SUPERCONDUCTING PHOTOINJECTORS

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Motivation / Applications

- Produce high average current beam at high brightness
- Applications:
  - ERL light sources
  - High power FELs
  - High-energy electron cooling
  - Electron-ion colliders
  - Potential polarized electron source for ILC

Why SRF Photoinjector?

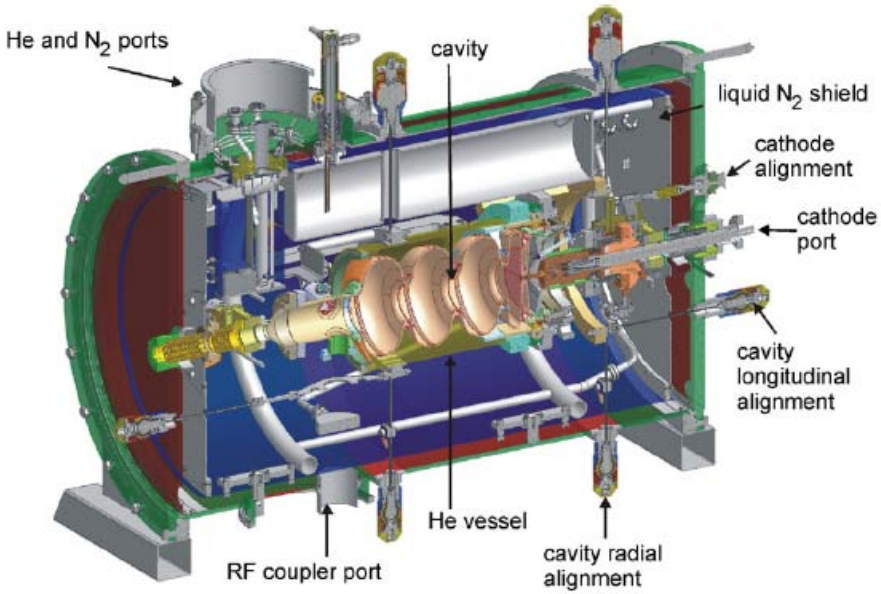
- The SRF photoinjector combines the best qualities of:
  - RF photoinjector, for high brightness electron beams (e.g. BNL ATF RF gun series)
    - High electric field for rapid acceleration and reduction of space-charge forces
    - Large total acceleration, to transport high energy electrons after the gun
  - SRF cavity, for CW operation at low RF power investment in cavity and high average current

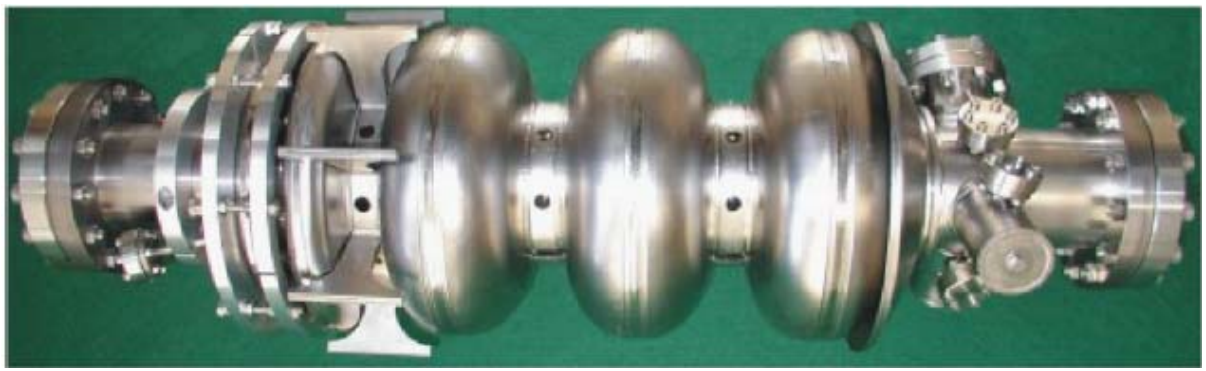
What is the SRF injector situation around the world?

- The first successful SRF photoinjector at Rossendorf, now a 3 ½ cell 1 mA (BESSY – FZ Rossendorf – DESY – MBI)
- All niobium SRF gun, now adapted with choke joint for polarized e^-. (BNL / AES)
- University of Peking 1 ½ cell gun with DC injector, now 3 ½ cell.
- Nb cavities with Pb cathode tested, now design for 1 ½ cell (DESY – BNL – JLab)
- BNL ½ ampere ½ cell gun – subject of this talk

BESSY / FZ Rossendorf / DESY / MBI Collaboration gun

- 3 ½ cell, 1.3 GHz, 10 kW, 10 MeV, 1 mA
- CsTe cathode, choke filter, LN2 cooled
- Ideal for MHz rate FEL
- <1 μm @ 77 pC





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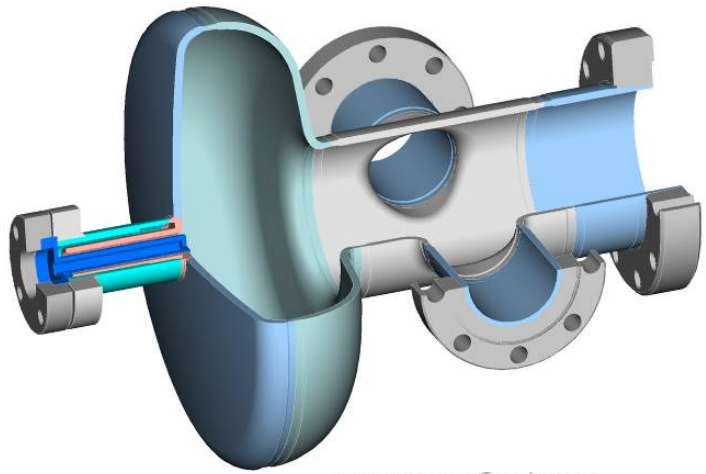
BNL all niobium gun and ongoing developments

