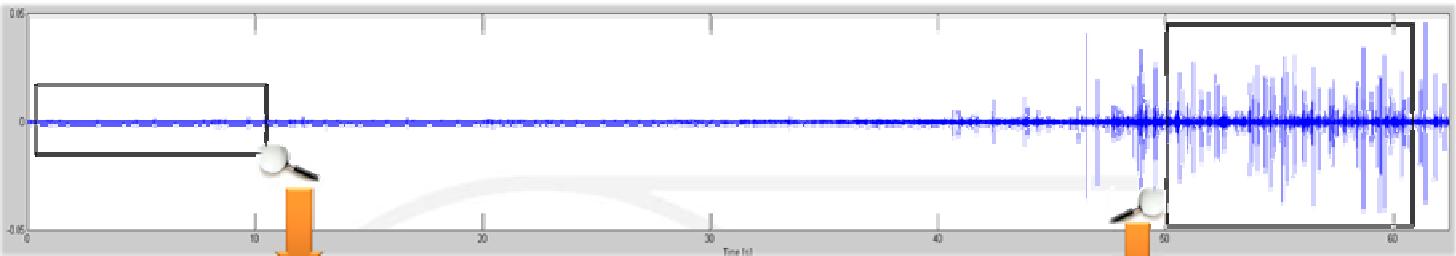
The CFD predictions performed with ANSYS CFX show a zone of high pressure drop at the turn.

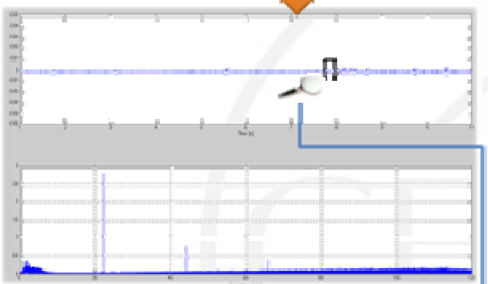
The bubbles created in this region are collapsing right after and creating pressure waves.

The waves are travelling toward the window where the laser measures the velocity vibration of the wall.

Cavitation detection

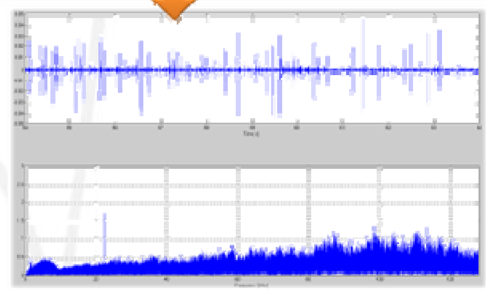
Experimental measurement: attempt to detect cavitation





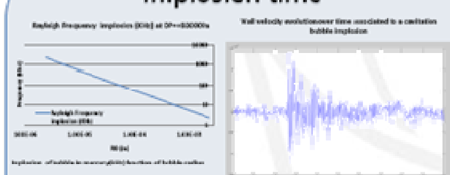
Time evolution of the Window wall velocity and the associated frequency spectrum for the first 10 seconds

This measurement shows the evolution over time (65 seconds) of the wall velocity. At t0 it was expected to have very little cavitation occurrences. Over the 65 sec the temperature increased by 0.5°C. Static pressure and flowrates remained constant.



Time evolution of the Window wall velocity and the associated frequency spectrum for the last 10 seconds

Implosion time



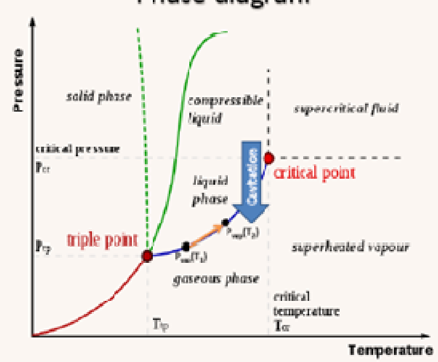
Implosion Rayleigh time:

