Muons, Inc.
www.muonsinc.com

Sheet Electron Probe for Beam Tomography
Project Progress Report
Award Number DE-SC0021581
Period of Performance: 02/22/2021 through 04/03/2024
Grant Recipient: Muons, Inc.
Principal Investigator: Dr. Vadim Dudnikov
Report Prepared: July 29, 2023

Company Background

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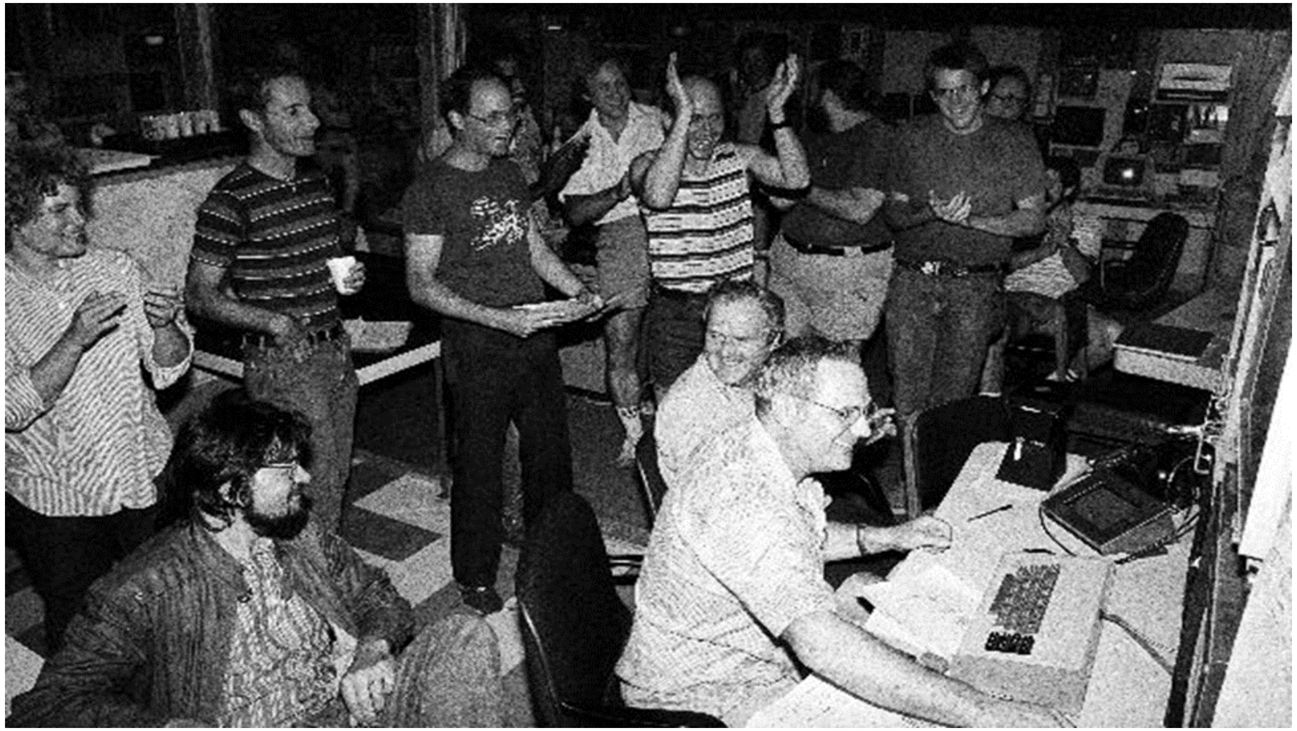


- Founded by National Lab scientists
- To help accomplish DOE Mission
- 21 years of R&D experience
  - particle accelerators
  - related technology
- Awarded and delivered $34M
  - Private and government contracts
- Partnerships
  - 11 National Labs
  - 9 Universities
- Supported
  - 18 postdocs
  - 7 Ph.D. Students

Present Company Interests

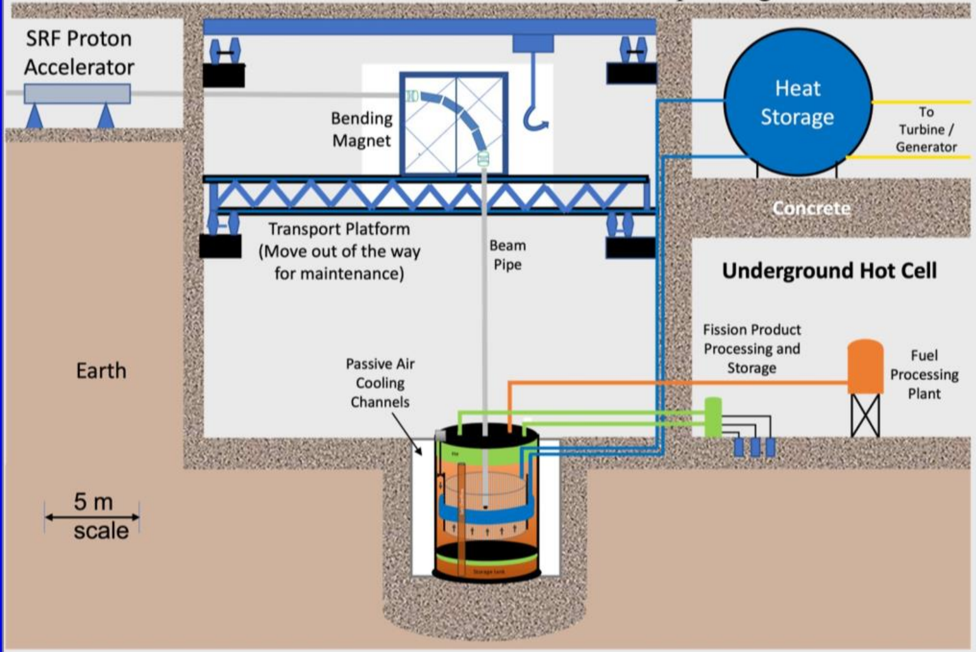
ARPA-E proposal

Accelerator Driven Fission

Underground Linac and Reactors

*Mu*STAR Nuclear Power Plants*

Mu*STAR (Muons Subcritical Technology Advance Reactor) is an Accelerator Driven Molten Salt Reactor with an Internal Spallation Target and Continuous Removal of Fission Products to consume Spent Nuclear Fuel from past, present and future reactors. Muons Inc is designing a 2 GWe Nuclear Power Plant to contribute to reaching the zero carbon goals of many US states in the next two decades based on subcritical power generation.



