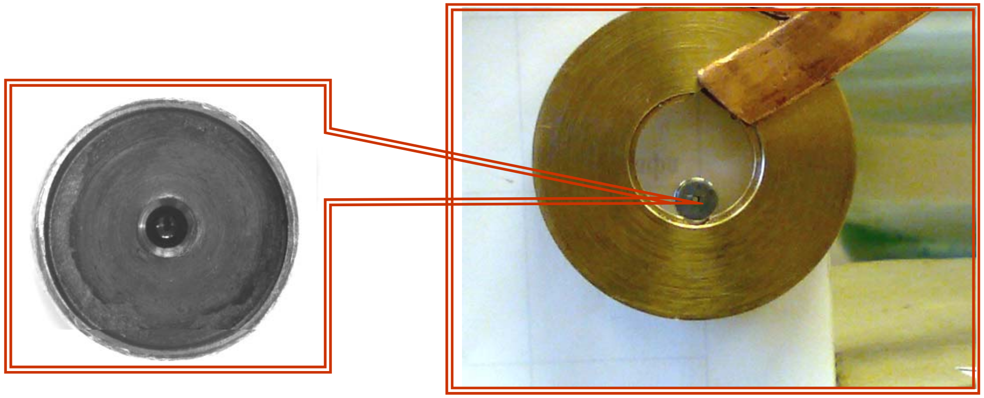
Cryogenic targets for LAPLAS experiments at FAIR: fabrication, manipulation and survival study



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SUMMARY

❑ This work was supported by the R&D contract between LPI, GSI and HEDgeHOB collaboration (2007 – 2008) and by the Russian Academy of Sciences in 2013-2014

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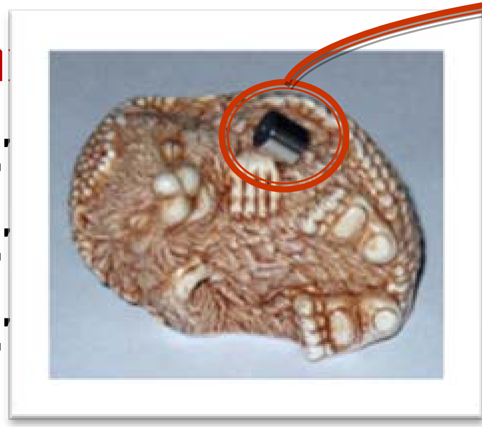
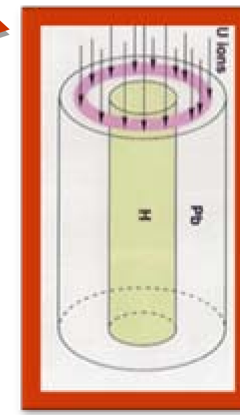




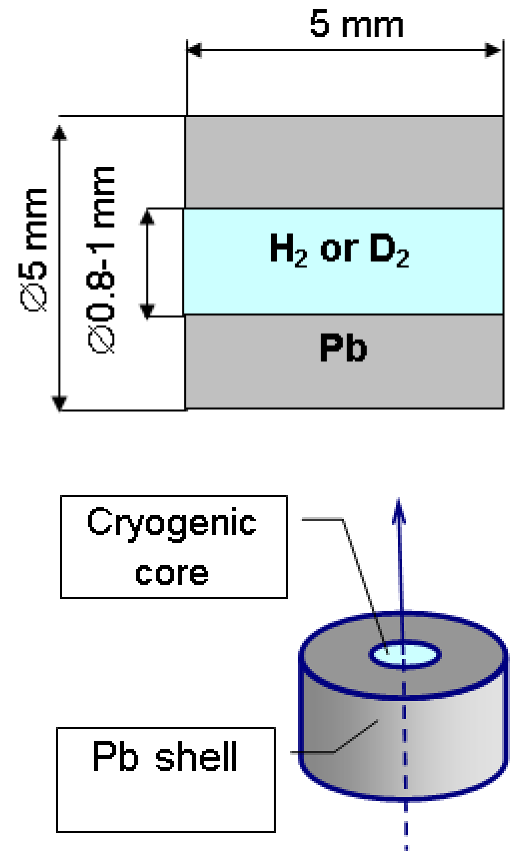
❑ **Results:**

1. Main functional modules of special cryogenic system (SCS) were determined
2. Technical requirements to the SCS modules were formulated
3. Three conceptual designs of the SCS have been proposed
4. Required standard equipment and materials have been listed

LAPLAS TARGET SPECIFICATION

	TARGET PARAMETERS	RANGE
OUTER SHELL	SHAPE	HOLLOW CYLINDER
	MATERIAL DENSITY (g/cm^3)	Pb 11.336
	MATERIAL GRADE	99,99%
	MASS, g	1.08
	OD, mm	5.0 ± 0.1 mm
	ID, mm	1 ÷ 0.8 mm ±1%
	LENGTH, mm	5.0 ± 0.1 mm
	SURFACES QUALITY	POLISH
CRYOGENIC CORE	SHAPE	SOLID CYLINDER
	MATERIAL DENSITY, g/cm^3 TRIPLE POINT (T_{tp}), K	solid H_2 and D_2 0.087 (H_2), 0.197 (D_2) 13,96 (H_2), 18,65 (D_2)
	MASS, g	$2.2 \cdot 10^{-4}$ (H_2), $5 \cdot 10^{-4}$ (D_2)
	OD, mm	(1÷0.8) mm ±1%
	LENGTH, mm	5.0±0.1 mm

Target T at the moment of irradiation: $T < T_{tp}$



Cryogenic target for LAPLAS experiment

[N.A.Tahir et al. High Energy Density Phys. **2**, 21, 2006]

TARGET SHELL MADE FROM Pb $\Rightarrow$ a key moment is the shell surface survival during target transport to the experimental chamber

Pb shell surface protection

1. Stainless steel tube. At the stage of Pb shell formation the ss tube play a role of forming element

2. Capsule from magneto-active material. At the stage of target e-m delivery this element play a role of driving body

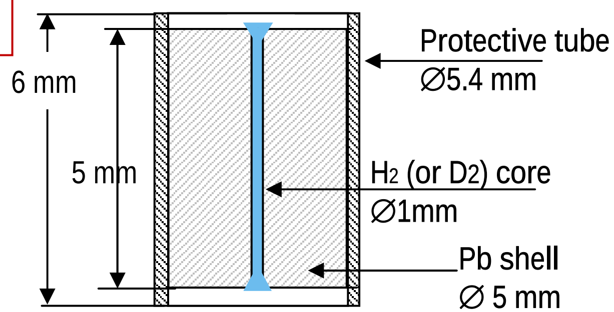
Pb features:
softness, plasticity, malleability

Examined treatment:
turning, casting, mold pressing

Optimal way:
mold pressing

TARGET SCHEMATICS

1



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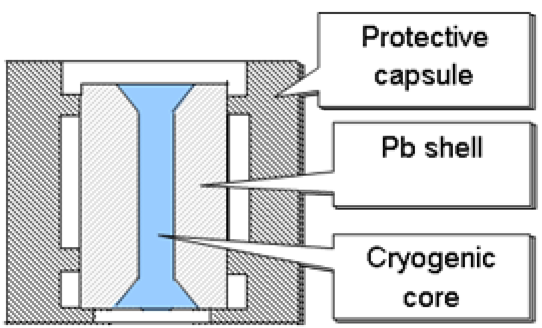


TARGET SHELL MANUFACTURING

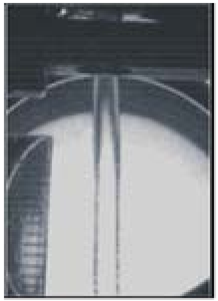
Side view **Top view**

TARGET SHELL
made from Pb by mold pressing
Pb shell OD=5 mm; ID=1 mm;
Protective s.s. tube OD=5.6 mm, ID=5 mm

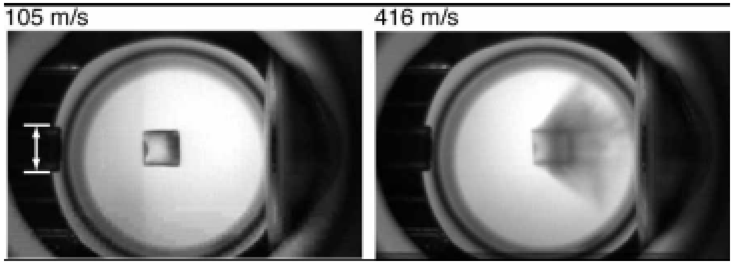
1

Parameters combination related to a target fuel core in the LAPLAS targets <u>was never realized before</u>
(bibliography analysis result)