$$T_i = 0.915 R_0 \cdot \sqrt{\frac{\rho}{P_\infty - P_v}}$$

Frequency of about 100 kHz

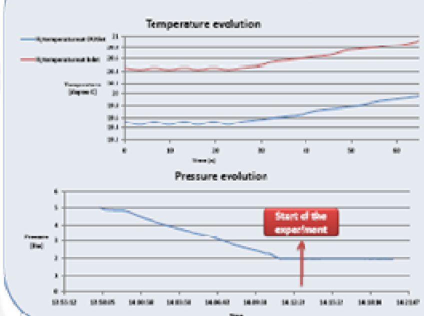
Bubbles between 10µm to 100µm

Phase diagram



The pressure limit between the liquid and the solid phase rises when the temperature increases.
The cavitation threshold is then lower as the static pressure and the flow pattern are kept constant.

Measurement of hydraulic parameters



Conclusion on the CGS design

- The experiment proved the feasibility of the concept
- A better and stronger design of the blades needs to be studied
- This design shows some weak points: the stress level in the window is rather high and might lead to a short lifetime

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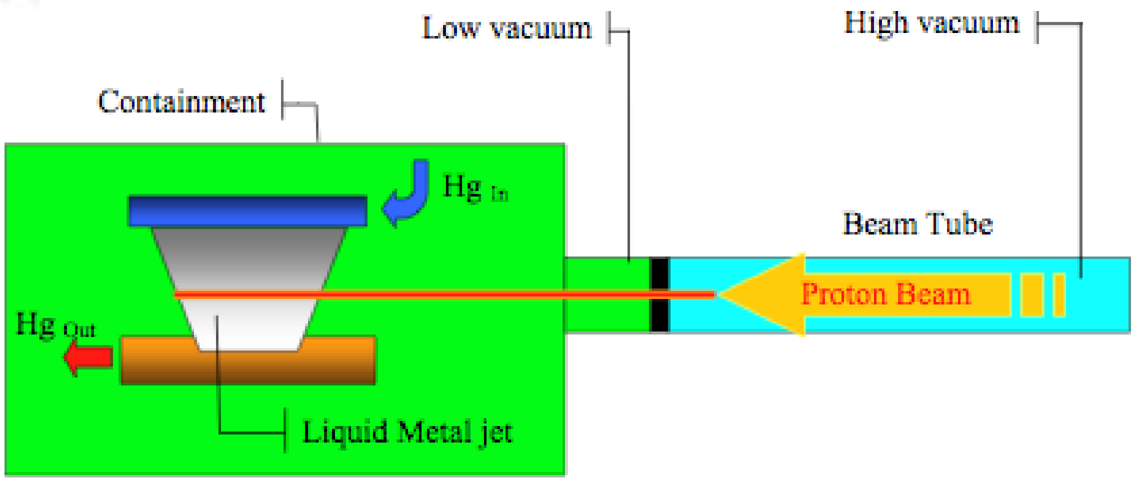
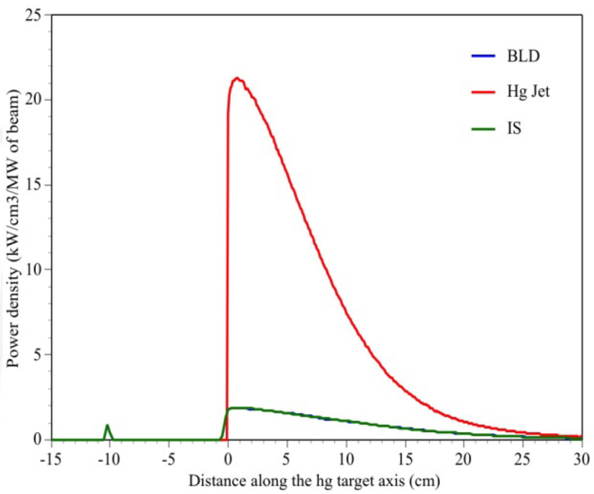
An innovative target design
The Windowless Transverse Film design (WTF)





The CGS design remain sensitive to the structural weakness linked with the window:

- Thermal stresses due to the high deposition in the window
- Pitting damage induced by possible cavitation

→These factor can drastically reduce the window life time

Therefore it was proposed to study another type of design, so called windowless.

The objective is to have the beam interacting directly with the spallation target material by the mean of a Free surface of liquid metal.

