Center for the Advancement of Natural Discoveries using Light Emission

# AREAL Facility Status and Highlights


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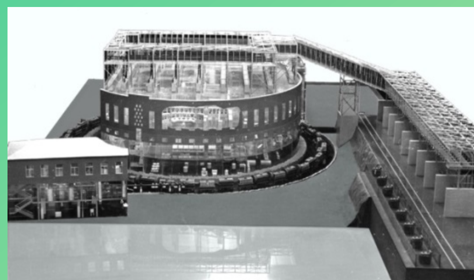
02 July 2019 , UBA, Yerevan

# Contents

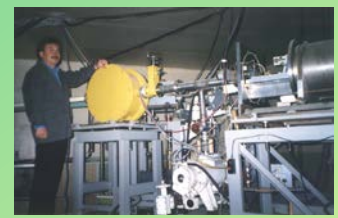
# Introduction

## 6 GeV synchrotron (1967)

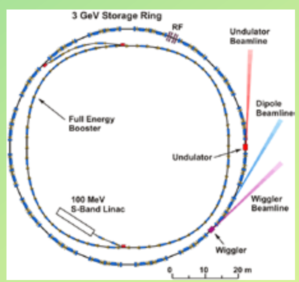
A.I. Alikhanian



## 3 Synch Rad Beamlines (1973)




## 3 GeV CANDLE Light Source




| | |
|---|---|
| Energy | 3 GeV |
| Current | 350 mA |
| Circumference | 216 m |
| *Emittance* | *8.4 nm* |

***The strong user community will emerge as the facility is readied.***

***Review Panel***

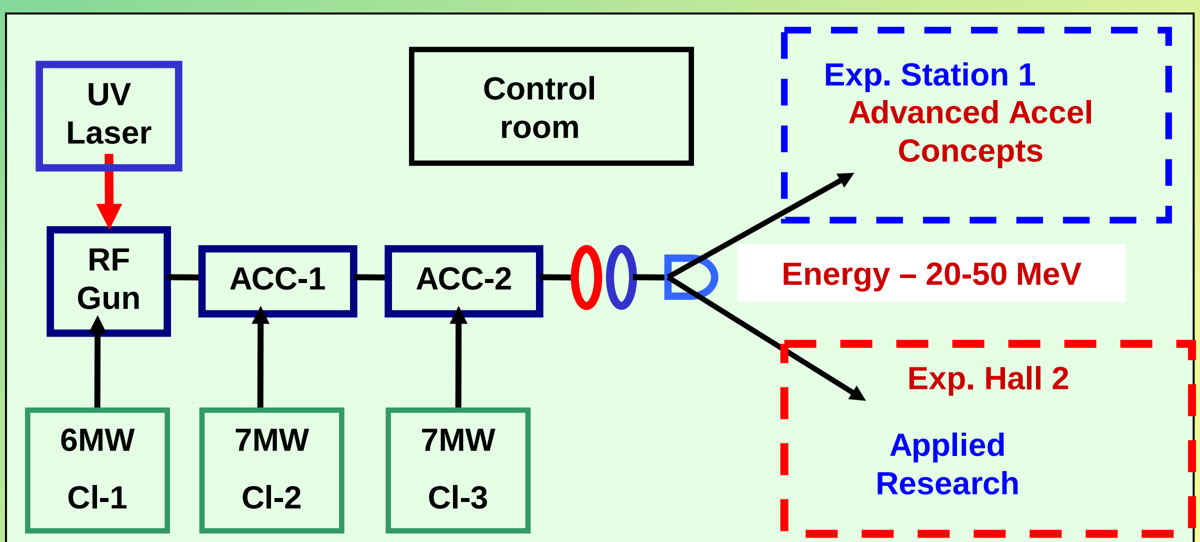
# AREAL – Exit Scenario

- Small facility + Limited investment
- State-of-the art facility
- Scientific & Technology asset
- Long Term Highlights
- Multiple applications

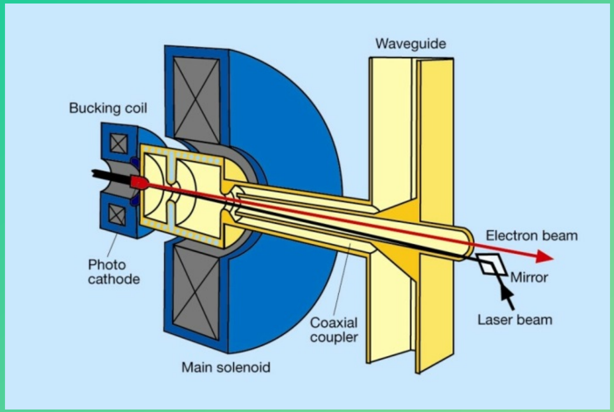
→ **Ultrafast Science and Technology**

→ Ultrashort $e^-$ bunches – sub ps
Small phase space < 1 um

→ **Free Electron Laser**




**AREAL – Advanced Research Electron Accelerator Laboratory**




**Beam Parameters**

**Energy – 5-50 MeV**
**Bunch length – 0.4-8 ps**
**Emittance < 1 μm**
**Bunch charge – 10-200 pC**
**Frequency – 1-50Hz**

**Figure of Merits**

**Photocathode**
- Quantum Effic.
- Work function
- Damage thresh.
- Lifetime
- Cost Maintan,

**RF Gun**
- Frequency
- Accel. grad
- Cost&Mainten

**Laser**
- Wavelength
- Power
- Pulse length
- Time-structure
- Cost & Mainten

# Photocathode

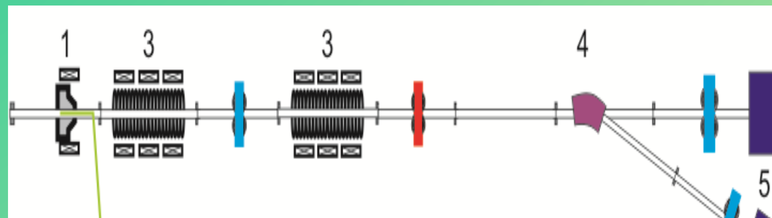
| Parameters | Metals (Cu) | Coated Met. (CuBa) | Semiconduct. ($Cs_2Te$) |
|---|---|---|---|
| QE (%) | 0.001-0.01 | 0.01-0.1 | 0.1-10 |
| Work funct W (eV) | 3.5- 4.5 | 2-3 | 1 -2.5 |
| Damage Thr($mJ/cm^2$) | **100** | 40 | 1-2 |
| Lifetime | **>Year** | **Months** | **Weeks** |
| Response Time (ps) | **<0.02** | ~ 0.5 | >1 |
| Vacuum ( nTorr) | **1.0** | 0.1 | 0.01 |
| Cost | **+** | - | - |

