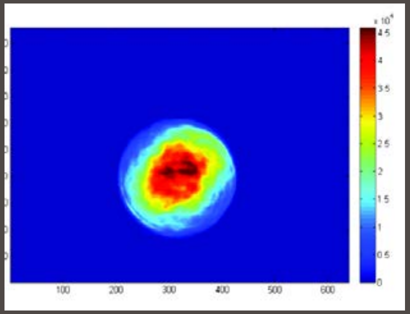
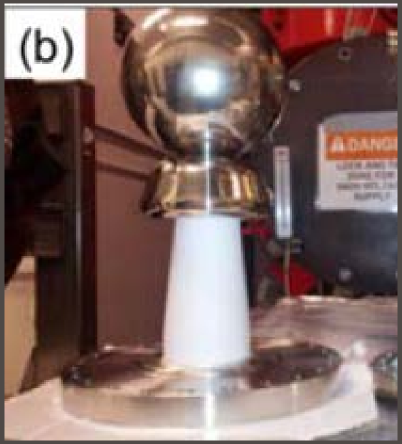
High Brightness Electron Source



options for TRIUMF e-LINAC

TRIUMF THz science workshop July 5, 2018

Friedhelm Ames



Requirements

RIB production

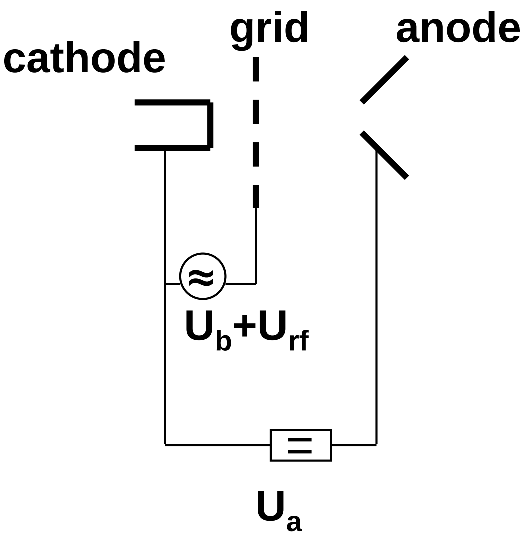
- 650 MHz
- 16 pC per bunch,
- ≈ 10 µm transverse emittance (normalized)
- pulse length
    - o with buncher <150 ps (at source)
    - o without buncher 10 ps

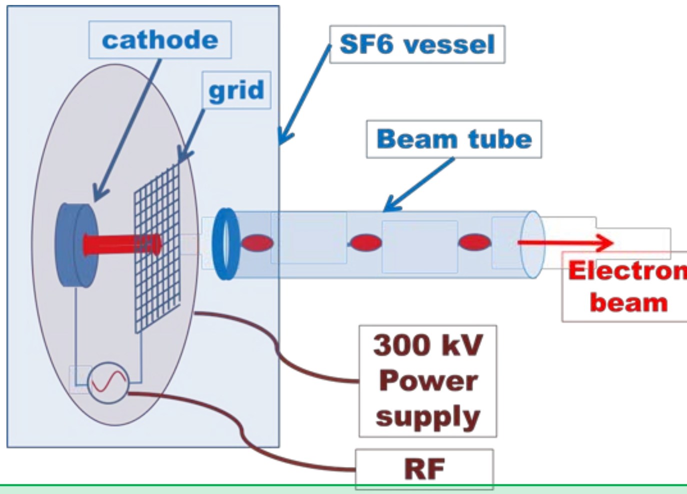
Infra-Red ERL or THz production

- 650 MHz/n (n=6)
- 100 pC per bunch,
- <1 µm transverse emittance (normalized)
- pulse length
    - o without buncher 1-10 ps

[Comment: for regime of nC/bunch, a different strategy would be adopted]