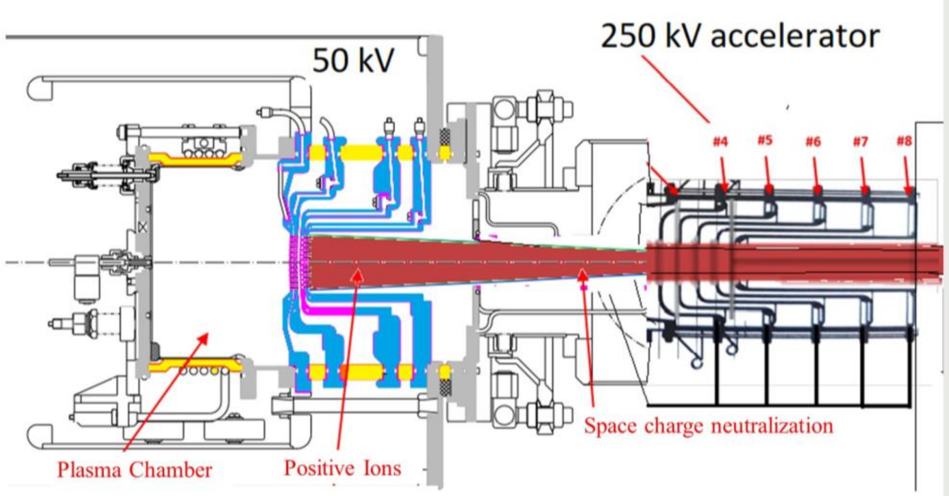
Converting SNF to MS Fuel Muons Inc. ORNL/TM-2018/989

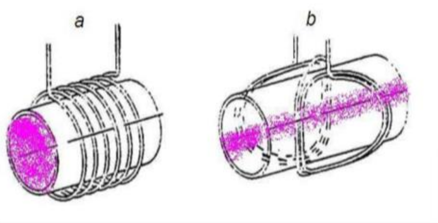
Accelerator Driven Fusion

T^+ and D^+ 300 keV ions for Italian Contract

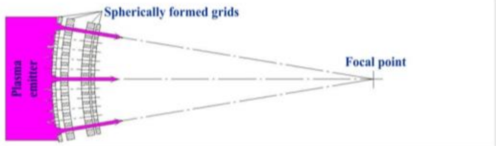
Sorgentina-RF Neutron Source

Muons is providing the ENEA ion source and accelerator to create fusion reactions on a rotating target for neutrons to convert Mo-100 to Mo-99.





Plasma *discharge* chamber a) solenoid b) saddle antennae



Ballistic Focusing by spherical extraction electrodes allows the simultaneous focusing of ions with different charge to mass ratios

$2M contract From ORNL SBIR project-led by Dudnikov

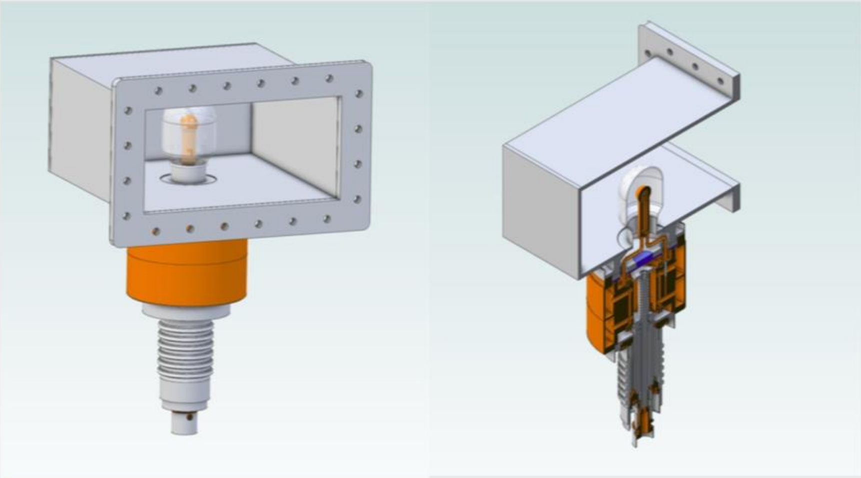
Company Interests (continued)

Efficient Magnetron RF Sources

Muons is developing designs and constructing prototypes of strap-and-vane and coaxial magnetron RF power sources at various frequencies and operating parameters with Richardson Electronics LLC (www.rell.com).

The photo on the right is our first 1497 MHz CW 20 kW prototype magnetron, now being tested at JLab as a possible high-efficiency replacement for CEBAF klystrons..

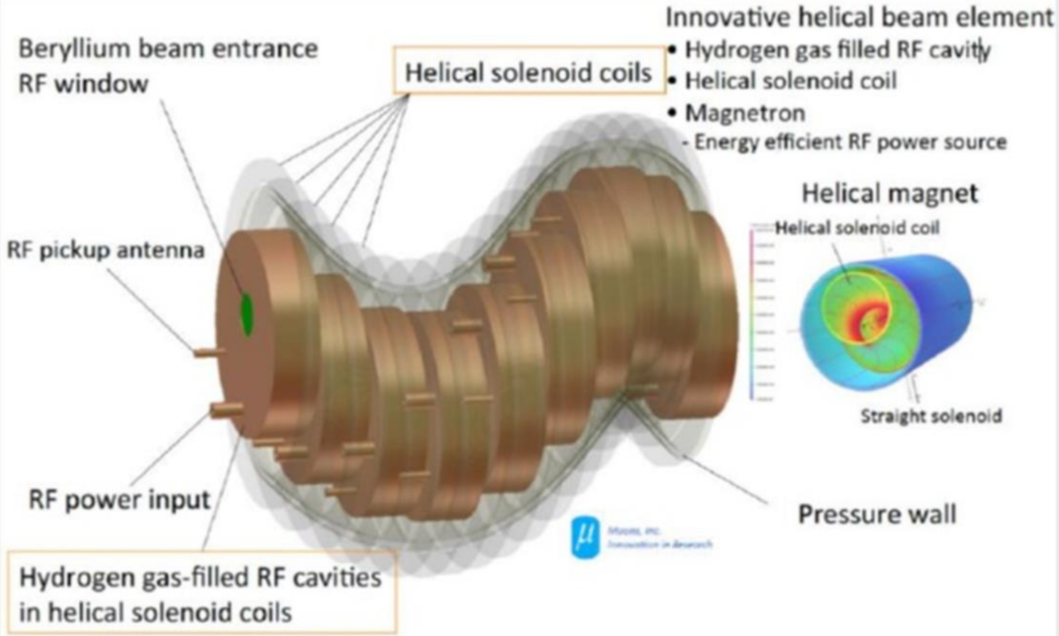
New methods of control are being pursued based on operating the magnetron with anode voltage below that needed for self excitation – that can allow a wider range of power output as well as the possibility to operate in pulsed mode without the need for expensive modulators.