$$P_L(W) = 1240 \frac{I(amp)}{QE \times \lambda(nm)}$$

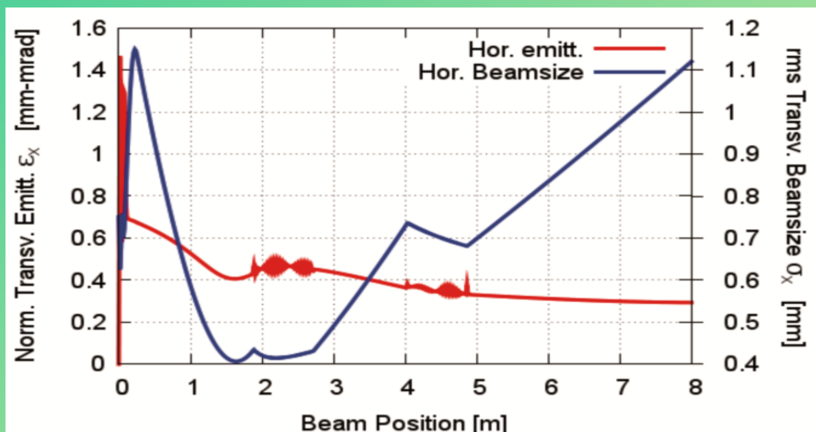
Cu → QE=0.01%

Cu → W= 4.5 eV

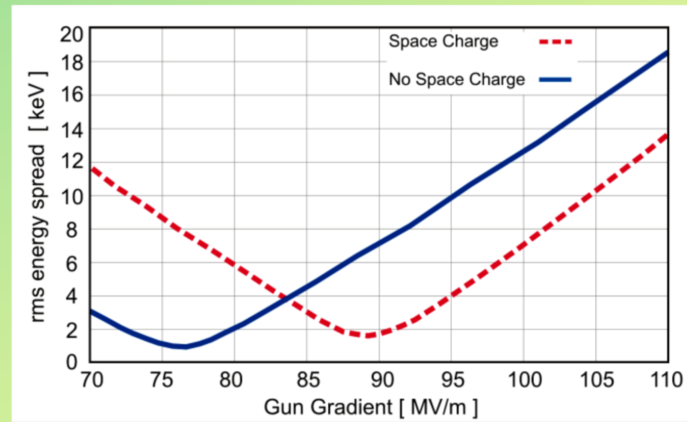
# Beam Physics



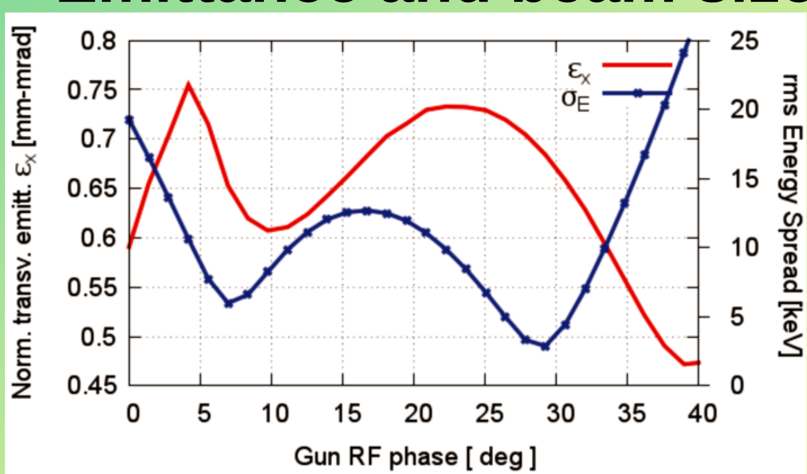

**Energy – 20-50 MeV**
**Emittance < 1 um**
**Energy spread -0.1%**
**Bunch length – 0.4-1ps**
**Bunch charge- 200pC**

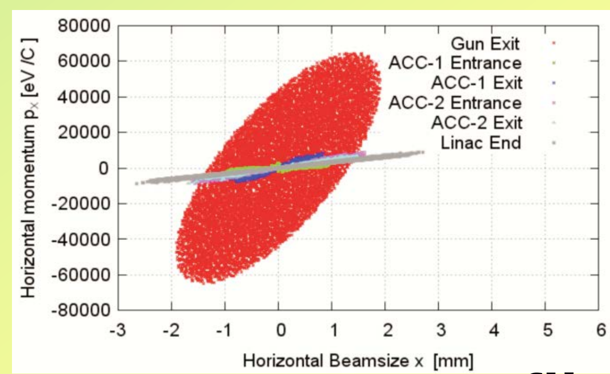



**Emittance and beam size**




**Energy Spread at Gun exit**

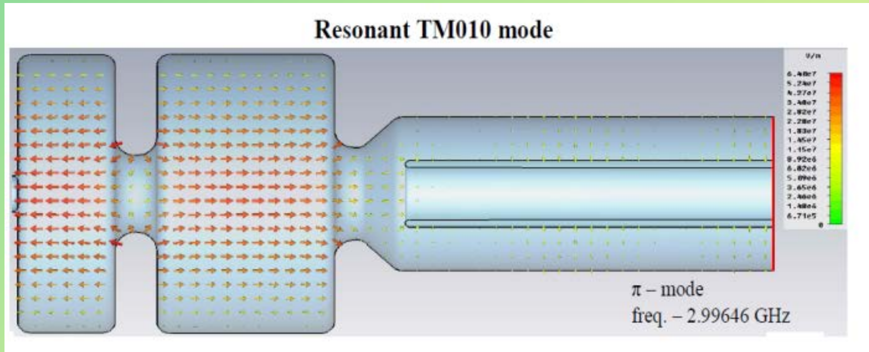


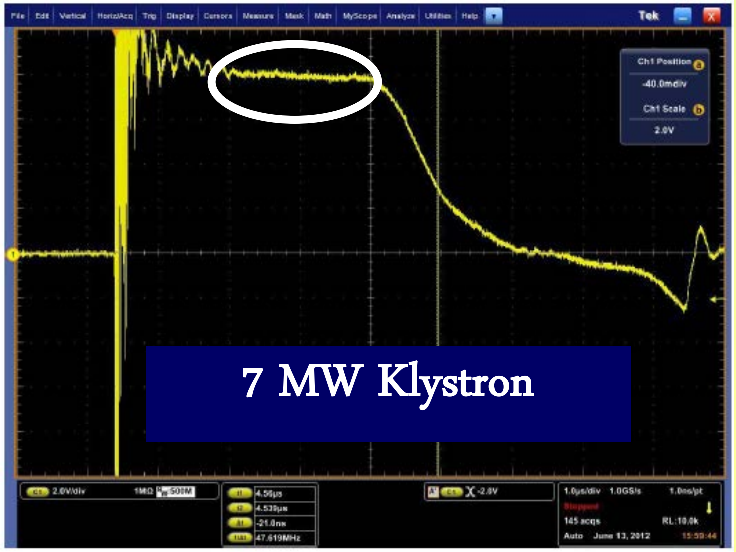

**Beam profile**

# RF System

Accel. Grad – 110 MV/m



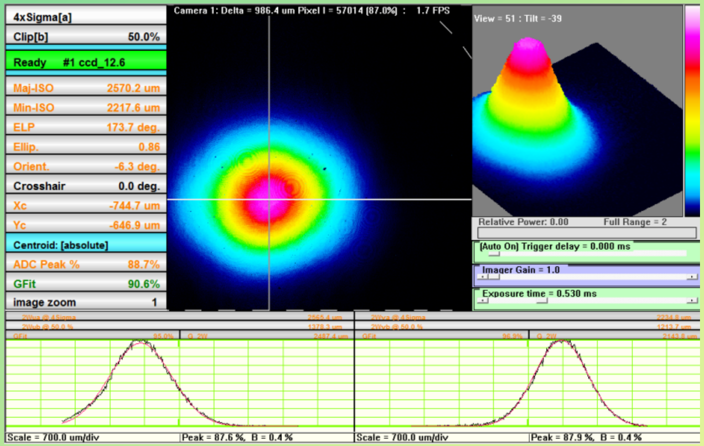

| | | |
|---|---|---|
| Main RF Frequency | (GHz) | 2.997925 |
| RF pulse Duration | (μ s) | 4 |
| Operating Repetition Rate | (Hz) | 1-50 |
| HV Pulse Duration | (μ s) | 4 |
| RF Peak power | (MW) | 7 |
| Amplitude Stability | (%) | <1.2 |
| Amplitude pulse-to-pulse stability | (%) | <0.5 |
| Phase Stabilization | (° @ 3GHz) | 0.1 |

