# *ADVANCED RESEARCH ELECTRON ACCELERATOR LABORATORY BASED ON PHOTOCATHODE RF GUN

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*Abstract*

The low energy sub-picosecond duration electron bunches with extremely small beam emittance have wide applications in advanced research of new accelerator concepts, radiation physics, time-resolved pulse radiolysis and electron diffraction. The conceptual design and experimental program of the Advanced Research Electron Accelerator Laboratory (AREAL) at CANDLE based on photocathode RF gun are presented. The AREAL design implies single and multibunch operation modes with variable beam energy of 5-20 MeV and 10-100 pC bunch charge. The design is based on 3 GHz 1.6 cells RF gun followed by S-Band accelerating linac.

## INTRODUCTION

CANDLE [1] project in Armenia is aimed to create a 3GeV synchrotron light facility as an international laboratory for advanced research in wide spectrum of natural sciences. As the first stage of the CANDLE project implementation the creation of Advanced Research Electron Accelerator Laboratory (AREAL) based on photocathode RF gun is under consideration. The basic approach to the new facility is the photocathode S-band RF electron gun followed by two 1 m long S-band travelling wave accelerating sections in order to effectively utilize the RF equipment provided by DESY.

The generation of short duration electron bunches with extremely low beam emittance is one of the promising directions for experimental studies of the wake field accelerator concepts, the impedances of various type structures, new coherent radiation sources. The potential application of ultrashort bunches is also very promising for electron diffraction experiments to study the dynamics of atomic and molecular processes [2]. The most effective way to produce short, low-emittance electron bunches is the technique of laser driven photocathode with radio-frequency (RF) cavity electron gun [3]. The new laboratory will also serve as a test facility for the development of various sub-systems and training of young scientists.

The preliminary conceptual design of AREAL implies single and multibunch operation modes with variable beam energy of 5-20 MeV, 10-100 pC bunch charge and sub-picosecond bunch duration. The new laboratory will be located in the CANDLE institute main building, where corresponding infrastructure is available (Fig.1, Fig.2). The schematic layout of the new facility is given in Fig.3.

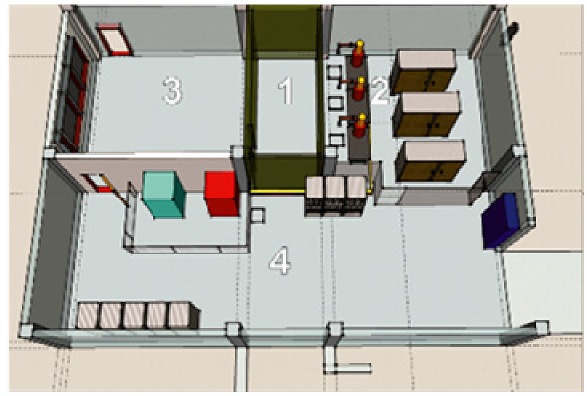


Figure 1: The AREAL supply infrastructure. 1- Laser room, 2- Klystron room, 3 –Control room, 4 - Auxiliary systems.

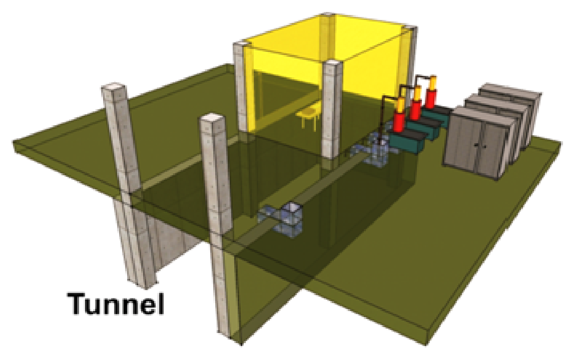


Figure 2: The AREAL tunnel and supply infrastructure.

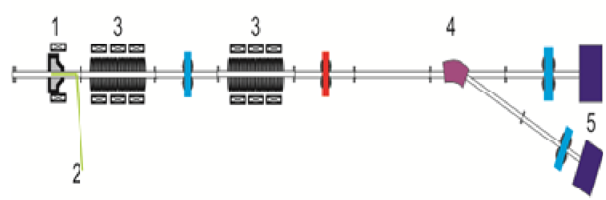


Figure 3: Schematic layout of AREAL 20 MeV S-Band linear accelerator. 1- RF –photo gun, 2- laser, 3- S-Band accel. sections, 4 –spectrometer, 5 - Beam dump.