Experiment	∅, mm	L, mm	L/∅
TOKAMAK	1 - 10	1 - 10	1
Z-PINCH	0.04 - 0.5	50 - 100	300 - 2500
ICF	0.4	10 - 20	25 - 50
LAPLAS	0.8 – 1.0	5.0	5.0 - 6.25



Road from solid H_2 (∅ 2.5 mm)
[R. Sakamoto Nucl.Fusion, 2006]



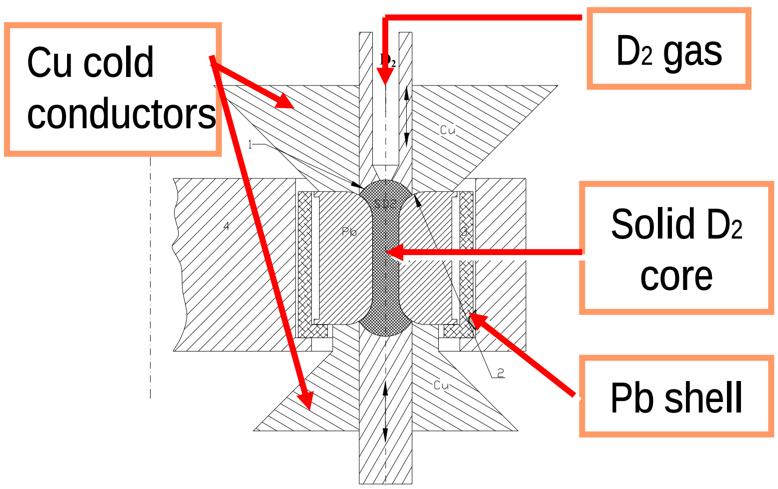
Solid D_2 pellet (∅ 5.3 mm)
[S.K. Combs, Fus.Eng.Des. 2001]

Notation to table: ∅ is target diameter, L is target length

IN-SITU & EXTRUSION: **these methods are considered as having prospects for perspective for solving the problem of cryogenic core formation**

IN-SITU METHOD

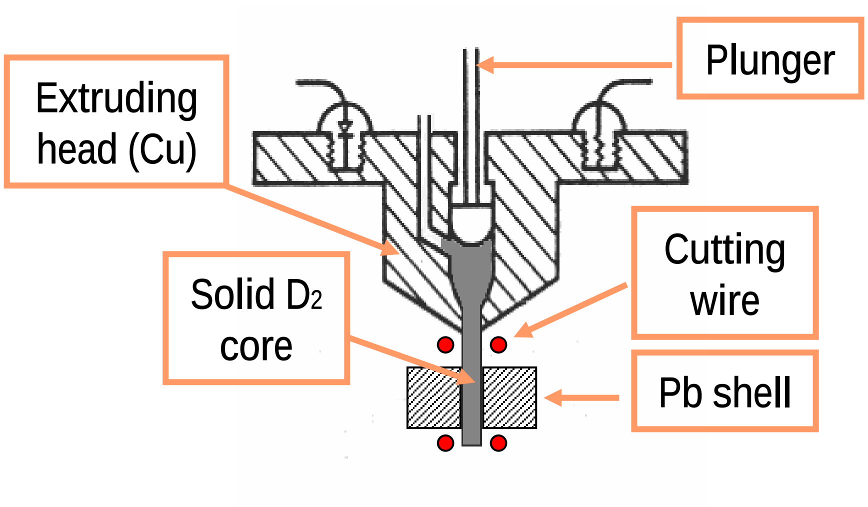
1. Short time of target fabrication: 15 min
2. Simple mechanic and electronic control: there are no or almost no movable parts.
3. Possibility to make a cryogenic core with faces of the required shape (if necessary).



Gradual freezing of the solid-D_2 core on the inner walls of the Pb shell (method in-situ)

EXTRUSION METHOD

1. Short time of target fabrication: 1-2 sec
2. Ability to supply cryogenic targets in real time
3. Cryogenic targets do not need a long-term storage
   ⇒ minimum consumption of the liquid helium
4. Perspective for a rep-rated targets production

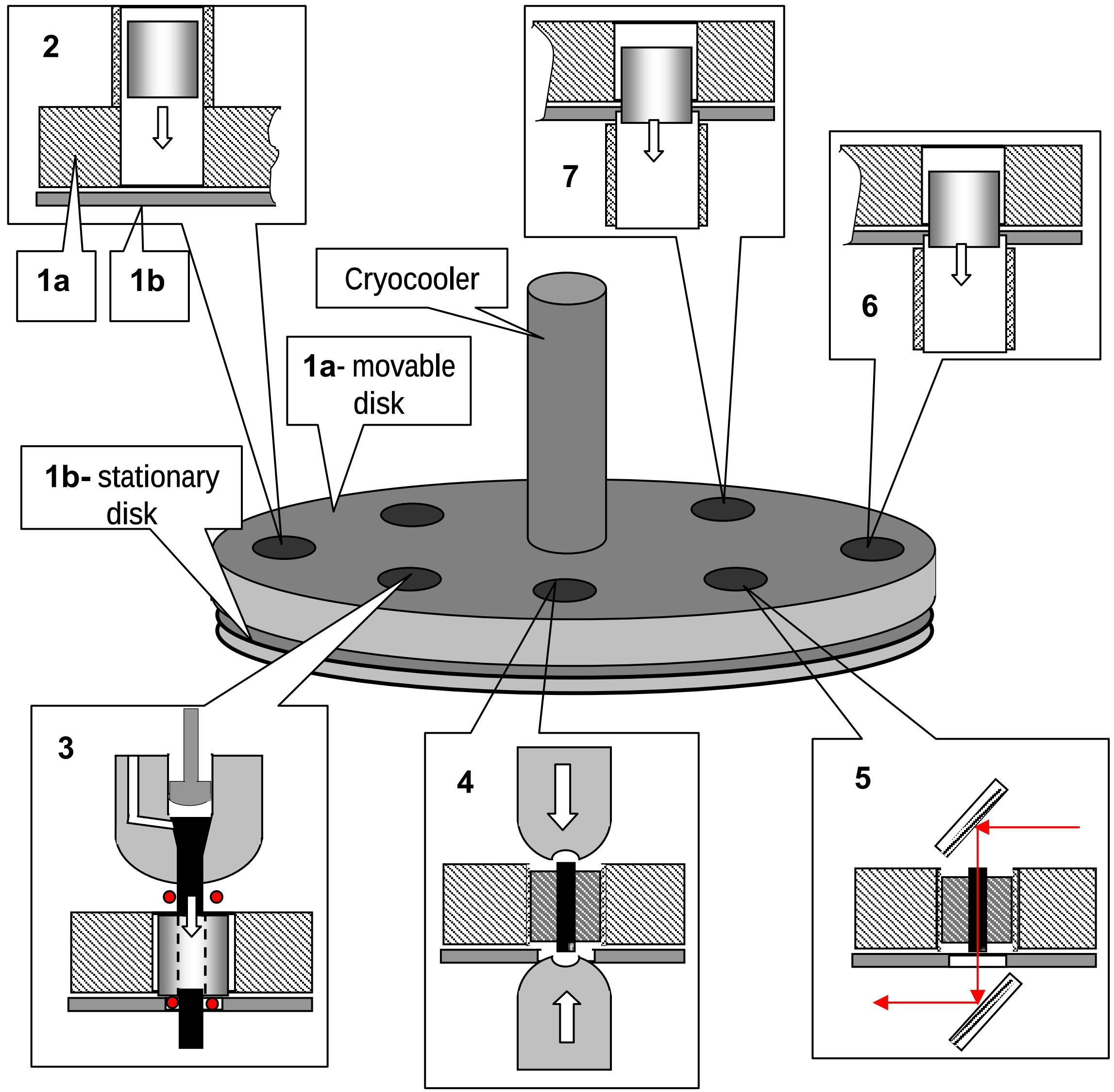


Method of solid D_2 core extrusion into cylindrical hole of the Pb shell

Module for cryogenic target fabrication & assembly (FAM) based on the extrusion method