- ½ cell, 1.3 GHz.
- Test bed for photocathode R&D
- Achieved 10 nC in 10 ns



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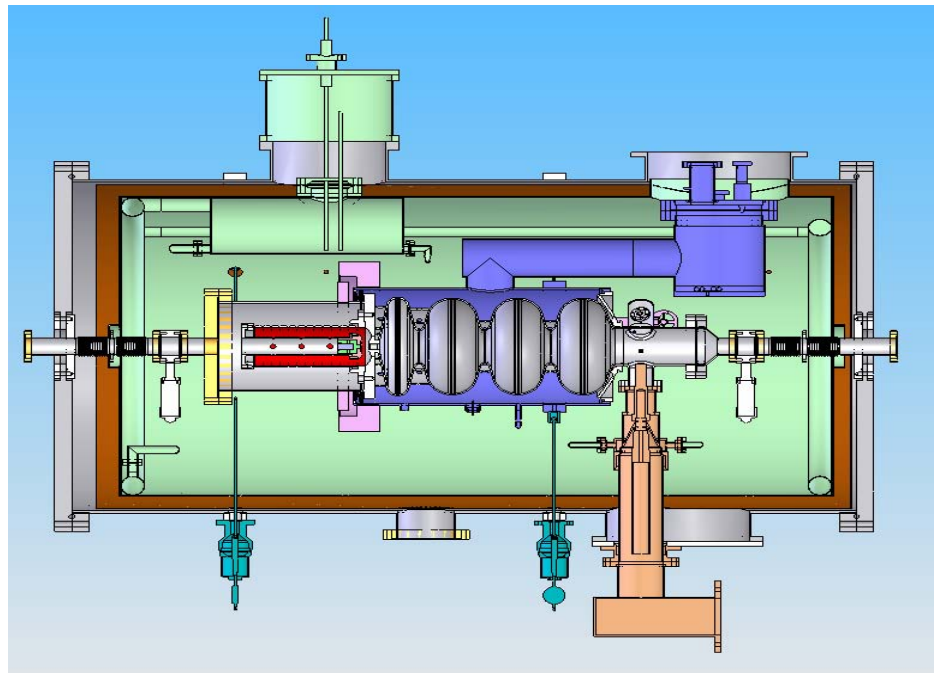
Peking University

- 1 ½ cell tested
- 2 ½ cell, 1.3 GHz, 5 MeV, 1 mA
- 3.6 μm @ 100 pC
- Integral DC injector



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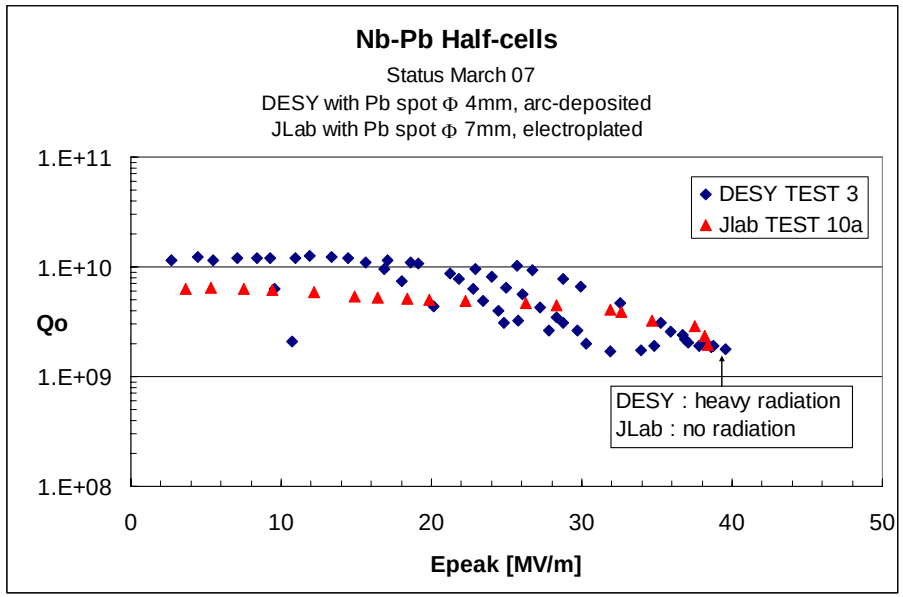
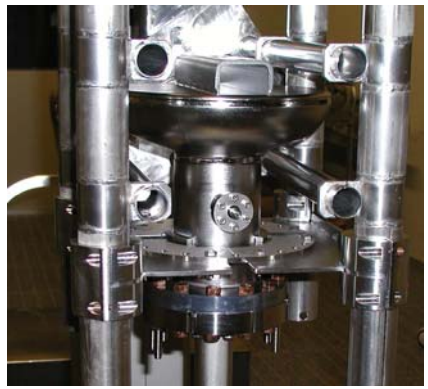
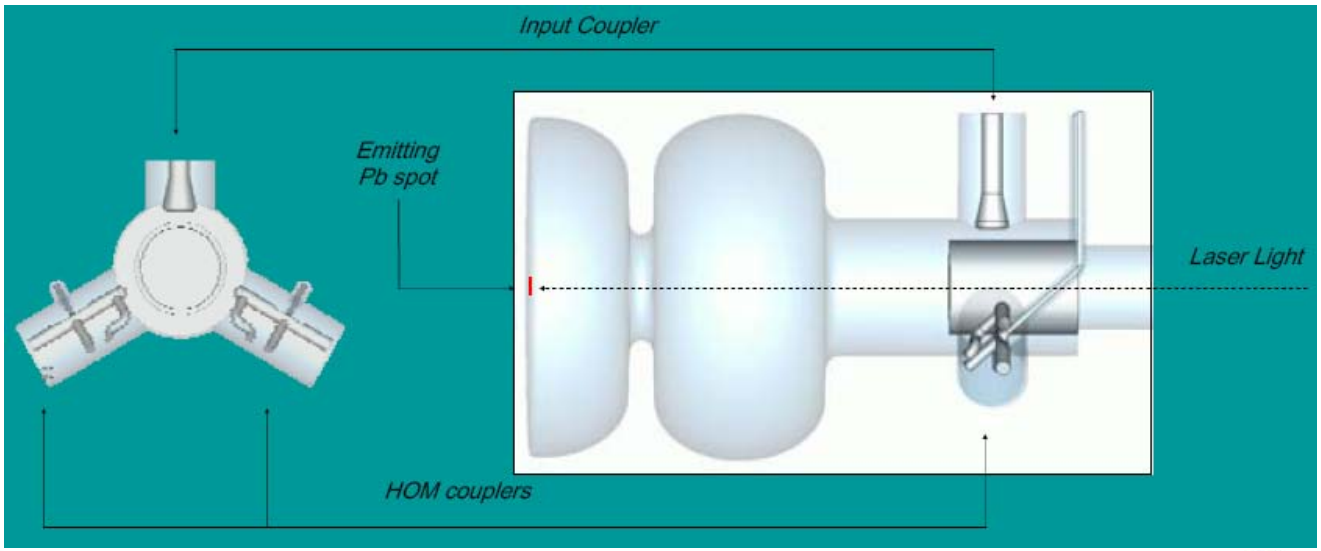
P. Kneisel, T. Rao, J. Sekutowicz, J. Smedley