RF modulated thermionic source



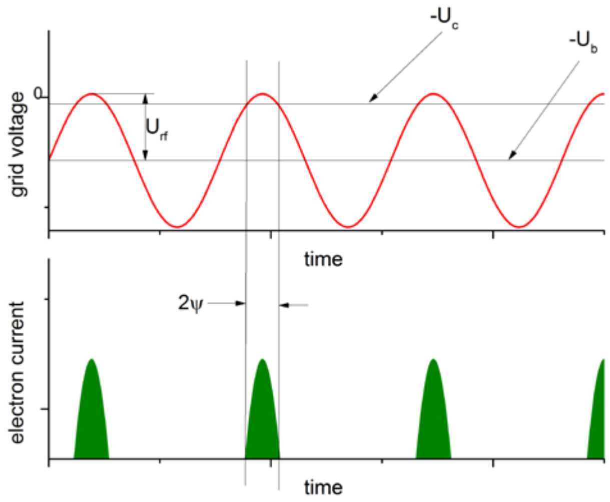


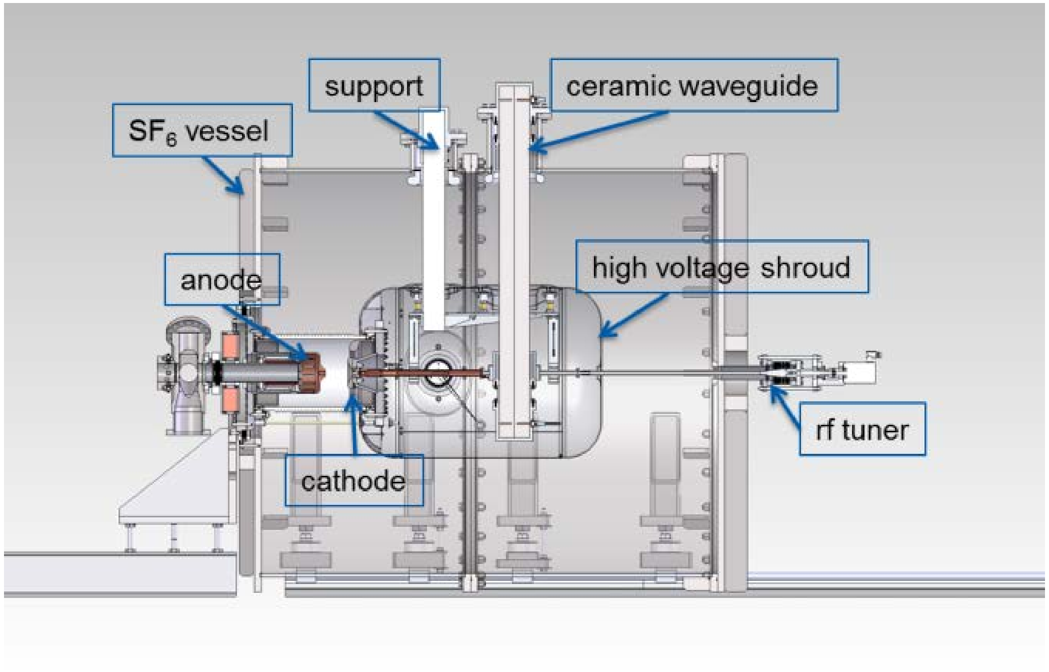
- kinetic energy **300** keV (β = 0.78)
- rf modulation frequency **650** MHz,
- pulse length +/- **16º** or +/- 68 ps (136 ps)).
- average current **10** mA
- charge / bunch **15.4** pC
- normalized transverse emittance ~**5-10** µm
- duty factor for macro pulsing **0.1-100**% (3 W-3 kW)

F. Ames et al., proceedings LINAC'16, JACoW.org

RF modulated thermionic source

TRIUMF electron source





source in SF$_6$ vessel

photo - gun

theoretical limits

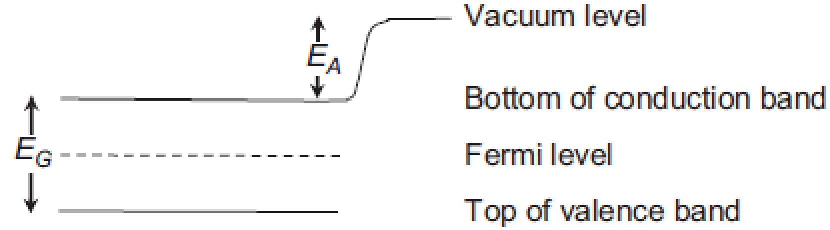
maximum charge per bunch: $Q = E\varepsilon_0\, \mathrm{A}$