STTR project w JLab

Plasma-enhanced Muon Beam Cooling

Plasma created by the Muon Beam passing through pressurized hydrogen gas creates space-charge neutralization for extra cooling to enable low emittance for high luminosity Higgs Factory and/or Energy Frontier Muon Colliders. The Helical Cooling Channel and enabling technologies were invented and developed by Muons, Inc. under DOE grants and contracts.



G4beamline, H_2-pressurized RF Cavities, Emittance Exchange in a Continuous Absorber, Helical Solenoid, HCC theory, Parametric Resonance Ionization Cooling - invented for Small Business Innovation Proposals.

SBIR Proposal for Higgs Factory

ELECTRON GUN FOR SHEET ELECTRON PROBE FOR BEAM TOMOGRAPHY*

Vadim Dudnikov†, Mary Anne Clare Cummings, Galina Dudnikova, Rolland P Johnson, Muons, Inc, Batavia, Illinois, 60510 USA

Background and Motivation

- Transverse electron beam scanners (TEBS) were
  - realized recently for use in the SNS storage ring by Aleksandrov et al.
- Laser beam scanners are used at
  - H^- Linacs, Optical Transition Radiation screens, Synchrotron Radiation Monitors for relativistic beams.
- Non-destructive transverse profile measurements
  - are preferred not only for single-path diagnostics at different locations in a transfer line
  - also to enable time-resolved observations of a stored beam within a synchrotron.
- A more practical, however essential, reason for minimal invasive diagnostics
  - is the large beampower available at modern hadron accelerators
  - which excludes the usage of intercepting methods
    - scintillation screens, SEM-grids or wire scanners
      - risk of melting when irradiated by the total beam intensity.

Advanced Sheet electron Probe Beam Profile Monitor

The advanced sheet electron probe beam profile monitor (SEPBPM) with the strip cathode is proposed as shown in Fig. 1. For the slice (6) of sheet electron probe formation is used the strip cathode (1) with extractor (2). The sheet electron probe is formed by a collimator with two slits (3) and (5). The short slice of sheet electron probe (6) slid after deflection by electric field of proton bunch is visualized on the luminescent screen (7) and fixed by a fast CCD camera for further processing by the corresponding software.

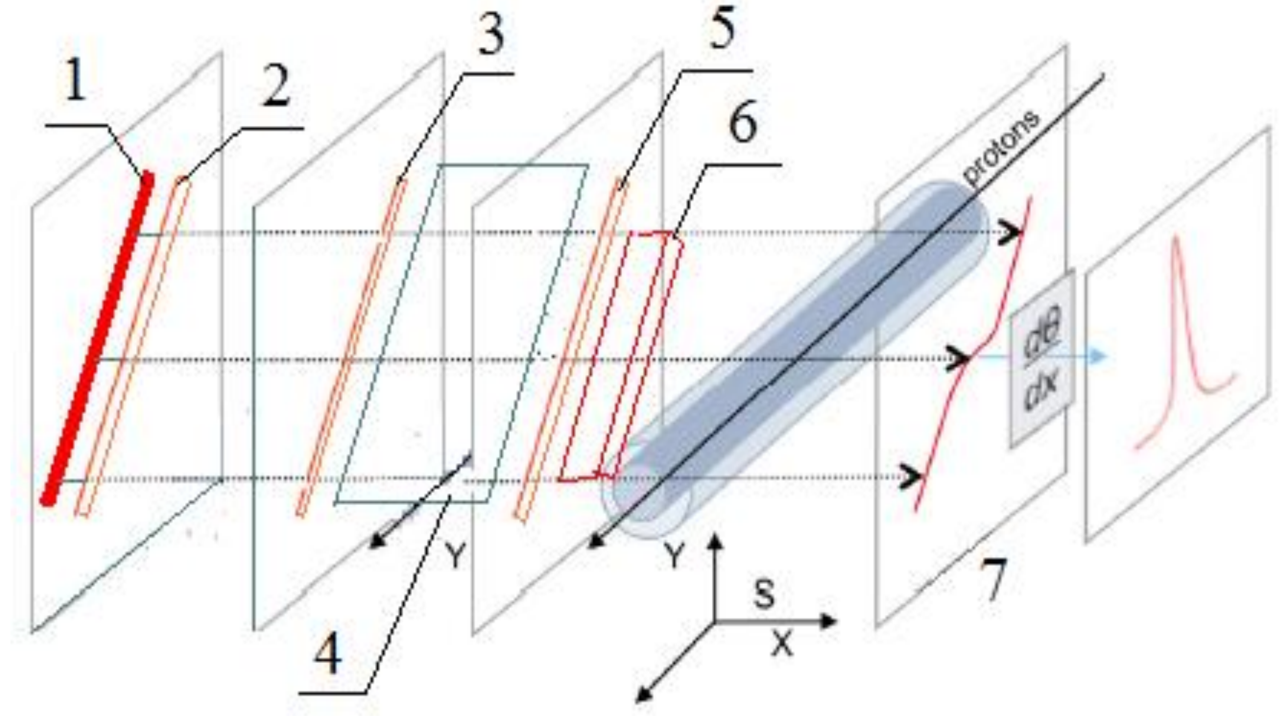


Fig. 1 Sheet Electron probe beam profile monitor with a strip cathode.

1-strip cathode; 2-extractor; 3-first slit of collimator; 4-deflecting plate; 5-second slit of collimator; 6-sheet slice of electron beam probe; 7-luminiscent screen

This version of the SEPBPM is smaller, and easy for fabrication, operation, and magnetic shielding. Several similar systems can be integrated for the production of the tomographic 3-D image of proton bunches. The proposed tomographic system is more compact, easier to operate, and less expensive than the residual gas ionization profile monitor (IPM) discussed above.

