TARGETS DEVELOPED IN THE 21ST CENTURY AT THE P.N. LEBEDEV PHYSICAL INSTITUTE OF RAS TO STUDY THE EXTREME MATTER PHYSICS USING HIGH-POWER LASER FACILITIES

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EXPERIMENTAL TEAM

STUDY, MAKE AND MEASURE LASER TARGETS: CONDENSED TO GASEOUS, SOLID TO AIR-GEL, DIRECT TO INDIRECT, CRYO- TO SURROGATE, AND MICRO- TO NANOSTRUCTURES

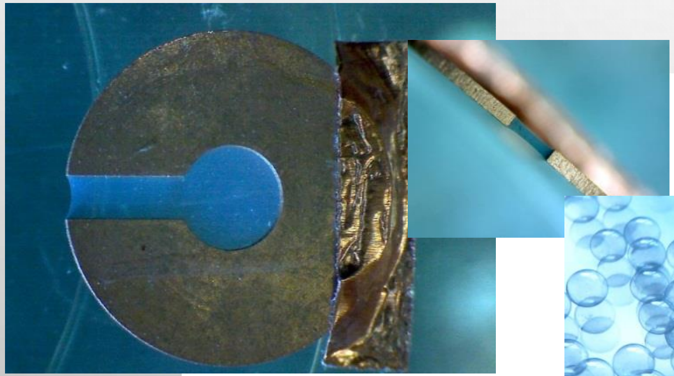
- WHAT IS TARGET MISSION AFTER 60 YEARS OF ICF IDEA AND IN THE ERA OF AI?
- HOW DO WE FEEL AFTER THE NIF RECORDS?
- WHAT ARE OUR TARGET ACHIEVEMENTS?
- LASER SHOT RESULTS WITH OUR SAMPLES?
- OUTSIDE LPI WE MOSTLY STRESS NOW ON THE LASER DRIVEN SOURCES OF MEV PHOTONS AND PARTICLES
- SEPARATE TARGET PARTS ARE DEVELOPED FOR APPLICATIONS BEYOND IFE

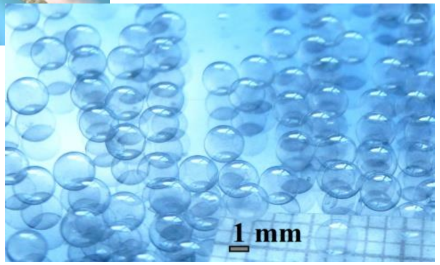
Targets to shoot

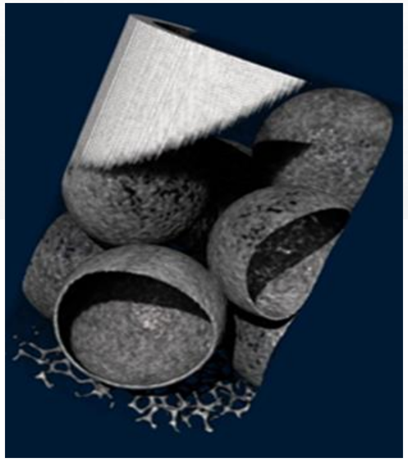
Micro and nanostructured targets, samples with 3 open surfaces.
Air-gels for accelerator-on-the-table.

No-neutrons thermonuclear reaction/
Metal foams in hohl-raum of indirect ICF, slow ions, converter to X-rays

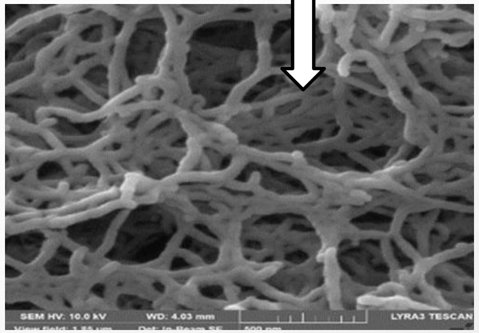
Surrogate targets (D)
Fuel containers and (sacrificed)

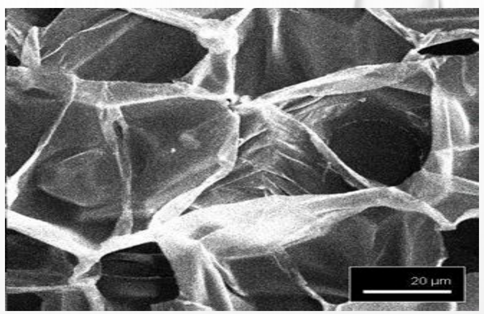




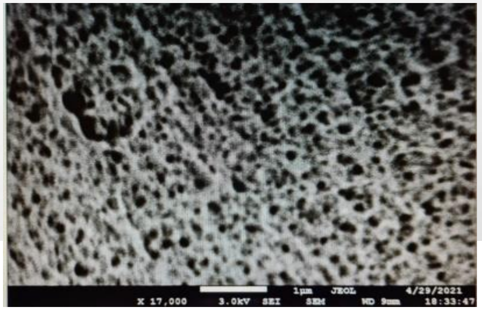


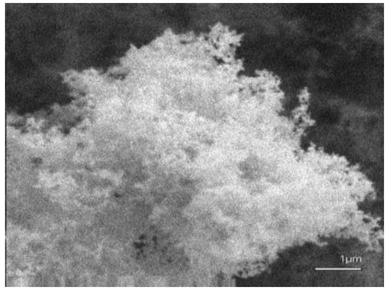
30-мкм pores
350-нм pores





Ag in CHO (SEM)
40-нм pores





Au-foam

SiO2

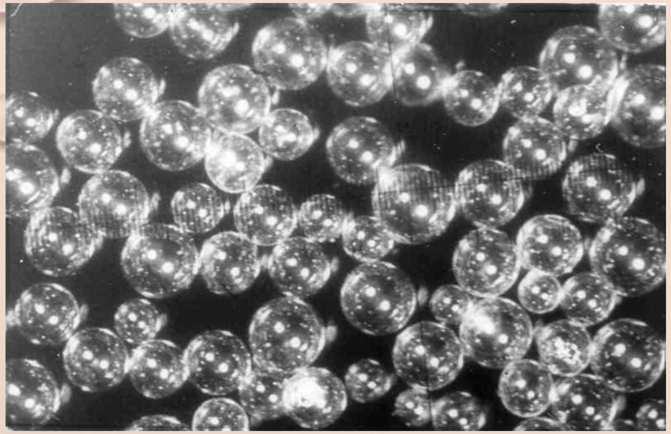
All these were in the laser experiments, in particular: of HiPER, FAIR, LaserLab, RFBR, DST-RAS programs, NC of Phisics and Math and others. The targets demonstrate new phenomena and stability of characteristics

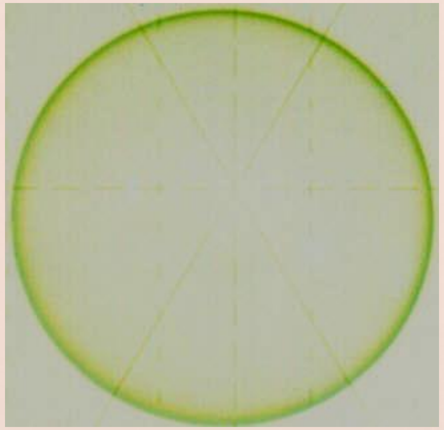
SPHERICAL SHELLS

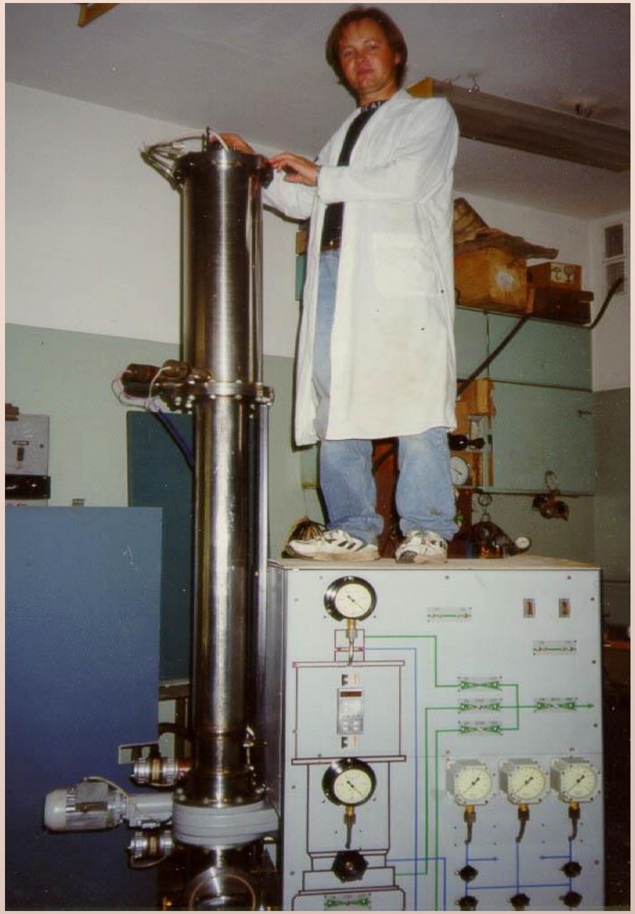
THERMONUCLEAR RESEARCH, H2-CONTAINERS, SACRIFICE SHELLS

FURNACES FOR POLYSTYRENE MICROSHELLS PRODUCTION

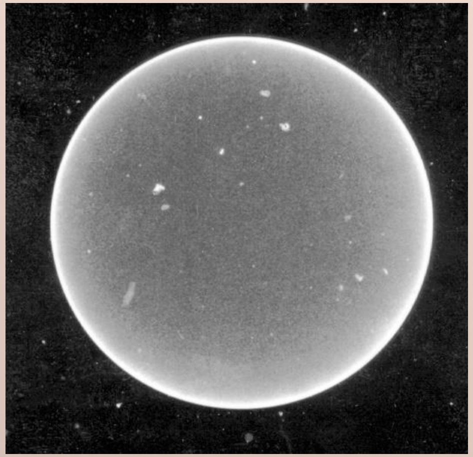
First shells from polystyrene, 1974

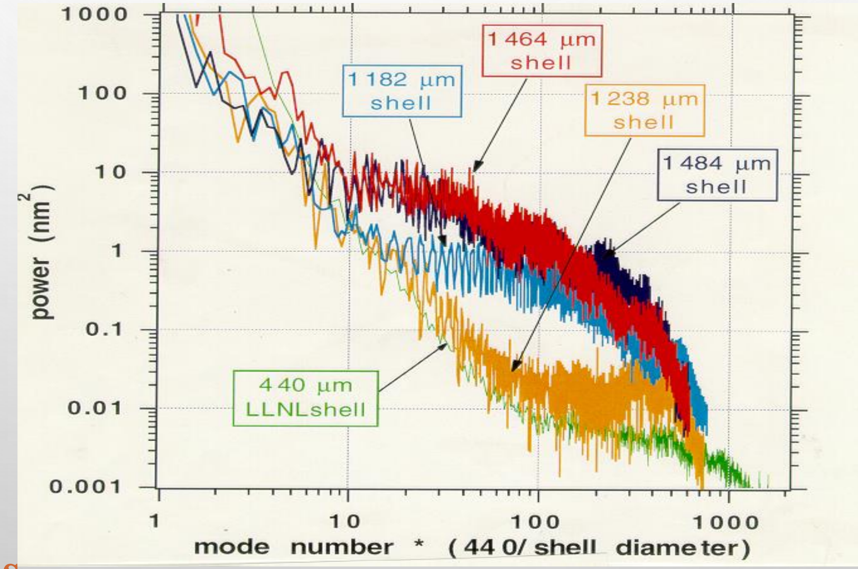






Quality of our polymer shells inspected in LLNL



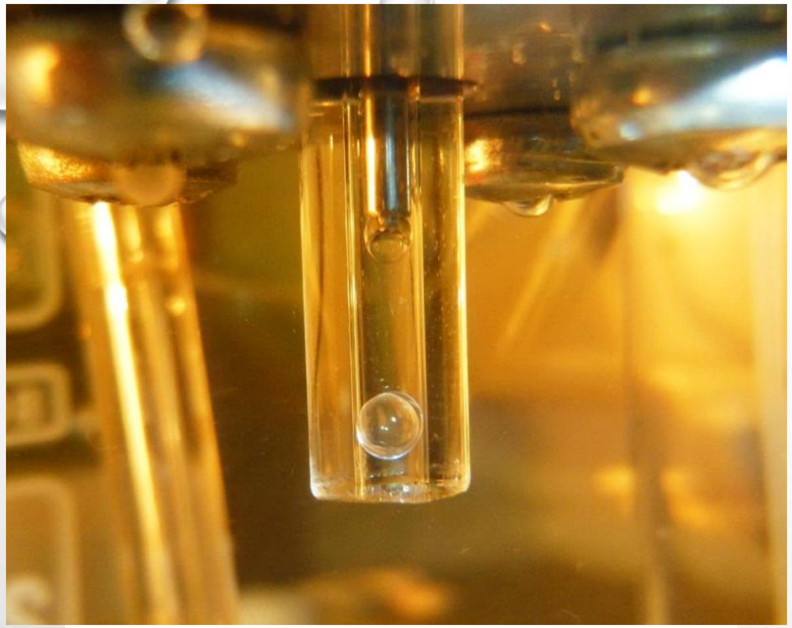


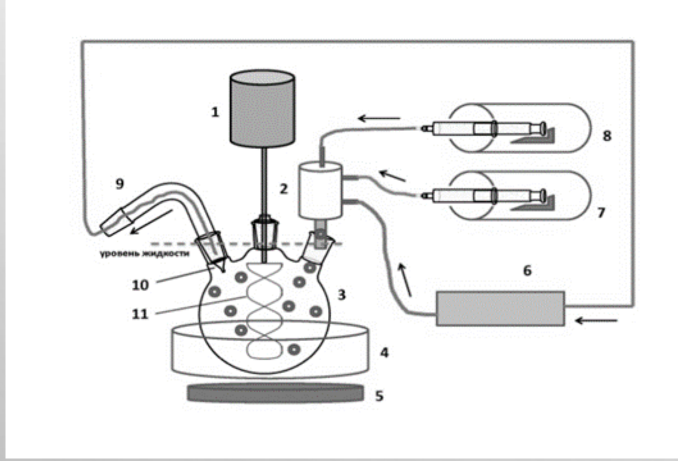
LLNL. X-ray picture of our polystyrene shells. Ø1.48 mm and thickness 9.2 microns. Dust on surface after flight from Moscow to San Francisco.