Nb – Pb cathode cavity TESTS at JLab







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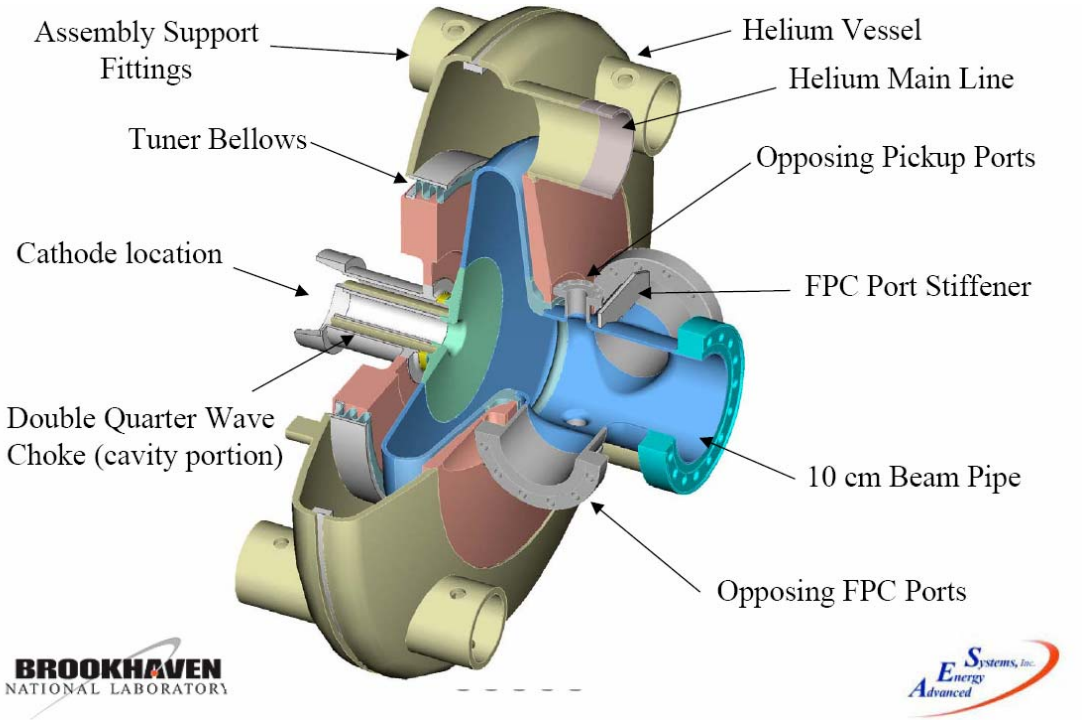
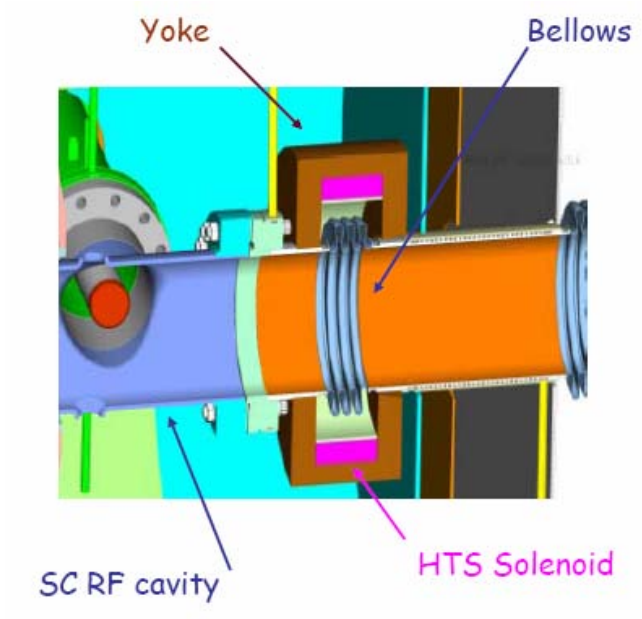
The RHIC connection

- Evolution of RHIC to a QCD laboratory calls for a luminosity increase through electron cooling and construction of a high luminosity electron-ion collider.
- These projects call for the development of a very high current ERL, including a high-current, high-brightness CW injector.
- Obviously one can use such techniques for high-power FELs, as been pointed out by the pioneers of SRF guns in KF Rossendorf.
- BNL's Collider-Accelerator Department and Advanced Energy Systems are developing a 0.5 ampere, 2 MeV SRF injector and doing R&D on polarized electron cathodes in SRF guns

Ampere-class SRF gun
BNL / AES





½ cell (1.5 cell future), 703.75 MHz, 1 MW, 2 MeV, 500 mA.
CsK2Sb cathode or diamond amplified photocathode.
Emittance compensation by HTS solenoid (picture on right)