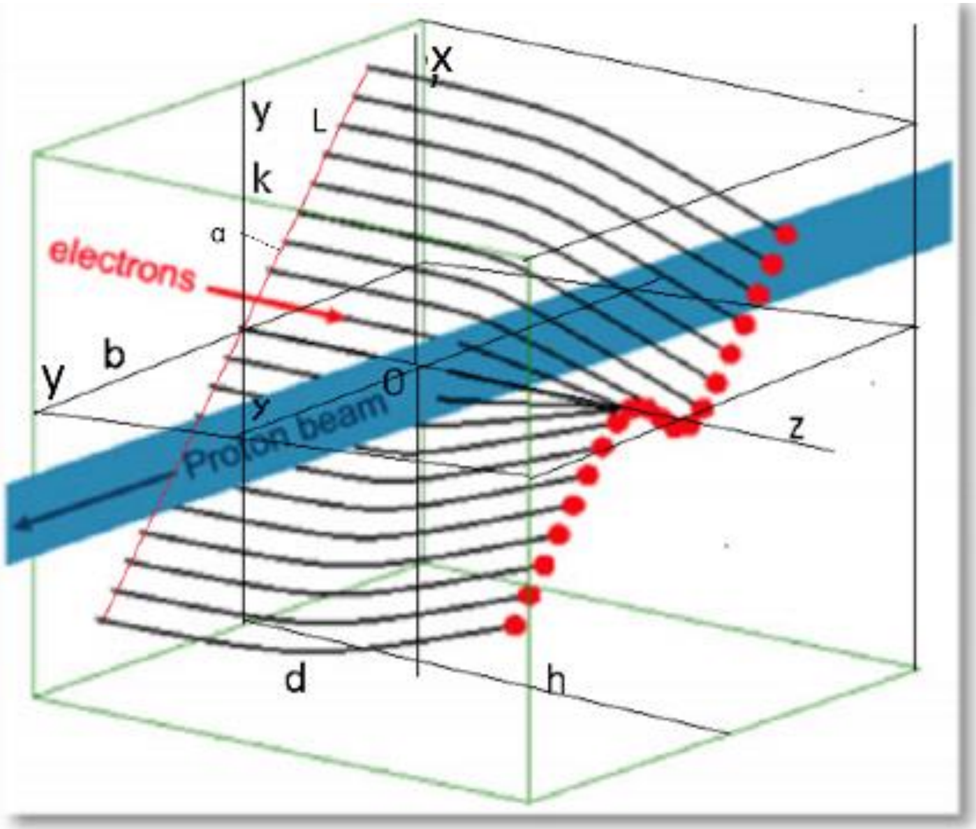


Fig. 2. Isometric view of Modification of strip e-beam profile monitor with a slice of the sheet electron probe.

SIMULATION OF PROBE BEAM DEFLECTION BY A PROTON BUNCH

A computer program for simulation probe beam deflection by proton bunch has been developed.

Examples of simulations are presented in Fig. 3 that shows deformations of the sheet electron probe beam with energy 30 keV by a proton bunch with γ=10 and different proton numbers.

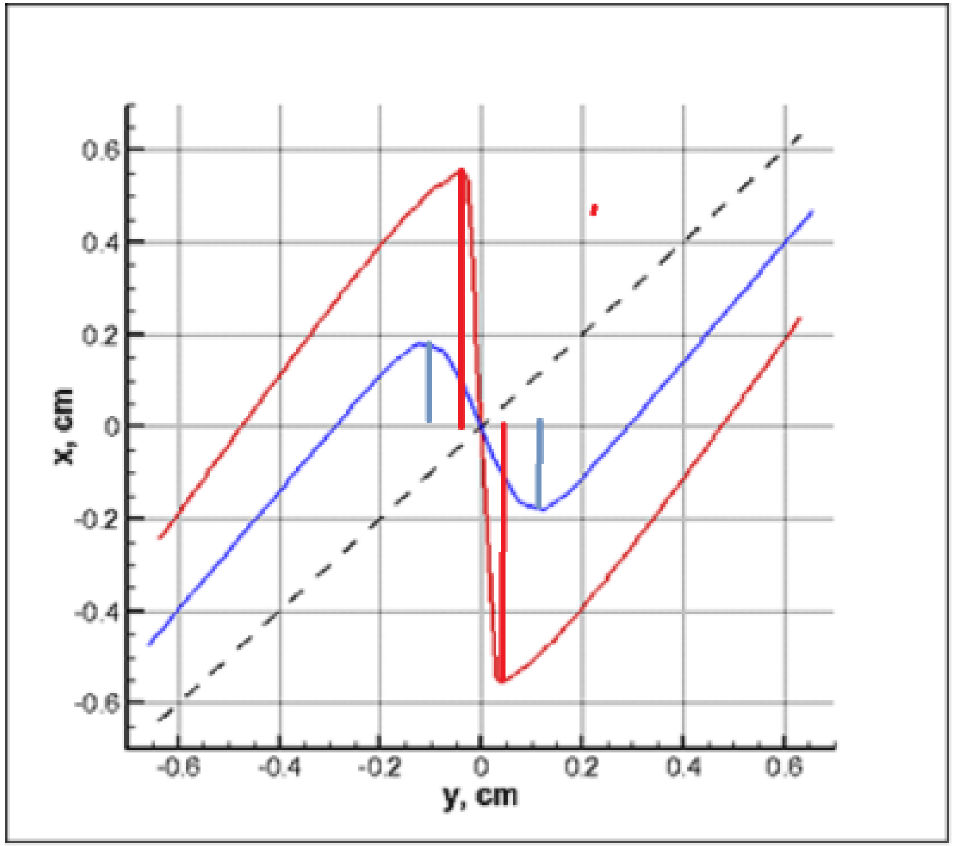
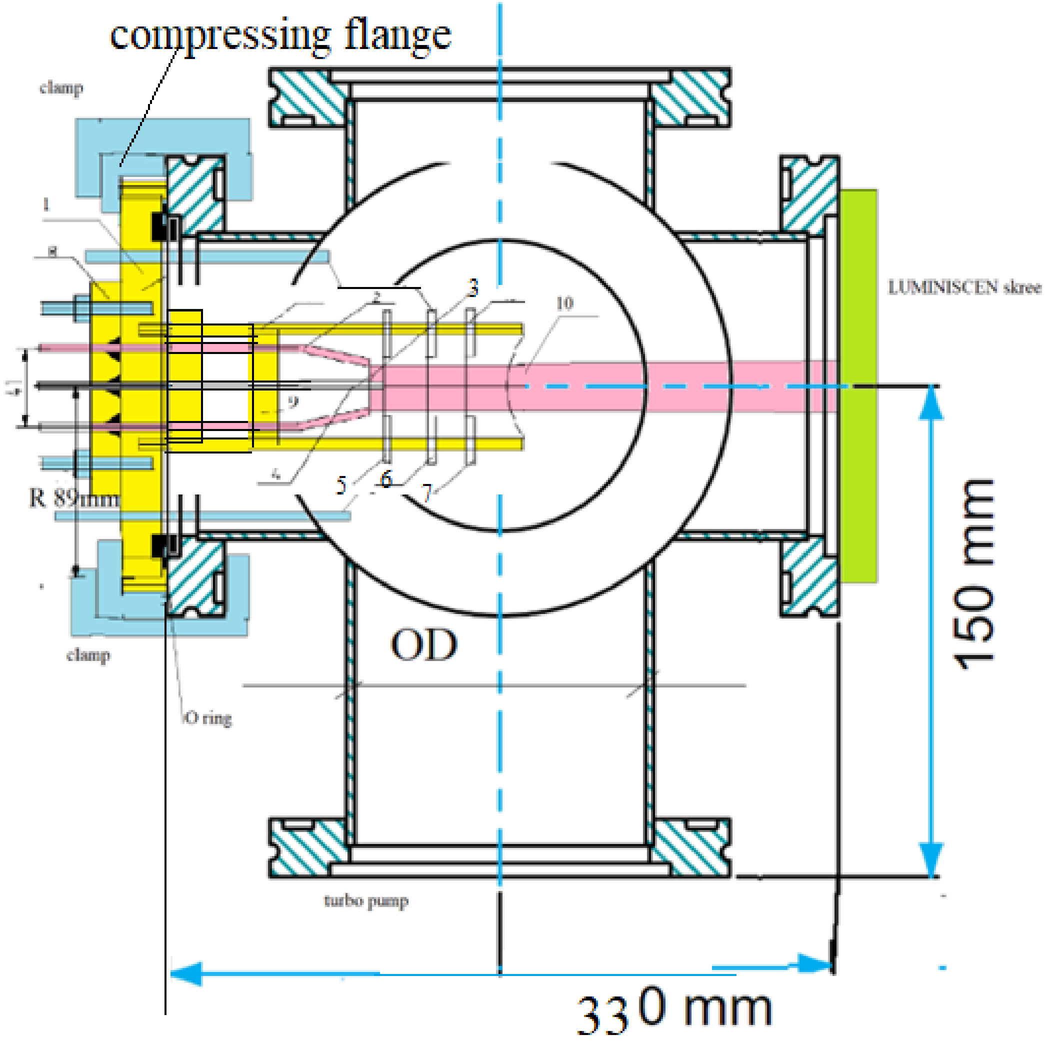