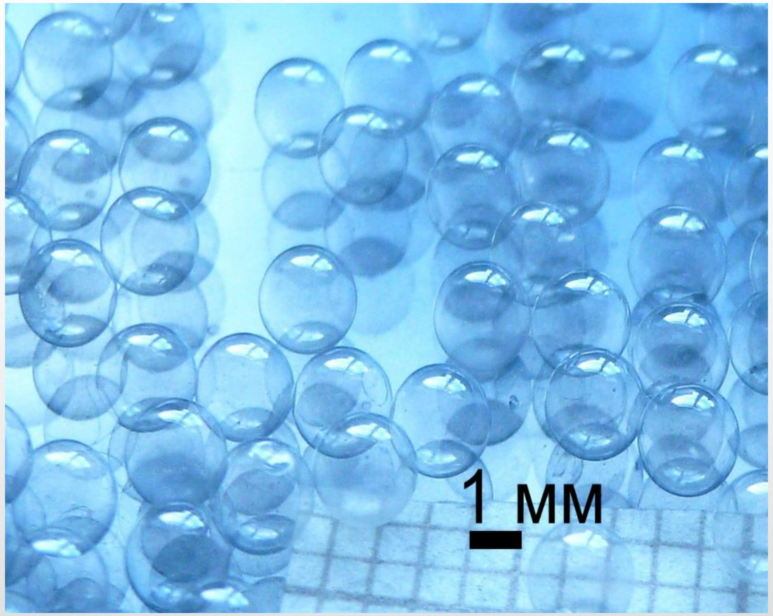
Roughness of outer surface of polystyrene shells. High modes because of dust. AFM

Drop tower furnace for China

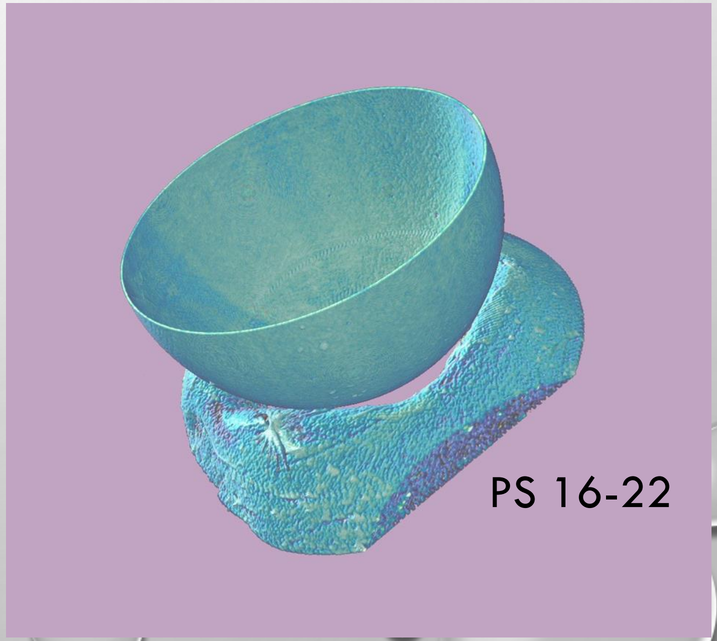
LPI-MADE DROP GENERATOR, A BATCH OF MICROSHELLS BY ENCAPSULATION AND X-RAY MICROTOMOGRAPHY SHELL RECONSTRUCTION







PAMS

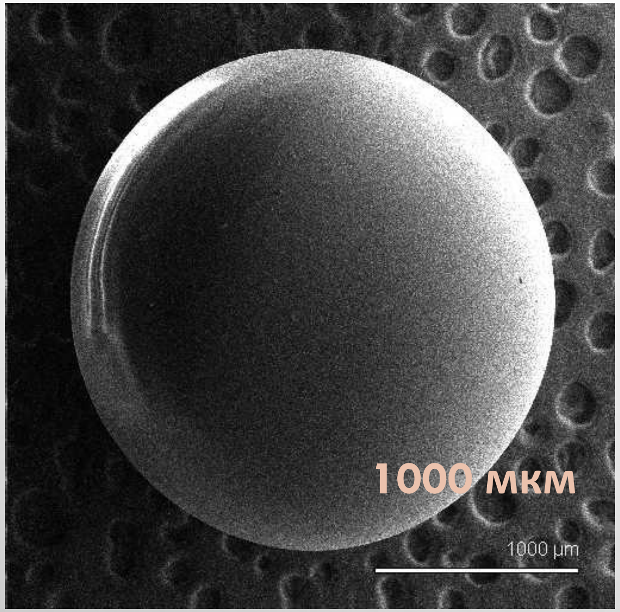


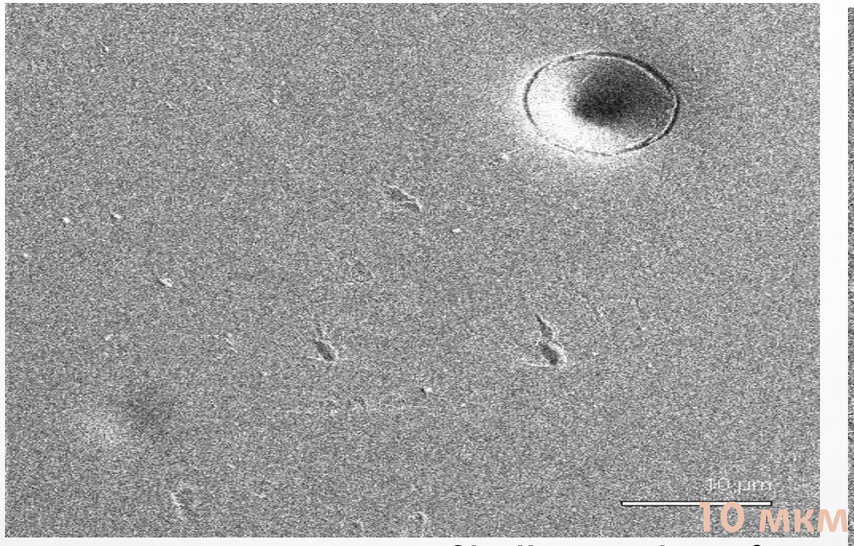
PS 16-22

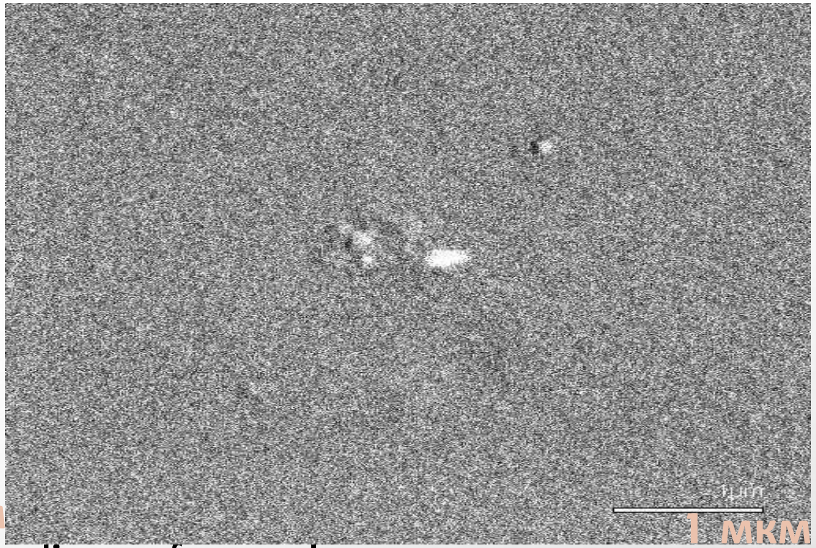
А.В. Пастухов, и др., Установка для получения полимерных микрокапсул сферической формы, Бюллетень изобретений, 13, RU 203 963 U1 (2021) Russian Bulletine of Inventions

SEM MEASUREMENT AND ELEMENTAL ANALYSIS OF THE SHELL

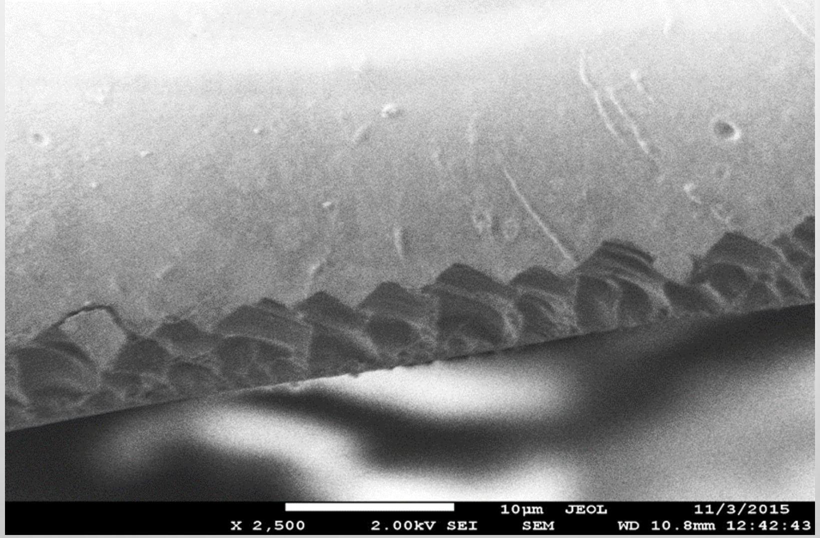
SHELL BATCH 28-1; GOLD DECORATED ~100 Å

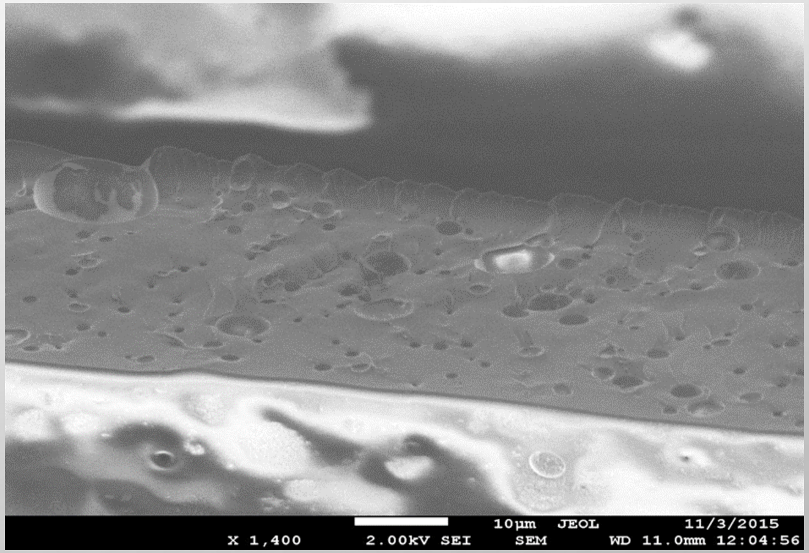






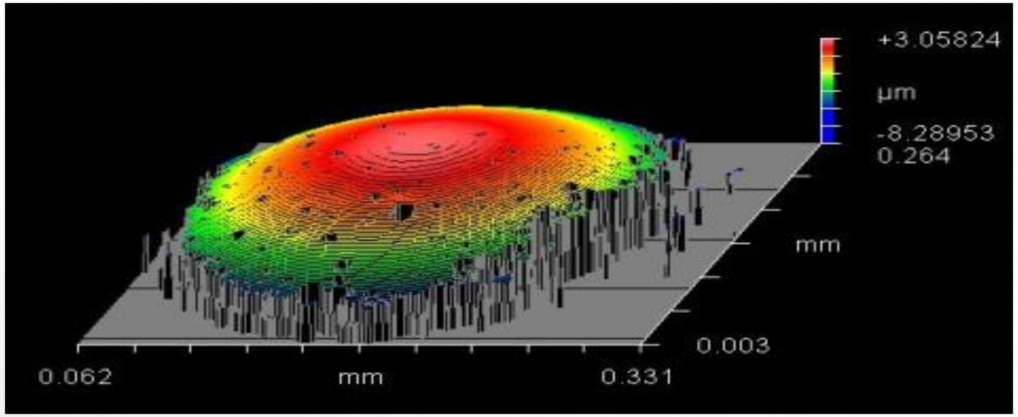
Shell smooth surface relieve of vacuoles

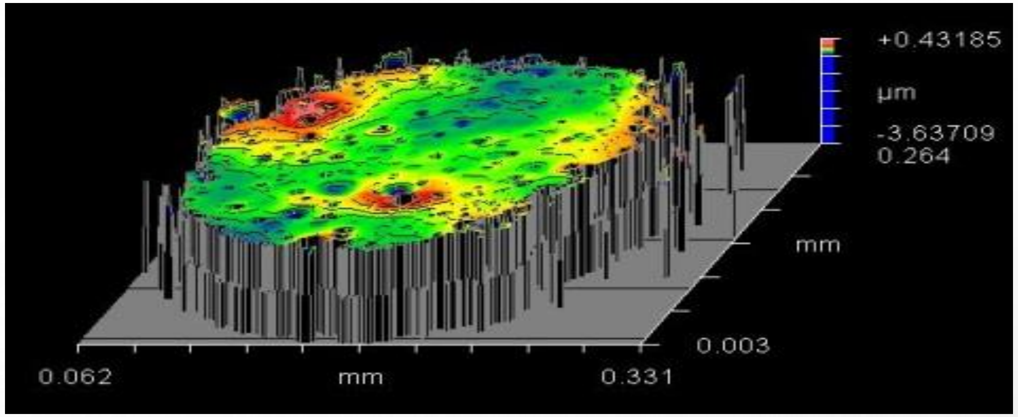


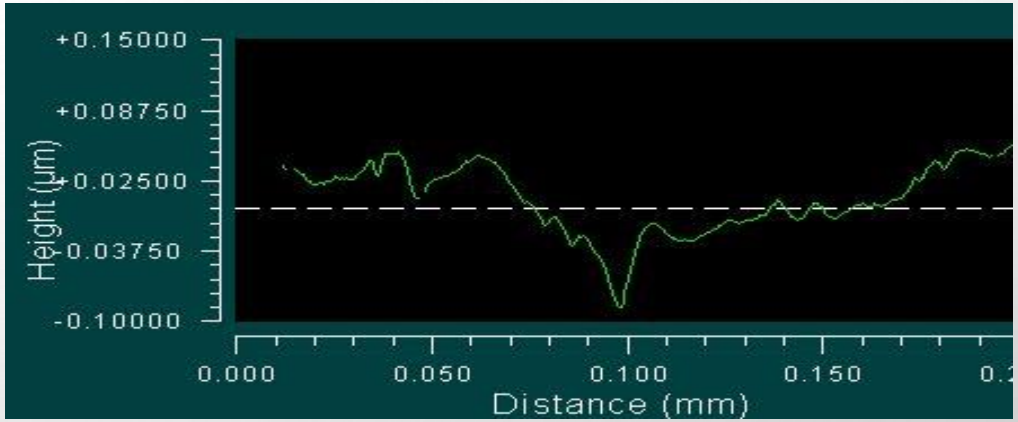


Shell cross-section. Left: inner material structure typical for polymers. Right: bubbles in the depth of polymer. No bubbles on the *surface*, solid layer of 2-5 micron there. NO GOLD

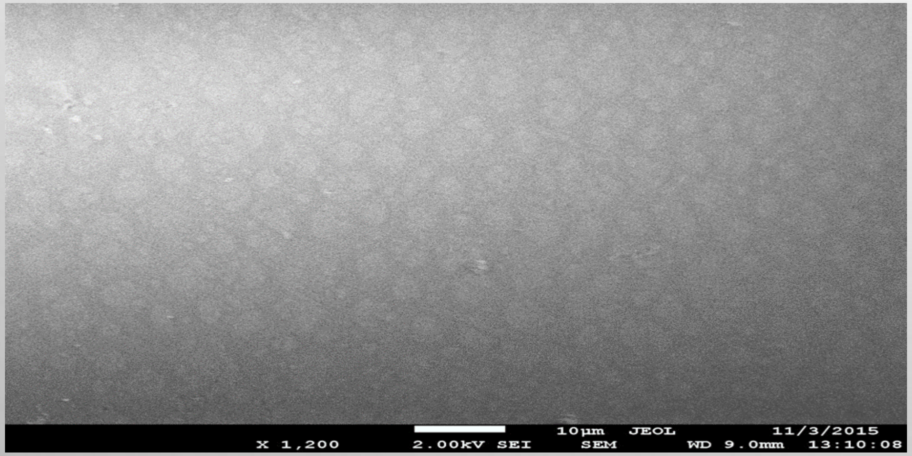
OPTICAL WHITE LIGHT INTERFEROMETER – PROFILOMETER ZYGO NEWVIEW 6800 OBJECTIVE 10X







Up: Scanned directly shell surface.
Right: same surface with sphere subtracted.
RMS = 37 nm, PV (vertical spread) = 0.2 micron
Bottom: SEM of the outer surface, no gold