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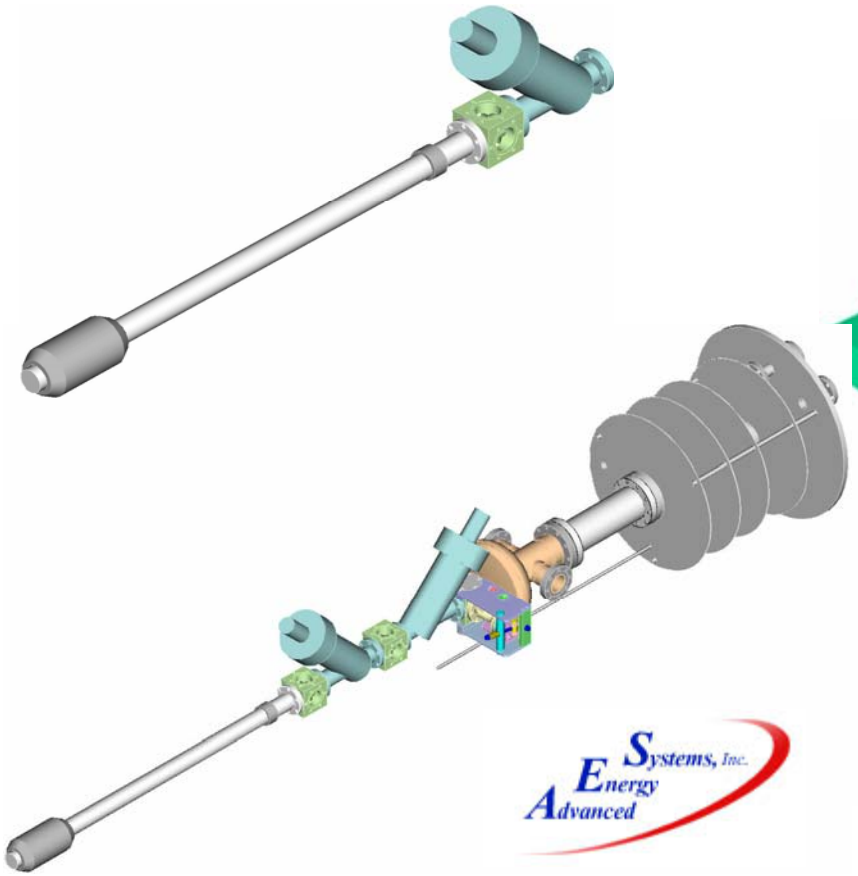
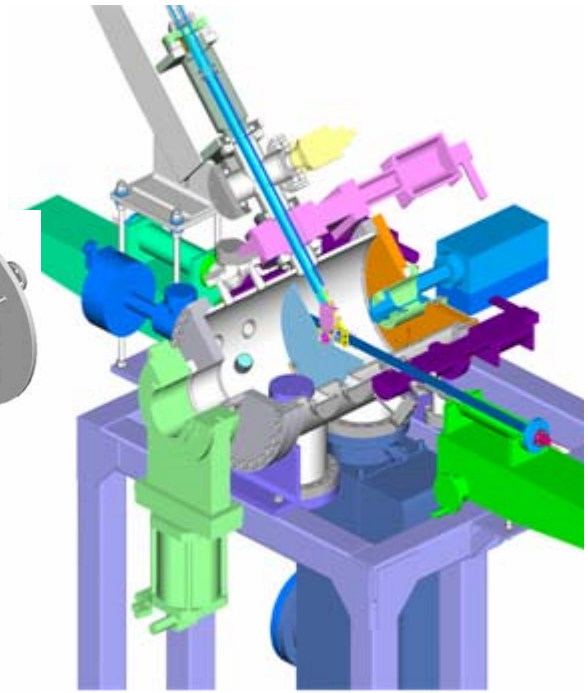
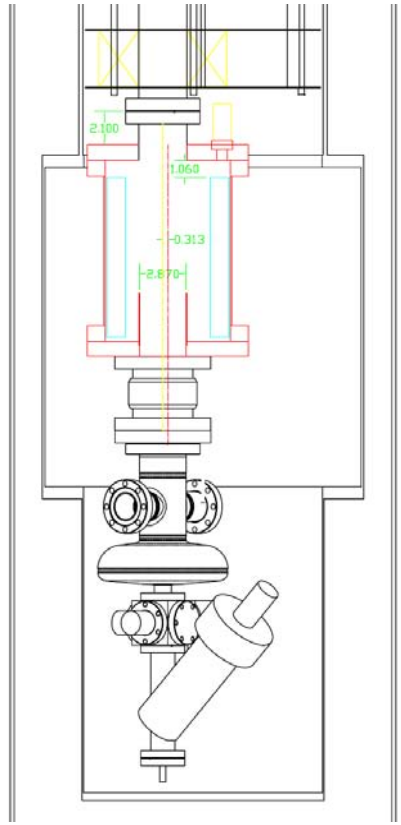
Cathode preparation chamber