→ field strength at Cathode for 100 pC and 1 mm laser spot radius:

E > 3.6 MV/m (present TRIUMF source: 3 MV/m)

emittance from semiconductor cathode:

$$\frac{\varepsilon_{semi,n}}{\sigma_x} = \sqrt{\frac{\hbar\omega - E_G - E_A}{3mc^2}}.$$



D.H. Dowell et al. / Nuclear Instruments and Methods in Physics Research A 622 (2010) 685–697

cathode properties

Table 3
Properties of semiconductor cathodes.

Cathode type	Cathode	Typical wavelength & energy, λ_{opt} (nm), (eV)	Quantum efficiency (electrons per photon)	Vacuum for 1000 h (Torr)	Gap energy+ electron affinity, E_G+E_A (eV)	Thermal emittance (microns/ mm(rms))	
						Eq. (7)	Expt.
PEA: mono-alkali	Cs_2Te	211, 5.88	0.1	10^{-9}	3.5 [42]	1.2	0.5 ± 0.1 [35]
		264, 4.70	–	–	"	0.9	0.7 ± 0.1 [35]
		262, 4.73	–	–	"	0.9	1.2 ± 0.1 [43]
	Cs_3Sb	432, 2.87	0.15	?	1.6+0.45 [42]	0.7	?
	K_3Sb	400, 3.10	0.07	?	1.1+1.6 [42]	0.5	?
	Na_3Sb	330, 3.76	0.02	?	1.1+2.44 [42]	0.4	?
	Li_3Sb	295, 4.20	0.0001	?	?	?	?
PEA: multi-alkali	Na_2KSb	330, 3.76	0.1	10^{-10}	1+1 [42]	1.1	?
	$(Cs)Na_3KSb$	390, 3.18	0.2	10^{-10}	1+0.55 [42]	1.5	?
	K_2CsSb	543, 2.28	0.1	10^{-10}	1+1.1 [42]	0.4	?
	$K_2CsSb(O)$	543, 2.28	0.1	10^{-10}	1+ < 1.1[42]	~0.4	?
NEA	GaAs(Cs,F)	532, 2.33	0.1	?	1.4 ± 0.1[42]	0.8	0.44 ± 0.01[44]
		860, 1.44	0.1	?		0.2	0.22 ± 0.01[44]
	GaN(Cs)	260, 4.77	0.1	?	1.96+?[44]	1.35	1.35 ± 0.1[45]
	$GaAs(1-x)Px$ $x\sim0.45$ (Cs,F)	532, 2.33	0.1	?	1.96+?[44]	0.49	0.44 ± 0.1[44]
S-1	Ag–O–Cs	900, 1.38	0.01	?	0.7[42]	0.7	?

The thermal emittances are computed using the listed photon, gap and electron affinity energies in Eq. (7) and expresses the thermal emittance as the normalized rms emittance in microns per rms laser size in mm.