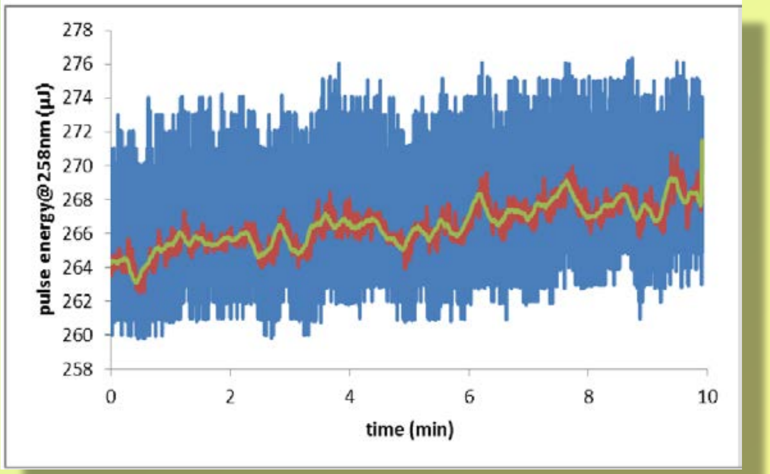



**Amplitude Flatness <1 %**

# Laser Performance


**UV – 258 nm**
**Energy – 300 μJ**
**Pulse Length – 0.4 ps**
**Shape – gaussian**



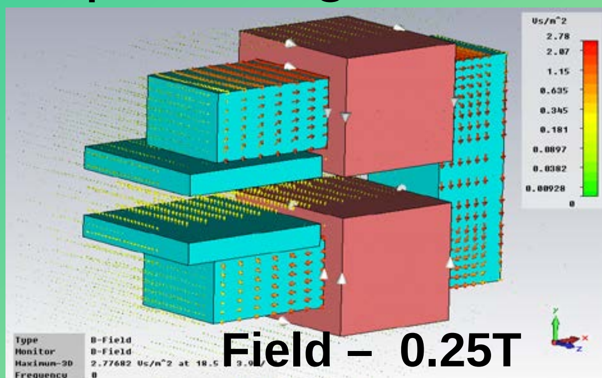




**Pulse Energy stability – 0.3%**

# Magnets

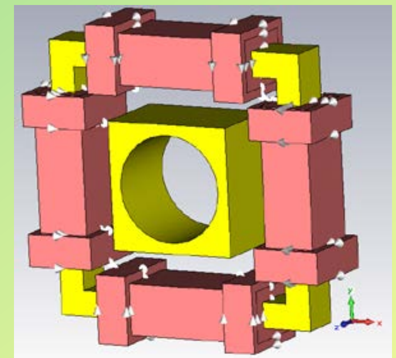
## Design-Simulations- Fabrication -Measurements

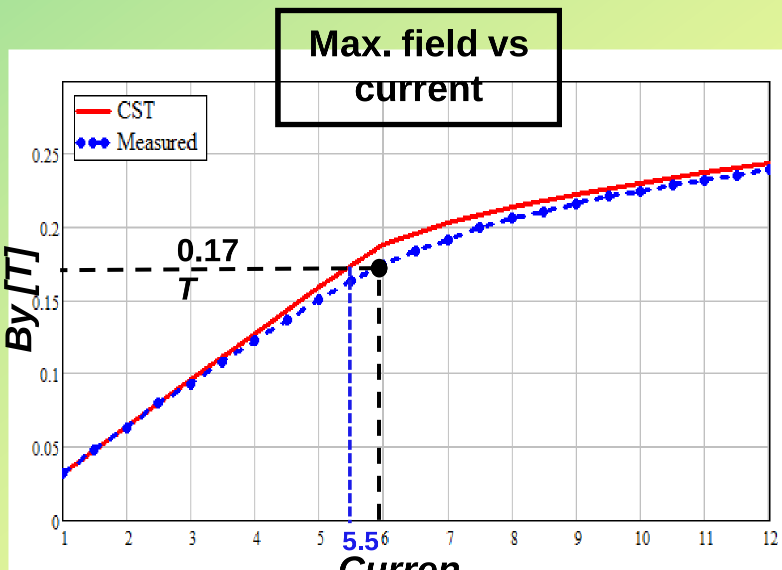
Dipole magnet



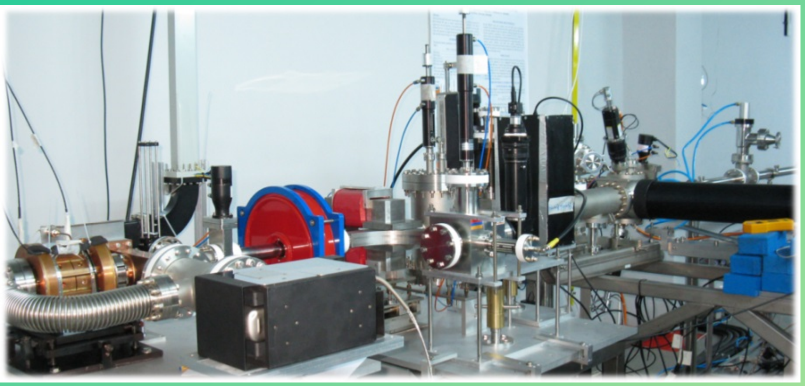

Solenoid

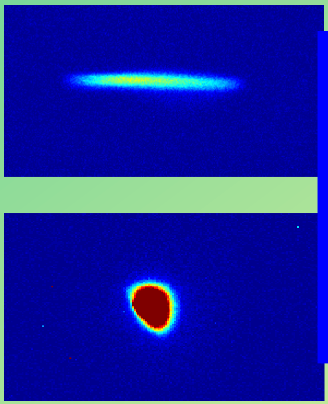

**Corrector**






# 2014- 2015 - AREAL





| | |
|---|---|
| Energy | 2.5- 5 MeV |
| Time structure | 0.3 – 8 ps |
| Emittance | ~ 1.14um |
| Charge | 300 pC |
| Repetition rate | 1-50 Hz |