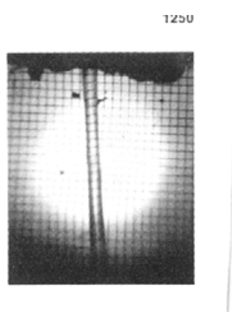
PHYSICAL LAYOUT

1. Pb shell loading under gravity (2)
2. Solid D_2 core extrusion into Pb shell (3)
3. Cutting off the upper & the lower parts of D_2 core using tungsten wire (3)
4. D_2 core face formation (4)
5. The created target characterization (5)
6. In accordance with the results of characterization, the target transport
   - to the delivery module (6), or
   - to the rejected targets collector (7)
7. Target loading under gravity to the corresponding unit (6 or 7)
8. High quality target delivery to the experimental chamber

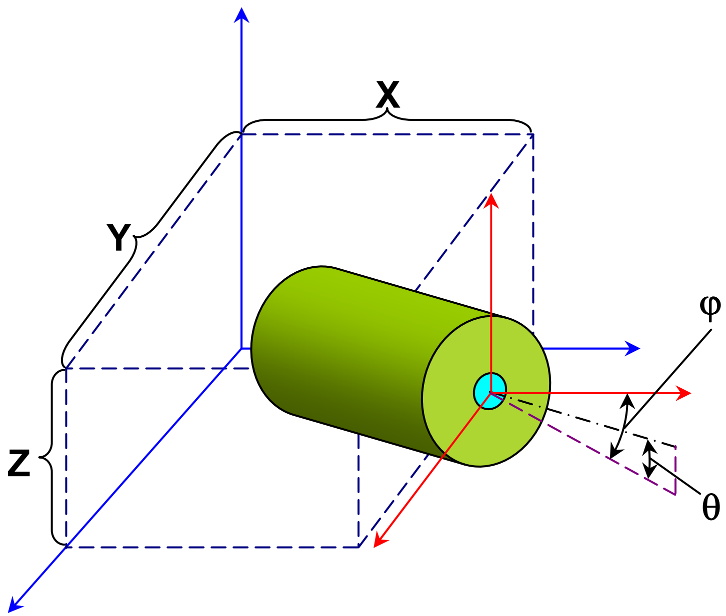


Extruded D2 rod against a wire mesh background (275 μm spacing)

[W.D.Friedman et al. Rev.Sci.Instrum. 45, 1974]



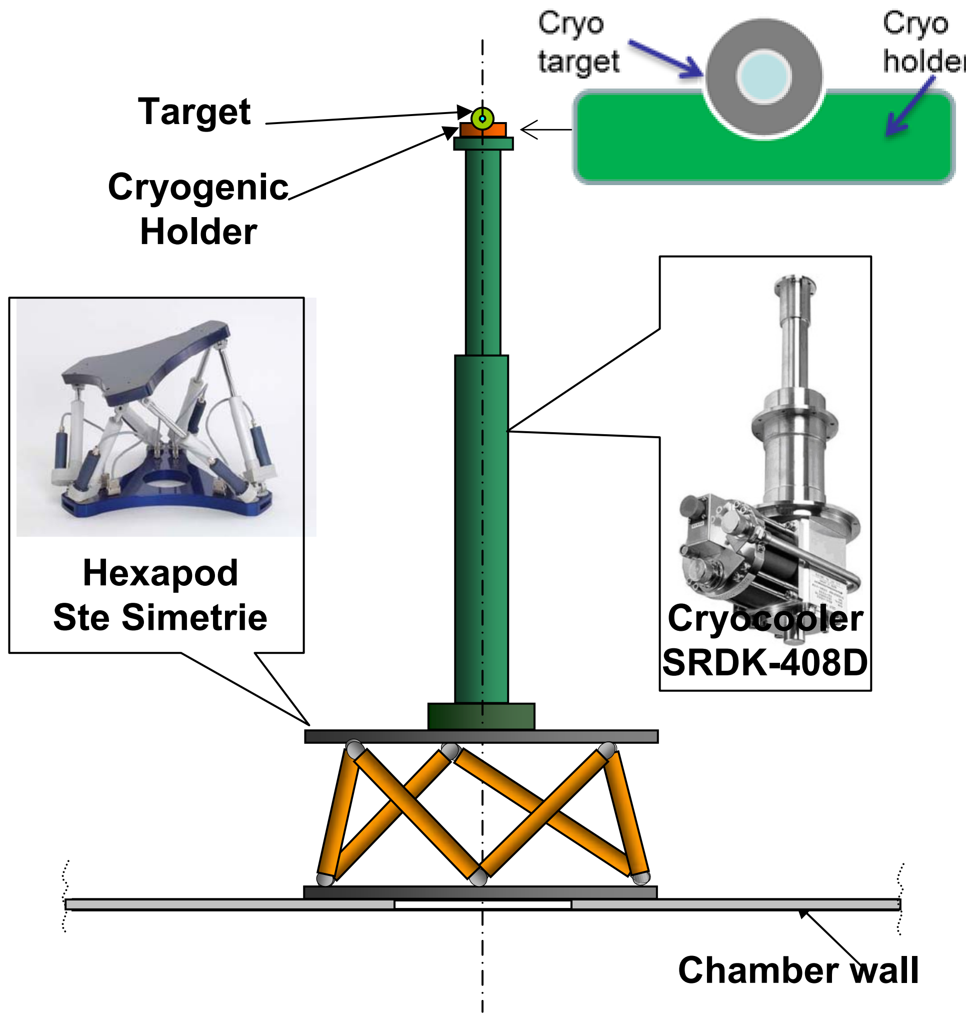
Target positioning inside the experimental chamber



Positioning coordinates of the target.
X, Y, Z – linear coordinates of the centre of the target in space;
θ, φ – angular coordinates of the target axis

TECHNICAL REQUIREMENTS

1. Target axis orientation: horizontal
2. Maximal X-У-Z displacement: ± 50 mm
3. Positioning accuracy: linear 10 um, angular 10 min
4. Holder optimal temperature: 10 - 11

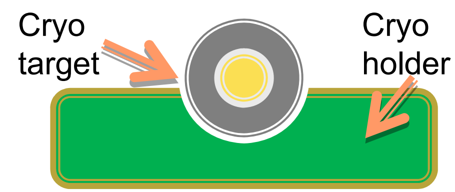


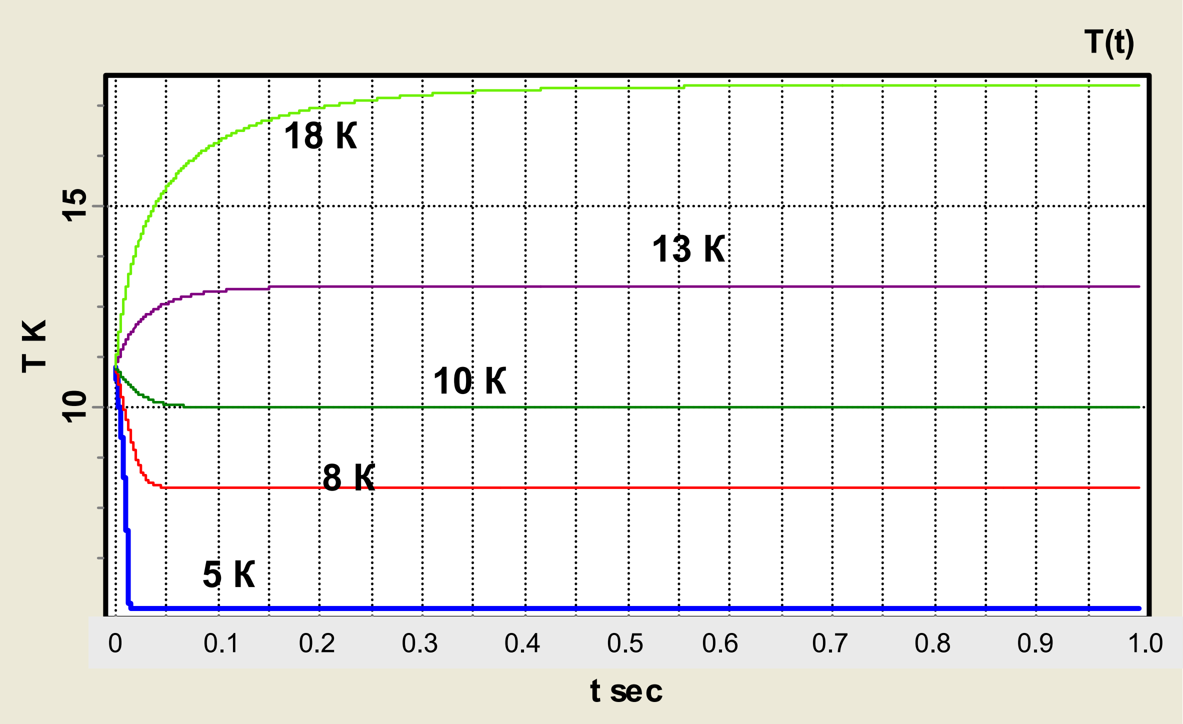
Target positioning scheme

*/ Hexapod Ste Simetrie was successfully used in cryogenic system developed for the LMJ facility [D.Chatain, JP. Périn et al. 3rd MWTA, Moscow, Russia, Oct. 2007]