It is also possible to design the target more compact and to reduce the beam size.

This design is called the Windowless Transverse Film design.

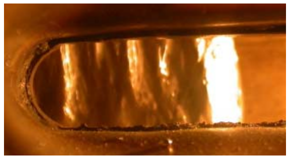
Initial design iteration

Experiments of Hg Transverse film on InGaSn Loop : Inlet Design

EURISOL Design Study

Erik Platacis et al. (IPUL, Riga)

Transverse Hg film



a

b

c

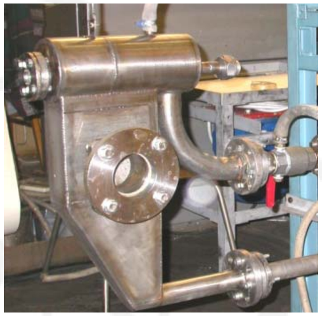
Modules of transverse film injectors

a

b

c

Test chambers



InGaSn test loop of transverse film target module

P=3 bar; Q~1.5 l/s

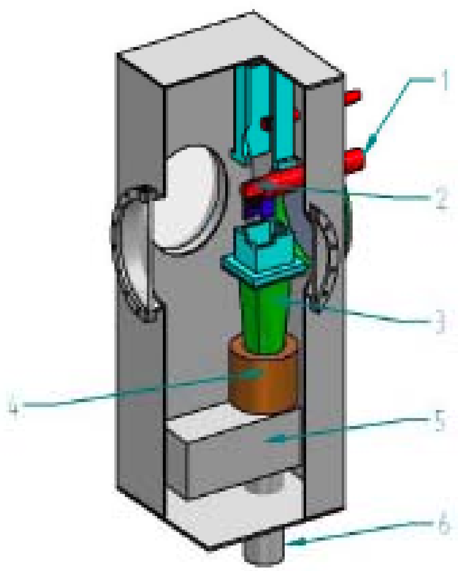
a – with rectangular cell inner structure
b – with round cell inner structure
c – with parallel separator inner structure

Cyril. Kharoua@esss.se / Workshop on Applications of High Intensity Proton Accelerators October 19-21, 2009 Fermi National Accelerator Laboratory, Batavia, IL, USA

Experiments of Hg Transverse film on InGaSn Loop : Inlet Design

EURISOL Design Study

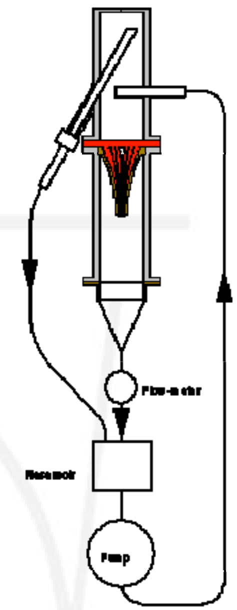
Erik Platacis et al. (IPUL, Riga)

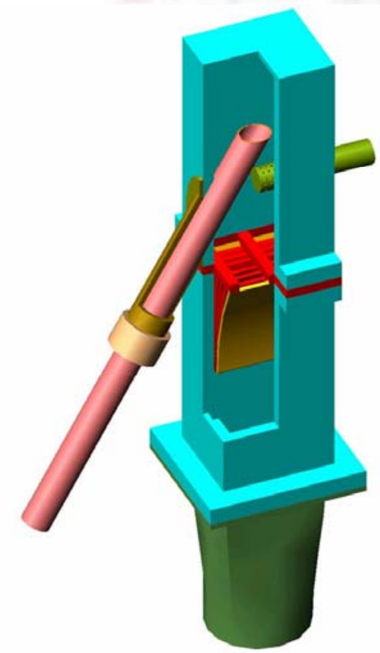


a) principle scheme

b) head of transverse film injector

Fig.19
Experimental unit of transverse film injector
1 -inlet tube; 2-transverse film former; 3- liquid metal distributor; 4- flowmeter; 5- supply tank; 6- outlet tube.