**Two-photon Microscopy Station**

## *DELTA Laboratory*

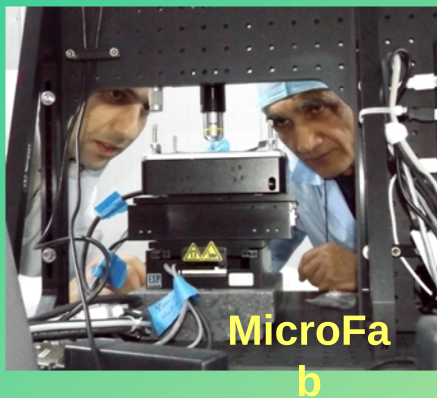
**Microfabrication Station**


- Bio-medicine
- Material science
- Environmental science

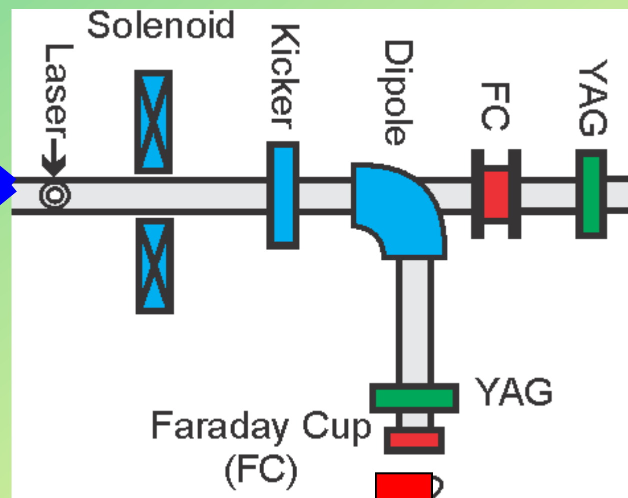
- Photonics, microelectronics, MEMS
- Polymers, semiconductors, ceramics
- Micro- and nano-structuring,

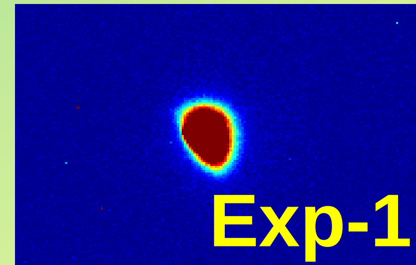
# 2015-2018 – Experimental Stations

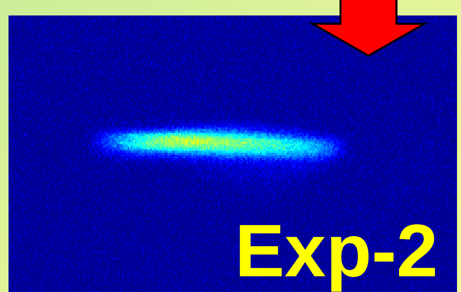
## AREAL 2-5 MeV




## DELTA


# Advanced Technologies

Laser System

Ultrafast electronics

Civil engineering

Ultrahigh vacuum


Precise machining

Radiophysics System

High Diagnostics & Control

Magnet system

# 2015-2018 – Exper. program

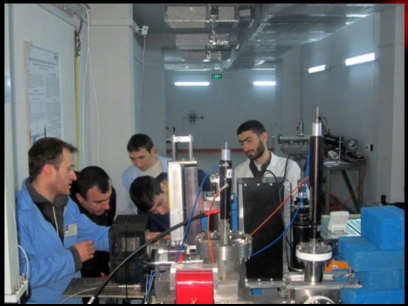
**Proposals –24**
**Institutions –14**
**Scientists – 68**

**Genetics**

**Molecular Physics**

**Biology**

**Microelectronics**



**Yerevan State Univ**
**Polytechnic Univ.**
**Yerevan Phys. Inst**
**Inst. Mol. Biology**
**Inst. Phys. Research**
**Inst of Biotechnology**
**Biomedical Inst (Russia)**

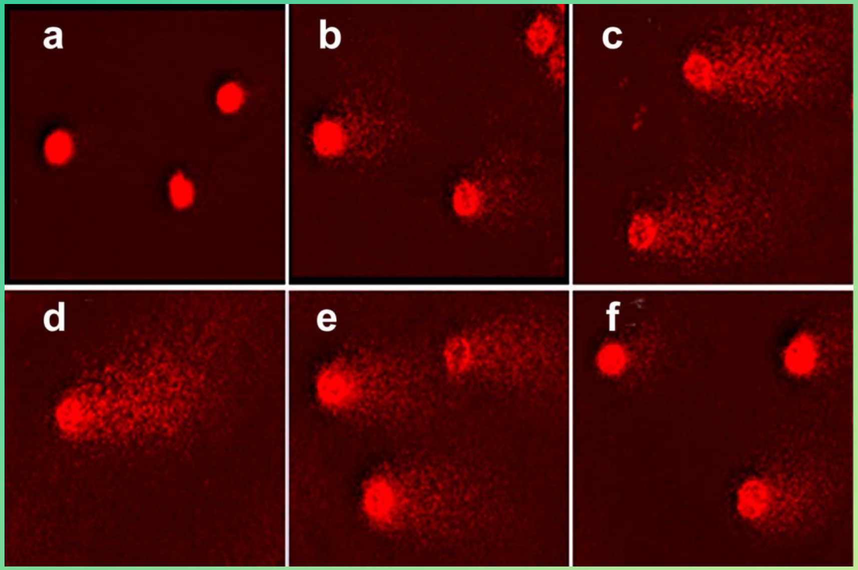
**New materials**

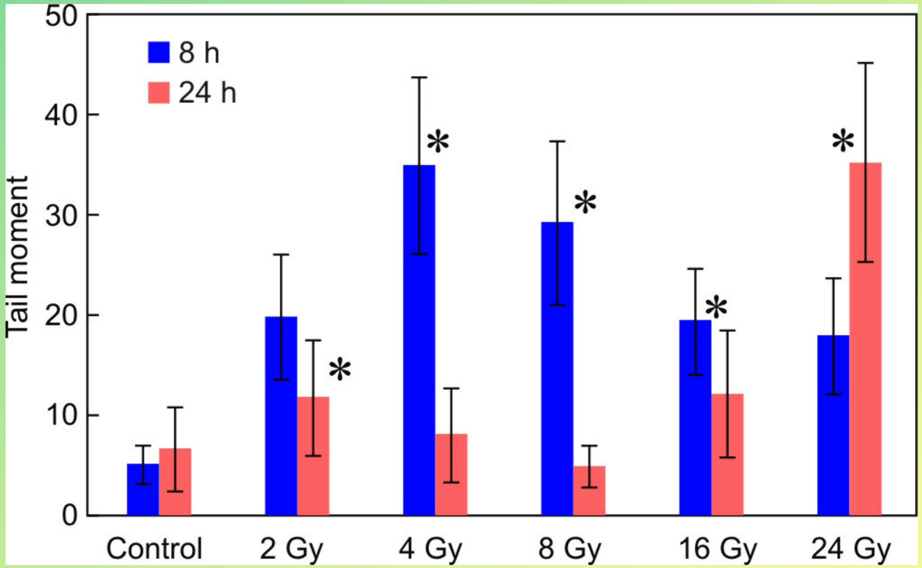
**Solid State Physics**

**Microfabrication**

**Oncology**

# Bio-Medical application




*Genetic Effects. DNA damage and repair under ultrafast irradiation.*

**N. Babayan et al, J. of Radiation Research, 2017.**
**G. Tsakanova et al, Biomedical Research Express, 2017**
**N. Babayan et al, J. of Radiology& Rad. Therapy, 2018.**
**R. Aroutiounian et al, Molecular Citogenetics, 2019**

# Material Sciences

sec

| | |
|---|---|
| $10^{-6}$ | Thermal processes |
| $10^{-7}$ | |
| $10^{-8}$ | |
| $10^{-9}$ | Secondary defects |
| $10^{-10}$ | |
| $10^{-13}$ | **Primary defects** |
| $10^{-14}$ | |
| $10^{-15}$ | |
| $10^{-16}$ | Atoms collision |
| $10^{-19}$ | Energy transfer to athoms |
| $10^{-20}$ | |