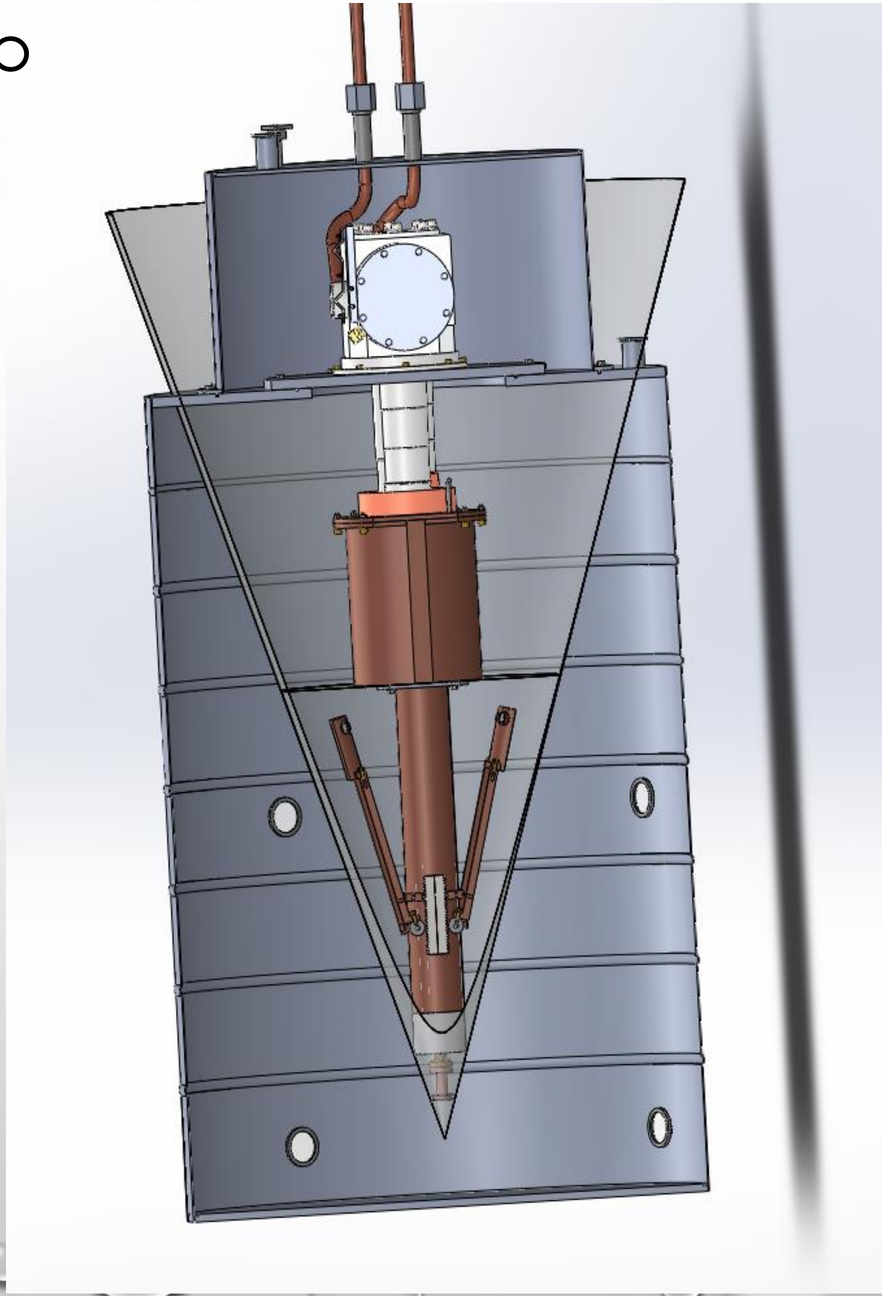
SPHERICAL TARGET FINAL STAGE OF THE LIFE-CYCLE

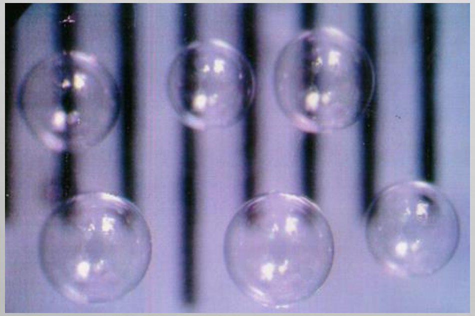
THERMONUCLEAR RESEARCH, FUEL FILLING AND CONDENSATION, EXPOSURE TO THE FOCUSED LASER BEAM, IMPLOSION AND BURN

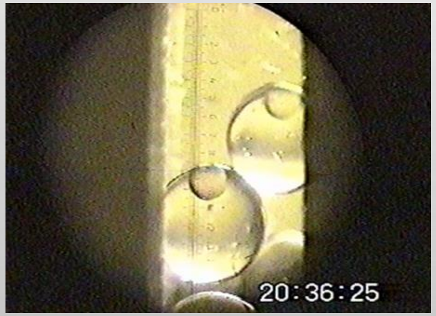
LPI DEVELOPED CRYOGENIC FUEL TARGET FORMATION AND EXPOSURE MODULE FOR MJ - CLASS LASER FACILITY

PROTECTIVE SHROUD IS SHOWN OPEN ON THE MODULE AS WHEN DT-FUEL IS FILLED IN THE TARGET, DELIVERED IN THE CENTER OF THE CHAMBER, KEPT COLD AND STABILIZED DURING THE BEAM FOCUSING AND FINALLY OPENED FOR EXPOSURE.

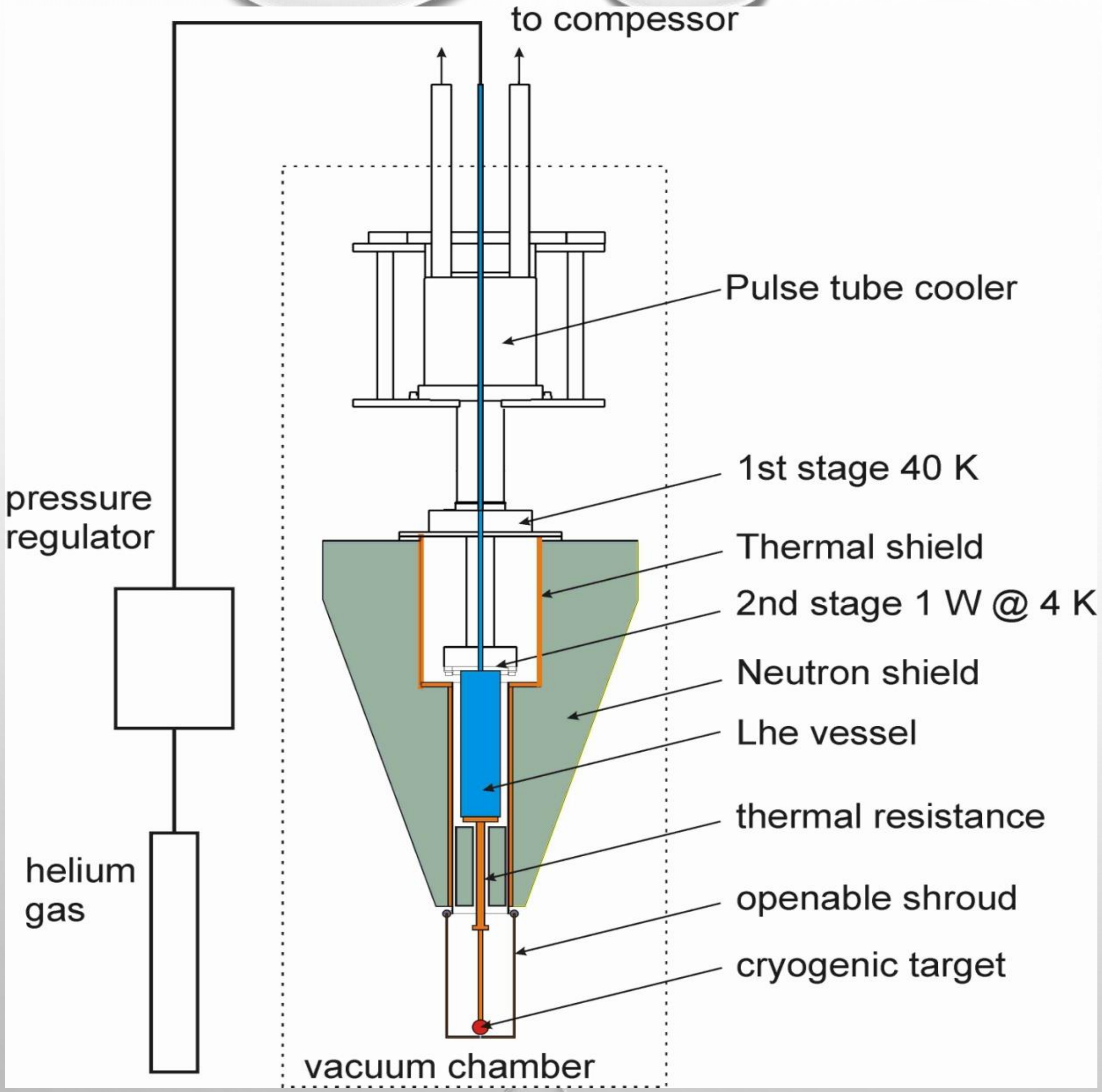
CRYO







Cryogenic setup for MJ class laser targets



Experimental Setup:

- Heater and controller to maintain the target's temperature

-Total weight of cryostat <70 kg

-operation mode is 3 minutes off and 15 min on

- 0.25 W of cooling on the target assembly

- Cooling / heating rate 1 mK – 3 K per minute

- Temperature stability ~1 mK

LOW-DENSITY MATERIALS AND TARGETS

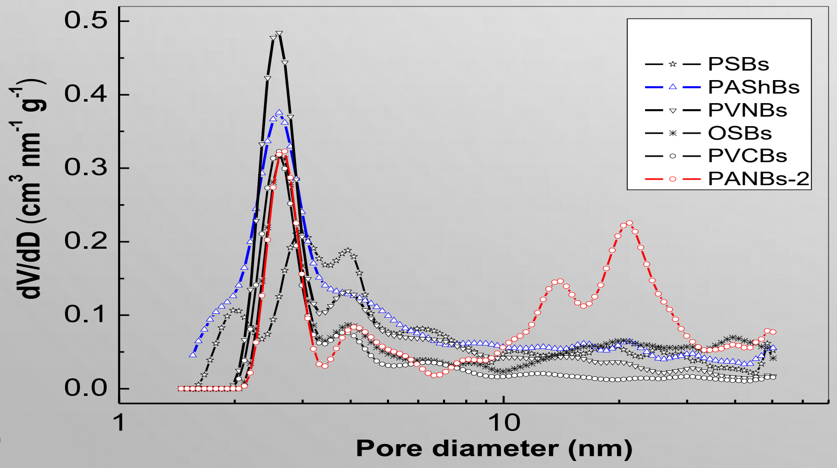
THERMONUCLEAR RESEARCH, SECONDARY PLASMA SOURCES OF PARTICLES, FUEL PREHEAT PREVENTION

Low-density supercrosslinked polymers and their pore structure studies

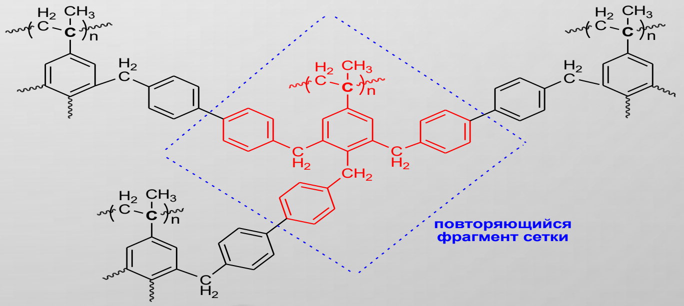
A range of synthesized and commercial polymers were tested and demonstrated the possibility to form polymer networks by crosslinking with the help of bischloromethyl benzene and diphenyl derivatives. Low-density air-gels could be formed then.

The initial polymer	Pore surface, м^2/г	Pore volume (P/Po=0.98), cм^3/г	Density, mg/cм^3
PS	1340	2.5	100
PAMS	1400	3.3	100
oliegomethylfenylsilocsan	900	3.0	150
poly-9-vinilcarbazol	670	1.2	60
poly-2-vinilnaftalene	1140	2.0	90
polyacenaftlene	1770	5.5	170

Cylinder blocks (in PE envelope)
In acetone, D=4 и 7mm, L=11 и 17 mm

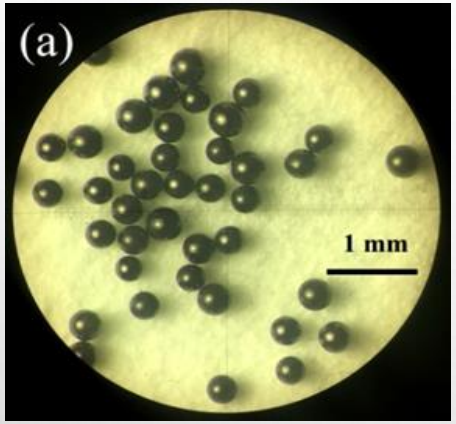


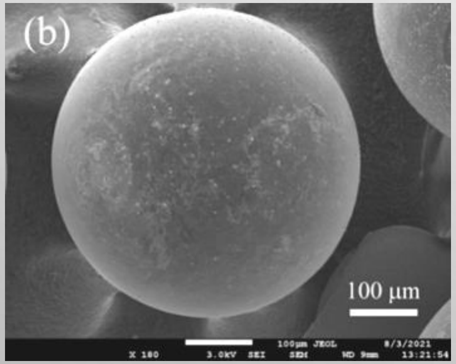
Pore size distribution

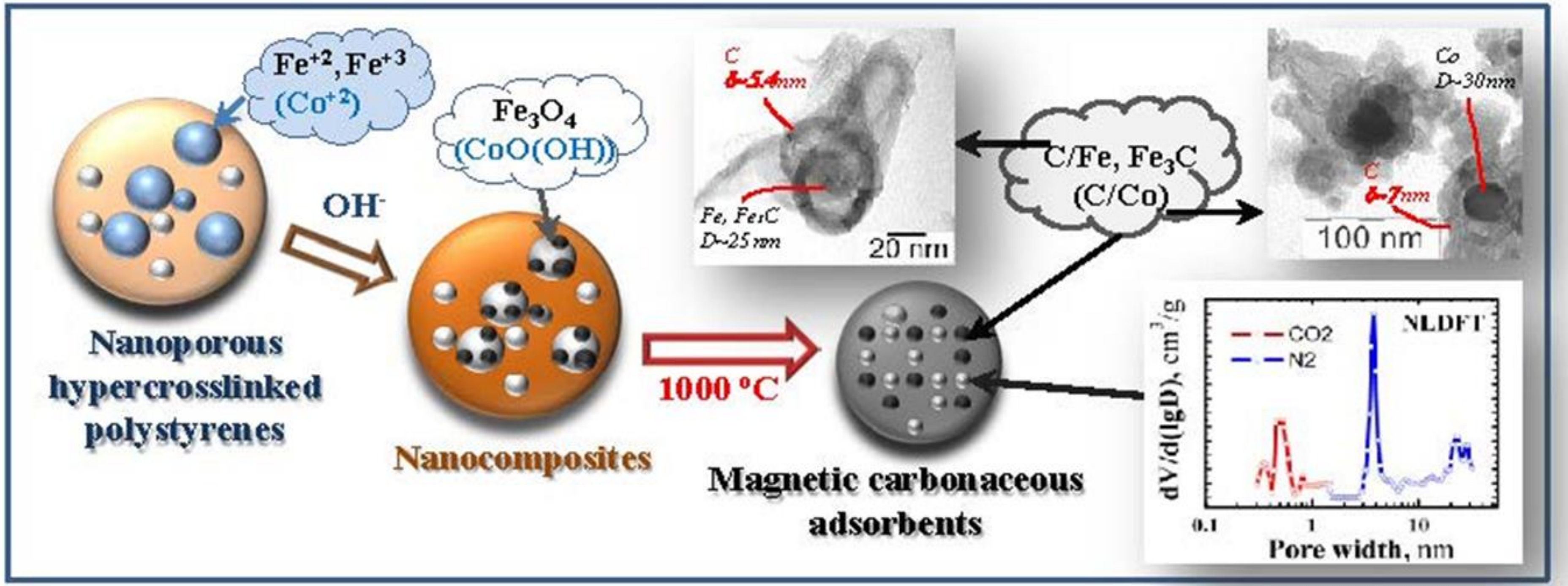


PAMS structure

MAGNETIC CARBON COMPOSITES WITH NANODISPERSED METALS AS A MODEL TO WORK WITH HEAVY ADMIXTURES IN HYPER-CROSSLINKED POLYMERS AND AS POTENTIAL TARGETS