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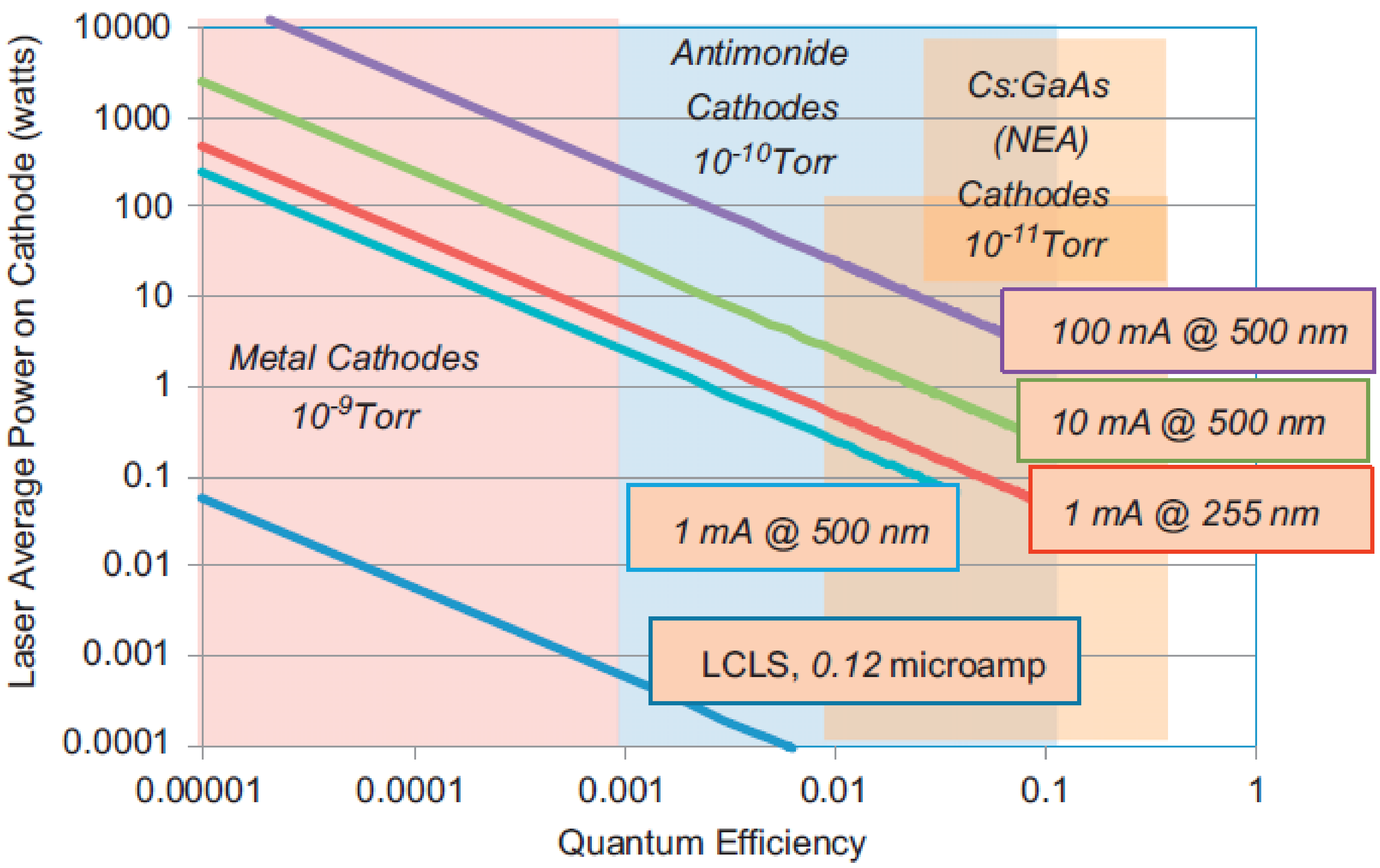
Photocathode choices for high (5-10 mA) average current

Cathode Type	Typical example	Typical QE at λ	P(W)xQE(%) for 10 mA
Negative electron affinity	GaAs(Cs,F)	8% at 750 nm	1.65 W%
Alkali antimonide	K_2CsSb	10% at 520 nm	2.38 W%
Alkali telluride	Cs_2Te	5% at 266 nm	4.66 W%

C. Sinclair (2009)

laser power and vacuum requirements

D.H. Dowell et al. / Nuclear Instruments and Methods in Physics Research A 622 (2010) 685–697



K_2CsSb cathode

Figure 1: Sealed photocathode.

commercial cathode from Photonis Inc.