The list of the beam parameters of AREAL preliminary design is given in Table.1

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Table 1: Beam Parameters List

| Main Parameters | Single bunch | Multibunch |
|---|---|---|
| Beam energy | 5-20 MeV | 5-20 MeV |
| Bunch Charge | 100 pC | 5-10 pC |
| Transv. norm emit. | <0.3 mm-mrad | <0.3 mm-mrad |
| Rms bunch length | <0.8 mm | <0.8 mm |
| rms energy spread | <20 keV | <20 keV |
| Bunches per RF pulse | 1 | 50 |

## RF GUN AND LASER

The copper cathode is chosen an electron source. Copper cathode is less effective in electron production compared to CsTe or Mg, etc. but it has longer lifetime. Emitted electrons are captured and accelerated by the electric field of RF gun. The S-Band 1.6 cell RF gun cavity will be supplied by 5 MW klystron. RF gun and the laser illumination scheme are shown in Figure 4.

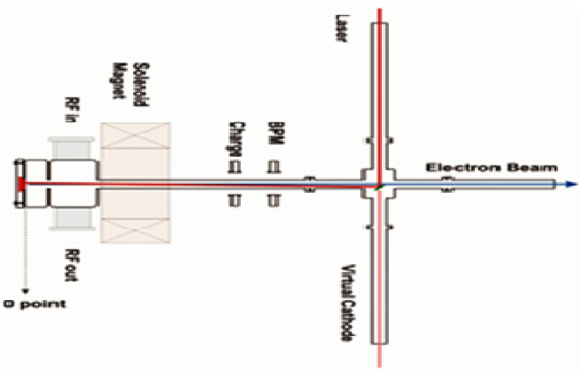


Figure 4: The layout of the photocathode RF gun section.

Using the ASTRA code [4], the gun gradient scan is performed to get the minimum transverse emittance and energy spread at the gun exit. The optimum, taking into account the space charge effects, is achieved for the RF gradient of about 80-90 MV/m [5].

Simulations are performed to obtain the minimum emittance and energy spread at the position of 0.25 cm from photocathode (the location of gun exit flange) by scanning the RF acceleration field phase. The optimal operating RF phase for gun is chosen 32 degree which is a compromise of the minimum emittance and energy spread at the RF gun exit [5].

An important task is to choose the appropriate laser system capable to produce electrons in single and multi bunch mode. Taking into account that RF pulse length is 1μs to fill up 50 of RF buckets, pulse frequency of 50 MHz is required, which can be achieved by splitting the laser power. In multibunch mode operation 5-10 pC charge per bunch is foreseen.

To obtain the specified bunch parameters for different operating regimes the laser system has to satisfy the requirements given in Table 2.

Table 2: Laser Specifications

| | |
|---|---|
| Wavelength | Center at 266 nm |
| Pulse-to-pulse Frequency | 1 MHz – 100 MHz (tuneable) |
| Pulse width | ~ 10 ps |
| Pulse time structure | 10 - 100fs |
| Energy (per pulse) | ~ 100 - 15 uJ |
| Beam Diameter | ~ 2 mm (at cathode) |
| Power Stability | 1% |
| Pulse-to-pulse jitter | <100 fs |

For 10 ps long bunch structure filling with 100 fs accuracy allows to obtain different bunch filling forms. Gaussian to pseudo-gaussian bunches are assumed for nominal operation. Variable laser pulse-to-pulse frequency allows to get different number of bunches per RF pulse. Some industrial or scientific laser systems are available for this option.

## RF SYSTEM AND ACCELERATION

As the RF power source, 3 S-Band klystrons with 7MW capability for the gun and accelerating sections will be operated. Supplying 4 MW power one can provide about 90MV/m accelerating gradient in RF gun, which is sufficient to capture and pre-accelerate electrons from cathode. About 3 MW of RF power will be used to correct and stabilize RF phase for the RF gun.

For travelling wave accelerating sections the same type of klystrons will be used, providing about 10-17 MV/m accelerating gradient in sections using 7 MW of RF power (Figure 5).

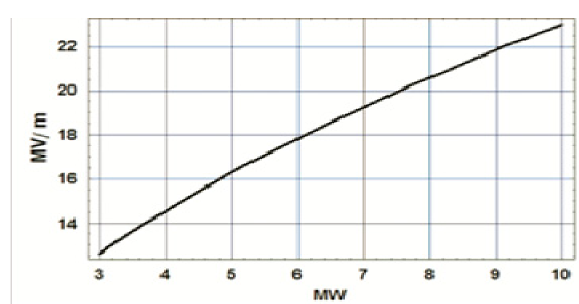


Figure 5: Obtained gradient vs RF power for S-Band accelerating sections.