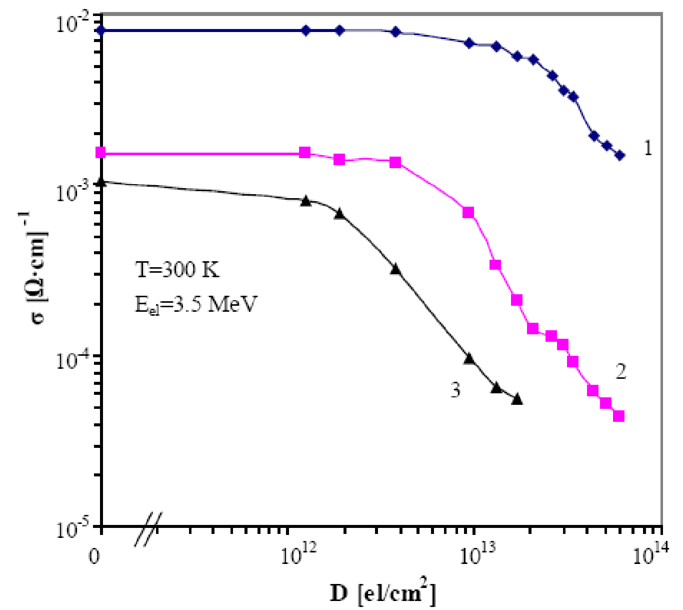
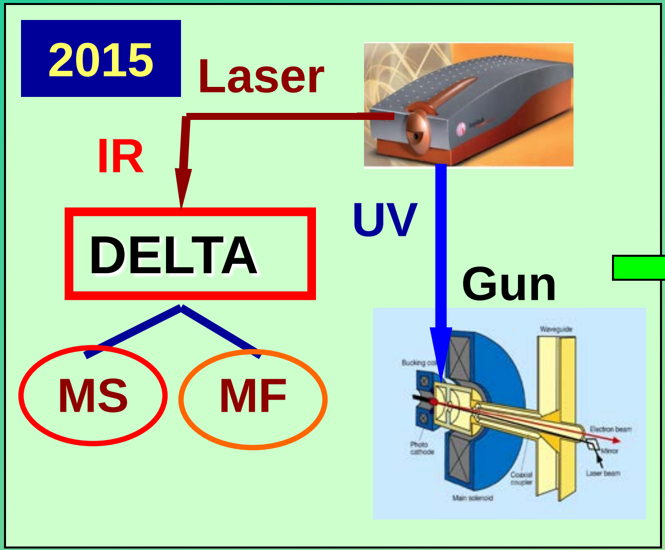


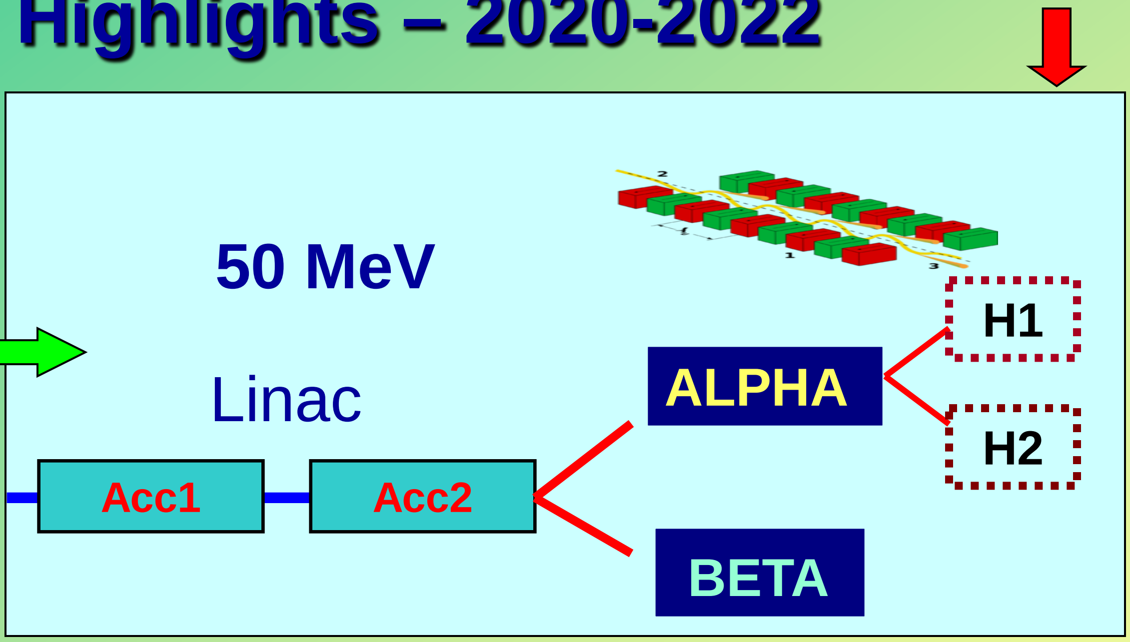

**Figure 1.** Silicon crystal (n-Si) electrical conductivity dose dependence by electron pico-second beam irradiation (energy 3.5 MeV). Samples specific resistivity: 1—100 Ω·cm, 2—700 Ω·cm, 3—950 Ω·cm. Maximum irradiation dose was $6 \times 10^{13}$ el/cm$^2$.

*Silicon-dielectric Structures.*

**H. Yeritsyan et al, JEM, 2017**
**V. Tsakanov et al, NIM, 2016**
**H. Yeritsyan et al, JEM, 2018**
**H. Yeritsyan et al, JMP, 2018**

# AREAL Highlights – 2020-2022



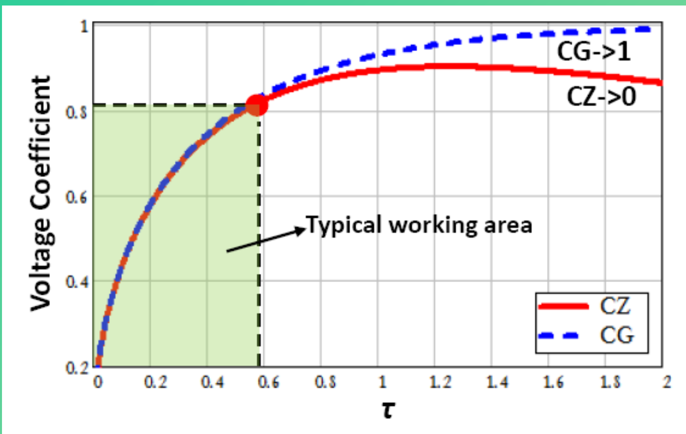

## Experimental Stations

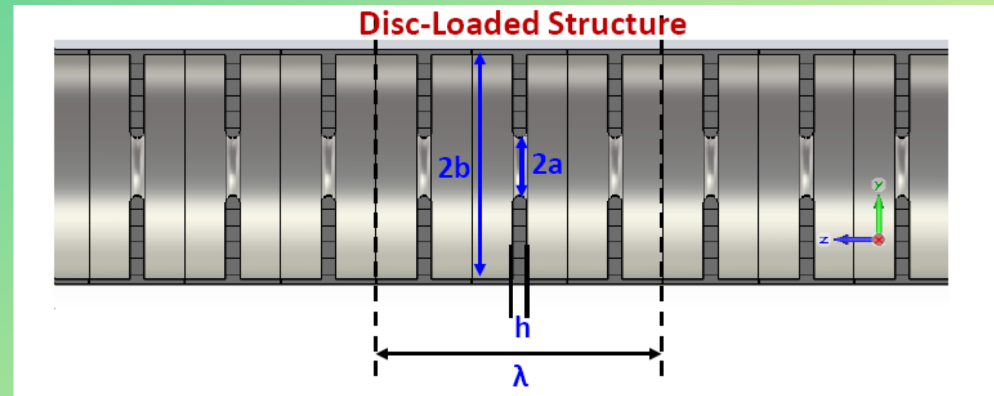
**DELTA** – Laser driven Microscopy and Microfabrication stations.