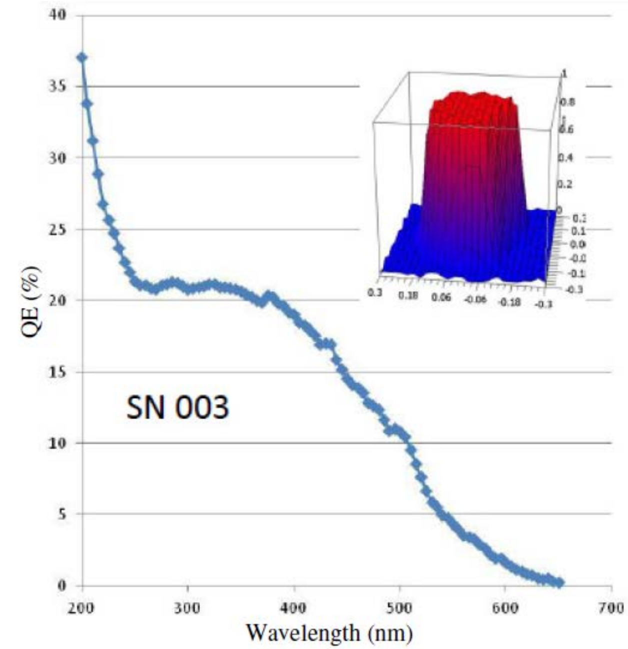


Figure 2: Spectral response of Photonis photocathode within the sealed tube. Inset shows spatial uniformity.

J. Smedley et al. proceedings PAC2013, Pasadena, CA, USA, 1178 (2013)
BNL, LBNL, Argonne, Stony Brook

Laser

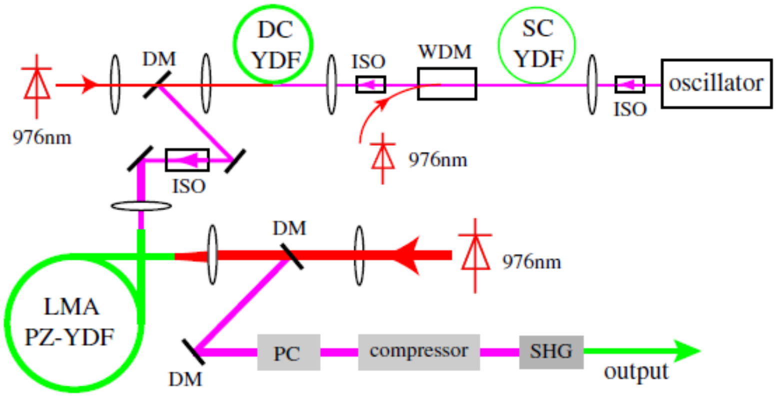


FIG. 8. Schematic of the 1300 MHz system: LMA, large mode area; PZ-YDF, single-polarization Yb-doped fiber; WDM, wavelength division multiplexer; SC, single clad; DC, double clad; ISO, optical isolator; DM, dichroic mirror; PC, Pockel's cell; the compressor is a pair of gratings; SHG, second harmonic generation.

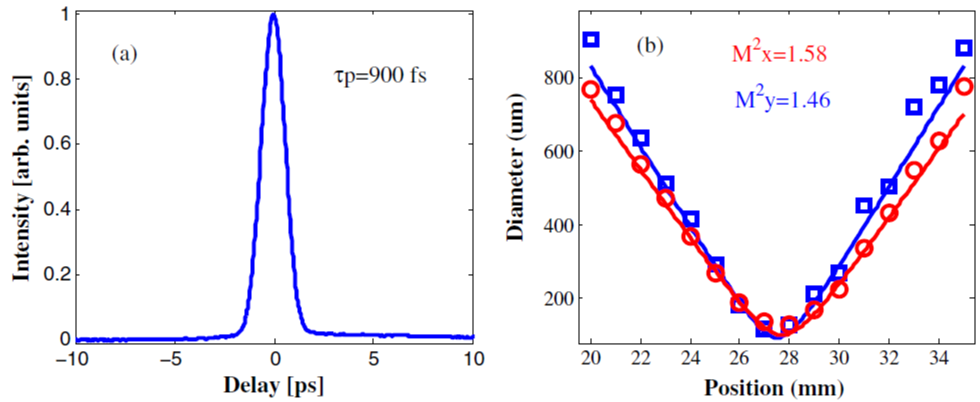


FIG. 10. (a) AC signal; and (b) M^2 measurement results of green light at 50 W.