TARGET SURVIVAL STUDY: target holder temperature optimization

Our calculations have shown that using the cryogenic holder one can protect the target from the thermal radiation of the chamber wall and fix target temperature in the required ranges ($T < T_{tp}$)





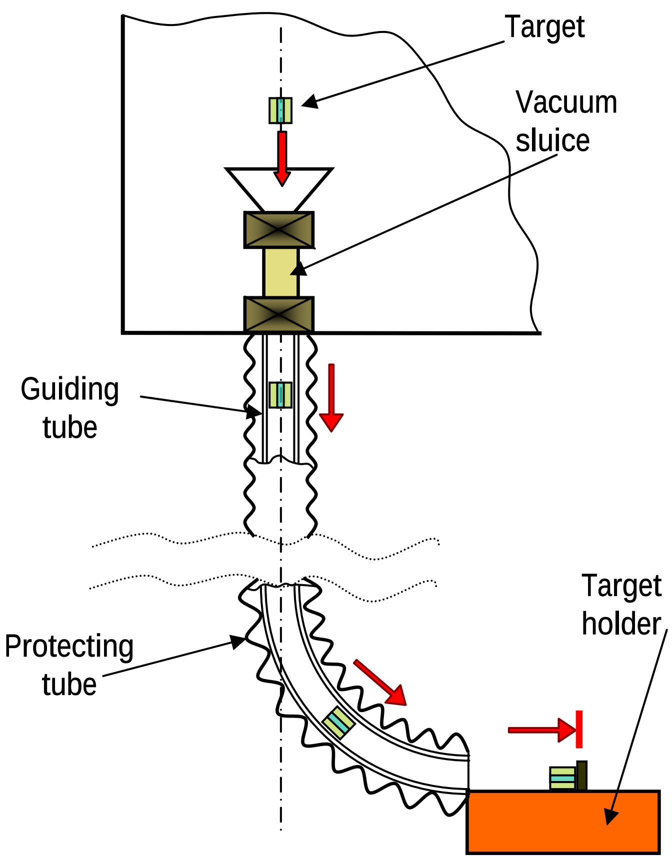
Stabilization of the cylindrical Pb shell temperature , which is placed inside the chamber onto the cryogenic holder

Calculation parameters: T_C =300 K, α = 10%, S_t=20% T_{holder} = 5, 8, 10, 13, and 18 K, T_i=11 K

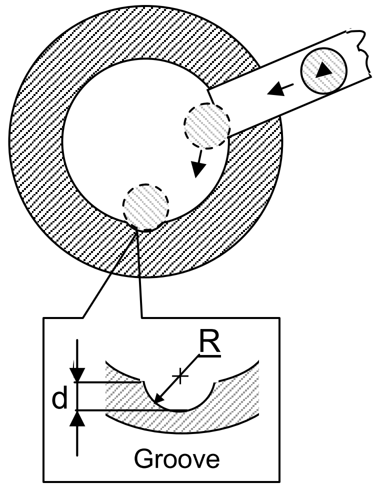
Calculations made for cylindrical Pb shell of 5 mm OD, 5 mm height, 2.1 mm thick

Target delivery from the FAM to the chamber center: GRAVITATIONAL APPROACH (two options of guiding tube)

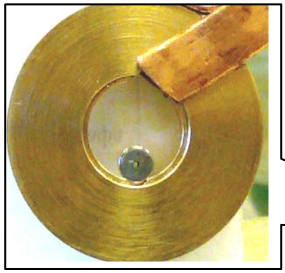
- most economical delivery means
- small delivery time (1-2 sec)
- no contamination of the chamber with foreign gases
- it is required the application of target protecting shroud (s.s. tube)



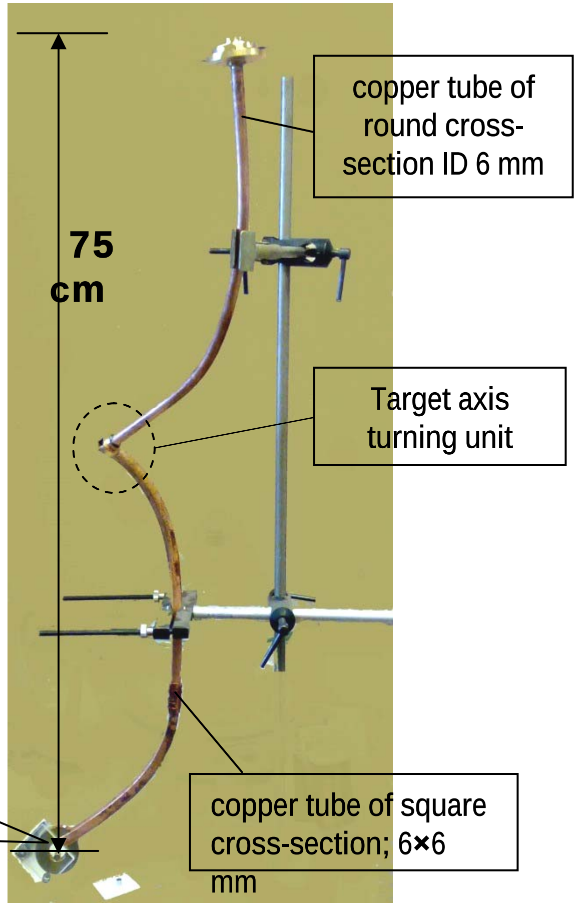
SCHEMATIC of target delivery using a guiding tube option 1



Schematic of target input into the holder



Cylindrical lead shell in the holder made from brass



PROTOTYPE MODEL for target delivery using a guiding tube option 2

Gravitational approach (guiding tube option 2). Experimental results at 300 K

❑ Two types of target movement were tested:
(a) sliding inside the round cross-section tube
(b) rolling inside the square cross-section tube

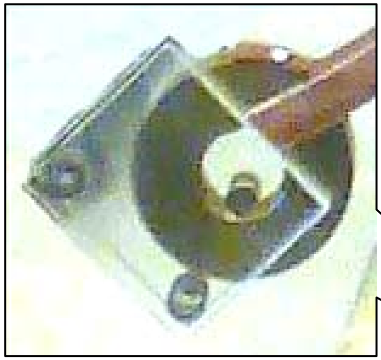
❑ Proven operations:

1. target axis rotation on 90^0 at the area of tubes coupling (round & square cross-section tubes);
2. target delivery along the guiding tubes at the distance of 0.75 and 1.5 m (supposed radius of the chamber)
3. target injection from the square cross-section guiding tube onto the holder
4. target fixing in the groove of the holder (20% contact area)

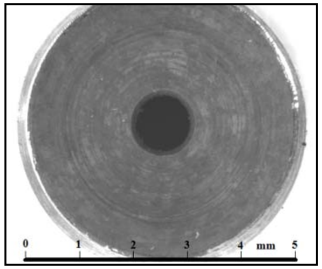
❑ Resume on the results obtained:

- Limiting shield is required in the holder
- Pb shell surface and faces should be protected from the mechanical destruction
- Possible protecting means is a thin-walled stainless steel tube and/or driving capsule made from magneto-active material