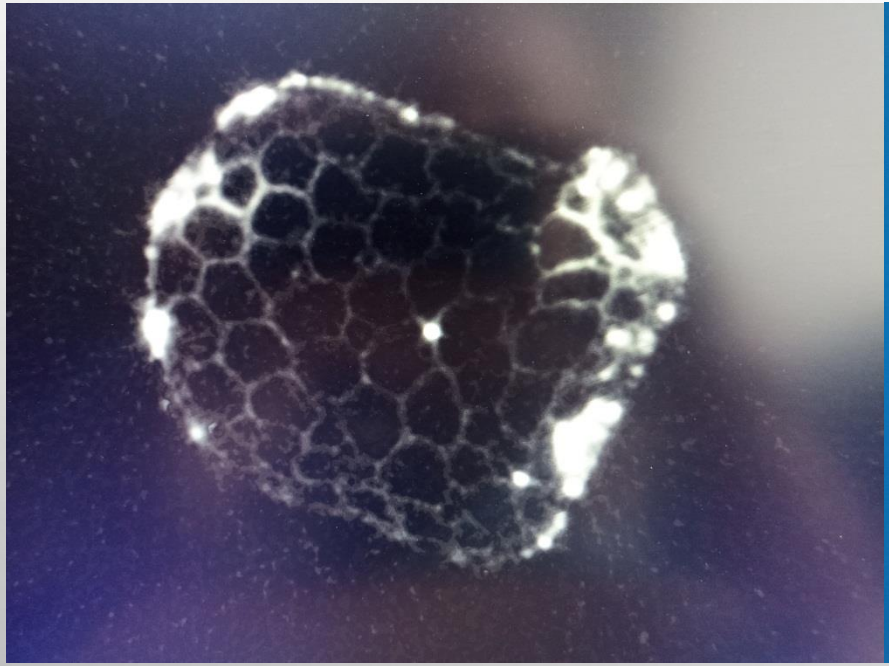


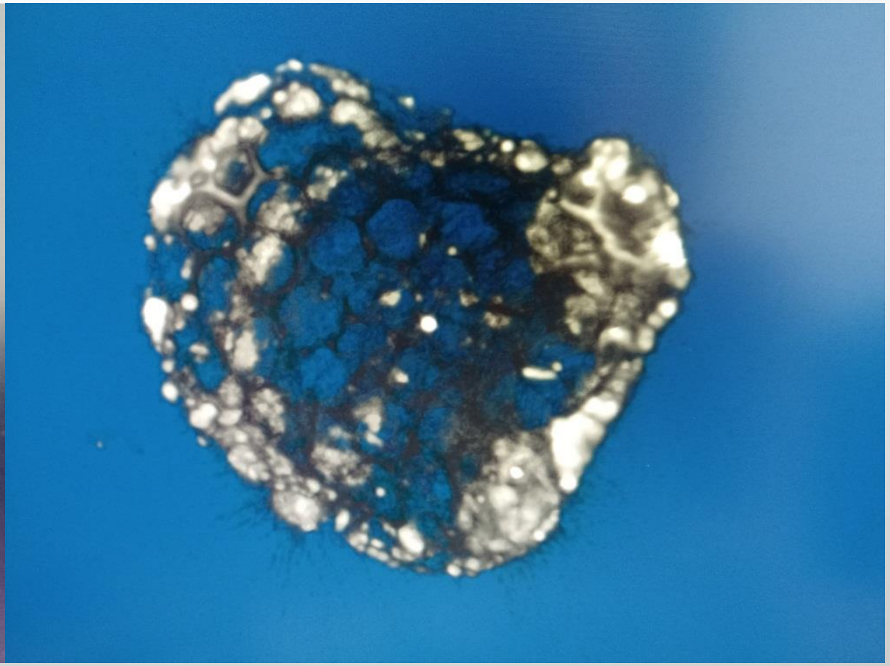




Co 11-18% mass in carbon, metal clusters enveloped in grafen layers. Pore sizes 150 – 200 м2/g
Saturation magnetization is15 - 23 Ga cc/g

MATERIALS AND SAMPLES:
CROSSLINKED CHITOZANE WITH RECOVERED SILVER IN THE POLYMER NETWORK. PORES ARE 200 MICRON LARGE. NEOSCAN N80



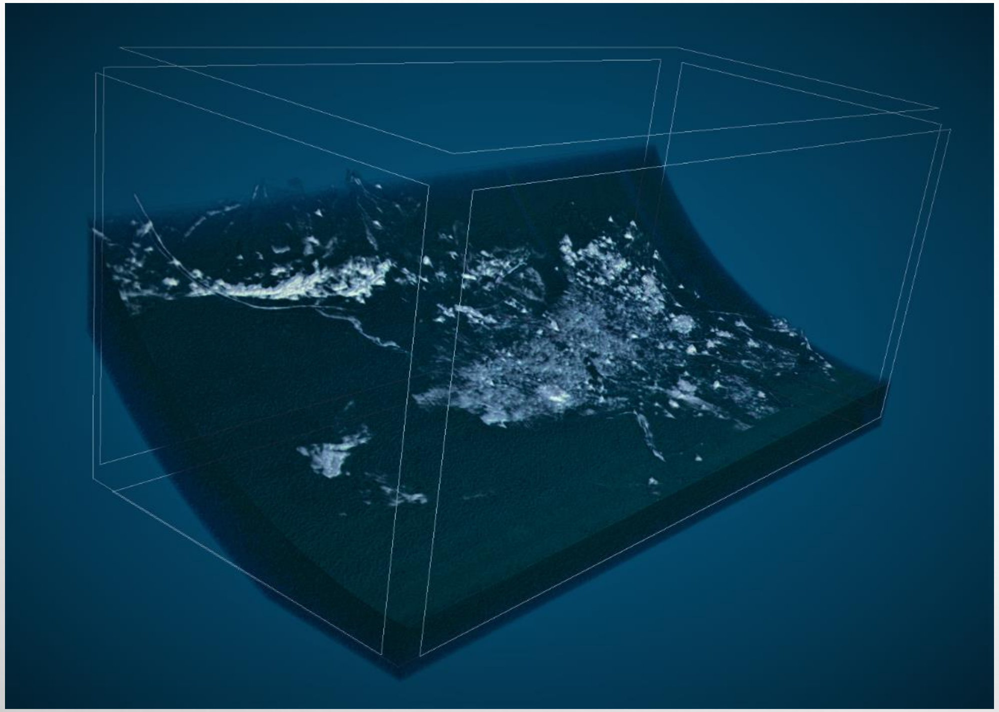


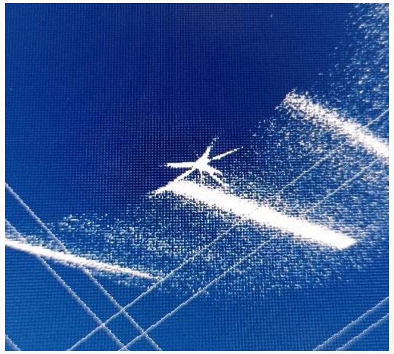
NEOSCAN N80

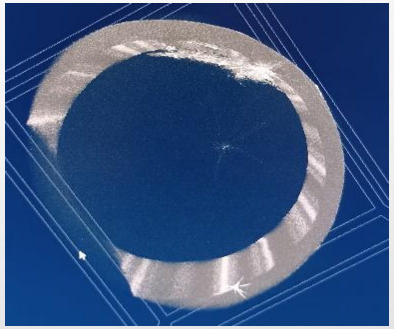
- PIXEL SIZE – SMALLER THAN 0.5 MM (CCD) / 1 MM (FLAT-PANEL), LOW-CONTRAST RESOLUTION (>10% MTF) – 2 MM
- SCANNING VOLUME – UP TO 100 MM IN DIAMETER
- MAXIMUM SCANNING LENGTH – 130 MM (CCD) / 150 MM (FLAT-PANEL)
- X-RAY SOURCE – 20…110 KV, 16W, W TARGET
- AUTOMATIC FILTER CHANGER – 20 POSITIONS: NO FILTER, AL 0.25 MM, AL 0.5 MM, AL 1.0 MM, CU 0.1MM, CU 0.25MM, CU 0.5MM, CU 1MM AND 12 POSITIONS FOR USER DEFINED FILTERS
- X-RAY DETECTOR – COOLED 16 MP CCD OR 7MP ACTIVE CMOS FLAT-PANEL
- SOFTWARE PACKAGE – SCANNER CONTROL, RECONSTRUCTION, VISUALIZATION
- RADIATION SAFETY - < 1 MSV/H AT ANY PLACE OF INSTRUMENT SURFACE

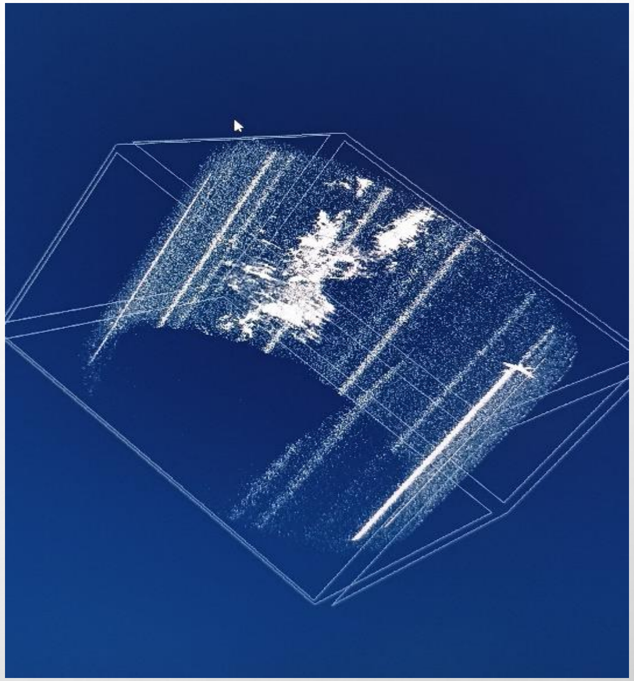
3D SCANNING AND RECONSTRUCTION OF THE PREHISTORICAL FRAGMENT IN THE TUBE, NO CONTRAST

<u>Neoscan N80</u>









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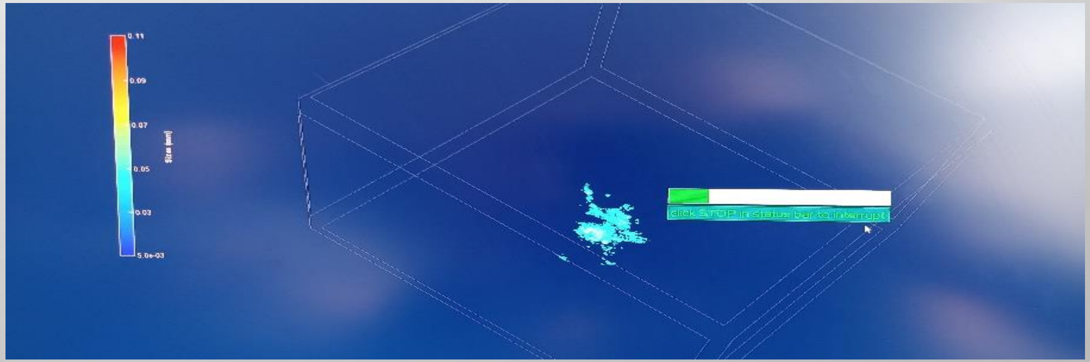
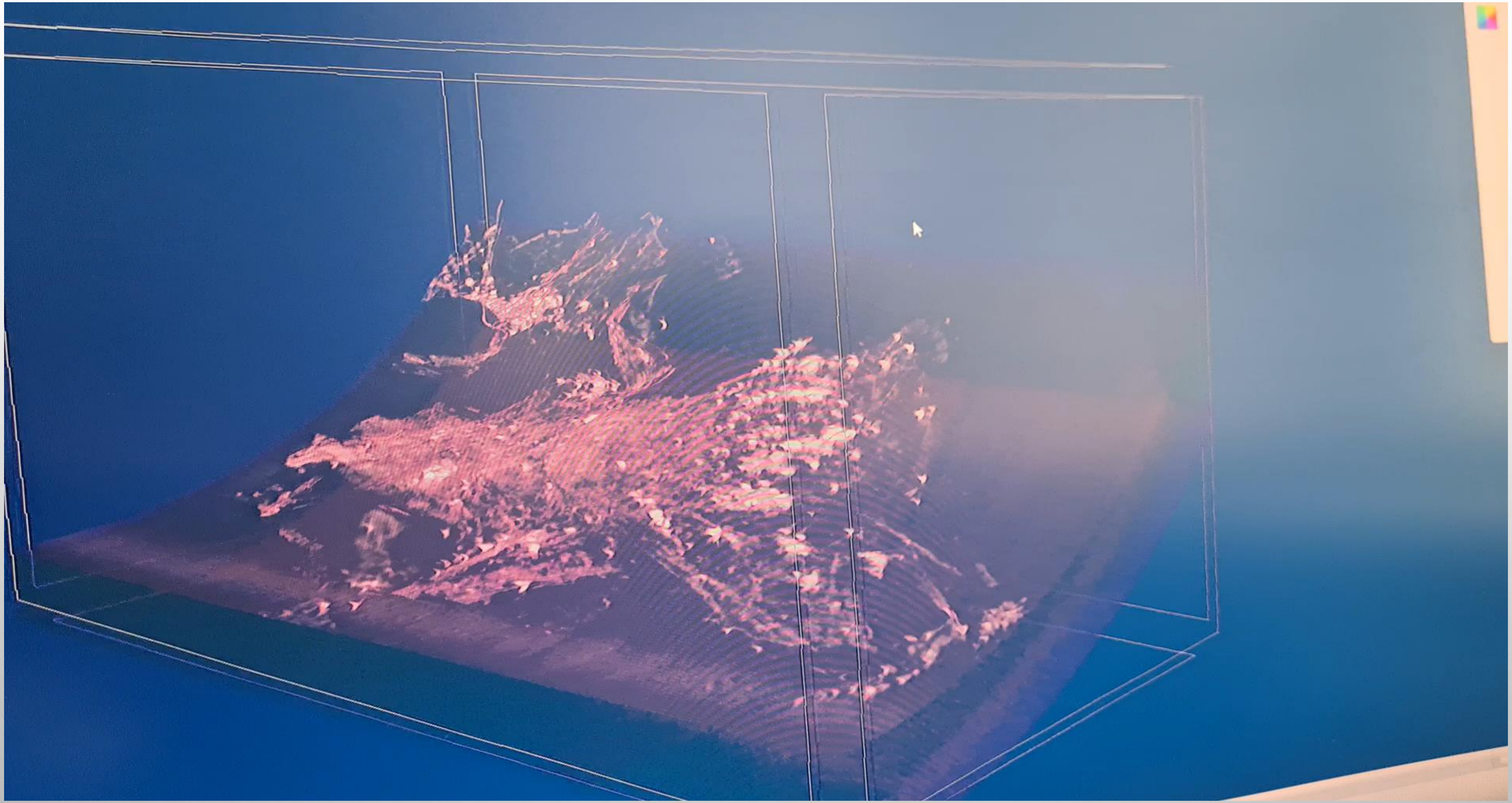
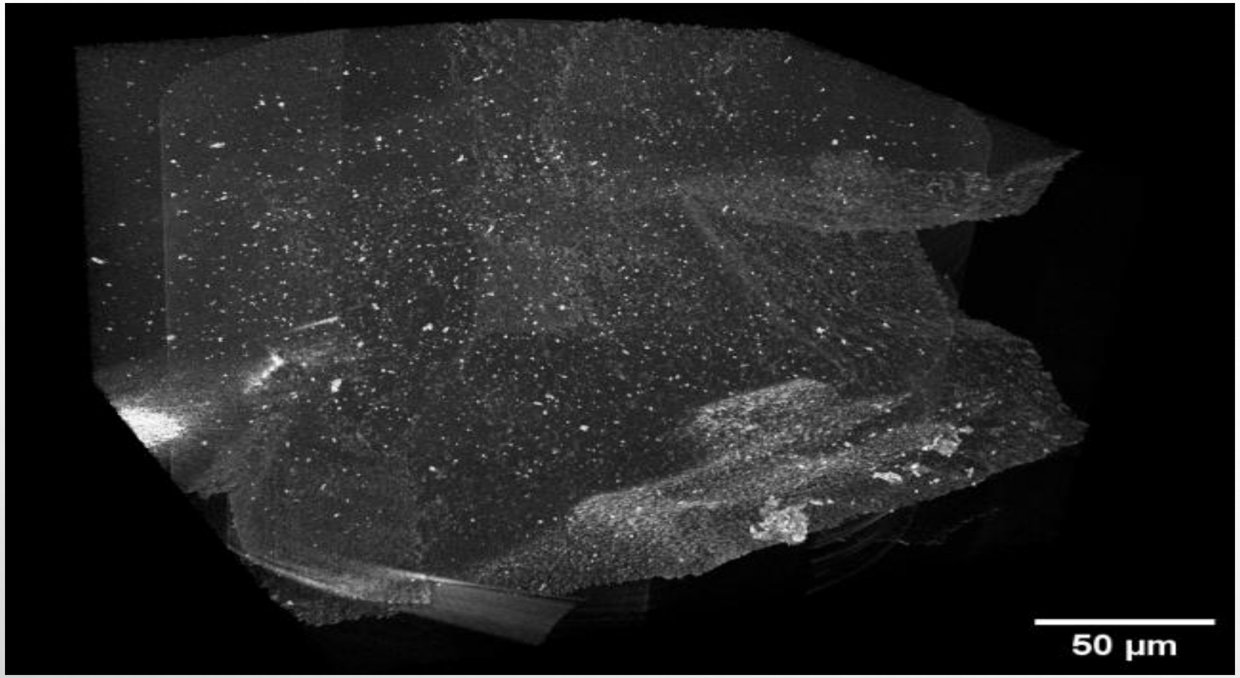