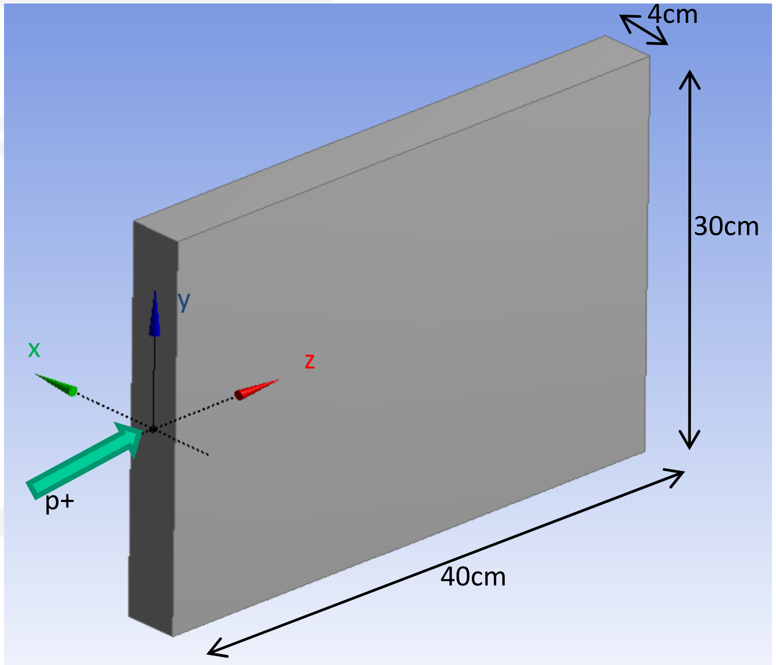


WTF converter CFD analysis

Largest power deposition occurs in the first 10 cm after the impact point for a 2mm σ beam:

➔maximum value of ~80 kW/cm^3/MW of beam power at ~0.5 cm from the impact point.

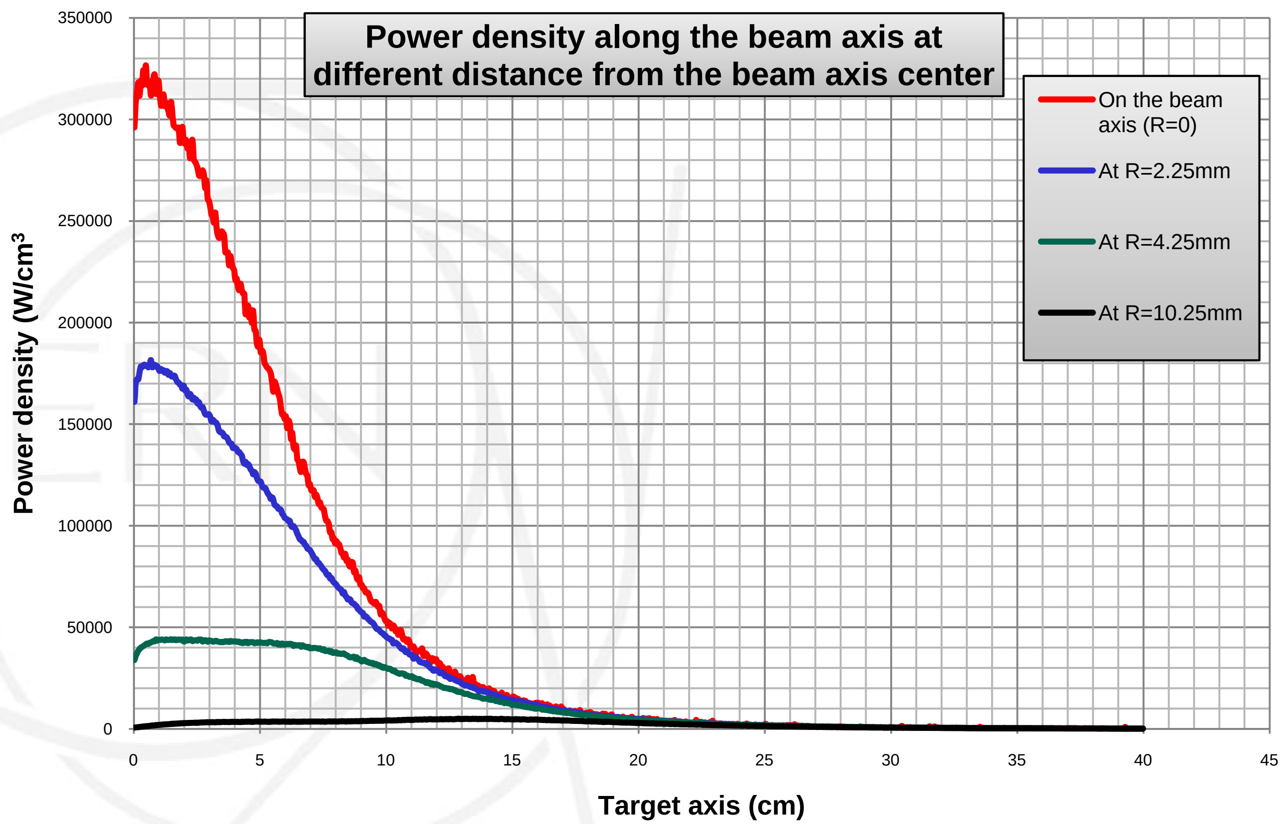
➔ Once the proton range is reached, the power densities drop sharply, to values below 500 W/cm^3/MW of beam.