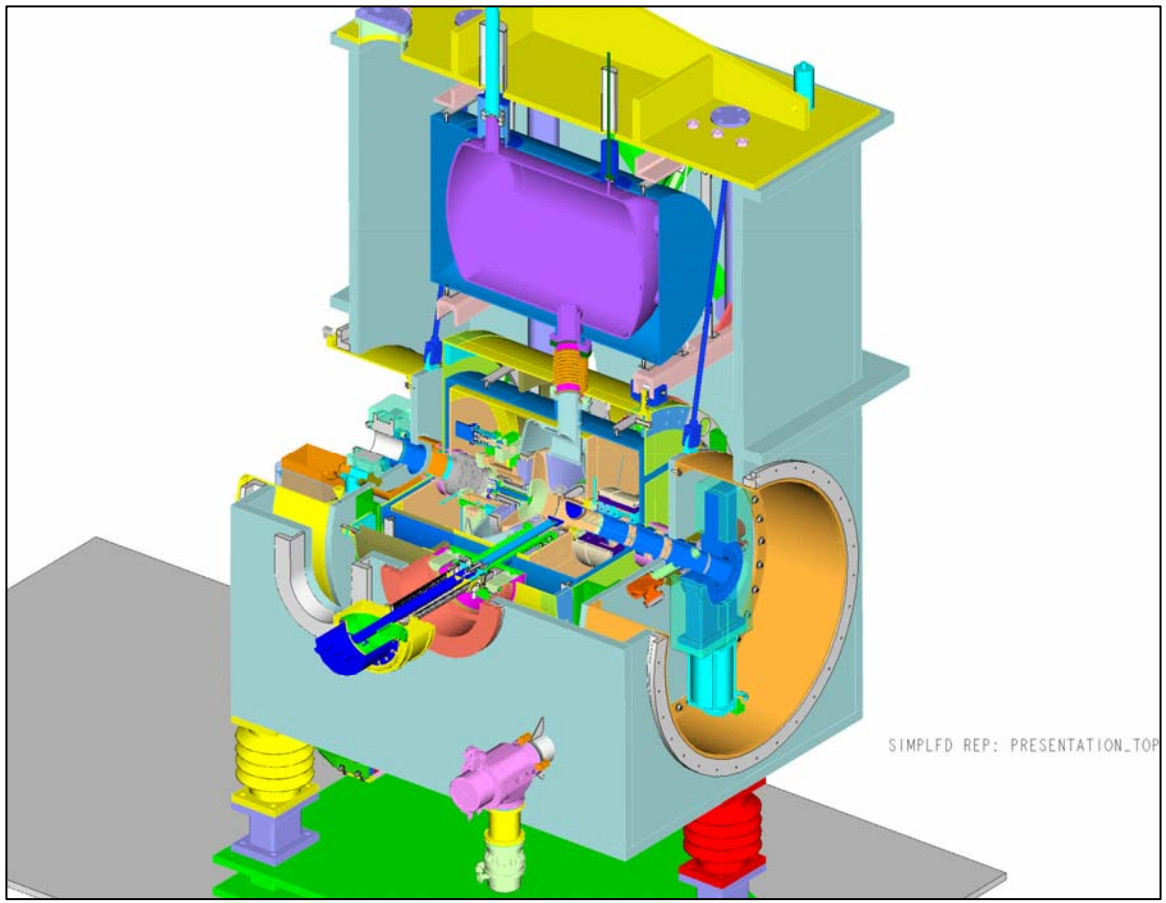


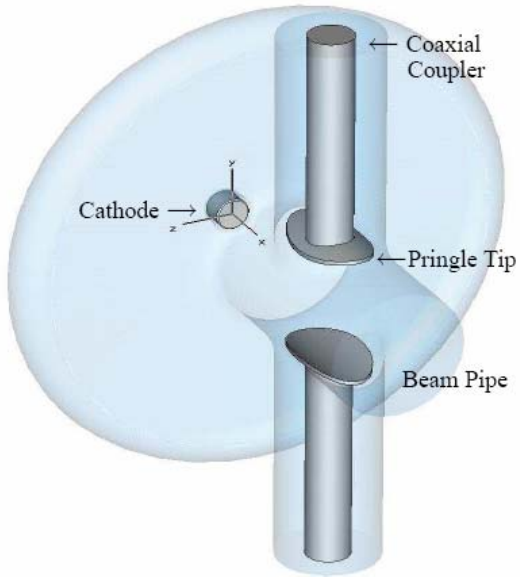


Objective: ILC / eRHIC polarized gun

Possible ILC performance <0.4 μm @ 3.2 nC

Gun in cryostat with cathode inserted





Schematic of the dual opposing high-power input RF couplers

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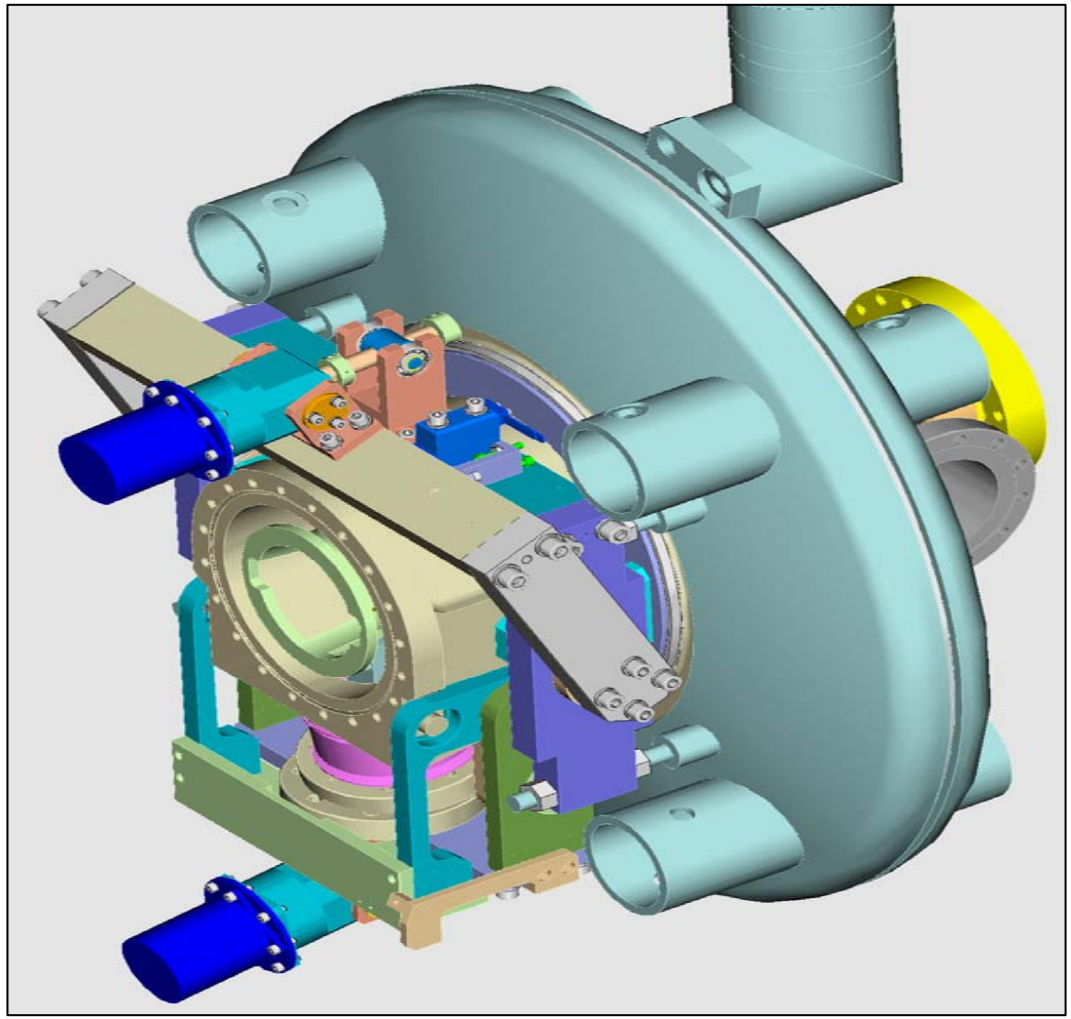
Tuner and cathode clamp