3D VISUALIZATION WITH A FRAGMENT OF STANDARD EPENDORF TUBE



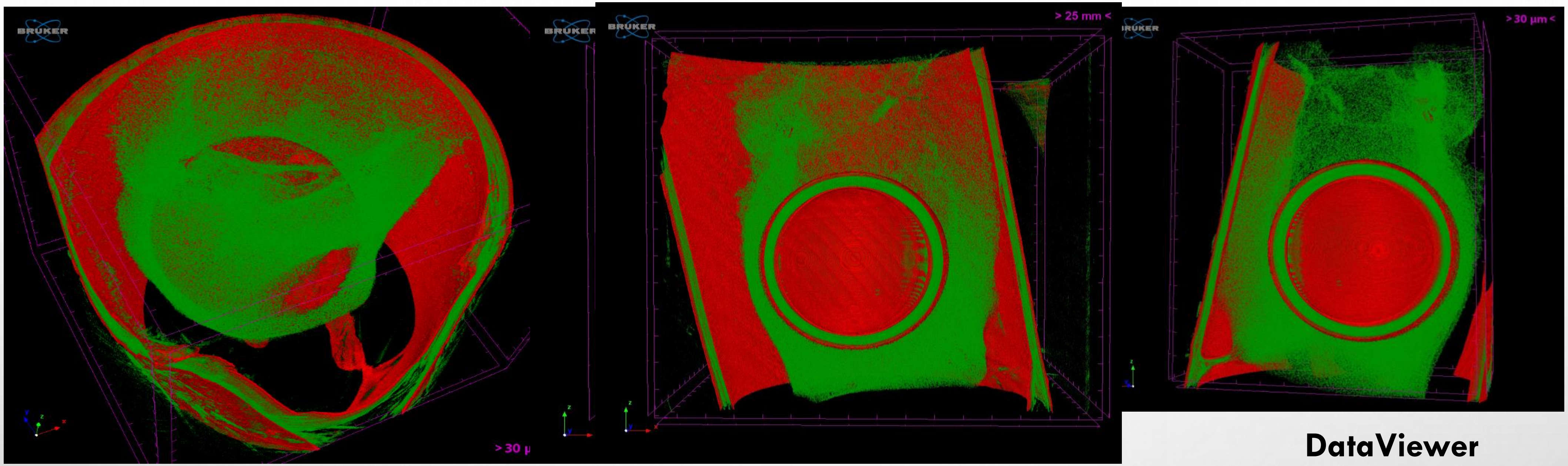
SYNCROTRON MICROTOMOGRAPHY



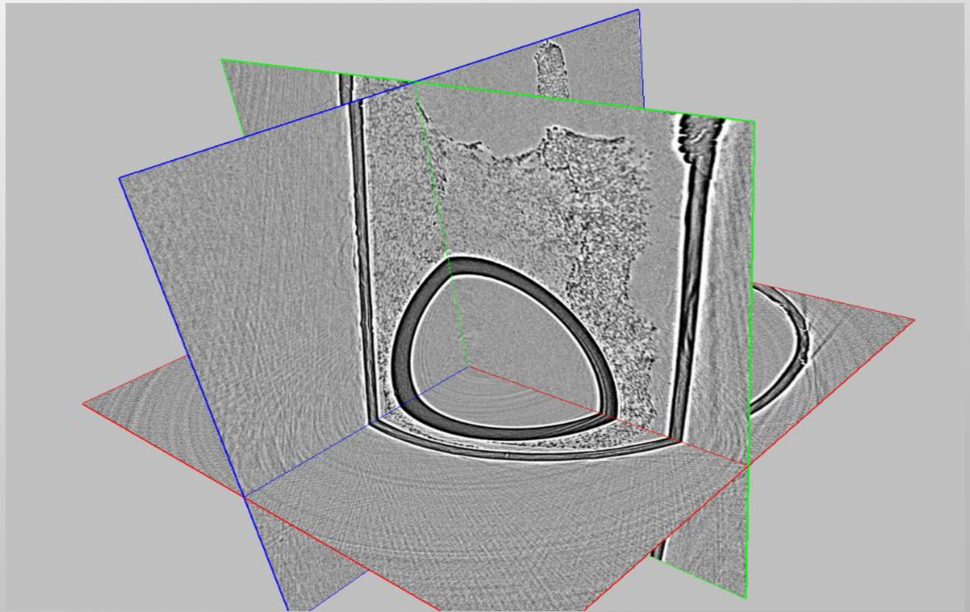
Experiment: chanal P015, synchrotron radiation (PETRA III, Germany), photon energy 12 кeV, pixel 0,325 micron
Sample: CHO-airgel (Nazarov) with Au recovered from $AuCl_3$ (Borisenko)

Artyukov, I.; Borisenko, N.; Burenkov, G.; Eriskin, A.; Polikarpov, M.; Vinogradov, A. X-ray 3D Imaging of Low-Density Laser-Target Materials. Photonics 2023, 10, 875.

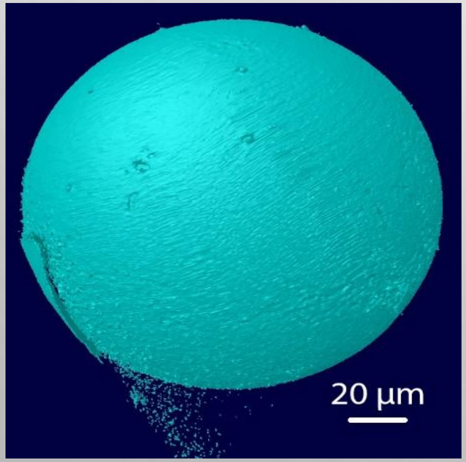
MICROTOMOGRAPHY PETRA III (COLORED)

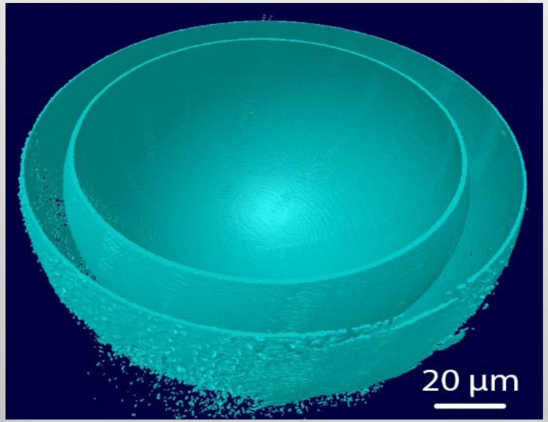


DataViewer

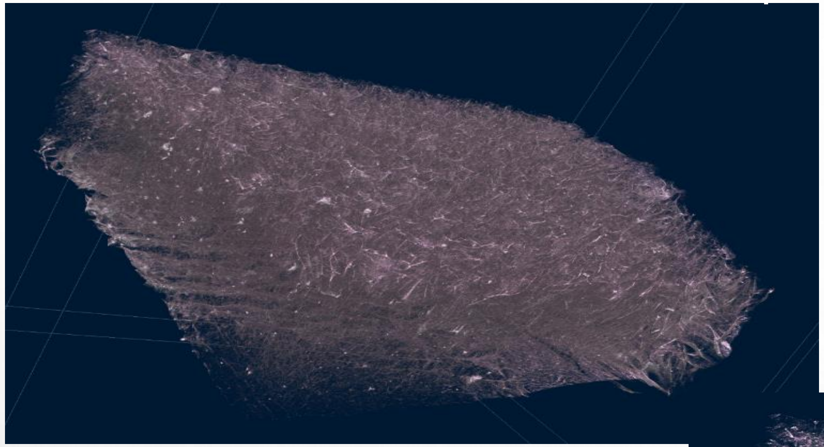


CT_VOX





CHITOSAN 138-2 WC (+AG) - FLAT LAYERS, LARGE PORES (1-10 MICRON), COMPOSITE OF CROSS-LINKED CHITOSAN WITH SUBMICRON AG-PARTICLES (8 - 18 MASS. %)



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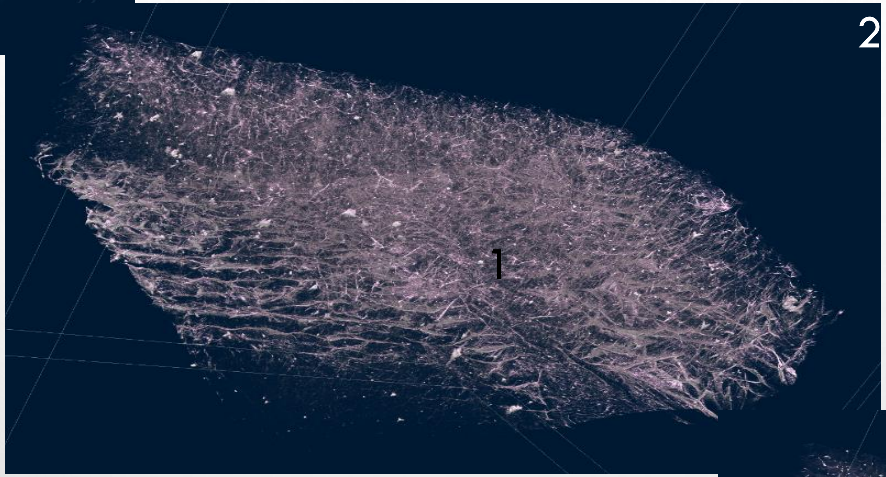

2

2

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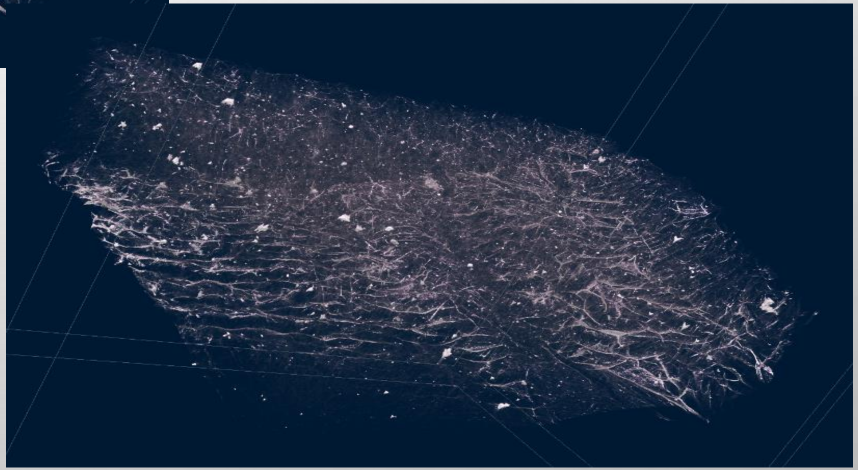
3



3

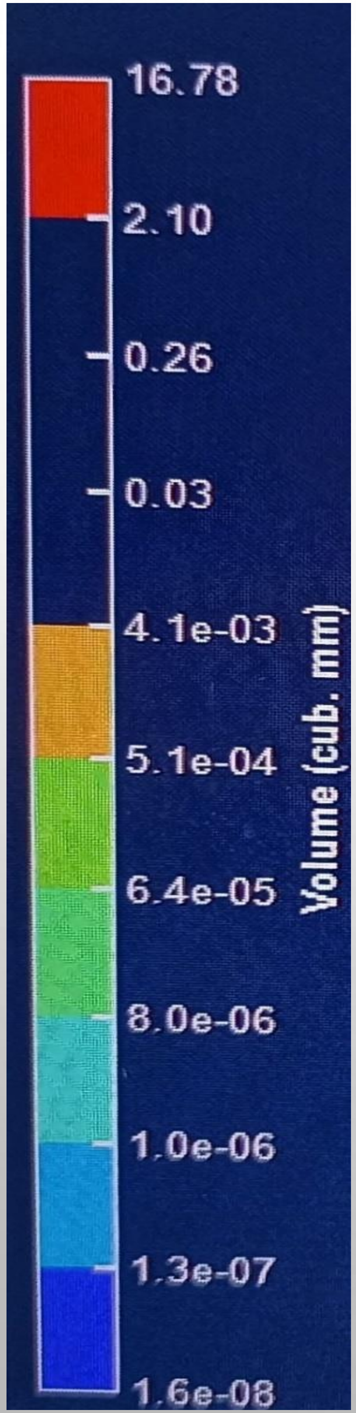
1. VOLUME UNIFORMITY

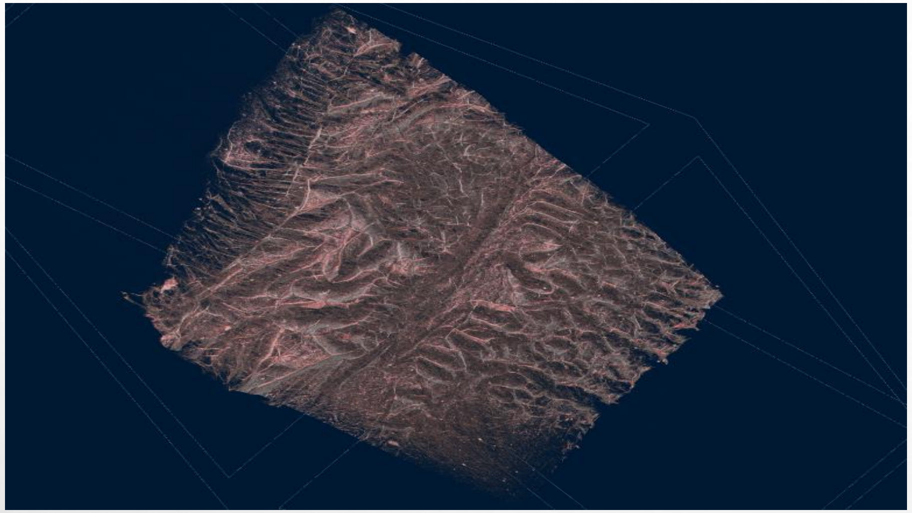
2. PORE STRUCTURE

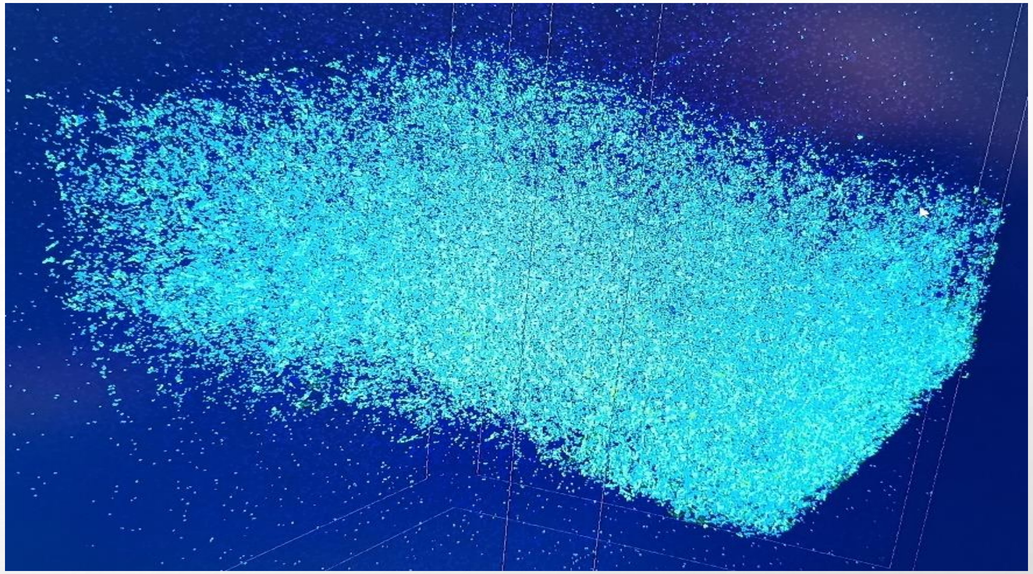
3. HEAVY METAL DISTRIBUTION

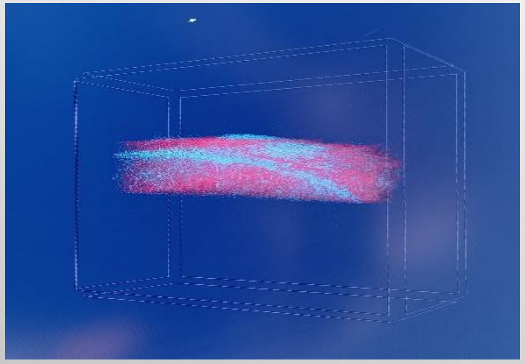
DIFFERENT VISUALIZATIONS NEOSCAN N80, LPI.