WTF converter CFD analysis

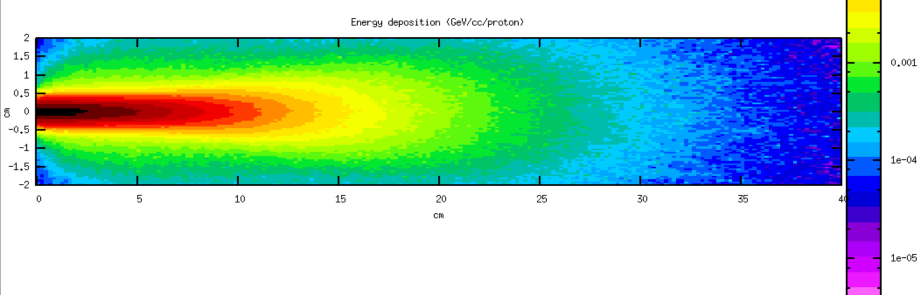
The maximum energy deposition calculated in the target is 0.08 GeV/ cm^3/proton which is equivalent to 80kW/ cm^3/MW of beam.

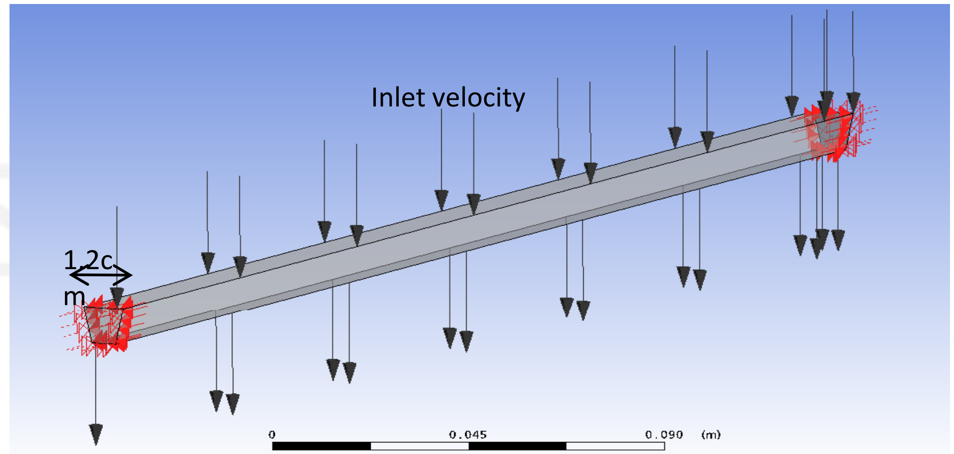
So in the case of a 4 MW beam, the peak power density corresponds to 320kW/cm^3.