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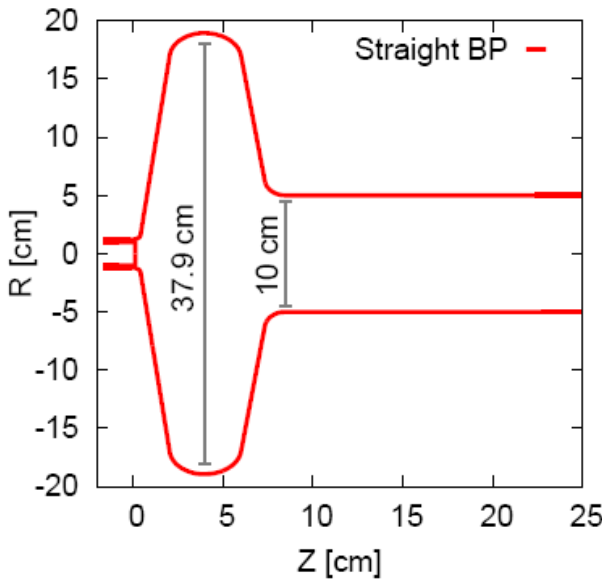

Parameter	Units	Value
Frequency	MHz	703.75
Iris radius	cm	5
Equator Diameter	cm	37.9
Cavity length	cm	25
Beam kinetic energy	MeV	2
Peak electric field	MV/m	35.7
Peak magnetic field	A/m	58740
Stored energy	Joule	8.37
QR_s (geometry factor)	Ω	3.52
R/Q	Ω	96
Q_e (external Q)		37000
Power input	MW	1
Maximum current	mA	500
Emittance at 1.4 nC	μm rms normalized	1.4
Cathode recess	mm	1
Cathode spot size	mm diameter	5
Emission phase	Degrees	25
Longitudinal loss factor	V/pC	0.7
Transverse loss factor	V/pC/m	32

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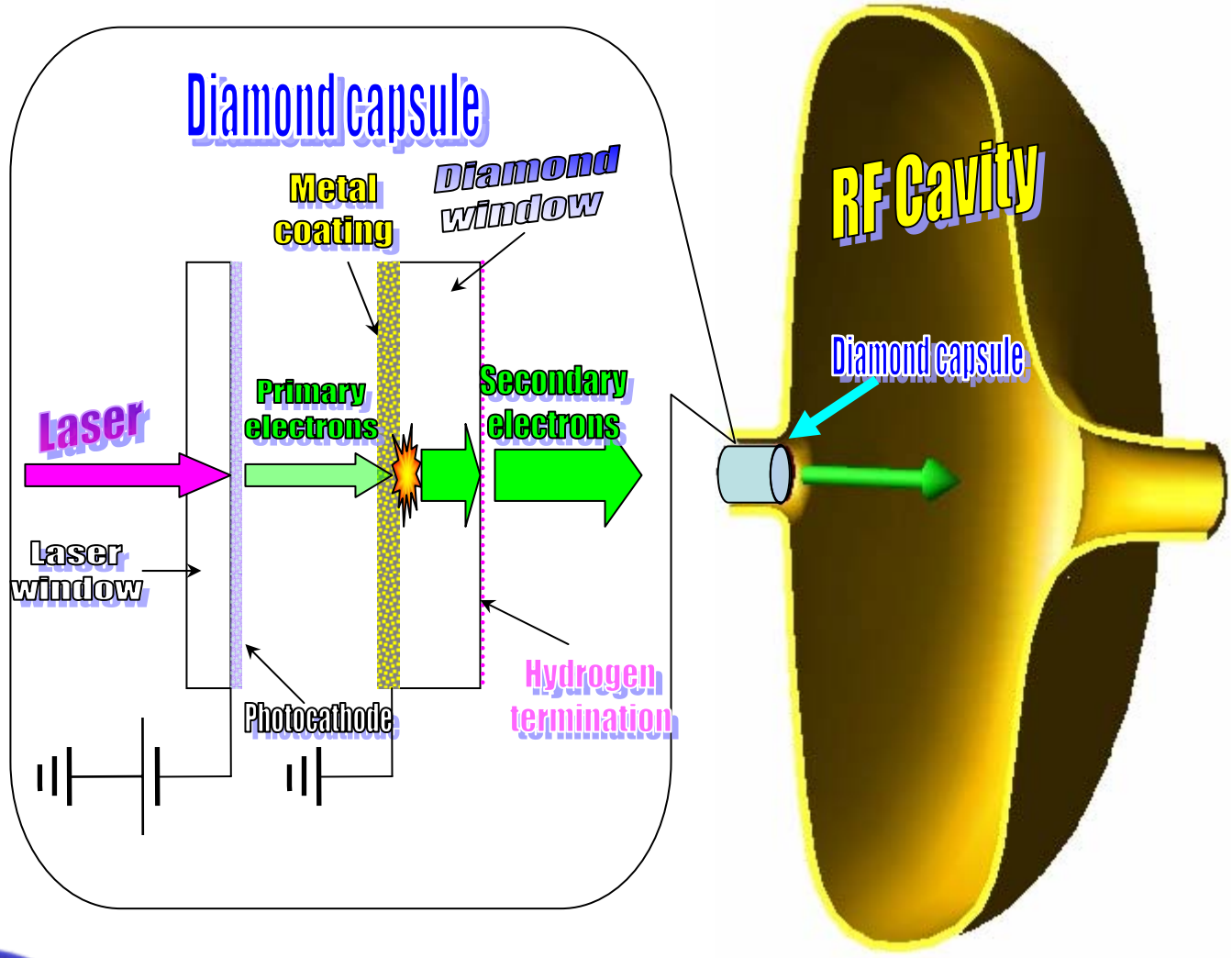
“Goal" parameters

- energy
  - 2 to 3 MeV in ½ cell gun
  - ~5 MeV in 1 ½ cell gun
- emittance @ charge (normalized rms)
  - 3 μm @ 5 nC for 1.5 cell
  - 1.4 μm @ 1.4 nC for ½ cell
- Current / repetition rate for ½ cell gun
  - 0.5 ampere at either 352 MHz or 704 MHz
  - 100 mA at 9.4 MHz