Fig.3. Tracks of deflected electron beam on the luminescent screen for RUN1-red, RUN2-blue. Dashed line is trace of non-deflected electron beam. Distance between max and min of red curves Δy=24 mm and Δy=36 mm for blue are related to horizontal dimension of proton bunch. Amplitude of deflection is proportional to the number of protons, γ-factor of proton bunch, and inverse proportional of electron beam energy



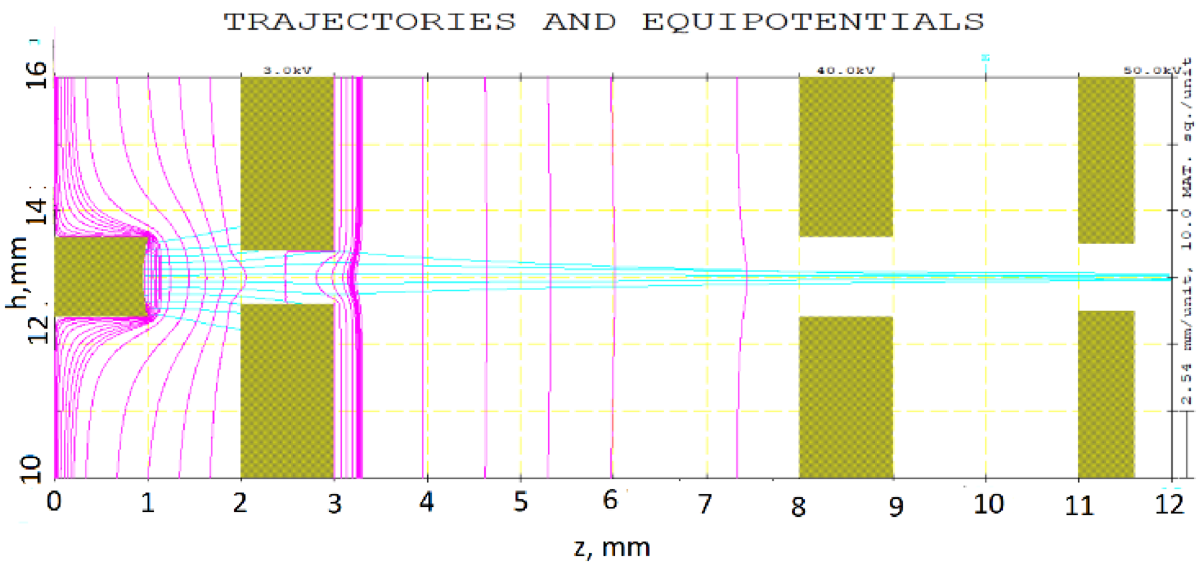


Fig. 5. Computer simulation of electron beam formation. Optimal focusing with low aberrations Vext=3 kV energy 40 keV.

Fig. 4. Schematic of electron gun for production of Sheet electron Probe Beam. 1-ceramic disc, 2-current leads, 3-IrCe emitter of electron, 4- feedthrough, 5- extraction electrode, 6-accelerating electrode, 6-ceramic support rods, 7-flange, 8-compression flange, 9-compression ceramic, 10-sheet electron Probe Beam.