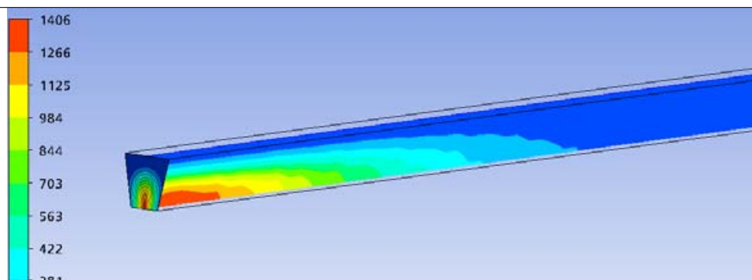


WTF converter CFD analysis

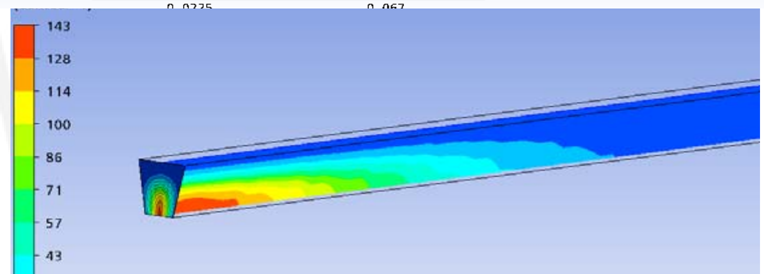
Power density (GeV/cm^3/primary) in a Hg target for a 1 GeV proton beam.







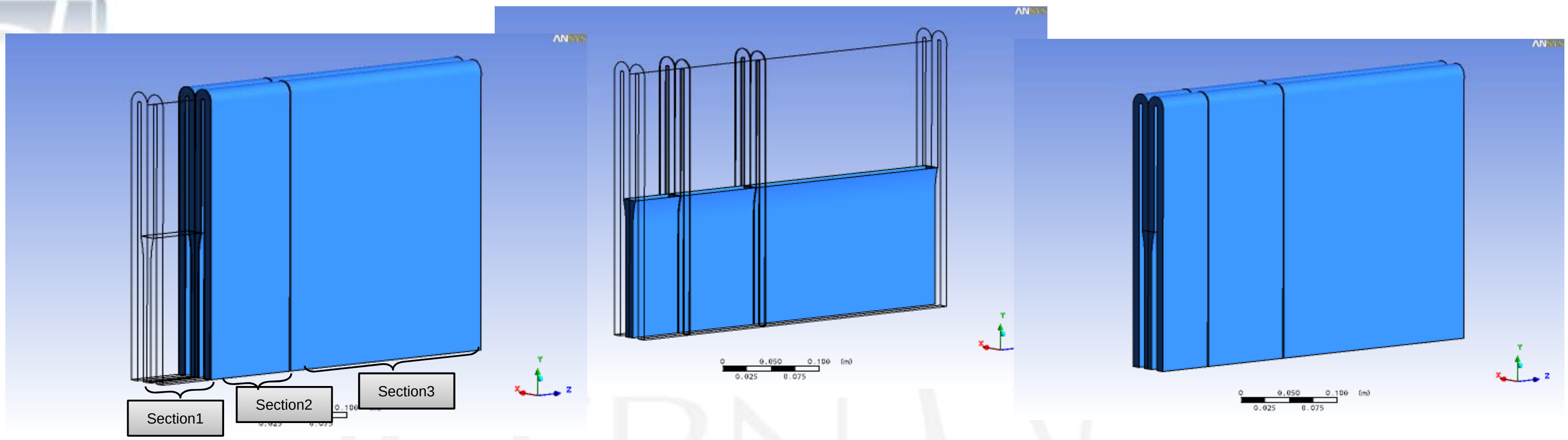
Temperature distribution in the Mercury flowing at 0.5m/s