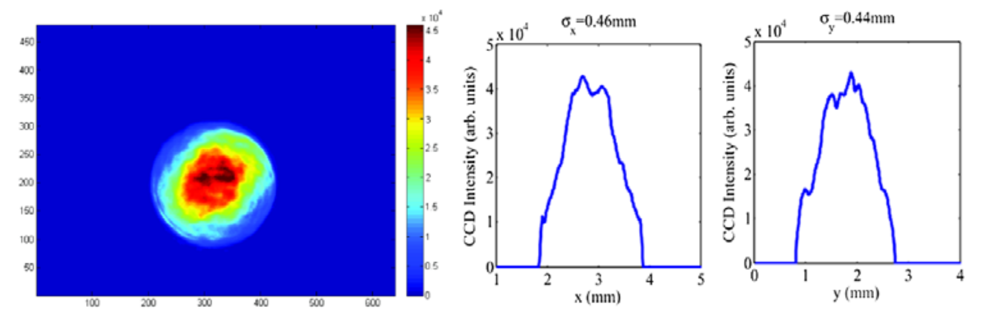


FIG. 18. Laser profile in the high-power operation (left), and the laser profile measured during high power operation (right).

TABLE II. Laser requirements for high power operation (diagnostic operation).

Parameter	Value
Min power at the cathode	50 W (2 W)
Wavelength	520 nm
Pointing stability	10 μm rms
Pulse length at the cathode	20–30 ps flattop
Transverse shape at the cathode	1–3 mm diameter truncated Gaussian
Extinction ratio	$>10^6$
Frequency	1.3 GHz (50 MHz)

Z. Zhao et al. Phys. Rev. STAB 17, 053501 (2014)
Cornell University

towards higher voltage

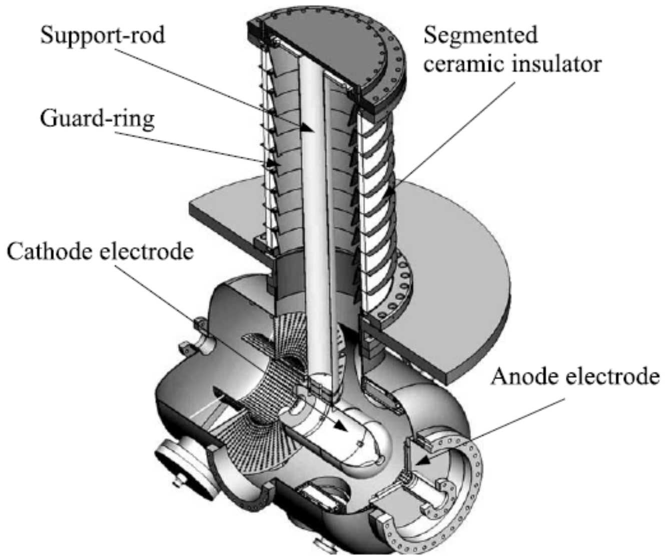


FIG. 4. Schematic view of the 500-kV dc photocathode electron gun.