Diamond amplified photocathode



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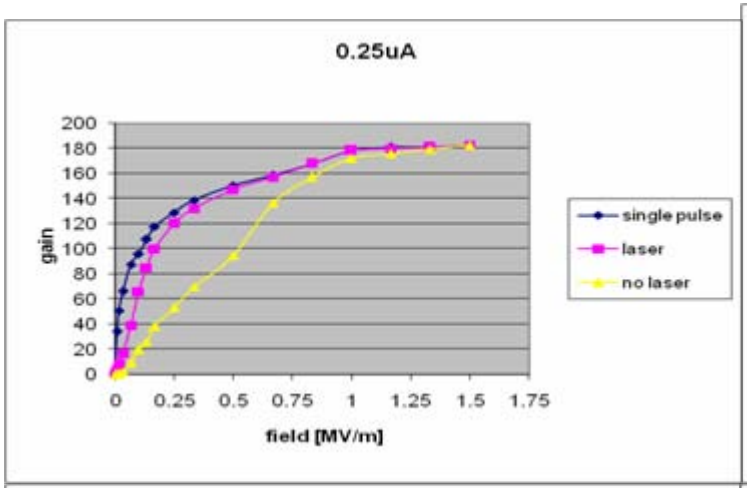
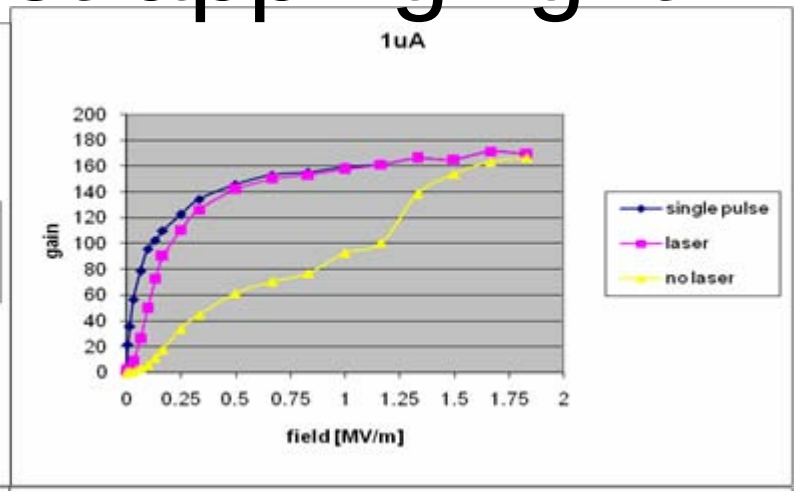
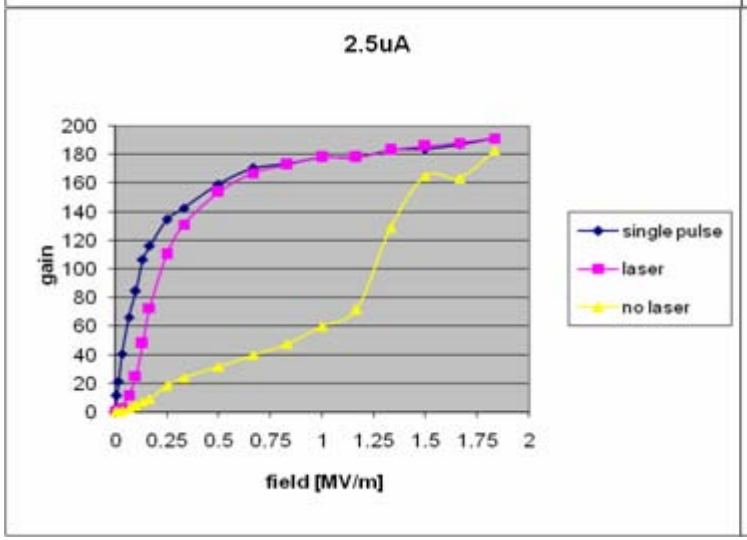
Properties of diamond amplified photocathodes

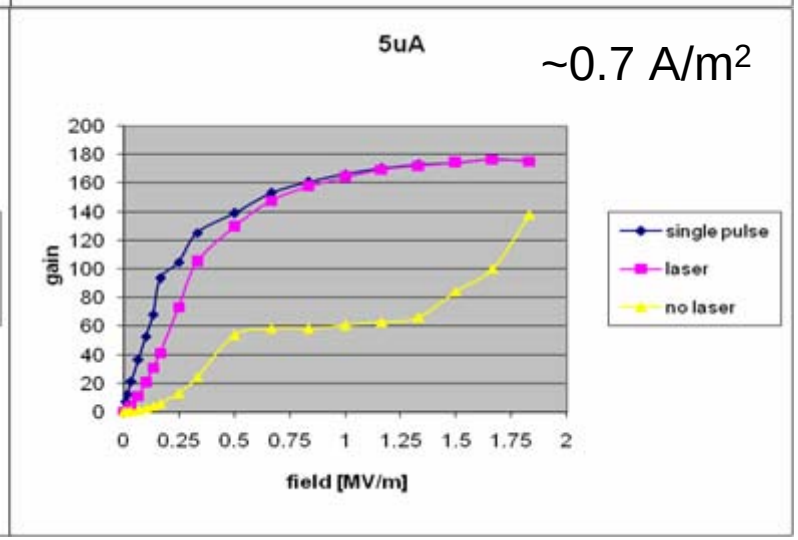
- High gain (secondary current / primary current), over 350 demonstrated
- Low thermal emittance (demonstrated in reflection mode by J. Yater)
- Negative electron affinity surface (hydrogenated diamond) that works following exposure to air.
- Absolute separation of gun and cathode.