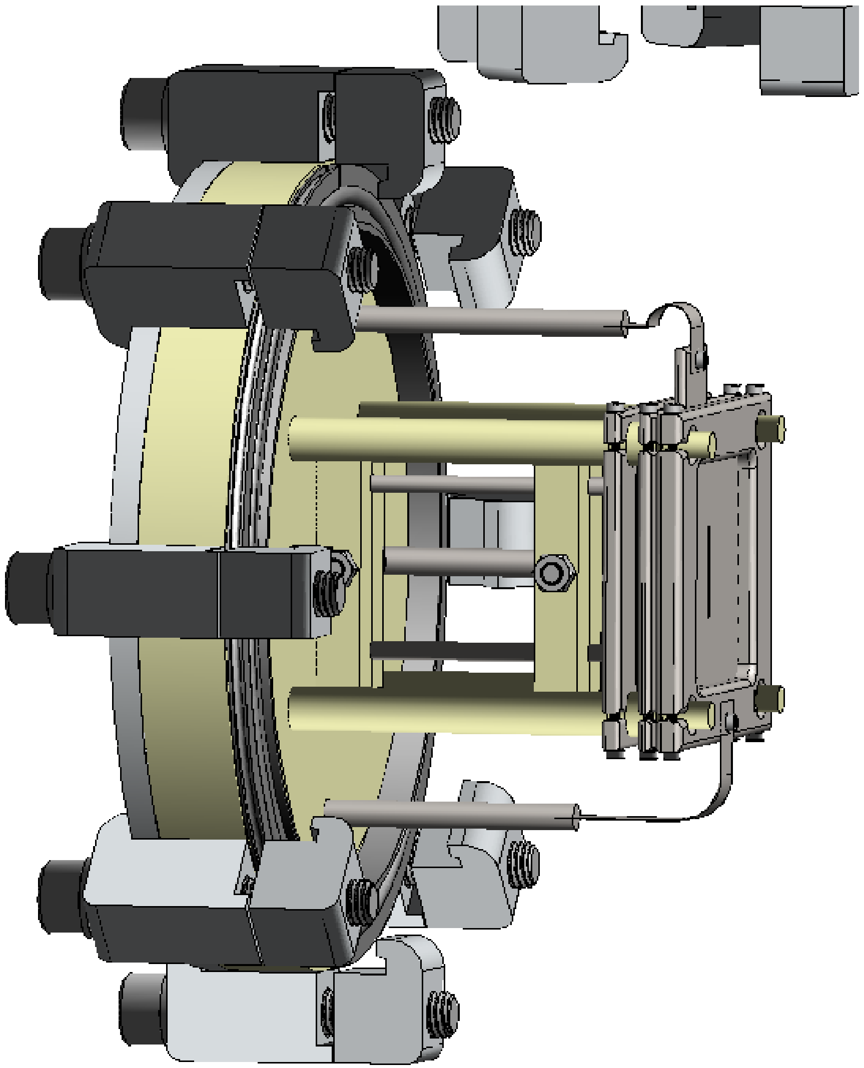
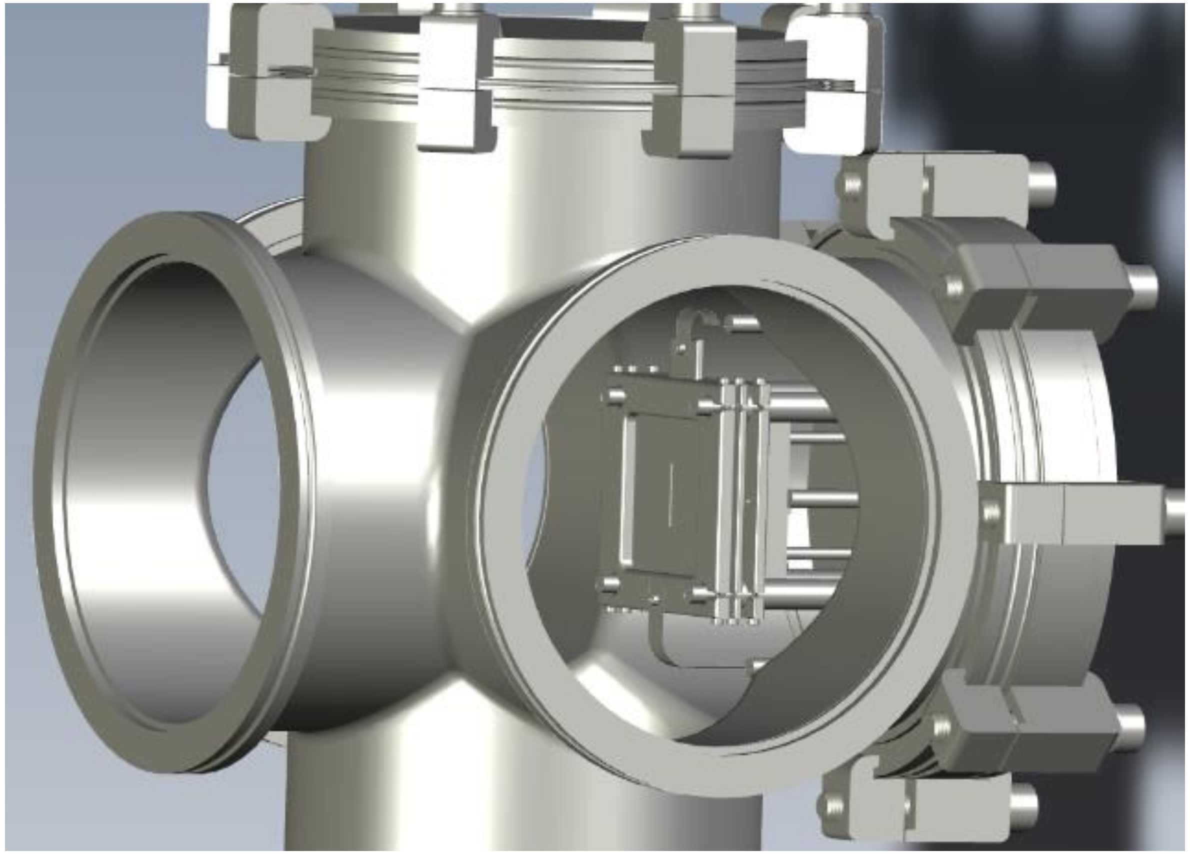