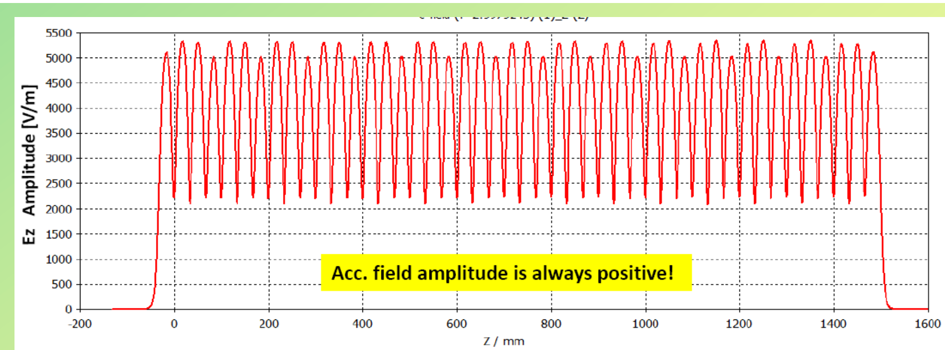
## ALPHA – Mid IR Free Electron LASER

## BETA- Advanced Accel. Concepts

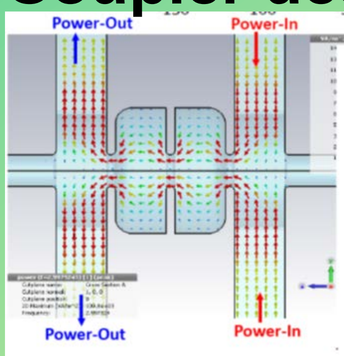
# TWA & Coupler for 3 GHz structure

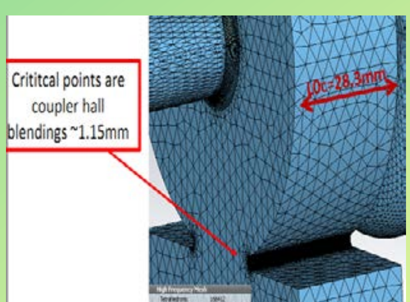



## Coupler design




TW- 2π/3 mode

Frequency - 2.9979 GHz

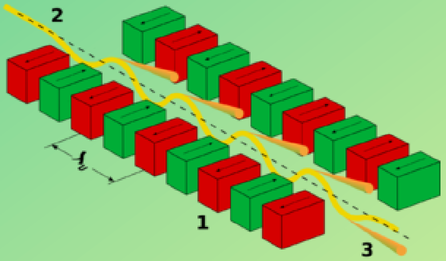
Nominal Grad. –15MV/m

Shunt Imp. – 32.7 MΩ/m

# Highlights

## *ALPHA* Station 1 – IR Free Electron Laser

**Energy – 15-50 MeV**

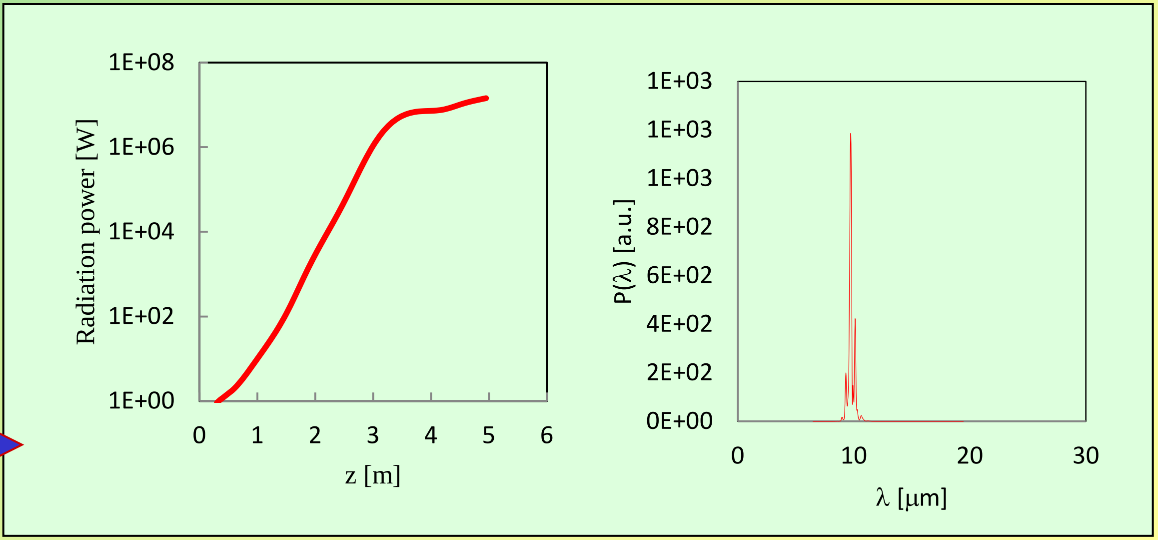




***FEL***

**Sat. length 2.1 – 3.2 m**

**Pulse energy 60-100 mJ**

**Power= 40 – 60 MW**




**Middle IR FEL**

**Wavelength –2.5 - 30μm**

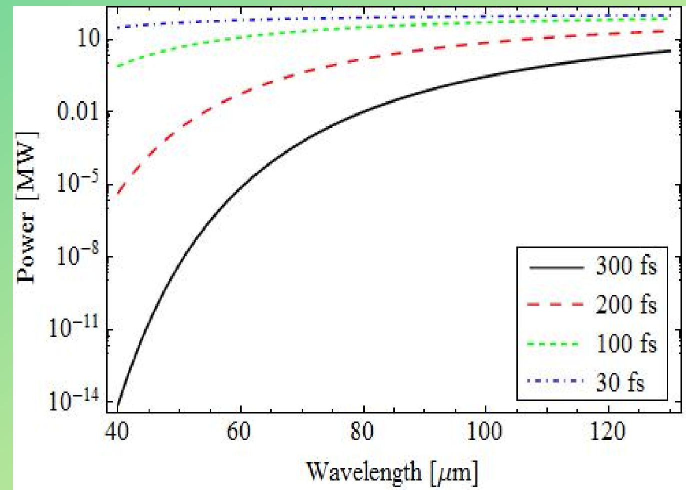
# *ALPHA* Station 2 – THz radiation source

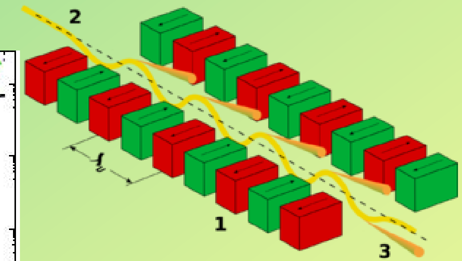
## Helical Undulator

| Type | Helical |
|---|---|
| Period length[cm] | 8 |
| K - Parameter | 0.8 - 2 |
| N of periods | 31 |

| | |
|---|---|
| Energy [MeV] | 20 – 50 |
| Bunch duration [fs] | 30 – 300 |
| Bunch charge [pC] | 50 - 300 |