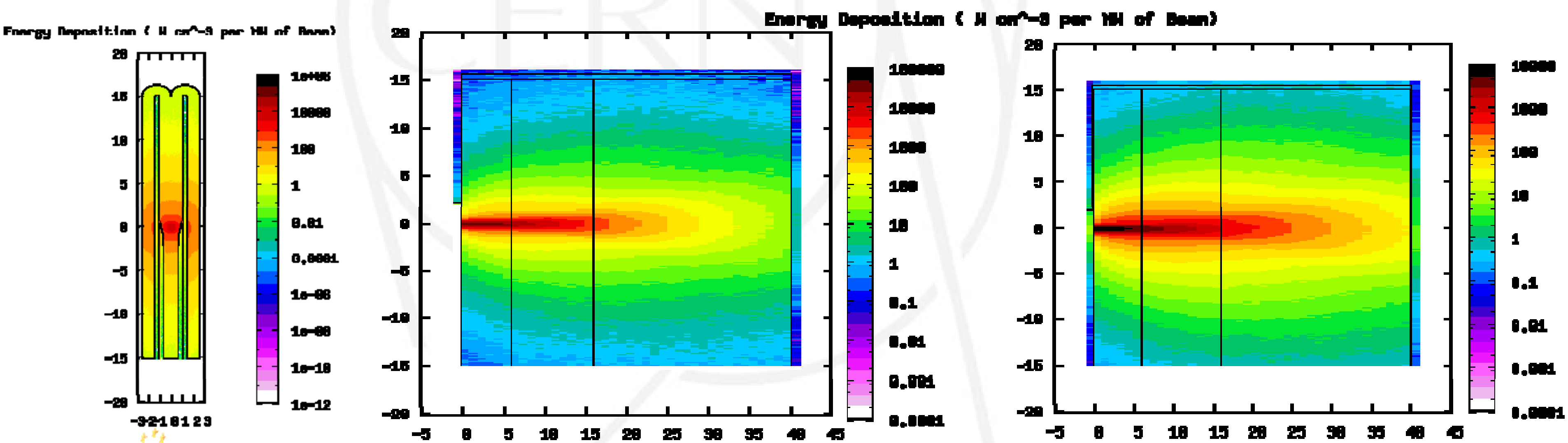


Temperature distribution in the Mercury flowing at 5m/s

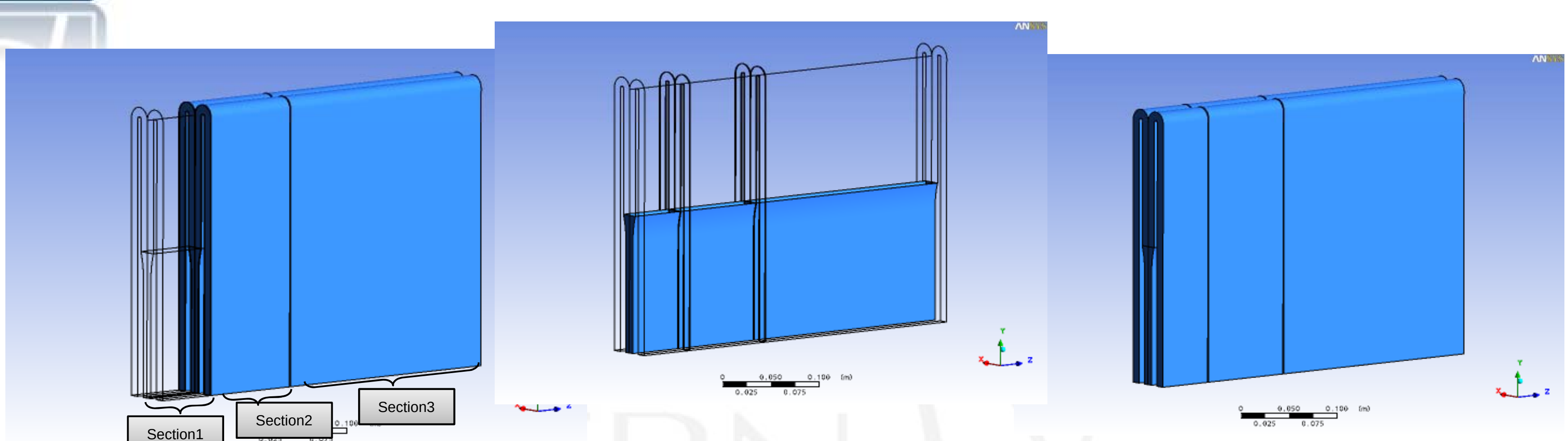
Need of 5m/s but not all the way along the beam
The target will be splited in 3 sections