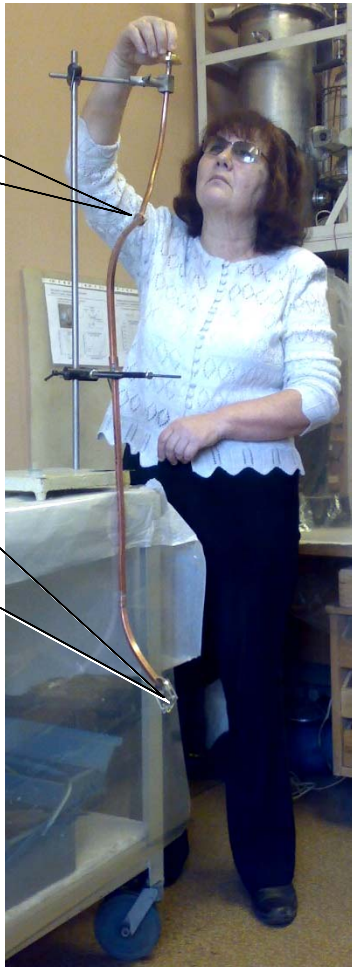
Target axis turning unit



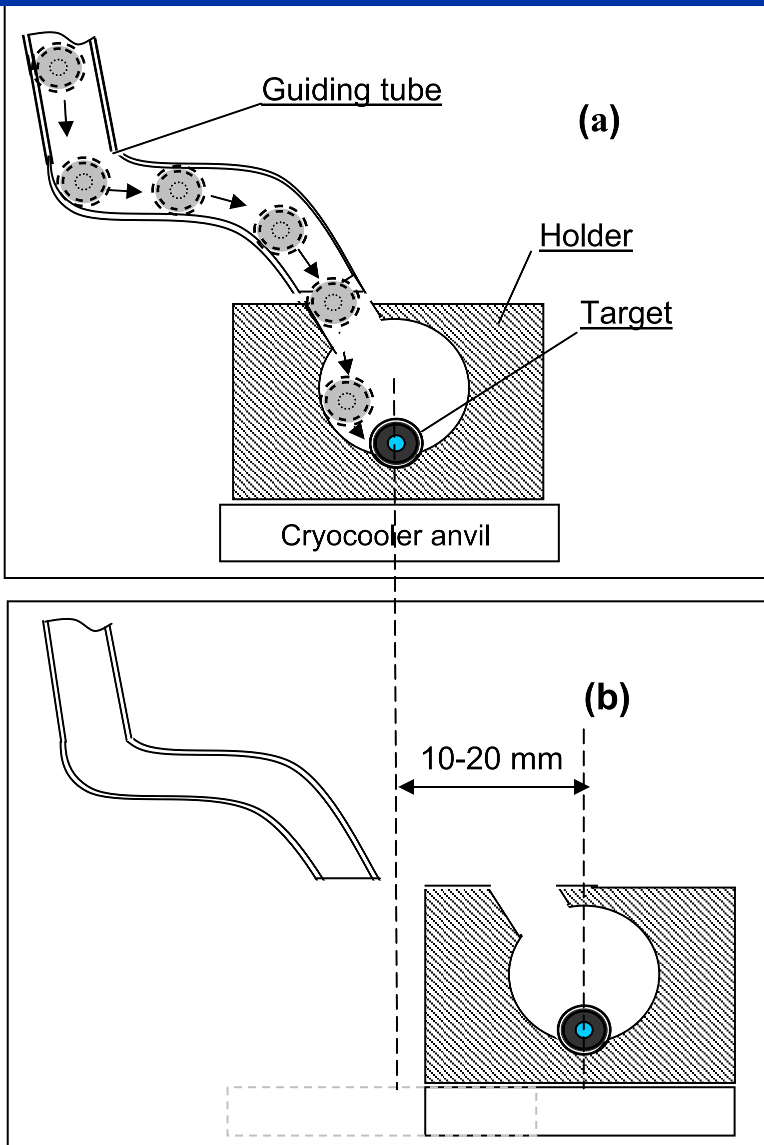
Limiting shield from plexiglass mounted on the brass holder

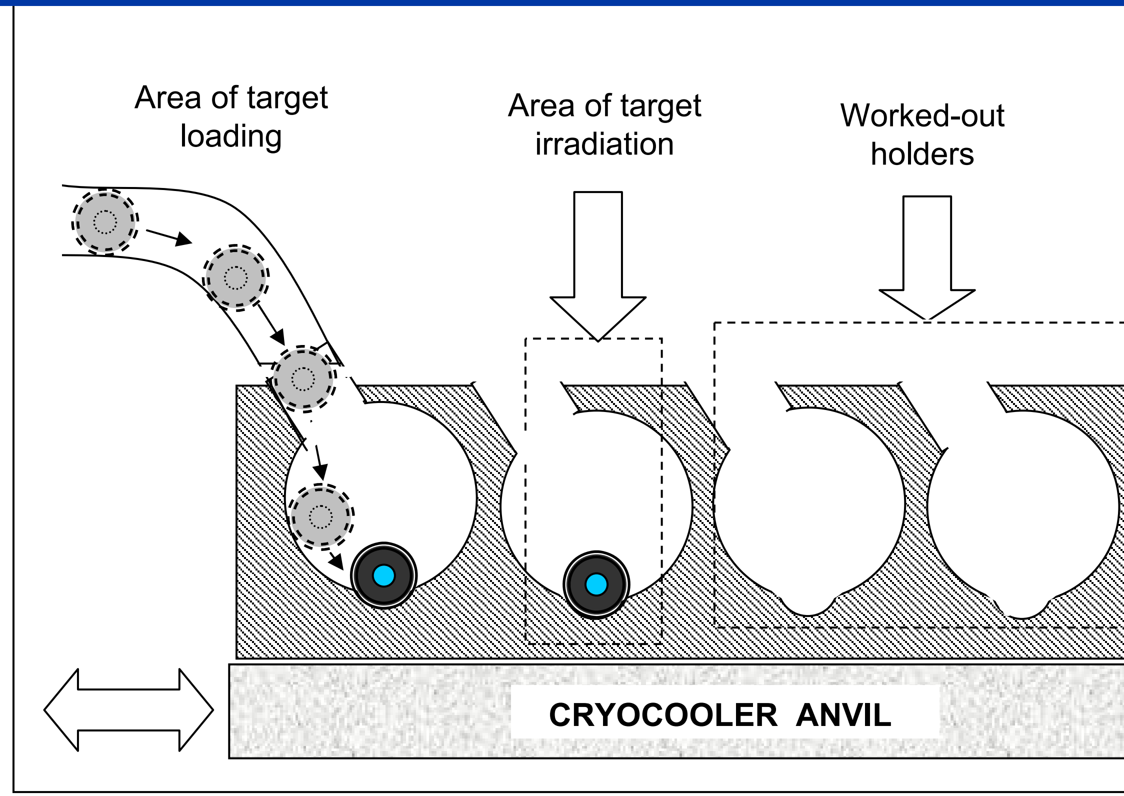


Pb shell enclosed in the protective s.s. tube



Possible layout of targets rep-rate delivery & irradiation. Gravitational approach (guiding tube option 2).





(a) Holder position at the stage of target loading from the delivery system

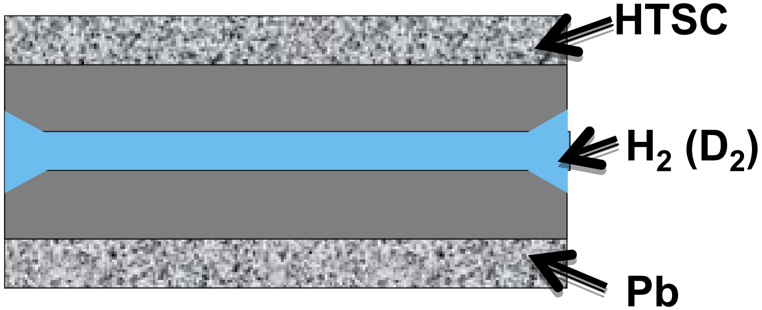
(b) Holder position at the stage of target irradiation

(c) Schematics of the holder intended for target rep-rate delivery at the area of irradiation

HTSC quantum levitation effect for risks minimization during target delivery ⇒ Shell surface protection from scratches, fuel protection from heat load. In addition it is excluded target steak due to its declination inside guiding tube

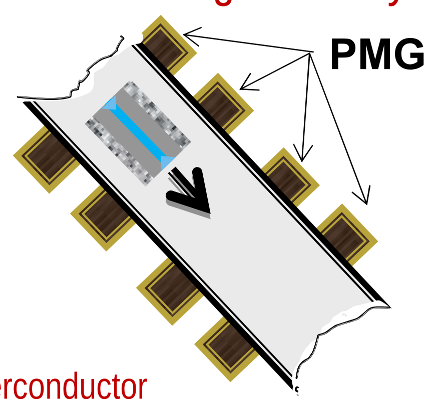
❑ For guiding tube option 1

1. Target with cylindrical shroud from HTSC



2. Guiding tube with the permanent magnets guideway (PMG) for non-friction target delivery

Target motion under gravity over the PMG: there is no contact between the target & the guiding tube