## Power -1-30 MW

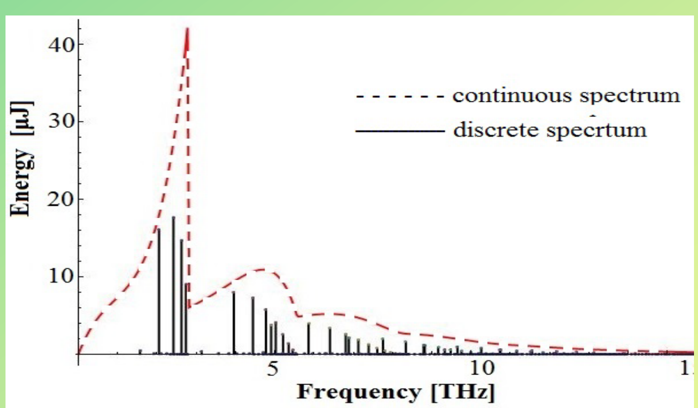


$$f = 2 - 10\,THz$$

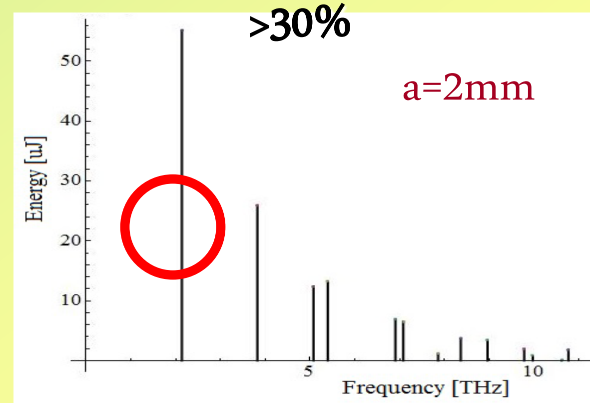
$$\lambda = 30 - 150\,\mu m$$

## THz FEL in undulator waveguide



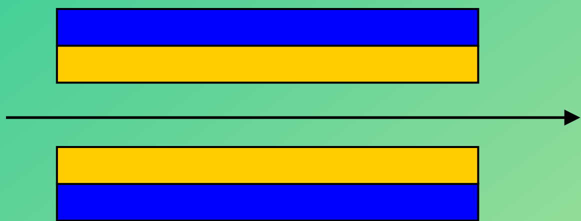

Rad. Diff. size

$$\sigma_r = \frac{\sqrt{\lambda L_u}}{4\pi}$$

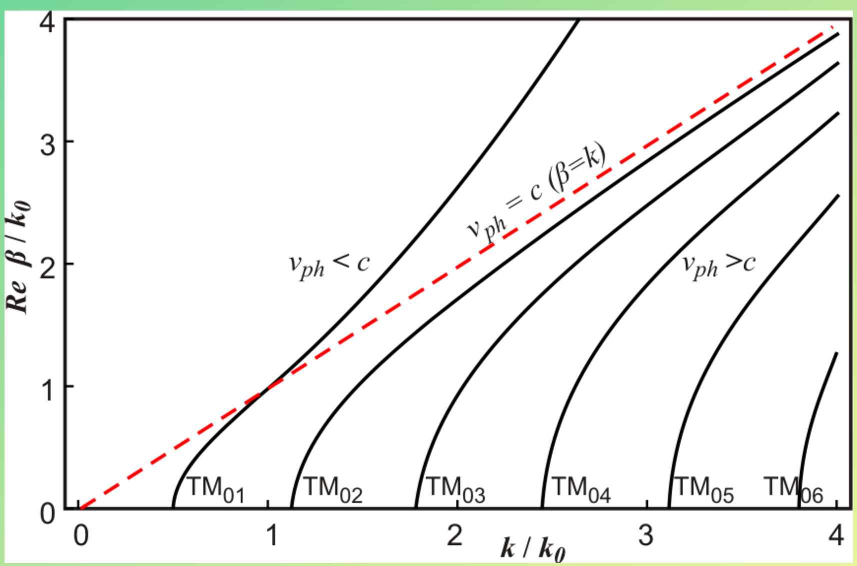


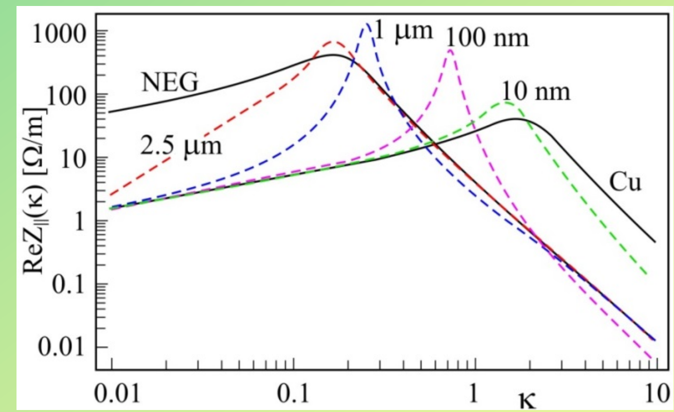
# BETA Station – THz Radiation & Acceleration