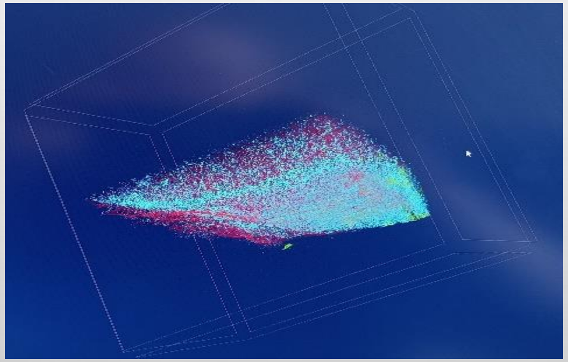
Particle analysis in chitosan foam with Ag-clusters (cub.mm)

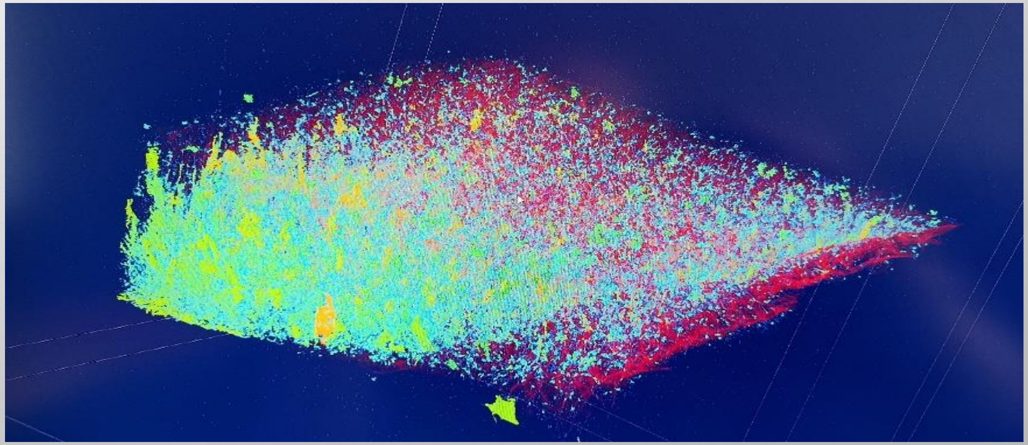




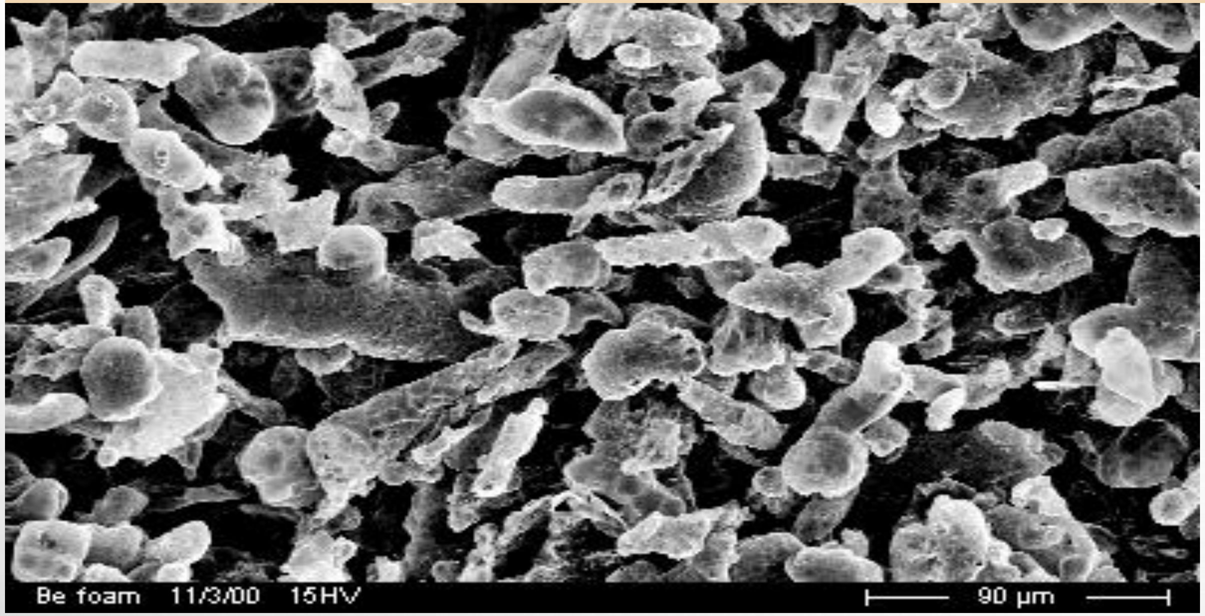


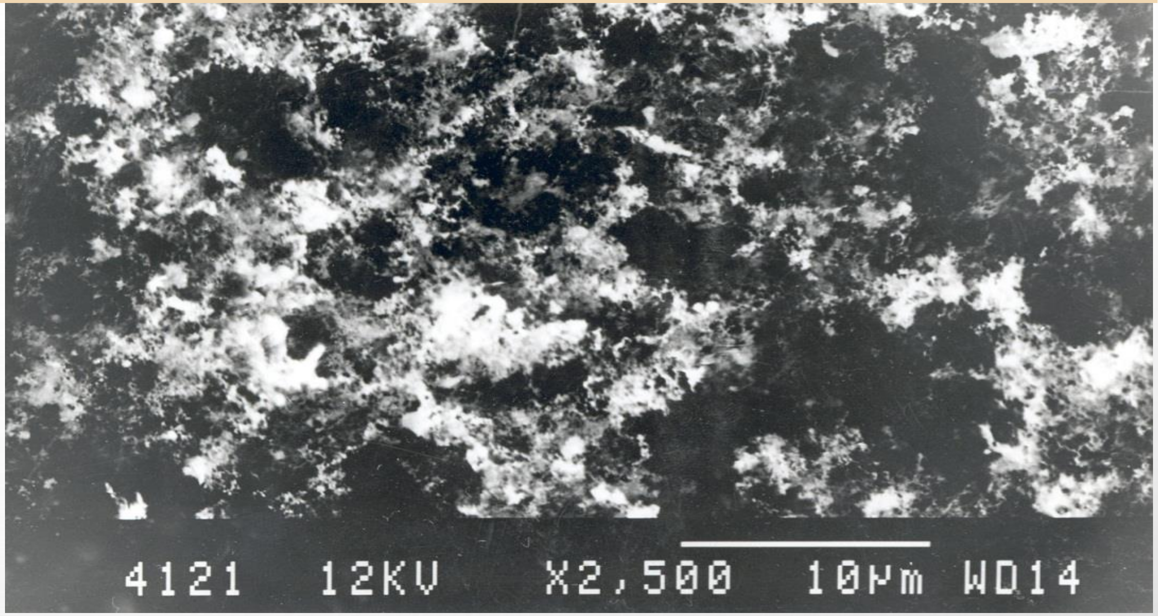






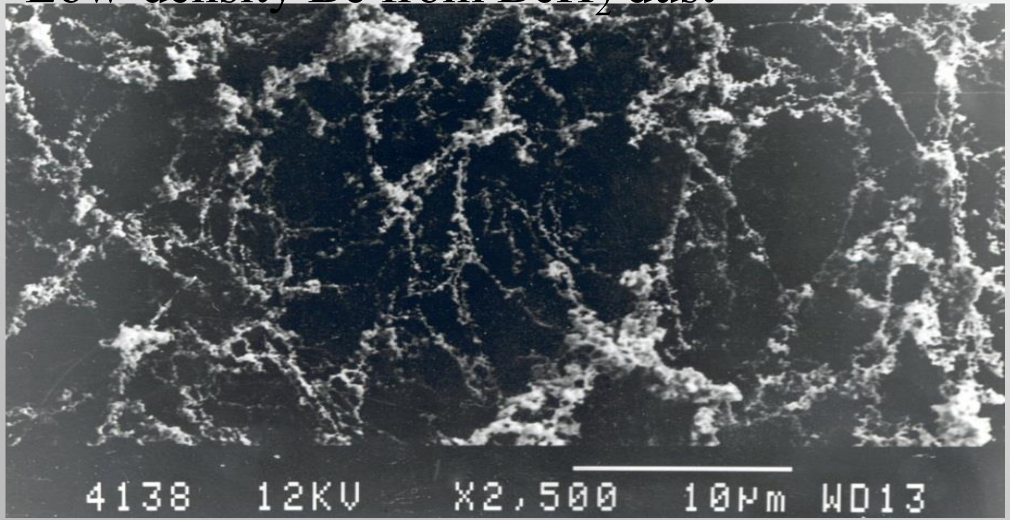
METAL FOAMS FOR LASER IRRADIATION EXPERIMENTS

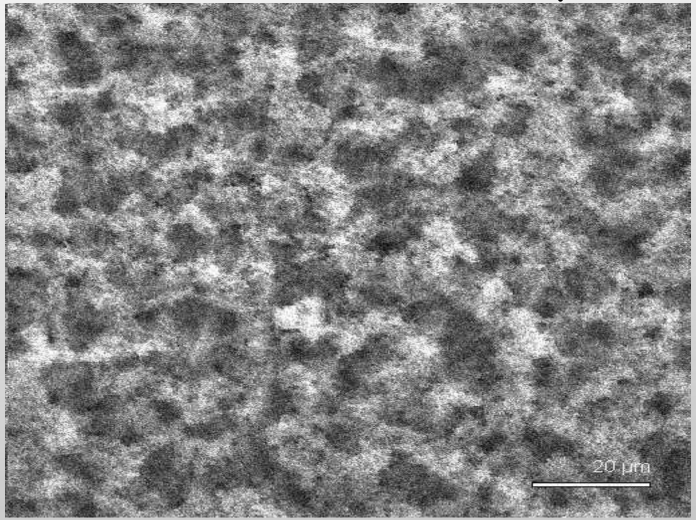


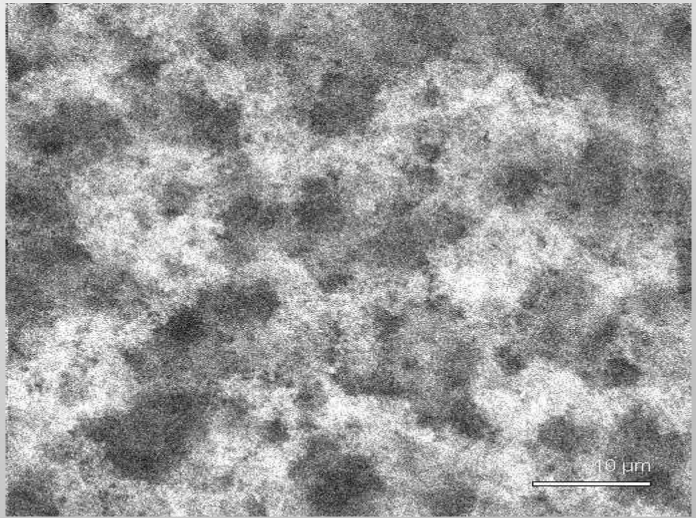


Low-density **Be** from BeH_2 dust

Cu scale – 10 µm



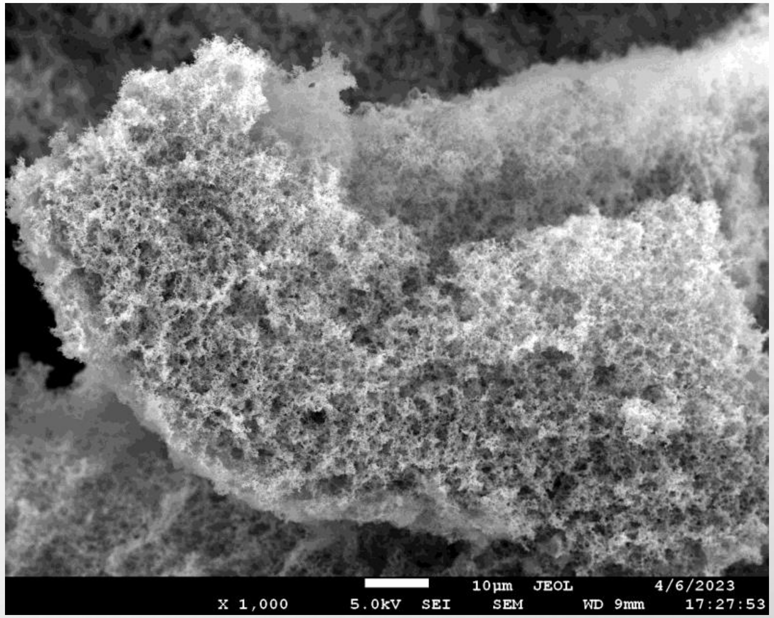


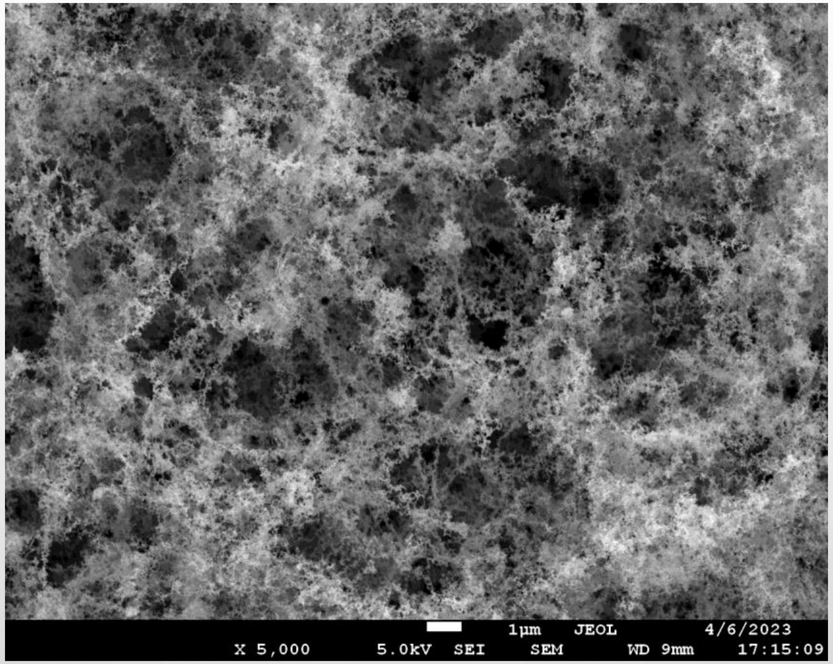


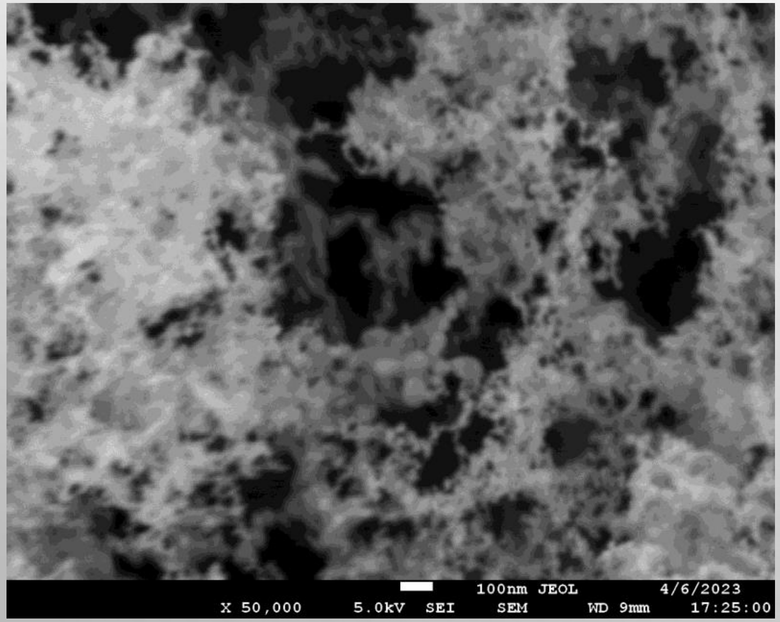
Au scale – 10 µm

Sn scales – 20 and 10 µm

UDP AU-ANNEALING



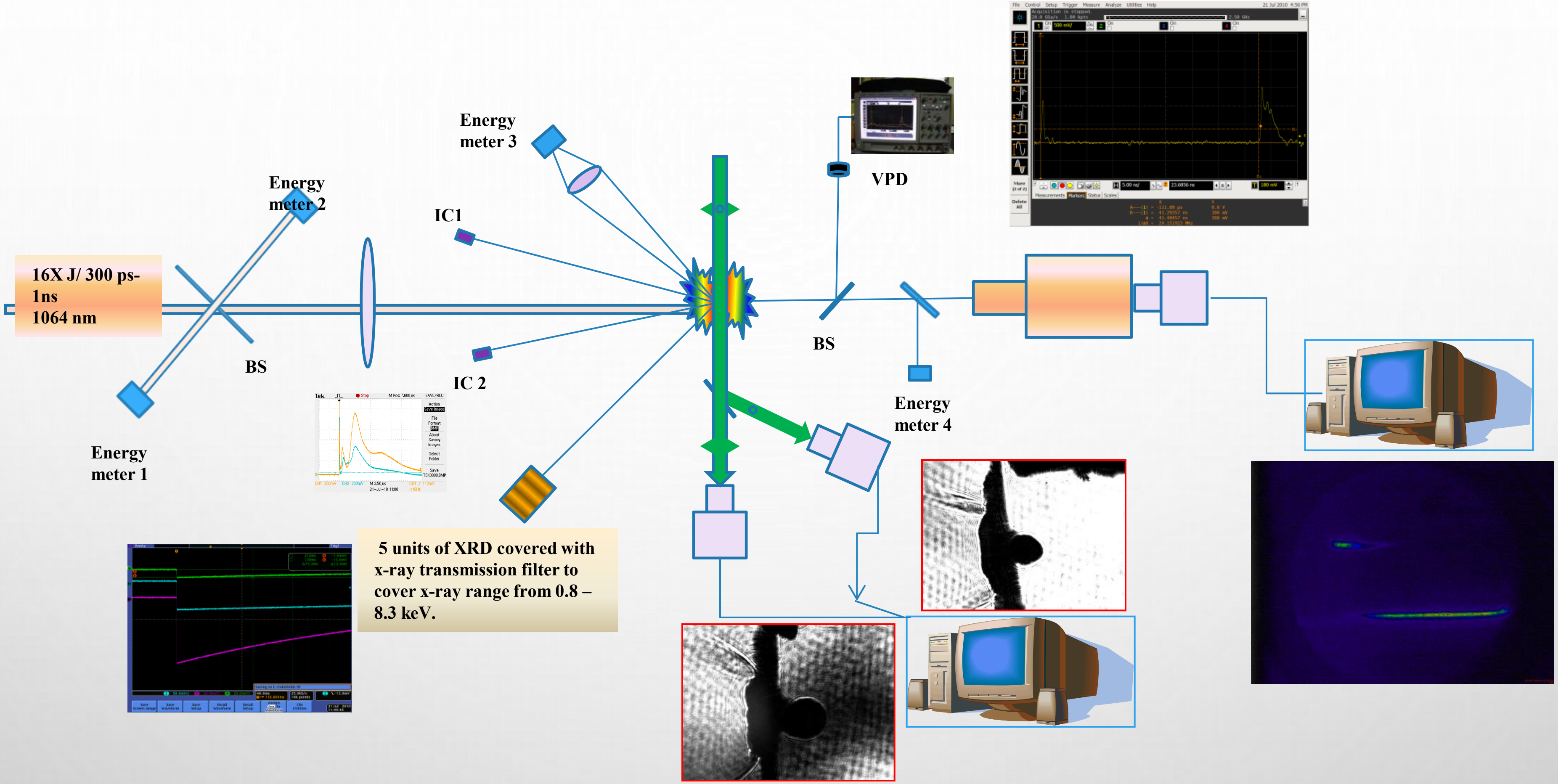




Chanprint Kaur, S. Chaurasia, N.G. Borisenko, A.I. Gromov, A.A. Akunets, G.V.Sklizkov, G.A. Vergunova and S.Y. Gus'kov."Demonstration of gold plasma as bright x-ray source and slow ion emitters".Plasma physics and controlled Fusion. Vol 61. issue 8, 084001, (2019)

LASER SHOTS WITH TARGETS FOR THE SAKE OF ICF/IFE AND PLASMA CONTROL

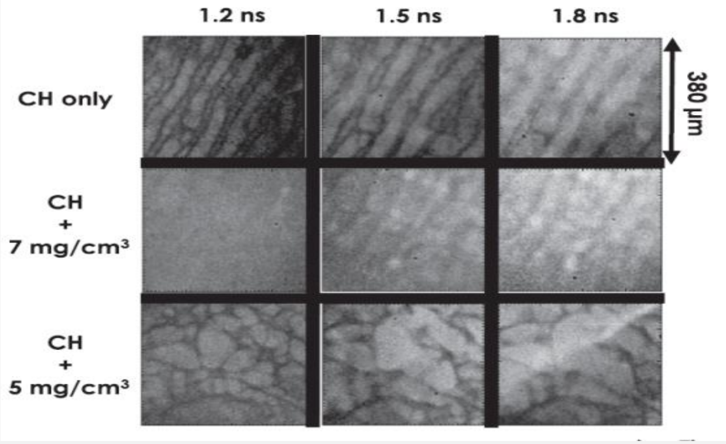
SELECTED EXPERIMENTS WITH DRIVERS



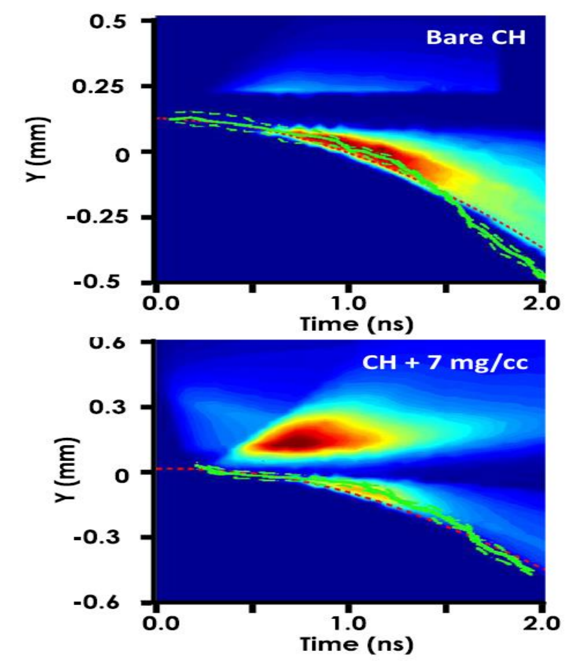
Measurements BARC (PI - S. Chaurasia)

1. Energy balance
2. Effect of foam on temporal profile of the laser pulse
3. Laser transmission through low density and other
4. Shock transit time in foam
5. SHG, SBS, SRS in foam under intense laser
6. Effect of foam on foil acceleration
7. Ion emission characteristics from foams
7. Thomson parabolas
8. X-ray enhancement in low density M (Bi) foams
9.Streak-cameras

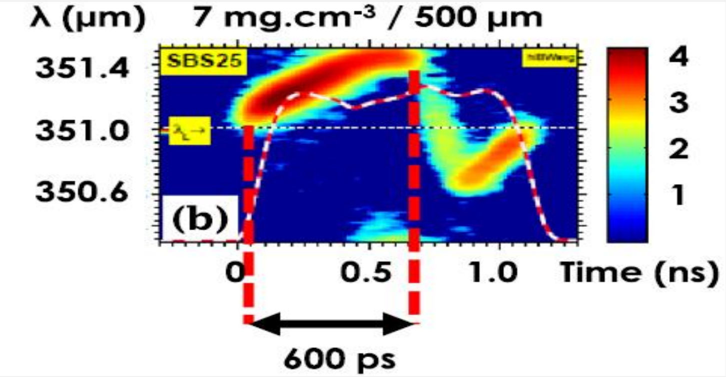
LASER THERMONUCLEAR TARGETS FROM LPI RAS IN 2016
OMEGA EXPERIMENT ON AIRGEL ASSISTED PLASMA STABILITY, TURBULENCE & ENERGY TRANSFER EFFECTS



Mass variations 3D structures in plasmas with different foams or no foam