HTSC = high temperature superconductor

This approach is perspective for both gravitation and electromagnetic delivery

❑ POP expt. carried out at LPI in 2013-2014: HTSC samples guiding using quantum levitation

1. HTSC sample stable levitation and alignment T=80K, B=0.4T

HTSC sample aligns with the line of minimal magnetic induction

Stable levitation of HTSC sample over the magnet

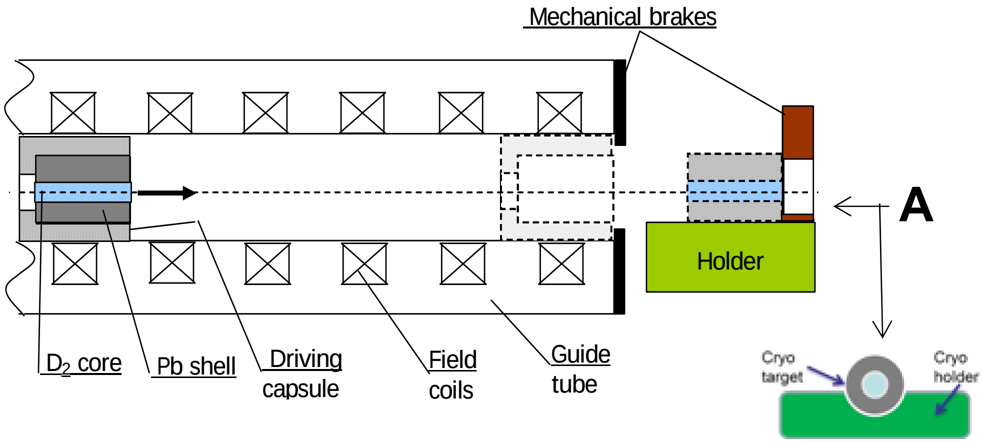
2. HTSC sample is centered in the ring from the permanent magnet

3. HTSC sample movement over the PMG

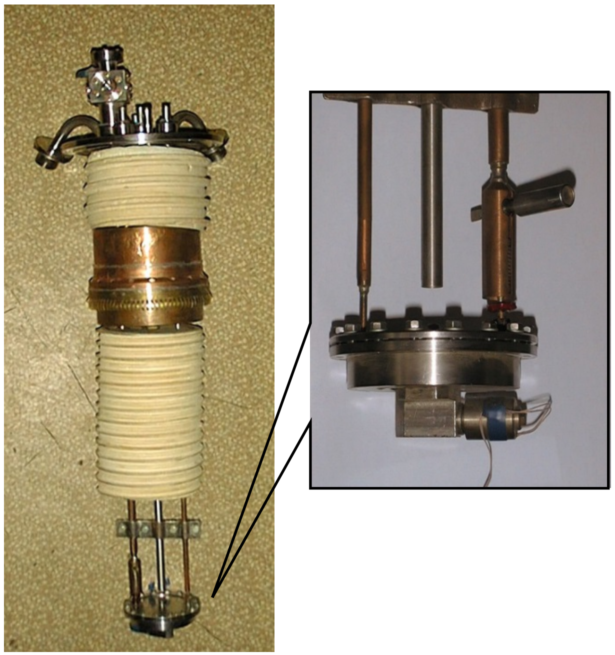
The HTSC samples have been made at LPI from YBa_2Cu_3O ceramics ($T_c \simeq 91$ K, $H_c \simeq 5.7$ T at 0 K)

Target delivery from the FAM to the chamber center: ELECTROMAGNETIC APPROACH

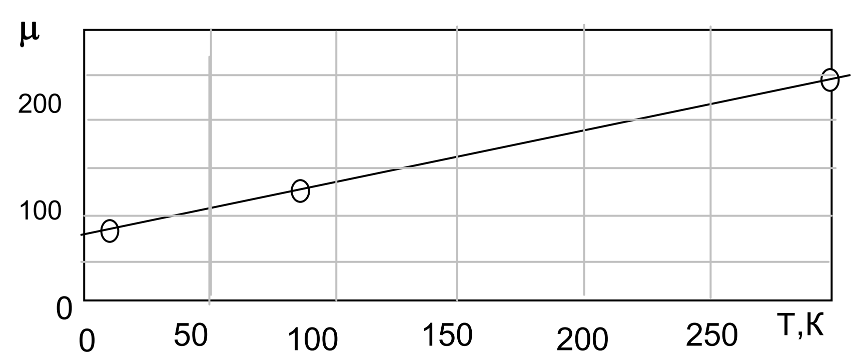
- ❑ contamination of the chamber with foreign gases is impossible
- ❑ easy control of target velocity
- ❑ application of magneto-active driving capsule is needed



SCHEMATIC of an electromagnetic linear accelerator for HEDgeHOB target delivery



TEST MODEL of e-m injector working at cryogenic temperatures



Magnetic penetration factor of the magneto-soft iron *vs.* T

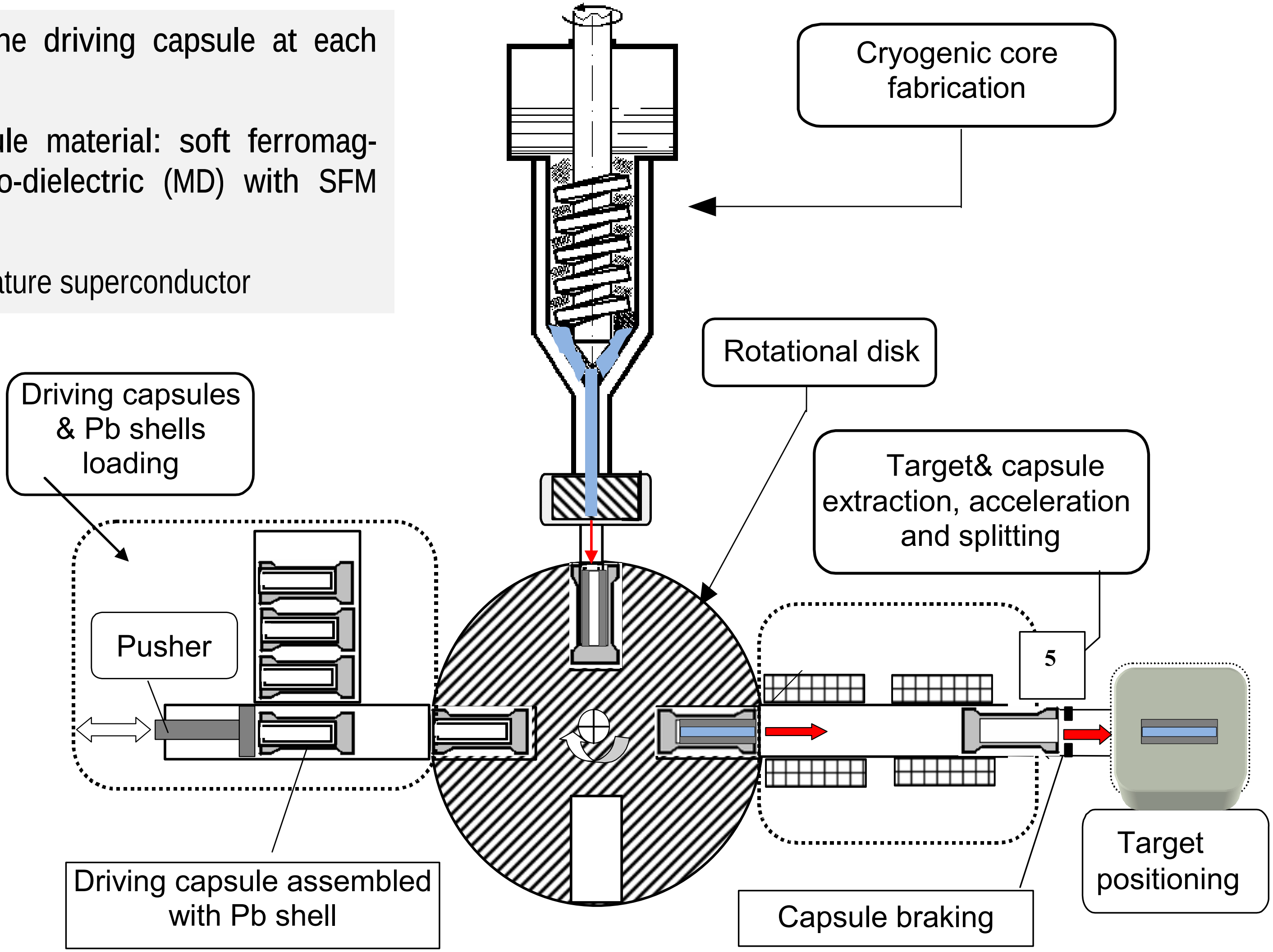
EXPERIMENT: driving capsule from magneto-soft iron can be used at solid H2 temperatures (T<14 K)