Fig. 6. Design of electron gun for sheet electron beam production



Sheet electron gun in vacuum chamber

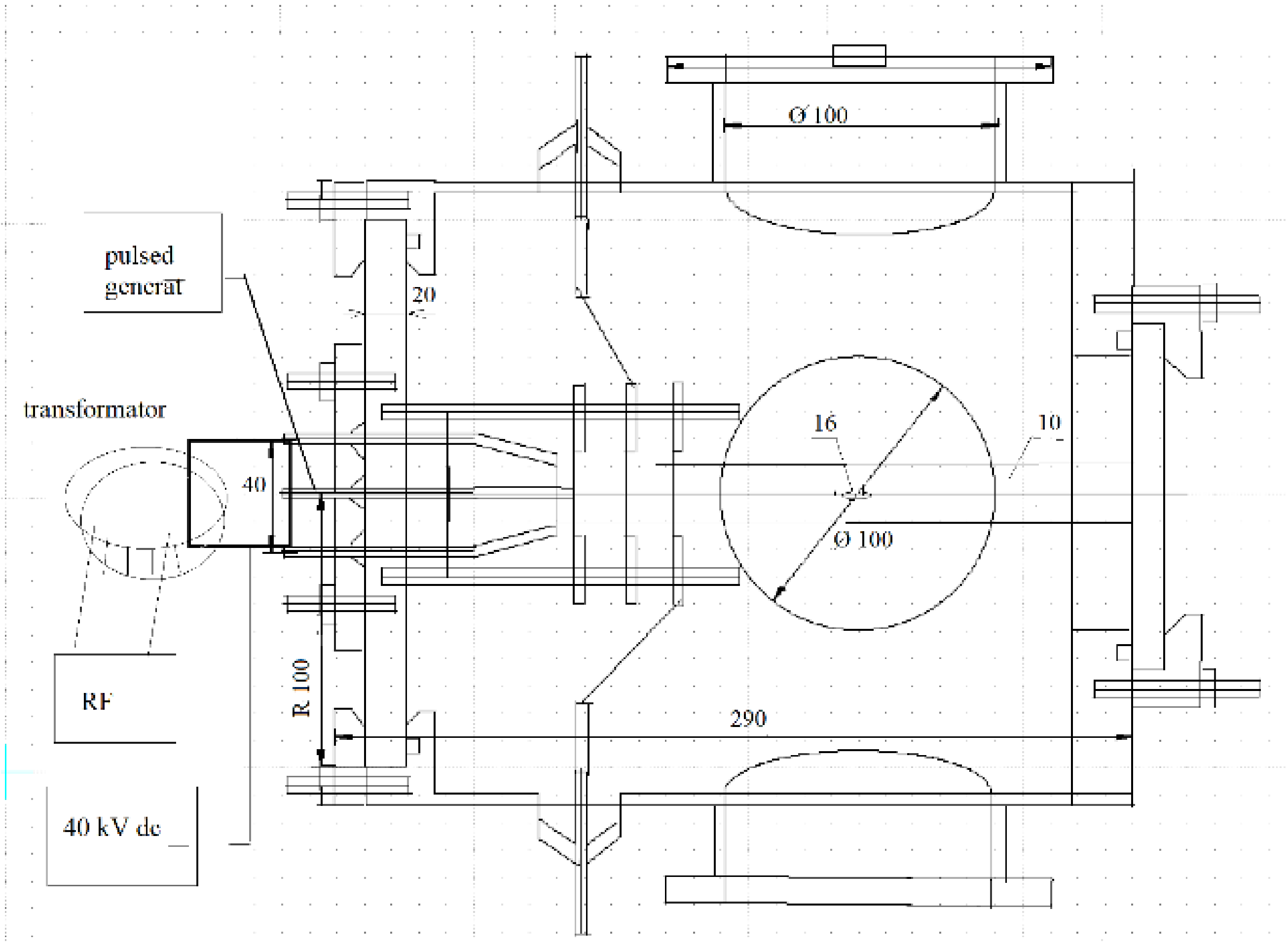


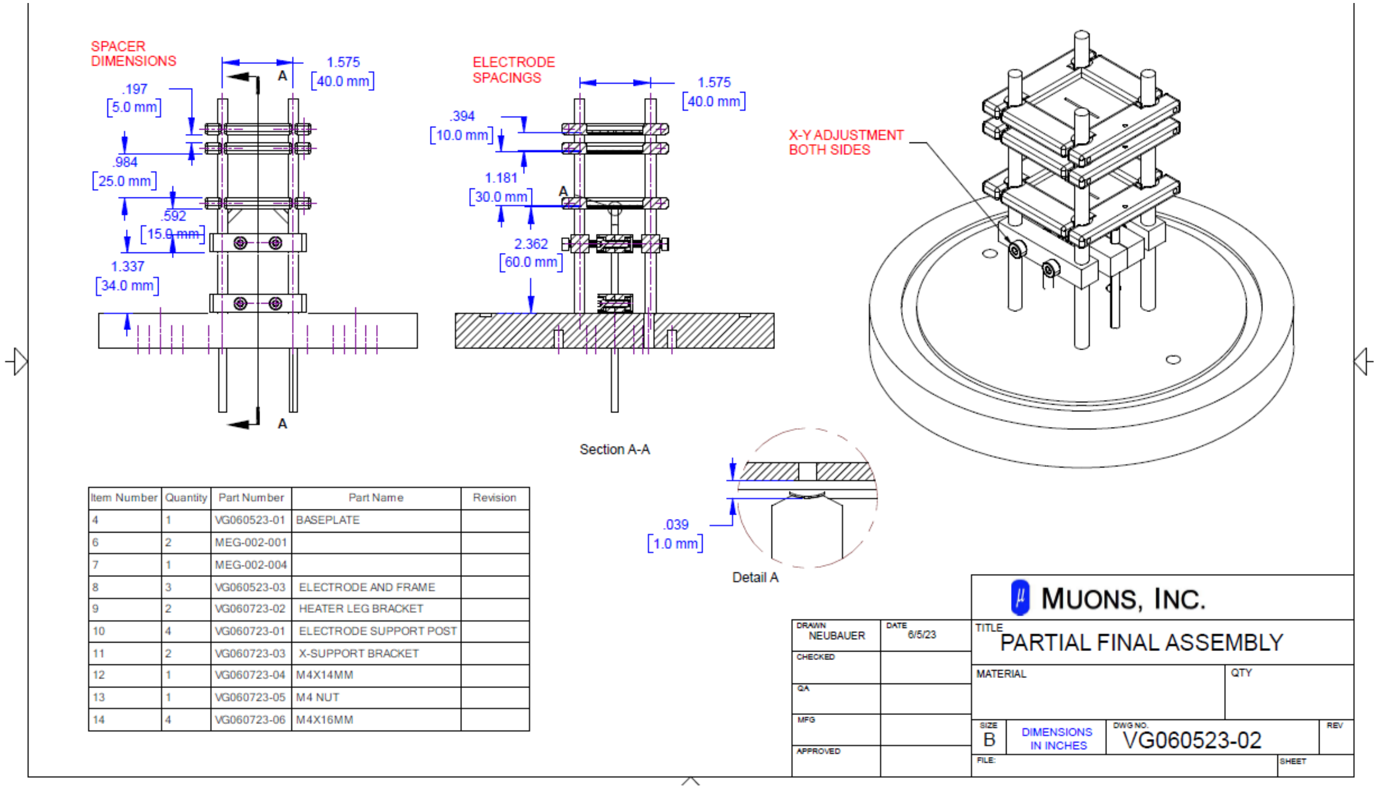
Fig. 8. Schematic power supplies for cathode of electron gun

High voltage DC power supply is connected with emitter.

1-- IrCe emitter of electron 0.1x2x20 mm, 2-current leads (material stainless steel), 3- extractor electrode, 4-extraction feedthrough, 5-accelerating electrode, 6-ceramic support roads, 7- ceramic disc (MACOR), 8-compression flange, 9-compression ceramic, 10-sheet electron Probe Beam, 11-vacuum chamber of a proton bunch, 12-acceleration feedthrough, 13-vacuum chamber of a proton bunch, 14-lead for focusing electrode, 15-focusing electrode, 16-proton bunch.