The corrections and control of RF stations will be performed by commercially available LLRF system. Synchronization with the laser pulse will be done by triggering pulse from master oscillator.

## START-TO-END SIMULATIONS

To optimize the layout of the facility main components and the RF parameters the tracking simulations are performed using the ASTRA code. The tracking simulations aimed to obtain the optimum accelerating voltage and RF phase in gun and accelerating section in order to obtain minimum beam emittance and energy spread. Figure 6 presents the evolution of normalized emittance (top) and the beam transverse size (bottom) along the entire facility.

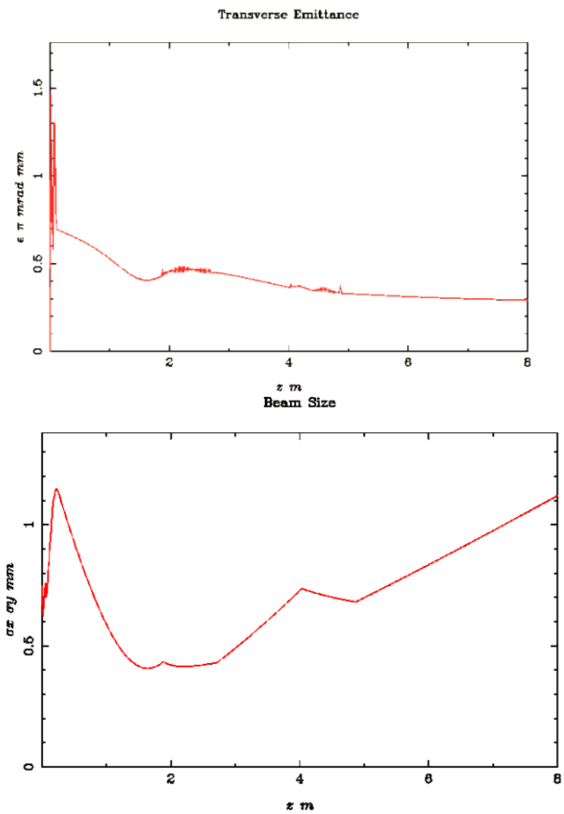


Figure 6: Transverse normalized emittance (top) and beam rms size (bottom) evolution along the linac.

At the linac exit the maximum beam energy is about 23.5 MeV with the normalized transverse emittance of about 0.3 mm-mrad and the rms energy spread is below 0.1%. The preliminary results of space charge dominated bunch tracking through linac have shown the potential for further optimization and improvements in design.

## DIAGNOSTIC AND CONTROL SYSTEM

The main function of the AREAL Diagnostic System is to measure the main parameters of the beam in time and space domain, providing the necessary data for the feedback system and machine control. The diagnostic tools of the facility imply the measurements of the beam position and current, the longitudinal and transverse profiles, the absolute energy and the energy spread. The diagnostic section will be equipped with the Faraday cup, fluorescent screen, DC current transformer, fast current transformer, integrated current transformer, beam position monitor, strip line, scrapers, beam loss monitor, CCD camera and streak camera.

For the Control System it is planned to use PCs with Linux and Windows operating systems. Almost any processors, analog or digital input/output modules and fieldbus interfaces are available in VME, so most of the device input and output channels will be connected via VME modules or fieldbus electronics to the device servers. All data communications between front-end systems, central systems and consoles will be Ethernet based. The main sections under control are RF system, power supply system, vacuum and cooling systems, safety. It is planned to use EPICS Control System software.

## SUMMARY AND OUTLOOKS

The preliminary design of the AREAL photocathode RF gun linear accelerator based on the existing infrastructure and RF equipment are studied. The optimization of the facility layout and the main parameters of the RF system are performed. The facility current design allows to obtain maximum beam energy of about 23.5 MeV at the linac exit with the electron beam normalized emittance of 0.3 mm-mrad and the rms energy spread below 0.1%.

As the highlights for the low emittance, short pulse electron beam application, the experimental program on AREAL is under development. The preliminary list of experimental program includes the study of

- High-frequency resonant properties of the multi-layered metallic and dielectric-metal structure.
- Coherent radiation of a few MeV ultrashort electron bunches in THz region.
- The energy modulation of the beam in beam plasma interaction by shaping the beam longitudinal distribution.
- Non-relativistic modulation of the electron beam density in beam –plasma interaction.

The AREAL parameters further optimization is in progress, including the development of the various sub-systems of the accelerator.

## REFERENCES

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