Special cryogenic system (SCS) for target fabrication & electromagnetic delivery

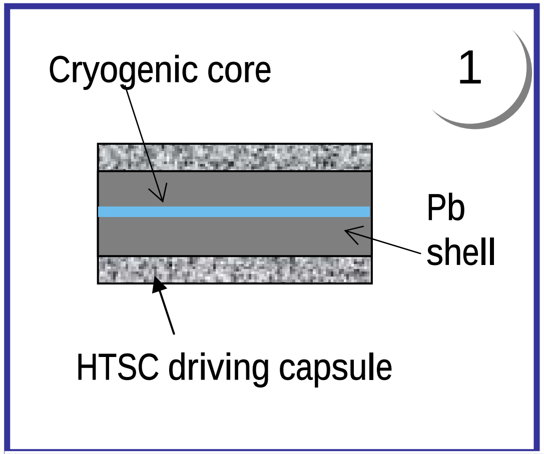
❑ Target is inside the driving capsule at each production stage

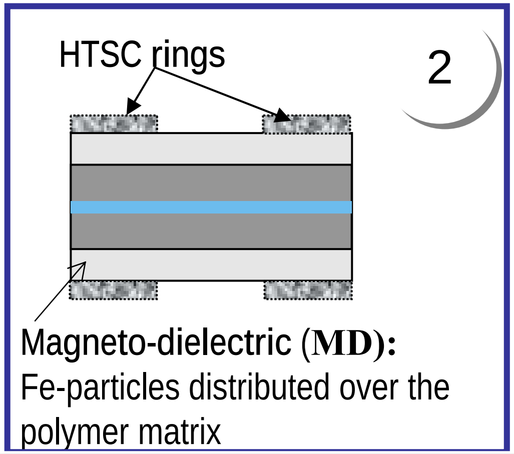
❑ The driving capsule material: soft ferromagnetic (SFM), magneto-dielectric (MD) with SFM and/or HTSC particles

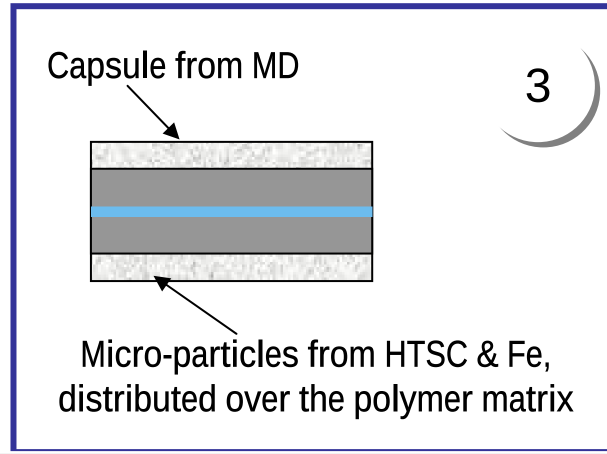
*/HTSC = high temperature superconductor



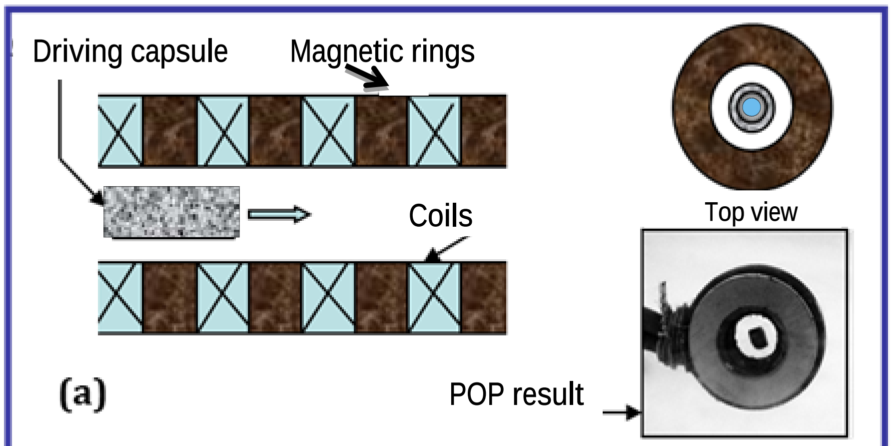
Application of the HTSC in driving capsule and PMG in e-m injector allows non-friction and accurate target delivery

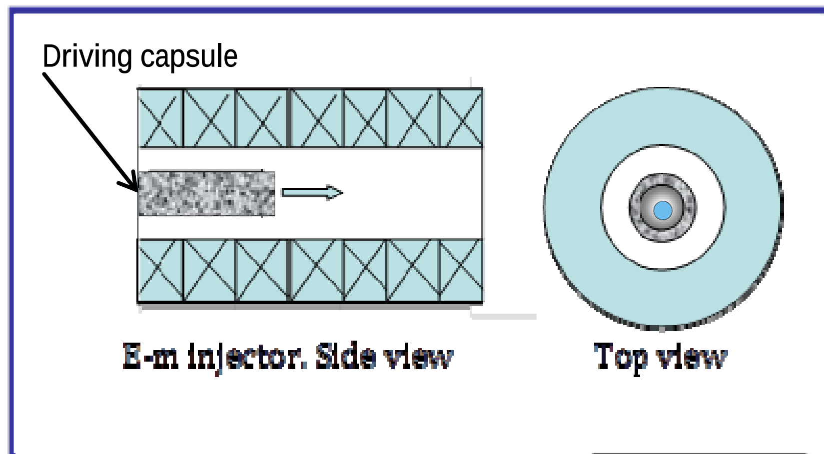






Different options of a driving capsule for almost non-friction motion of a target inside the e-m injector. This enhance the operating efficiency of the injector and save target parameters.

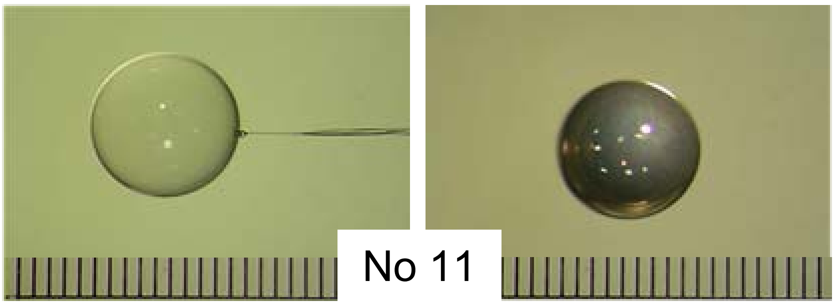


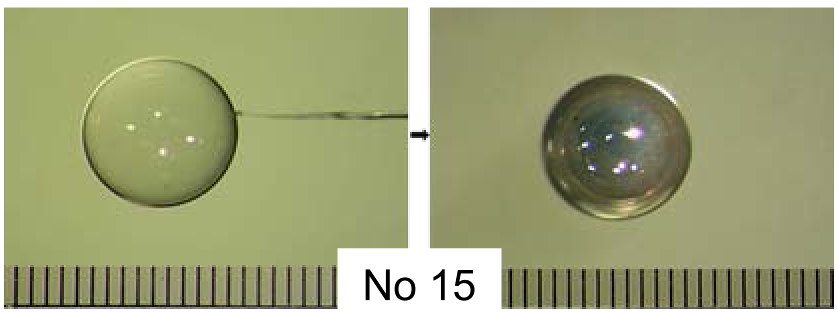


E-m injector . A design options with the HTSC capsule

This work was performed in 2013-2014 under support of Russian Academy of Sciences

Why not use Pb? ⇒ **Our POP experiments showed unsuccessful shell levitation due to superconductivity collapse caused by a sufficiently small value of the critical magnetic field for Pb** (Pb is the Type-I superconductor: Tc=7.2K, Bc= 0.08T)





鉛蒸着前(組立日：2012.07.18)
鉛蒸着 0.16umt 後 (蒸着日:2012.07.31)
CH中空球No.11直径約996ミクロン　膜厚約11ミクロン　CH中空球No.15 直径約1040ミクロン 膜厚約11ミクロン

Pb-coated targets (Japan) for our POP expts were fabricated by the evaporation coating using the electron beam heating the Pb-powder

Prof. T.Norimatsu (ILE, Osaka) and Prof. R.Tsuji (Ibaraki Univ.) have supported our research with Pb-coated targets. They consider that the magnetic lens scheme will be important technology in future injection of IFE direct drive targets.