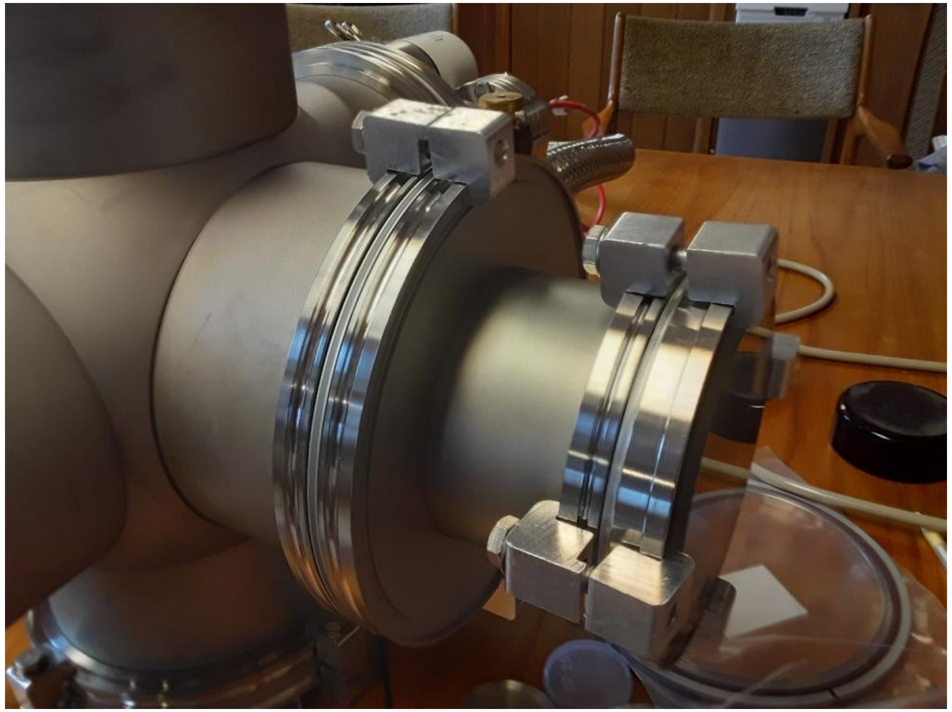
The emitter is heated by RF current delivered from RF generator by an insulating transformer (Fig. 8).

Vacuum pumping of 6-way cross vacuum chamber



Item Number	Quantity	Part Number	Part Name	Revision
4	1	VG060523-01	BASEPLATE	
6	2	MEG-002-001		
7	1	MEG-002-004		
8	3	VG060523-03	ELECTRODE AND FRAME	
9	2	VG060723-02	HEATER LEG BRACKET	
10	4	VG060723-01	ELECTRODE SUPPORT POST	
11	2	VG060723-03	X-SUPPORT BRACKET	
12	1	VG060723-04	M4X14MM	
13	1	VG060723-05	M4 NUT	
14	4	VG060723-06	M4X16MM	

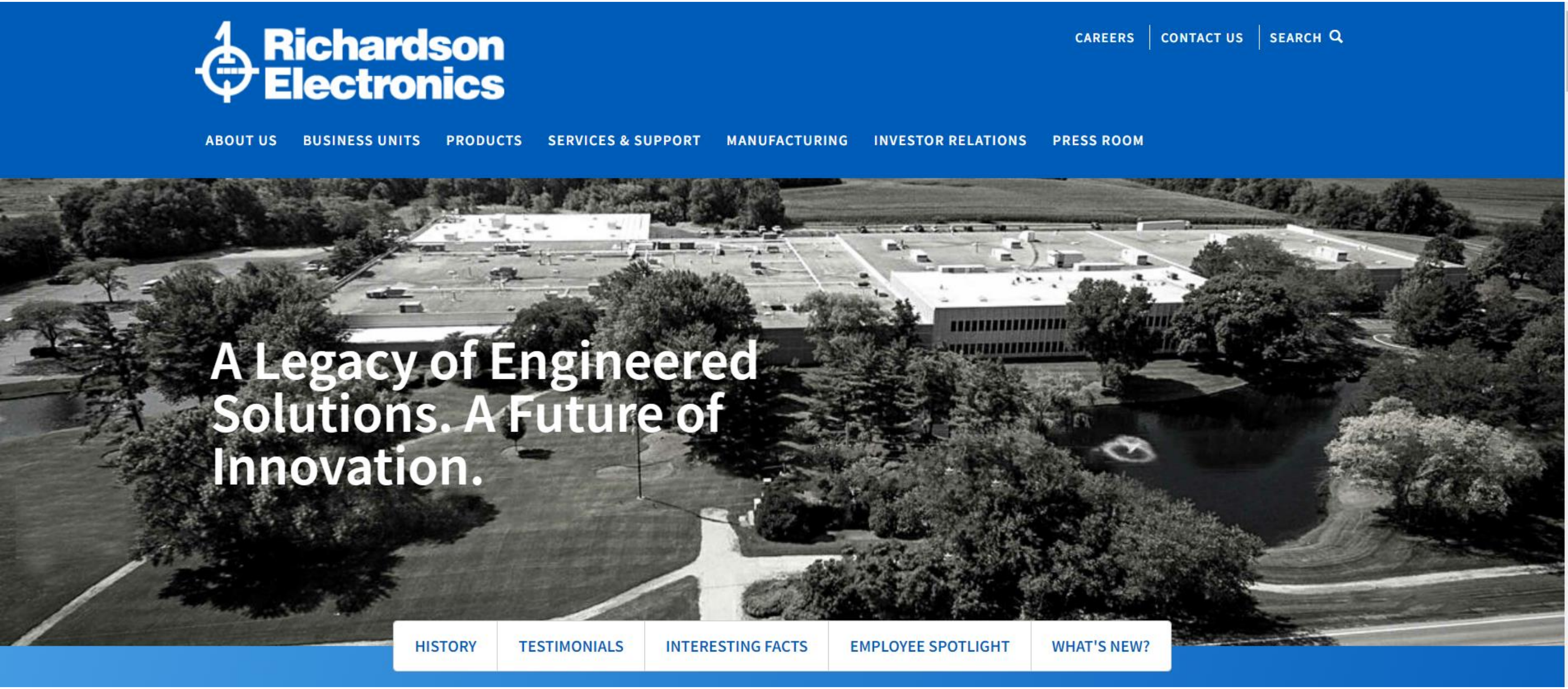
Design of sheet electron gun



Vacuum Chamber Design

6-Way ISO-K HV Cross

Richardson Electronics (RELL.com, LaFox, IL) - Manufacturing partner for Muons, Inc. products: Beam Diagnostics, Magnetron power sources, Italian 1 A 300 kV D+ T+ fusion project for Mo-99



Conclusions and Next Steps

- Sheet electron gun
  - Simulated
  - Designed
  - Components Constructed or Acquired
- Test setup Prepared
- Programs Developed
- Commercialization Partner Identified

- Next Steps
- Assembly, Operation, Testing
- Plan for Commercialization

Thank You very much