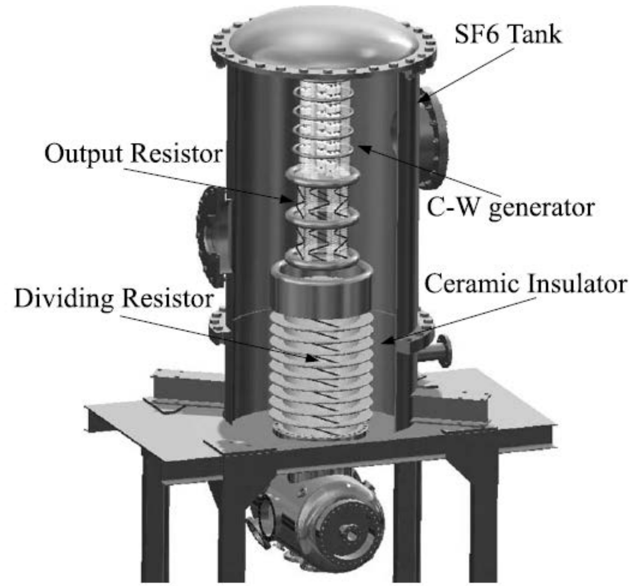


FIG. 5. Schematic view of the 500-kV dc photocathode electron gun together with the pressurized insulating gas tank.

R. Nagai et al, Rev. Sci. Instrum. 81, 033304 (2010)
JAEA, KEK

[Comment: having the HV stack in SF6, rather than air, makes this design much more compact]

tested up to 550 kV

Test Stand towards higher voltage (2)

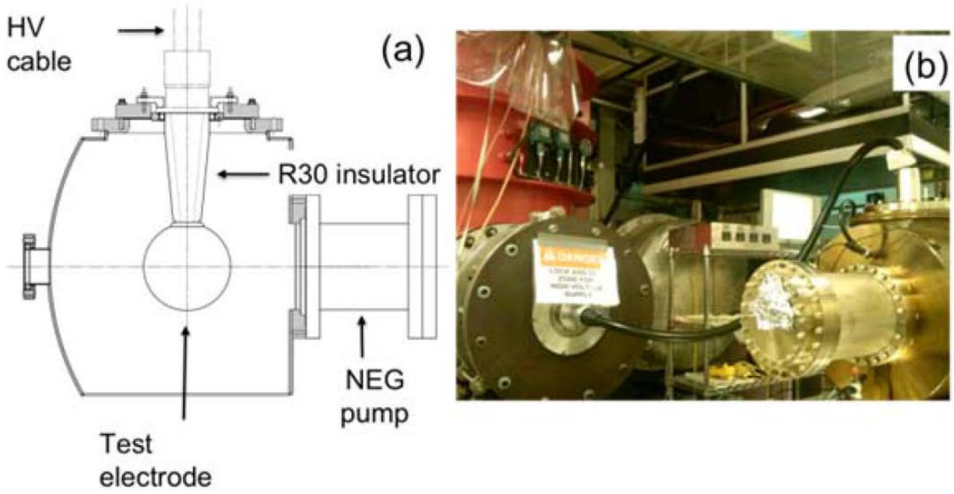


Figure 1. Schematic representation of the photogun high voltage vacuum chamber showing the test electrode (15.25 cm diameter) supported by an R30 inverted insulator (a) and photograph of the high voltage test chamber connected to the power supply via a commercial high voltage cable (b). The high voltage power supply resides within the red-colored SF_6 tank.

insulator with electrode

operated at 350 kV

C. Hernandez-Garcia, M. Poelker, and J. Hansknecht
IEEE Transactions on Dielectrics and Electrical Insulation Vol. 23, No. 1; February 2016, 418-427

field emission studies: possible operation >10 MV/m with He or Kr gas conditioning
M. BenastaniNejad et al. NIM A762 (2014) 135–141

Summary

state of the art photo guns can fulfill all requirements for
RIB, ERL or THz production operation mode for the TRIUMF e-LINAC

most promising solution is a photo gun with a K_2CsSb cathode
commercial cathodes may be available

for simultaneous operation of RIB and ERL
2 laser systems with frequency doubled fiber laser operated at 520 nm

Operation at higher voltage than the presently used 300 kV is recommended
several examples of successful operation up to 500 kV
and at higher voltage gradients exist

Thank you!
Merci

TRIUMF: Alberta | British Columbia | Calgary | Carleton | Guelph | Manitoba | McGill | McMaster | Montréal | Northern British Columbia | Queen's | Regina | Saint Mary's | Simon Fraser | Toronto | Victoria | Western | Winnipeg | York