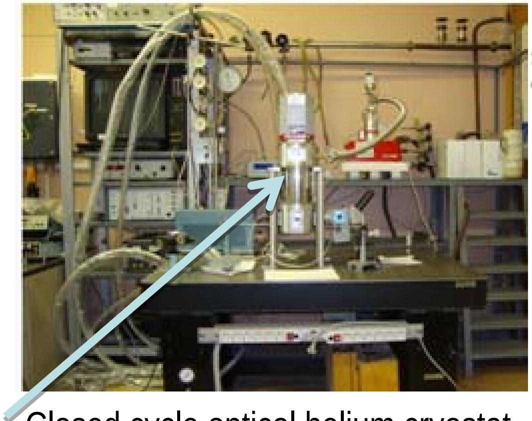
Target parameters

No.	直径 [um]	膜厚 [um]	鉛コート厚 [um]
3	1036	11	0.16
8	1074	13	0.16
9	1010	11	0.16
11	996	11	0.16
15	1040	11	0.16

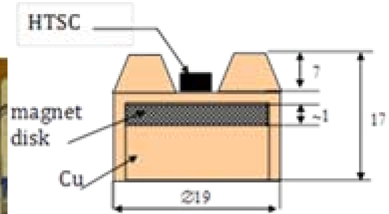
We have proposed to use HTSC as they possesses high Tc & high Bc.

POP experiments carried out at 80-to-6 K have shown the possibility of both stable levitation & non-friction transport of the HTSC samples

❑ Experimental set up



Closed cycle optical helium cryostat

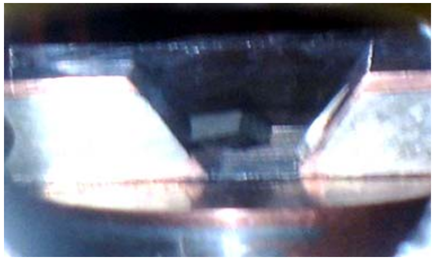


Sample holder schematic & general view

❑ Stable levitation of the permanent magnet over the HTSC sample, T=6 K

Magnet: NdFeB, B = 0.4T (commercial), Size 6x2x4 mm

HTSC disc:
YBa_2Cu_3O pellet (made at LPI), 12.4 mm - diam



In our expts we used HTSC made at LPI:
YBa_2Cu_3O with T_c = 91K & B_c = 5.7T at 0K

❑ Maglev braking of lateral motion of the HTSC projectile, T=80 K

PMG made from a soft ferromagnetic plate mounted onto NdFeB magnet (B=0.4T); HTSC made from YBa_2Cu_3O ceramics

YBa_2Cu_3O pellet
∅ 12.4 mm x 2 mm

YBa_2Cu_3O coated CH shell of 2 mm-diam

❑ Stable levitation of the HTSC samples over the permanent magnet, T=18K & 80K

Magnets: NdFeB, B = 0.4 T, commercial

T = 18 K
HTSC sample: YBa_2Cu_3O ceramics (made at LPI)
Size 6x2x2 mm

T = 80 K
HTSC sample: YBa_2Cu_3O coated CH shell of 2 mm-diam.
(made at LPI)

Some open questions to be solved at the next stage of development

1. **First of all:** Is it possible to irradiate the target enclosed into the protective element (ss tube, HTSC shroud, etc.) ?

2. **Concerning the quality requirements to the cryogenic core :**

- What is the permissible size of structure inhomogeneity?

- What is the permissible roughness of faces?

3. **Urgent question: whether the cryogenic core faces degrade before completion of target positioning?**
   If yes, it is necessary to perform a special face shaping in the stage of the core formation? In this connection, the problem of thermal degradation of the cryogenic core faces requires a thorough theoretical analysis at the next stage of development.

4. **LPI proposes to discuss once again the requirements to the rate of target delivery:** - **If the delivery rate is more than 1 target per day, one must work with free-standing targets:** application of FAM, delivery by gravitation or electromagnetic injector are required - **If the delivery rate is less than 1 target per day one can consider a traditional method of target fabrication & delivery:** in situ method using Pb shell pre-mounted on the holder

SCS for LAPLAS target in-situ fabrication & positioning:

design option for the delivery rate of about **1 target per day and less**

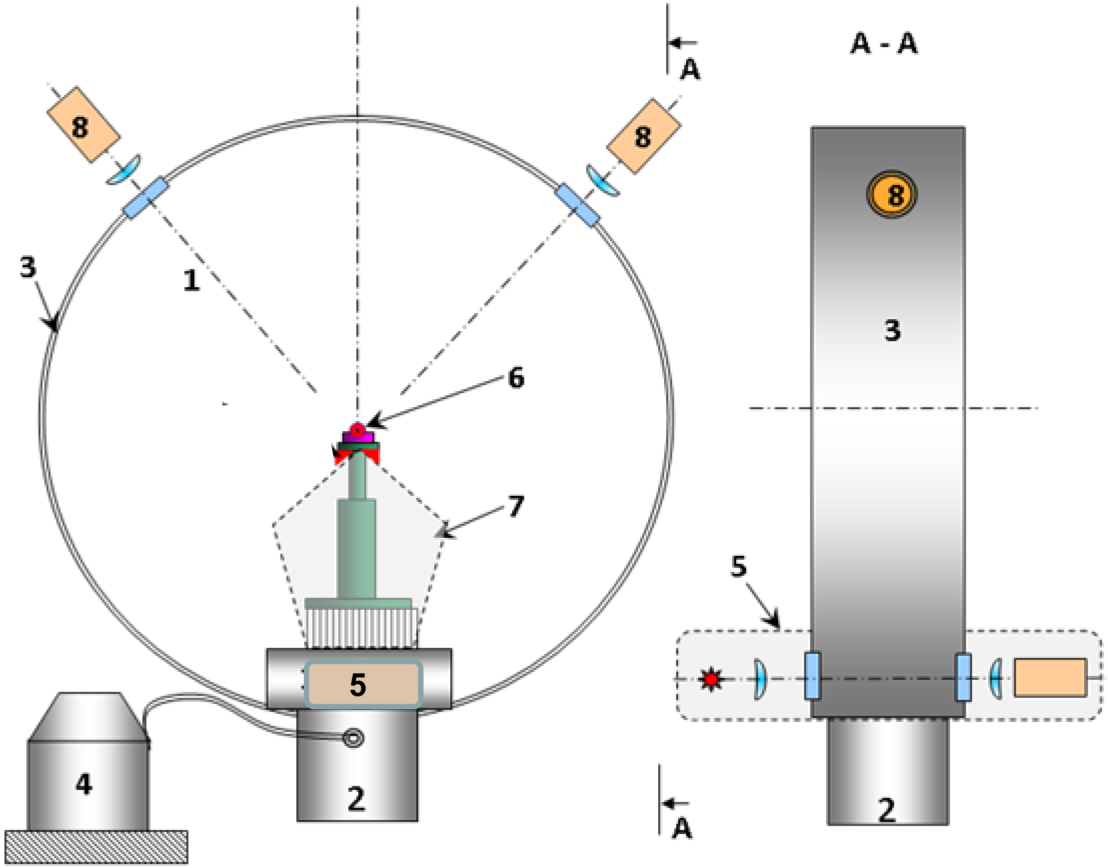
Cryogenic core fabrication just in the irradiation area: traditional method "in situ"

Advantages:

- Risks connected with target delivery are excluded
- Space-saving
- Minimal cost

Disadvantages:

- Rep-rate irradiation is impossible



1 – FAM, 2 – Gateway for target shell loading, 3 – Experimental chamber, 4 – Refrigerating system, 5 – System for target quality control, 6 – Target on the holder, 7 – Target positioning system, 8 – System for target positioning control

THANK YOU FOR YOUR ATTENTION!

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