## THz Single Mode Accelerating Structure

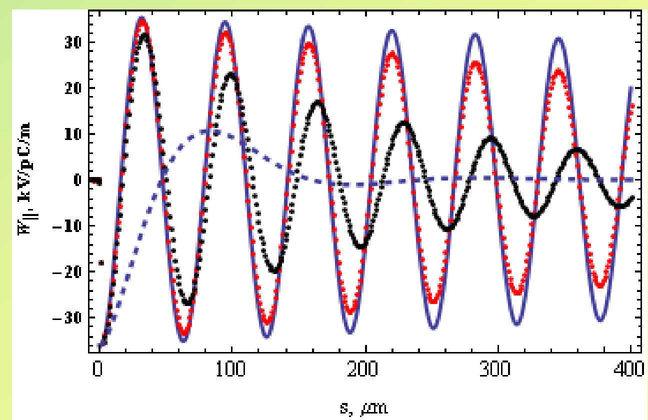


$$\omega = c/\sqrt{2ad}$$




Impedance

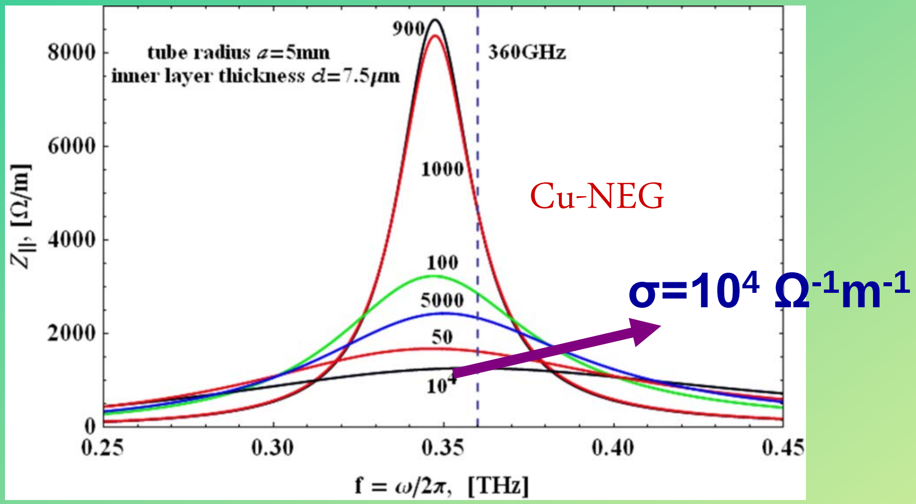



Wake potentials

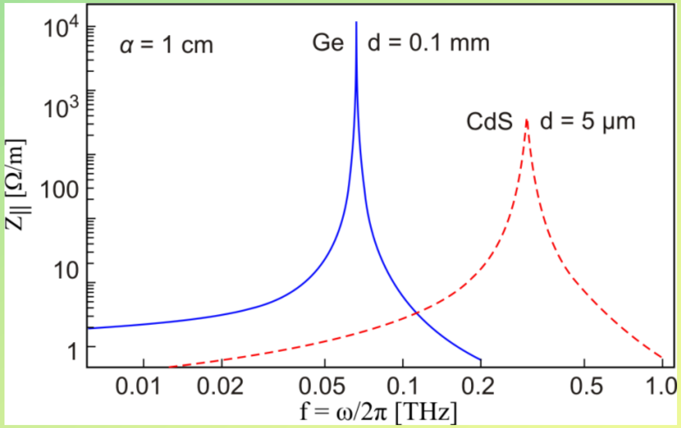

M. Ivanyan, Phys. Rev STAB 7, 114402 (2004)
M. Ivanyan et al, Phys. Rev STAB 17, 021302 (2014)
M. Ivanyan et al, Phys. Rev ST - AB 17, 074701 (2014)

# Accelerating Structures at 0.35 THz

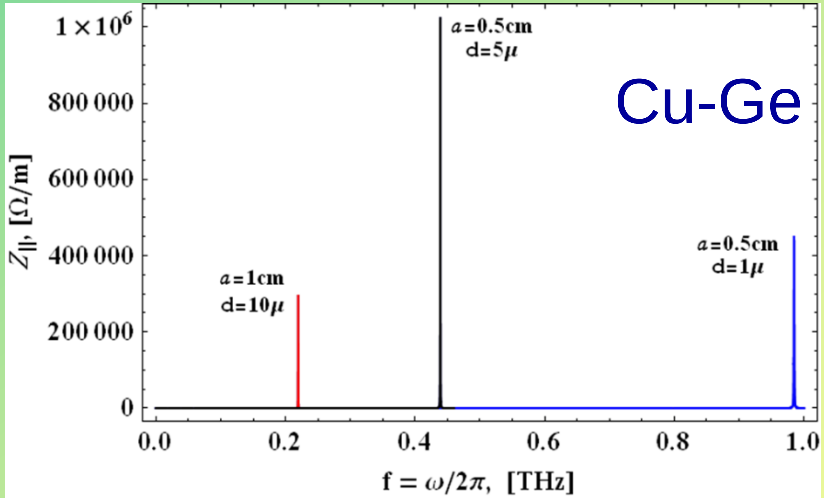
Potential candidates

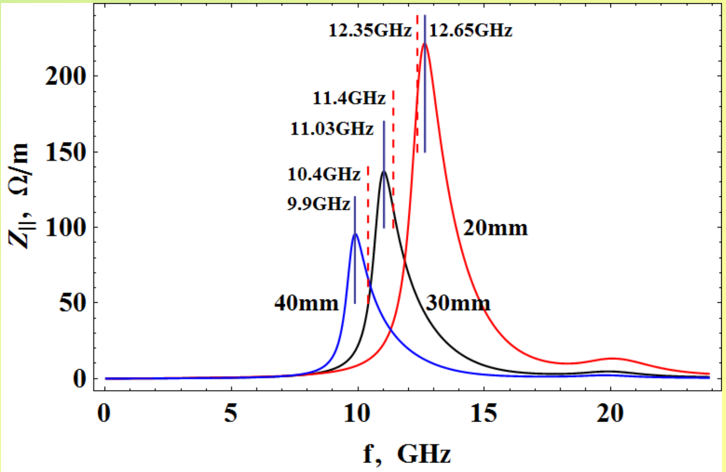



**$\sigma(CdS) = 600\ \Omega^{-1}m^{-1}$**




**$\sigma(Ge) = 2\ \Omega^{-1}m^{-1}$**




**Measurements**

# R&D on THz Coated Metallic Structures (CMS)

- NEG Electrodynamical properties
- Thickness, flatness and roughness
- Structure Reproducibility
- Dipole and high order modes
- New laminated structure
- THz acceleration in CMS structures
- Principal proof experiment

# Experimental Program

**AREAL**

## User Community

### Applied Research

- Material Science
- Life Sciences
- Environmental Science

### Experimental Technique

- Ultrafast Irradiation
- Diffraction, Imaging
- Spectroscopy
- Pulse radiolysis
- Time-resolved exper.

## Accelerator community

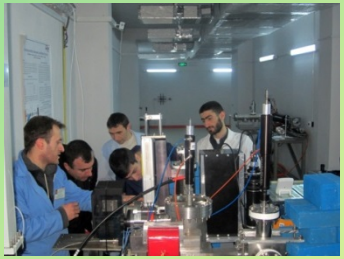
### Advanced Concepts

- New structures
- Ultrashort pulses
- New accel. methods
- New Radiation Sources

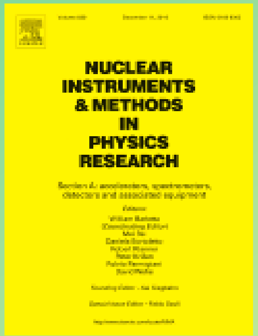
### Accel. Technology

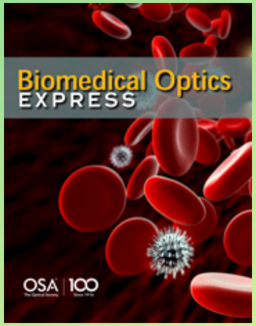
- New diagnostic tools
- Ultrafast timing& Control
- Beam manipulations
- High brightness beams

# Summary

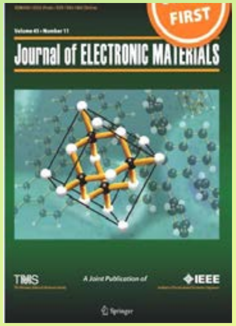


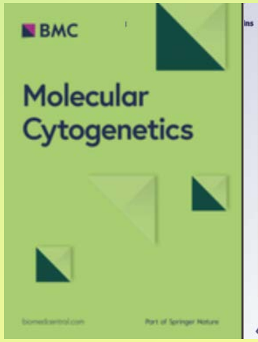
- After a 30 year break, the accelerator driven research in Armenia is recreated.
- Establishment of international user community.
- Strong User community – key for the AREAL

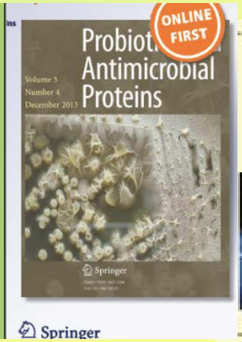


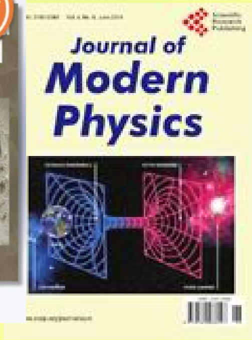








**Thank You !!!**