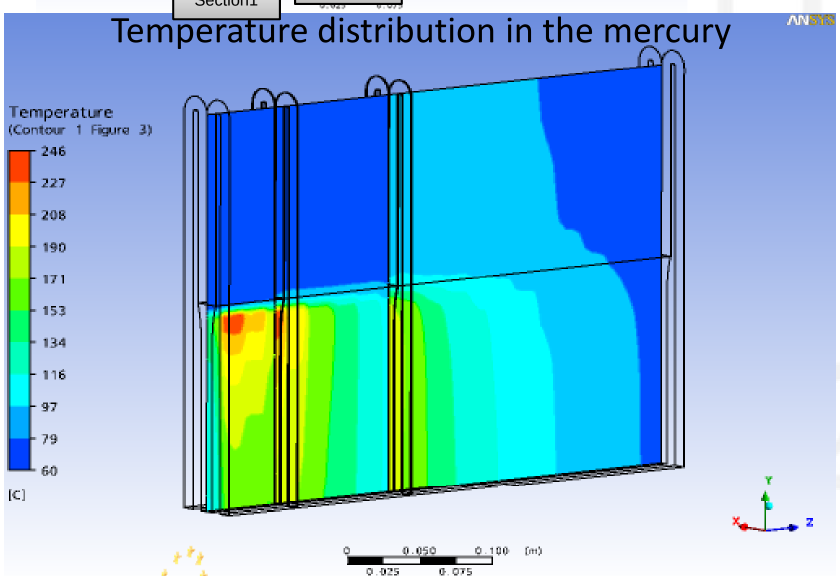
WTF converter CFD analysis

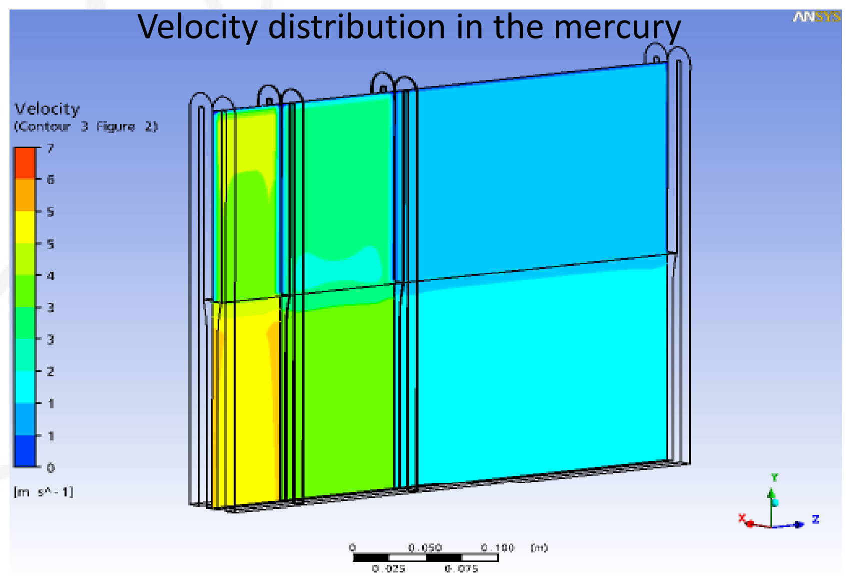




WTF converter CFD analysis







WTF converter Experience

Section 3 with ~300mm long and 16 mm width. Flow velocity of 2.2 m/s

Movie on section 3

Collector and Nozzle test banch

Movie on section 1 and 2

Conclusion on the WTF design

•Considerable efforts were put into the design of the inlet nozzle

•More efforts have to be made on:

- The measurement to characterize the integrity of the "curtain"
- The overall design of the target

The MMW target station Integration

→The EURISOL MMW target is made to provide an intense flux of neutron … but the aim of the station is to produce intense Radioactive Ion Beam (RIB) though Fission

Summary and Outlook

- A conceptual lay-out of the target station with all target positions and services has been achieved
- Detailed neutronic and release studies have been carried out for different combinations of moderators and fission target composition
- R&D effort are still required on the target development for both design

Thank you for your attention…

Thank you to all contributors