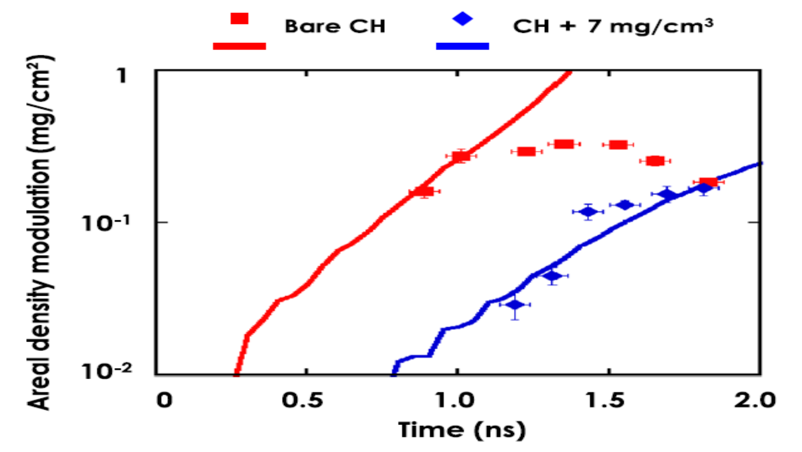


X-ray streak-camera register the changed radiation front movement with/without foam



← SBS with undercritical foam

Laser imprint mitigation caused by foam under laser irradiation



Joint French-US-Russian-UK experiment (**OMEGA, 500J 2ns** LLE, Rochester University) demonstrated experimentally twice as low PT-instability on the ablation front of CH-foil with nano foam CHO, compared to bare CH. The effect is critically important to ICF.

B. Delorme, M. Olazabal-Loumé, A. Casner, Ph. Nicolaï, D. T. Michel, G. Riazuelo, N. Borisenko, J. Breil, S. Fujioka, M. Grech, A. Orekhov, W. Seka, A. Sunahara, D. H. Froula, V. Goncharov, and V. T. Tikhonchukl. Experimental demonstration of laser imprint reduction using underdense foams. Physics of Plasmas 23, 042701 (2016); doi: 10.1063/1.4945619

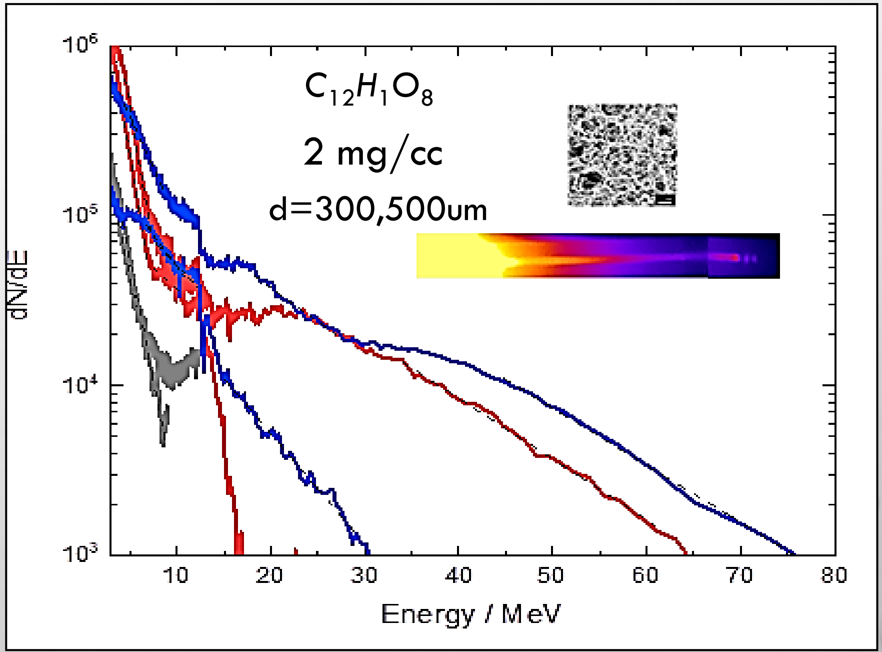
PHELIX at GSI Darmstadt: DLA and stochastic e- heating in long-scale NCD plasma at 10^{19}W/cm^2

2019 on

1000-fold higher ϒ-rays and electrons E>30 MeV (by10-chanel TLD-spectrometer) from preheated CHO-airgel of near critical density as compared to metal foil, irradiated by the laser beam with good contrast.

Thot for hot e when heated by relativistic beam shifted from 1.5÷2 MeV of Cu-foils with high Laser light contrast up to 13 MeV of laser irradiated preionized foams (red and blue curves). Electrons escaping charge of E > 12 MeV reached 0.4 μC.

Nd:glass : up to 100 J, 750 fs, 2-5× 10^{19} W/cм^2

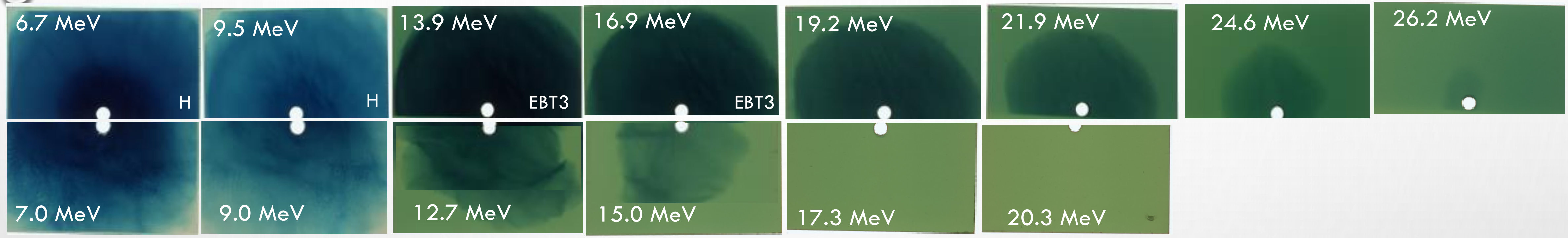


O. N. Rosmej, N. Andreev, L. Pugachev, S Zähter, N. Zahn, D. Khaghani, N. Borisenko, G.Sklizkov et al. Interaction of relativistically intense laser pulses with long-scale near critical plasmas for laser based sources of MeV electrons and gamma-rays, New J.Phys. **21**, 043044 (2019).

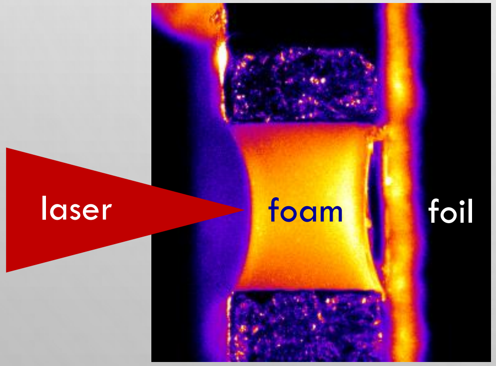
Forward accelerated protons (RCF-stack)

well collimated proton beam with **sharp borders** and **high cut-off** in case of **foam + thin foil**

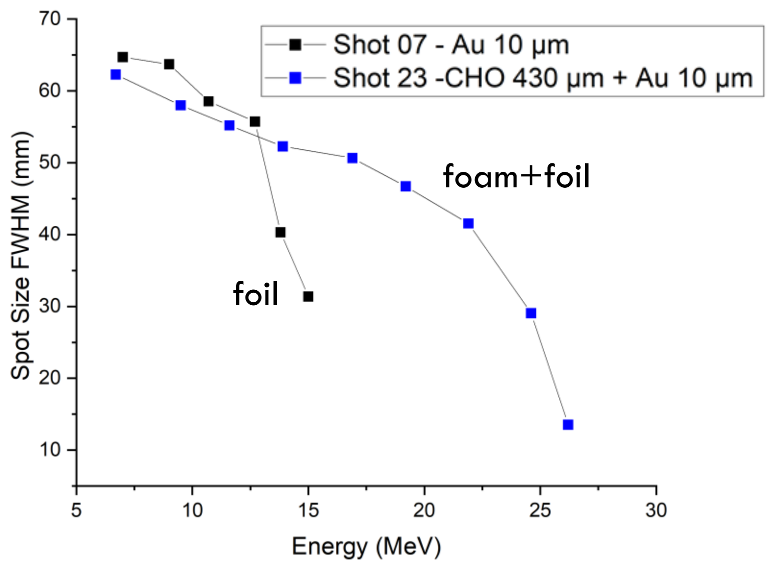
sh23: 65.9 J (17 J, 1.7x10^{19} W/cm^2); 3 ns, ~ 0.3%, delay 1,5 ns CHO 430 µm + Au 10 µm (-10°)



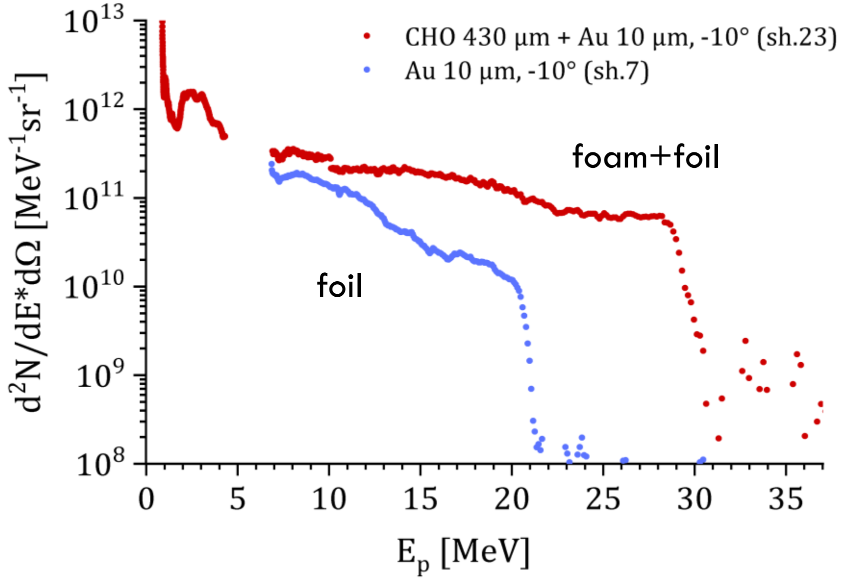
sh7: 79.9 J (17.2 J, 1.3x10^{19} W/cm^2); Au 10 µm (-10°)



proton beam size at 8 cm from TCC



spectra from magnetic spectrometer (-10°)



APPLICATIONS

NON-THERMONUCLEAR RESEARCH

Interdisciplinary research with sub-kJ, sub-PW lasers (PI O.Rosmej)

By using low density polymer foams for production of long-scale NCD plasmas, one can strongly boost parameters of laser driven sources of particles and radiation

Universal character of foam targets:

No high laser contrast, no ultra-high laser intensity, no pointing stability, no changes in the experimental set-up are required.

Plasma Physics, HED-research:

foam and foam stacked with thin foil:

- Ultra-intense betatron and THz radiation,
- Well-directed beam of super-ponderomotive electrons
- Well-collimated proton beams with high cut-off energy

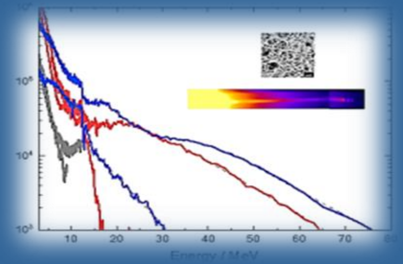
Nuclear Physics:

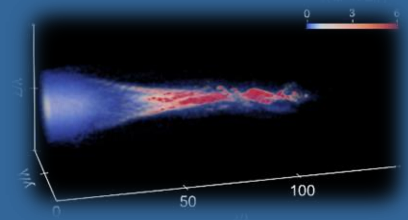
foam stacked with thick high Z convertor or thin foil:

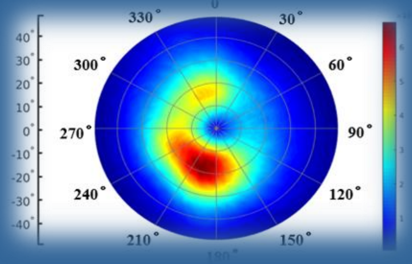
- High yield nuclear reactions in GDR region
- High fluence/ flux gamma and gamma-driven neutron sources / proton-driven neutron sources

Biophysics:

- Ultra-high dose-rate (10ns of TGy/s) of ionizing radiation for investigation of the FLASH-effect







CONCLUSION

- LASER THERMONUCLEAR TARGET IS A UNIVERSAL INSTRUMENT OF SCIENTIFIC RESEARCH: FOR ICF/IFE, FOR ASTROMODELLING, IT ALSO ALLOWS FOR ALMOST ARBITRARY SCALING FOR NATURAL AND ARTIFICIAL PHENOMENA WITH HIGH ENERGY DENSITY IN THE MATTER.
- INDEPENDENT OF ENERGY PROSPECTS TARGETS PROVIDE AN INTERESTING RESEARCH OPPORTUNITY WITH ALMOST EVERY LASER ALREADY EXISTING.
- MATERIAL ASPECTS ARE OF SPECIAL INTEREST AND DIFFICULTY FOR THE RESEARCHERS INVOLVED. THE SUCCESSFUL TARGET GIVES RISE TO SEVERAL SCIENTIFIC SCHOOLS AT ONCE. IT BECOMES NECESSARY WORLDWIDE.
- LASER TARGETS DEMONSTRATED STIMULATING ROLE IN THE LASER AND PARTICLE BEAMS INTERACTION WITH MATTER.

Publications (selected)

1. M. M. Günther, O.N. Rosmej, P. Tavana, M. Gyrdymov, A. Skobliakov, a. Kantsyrev, S. Zähter, N.G. Borisenko, A. Pukhov, and N.E. Andreev, “Prospective insights in laser-generated ultra-intense gamma-ray and neutron sources for nuclear applications and science”, **Nat Commun 13**, 170 (2022); https://doi.org/10.1038/s41467-021-27694-7

2. N.E. Andreev, V.S. Popov, O.N. Rosmej, A.A. Kuzmin, A.A. Shaykin, E.A. Khazanov, A.V. Kotov, N.G. Borisenko, M.V. Starodubtsev, A.A. Soloviev, „Efficiency improvement of the femtosecond laser source of superponderomotive electrons and X-ray radiation due to the use of near-critical density targets”, **Quantum Electronics 51** (11) 1019 – 1025 (2021), https://doi.org/10.1070/QEL00000

3. O. N. Rosmej, X. F. Shen, A. Pukhov, L. Antonelli, F. Barbato, M. Gyrdymov, M. M. Günther, S. Zähter, V. S. Popov, N. G. Borisenko, and N. E. Andreev, Bright betatron radiation from directlaser-accelerated electrons at moderate relativistic laser intensity, **Mat. Radiat. Extremes 6**, 048401 (2021); https://doi.org/10.1063/5.0042315

4. X. F. Shen, A. Pukhov, M. M. Günther, and O. N. Rosmej, Bright betatron x-rays generation from picosecond laser interactions with long-scale near critical density plasmas, **Appl. Phys. Lett. 118**, 134102 (2021); https://doi.org/10.1063/5.0042997

5. O N Rosmej et al, “High-current laser-driven beams of relativistic electrons for high energy density research”, **Plasma Phys. Control. Fusion 62** (2020) 115024 (15pp) https://doi.org/10.1088/1361-6587/abb24e

6. Rosmej, O.N. et al., “Interaction of relativistically intense laser pulses with long-scale near critical plasmas for optimization of laser based sources of MeV electrons and gamma-rays”, **New J. Phys. 21** (2019) 043044 https://doi.org/10.1088/1367-2630/ab1047.

Publications for targets' proposals realized (selected)

8. N.G. Borisenko, A.E.Bugrov, I.N. Burdonskiy, et al." Physical processes in laser interaction with porous low-density materials" Laser and Particle Beams, V. 26, 04, pp. 537-543. (2008)

9. N.G. Borisenko, A.I. Gromov, Yu.A. Merkuliev. et al." Laser study into and explanation of the direct-indirect target concept".Book of abstract IFSA, p.218. (2011).

10. A.A.Akunets, L.A. Borisenko, N.G..Borisenko, et al "Modern trends in low-density materials for fusion" IFSA 2013.Book of abstracts, Nara, Japan, 8-13 September,p 315. (2013).

11. L.A.Borisenko, I.V. Akimova, A.A.Akunets. et al."Metal produced as nano-snow layers for converters of laser light into X-ray for indirect targets as intensive EUV sourses" Journal of Radioanalytical and Nuclear Chemistry Vol 299.Num 2. pp 955-960. (2014).

12. A.I. Gromov, I.V.Akimova, A.A Akunets.et al. "The questions of monitoring of ultra-dispersive layers for ICF targets" Contribution to the XLII International Conference on Plasma Physics and Controlled Thermonuclear Fusion (Zvenigorod, Moscow Region, RF, Feb 9-13 Book of Abs p 148. (2015).

13. A.S. Orekhov , A.A.Akunets, L.A.Borisenko,.et al " Modern trends in low-density materials for fusion". Journal of Physics: Conference Series,, 688 (1) 012080.(2016).

14. I.V. Akimova, A.A.Akunets, N.G.Borisenko. et al" Metal nano-particles modernized layers, including those with polymers, fo laser thermonuclear fusion targets" IOP Conf Series: Journal of Physics: Conference Series 907 012018. (2017).

15. Chanprint Kaur, S. Chaurasia, N.G. Borisenko, A.I. Gromov, A.A. Akunets, G.V.Sklizkov, G.A. Vergunova and S.Y. Gus'kov."Demonstration of gold plasma as bright x-ray source and slow ion emitters". Plasma physics and controlled Fusion. Vol 61. issue 8, 084001, (2019)

PUBLICATIONS FOR IFE-RELATED RESEARCH (SELECTED)

- **16. БОРИСЕНКО Н.Г.**, АРТЮКОВ И.А., ЕРИСКИН А.А., АКУНЕЦ А.А., ГРОМОВ А.И., КУВШИНОВ И.Р., ПАВЛОВ Д.В., ПАСТУХОВ А.В., ОБ ОПЫТЕ МИКРОТОМОГРАФИИ НАНОСТРУКТУРИРОВАННЫХ ОБЪЕКТОВ. СБОРНИК МАТЕРИАЛОВ КОНФЕРЕНЦИИ. IV ВСЕРОССИЙСКАЯ НАУЧНАЯ КОНФЕРЕНЦИЯ «ПРАКТИЧЕСКАЯ МИКРОТОМОГРАФИЯ», РХЦ ГОСУДАРСТВЕННОГО ЭРМИТАЖА «СТАРАЯ ДЕРЕВНЯ» Г. САНКТ-ПЕТЕРБУРГ, ПОД РЕД. С.В. КОШЕВЕРСКОЙ. 2023 ГОДА. СТР.10-16. ISNB 978-5-4386-2337-3 ГОСУДАРСТВЕННЫЙ ЭРМИТАЖ, 2023 (E-LIBRARY).
- 17. JAKUB CIKHARDT ET AL. **"CHARACTERIZATION OF BRIGHT BETATRON RADIATION GENERATED BY DIRECT LASER ACCELERATION OF ELECTRONS IN PLASMA OF NEAR CRITICAL DENSITY"** MATTER AND RADIATION AT EXTREMES. – 2024. – T. 9. – №. 2. DOI: 10.1063/5.0181119
- 18. ARTYUKOV I. A., **BORISENKO N, ERISKIN A.A. ET AL.** X-RAY 3D-IMAGING OF LOW-DENSITY LASER TARGET MATERIALS //PHOTONICS. – 2023. – T. 10. – №. 8. – C.875. **DOI: 10.3390/PHOTONICS10080875**
- 19. P**ASTUKHOV A.V.**, PERVAKOV K.S., **AKUNETS A.A., KUVSHINOV I.R., BORISENKO N.G.** FABRICATION OF HOLLOW POLY(ALPHA-METHYLSTYRENE) SHELLS FOR INERTIAL CONFINEMENT FUSION TARGETS / JOURNAL OF APPLIED POLYMER SCIENCE. 2022. V.139. ISSUE 41. E52997. (DOI: 10.1002/APP.52997) .
- 20. S. DEPIERREUX *ET AL*. **EXPERIMENTAL INVESTIGATION OF THE INTERPLAY BETWEEN OPTICAL AND PLASMA SMOOTHING INDUCED ON A LASER MEGAJOULE BEAMLINE** PHYSICAL REVIEW RESEARCH **5**, 043060 (2023) DOI: 10.1103/PHYSREVRESEARCH.5.043060
- 21. PH. NICOLAÏ, M. OLAZABAL-LOUMÉ, S. FUJIOKA, A. SUNAHARA, N.BORISENKO, S. GUS'KOV, A. OREKOV, M. GRECH, G. RIAZUELO, C.LABAUNE *ET AL.*, EXPERIMENTAL EVIDENCE OF FOAM HOMOGENIZATION, PHYS. PLASMAS **19**, 113105 (2012).
- 22. J. LIMPOUCH, V. T. TIKHONCHUK, …, N. G. BORISENKO, ET AL , CHARACTERIZATION OF RESIDUAL INHOMOGENEITIES IN A PLASMA CREATED BY LASER IONIZATION OF A LOW-DENSITY FOAM, PLASMA PHYS. CONTROLLED FUSION **62**, 035013 (2020).
- 23. C. LABAUNE, S. DEPIERREUX, V. T. TIKHONCHUK, D. T. MICHEL, C. STENZ, N. G. BORISENKO, *ET AL.*, LASER-PLASMA INTERACTION PHYSICS IN MULTI KILOJOULE EXPERIMENTS, J. PHYS. CONF. SER. **244**, 022021 (2010).
- 24. A. M. KHALENKOV, N. G. BORISENKO, ET AL, EXPERIENCE OF MICRO-HETEROGENEOUS TARGET FABRICATION TO STUDY ENERGY TRANSPORT IN PLASMA NEAR CRITICAL DENSITY, LASER PART. BEAMS **24**, 283 (2006).

Thank you for your attention!

There is always something to teach the AI !