Gain vs. field as function of primary current and detrapping light

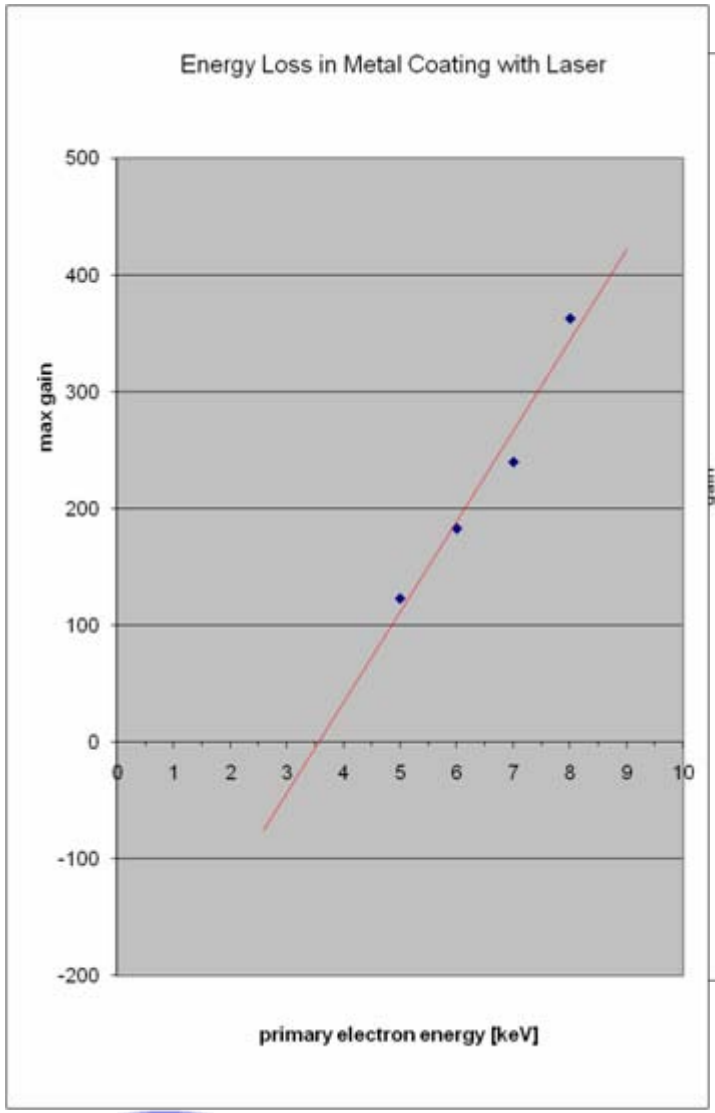


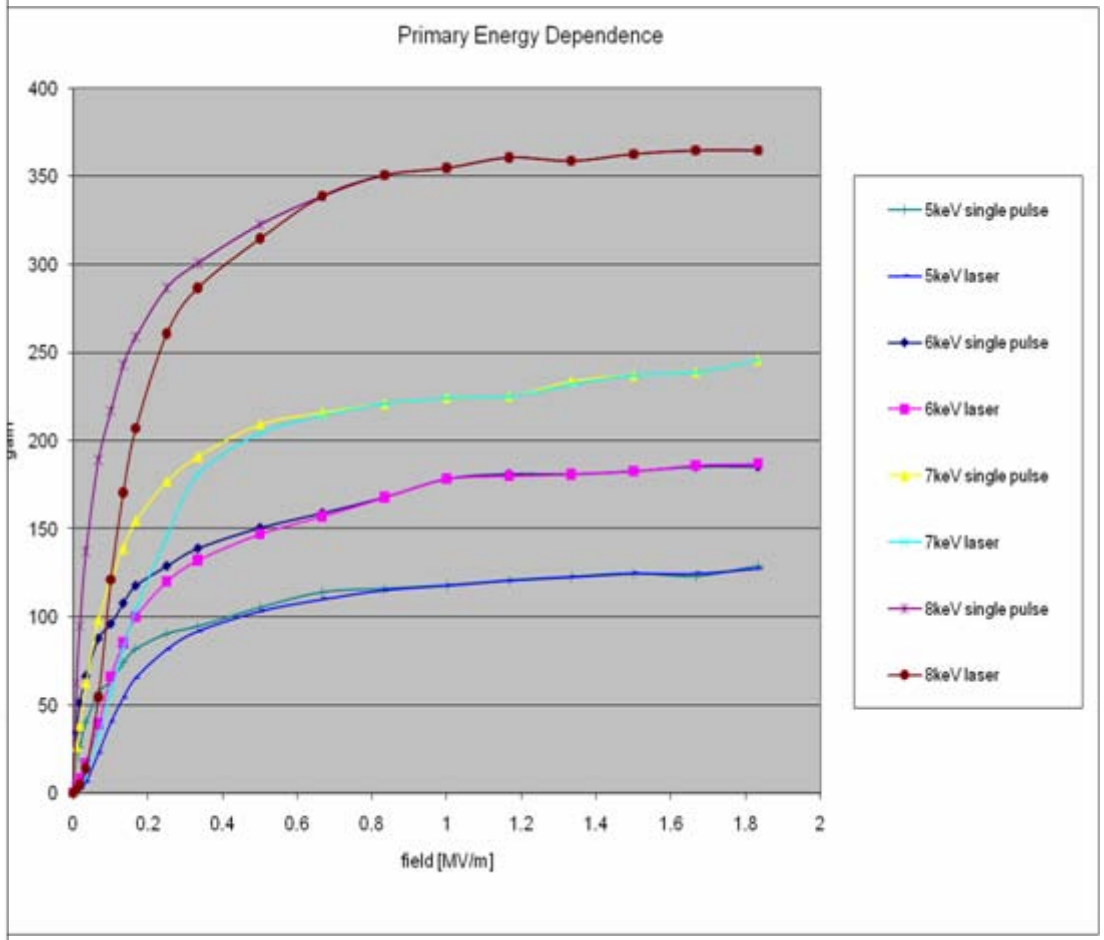






~0.7 A/m^2





Energy per electron-hole pair ~13 eV

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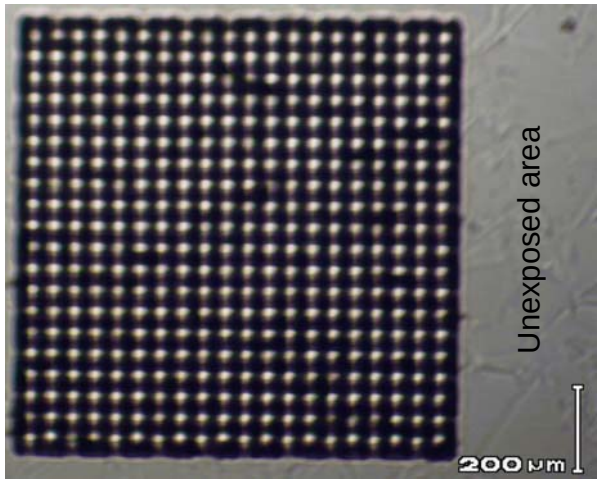
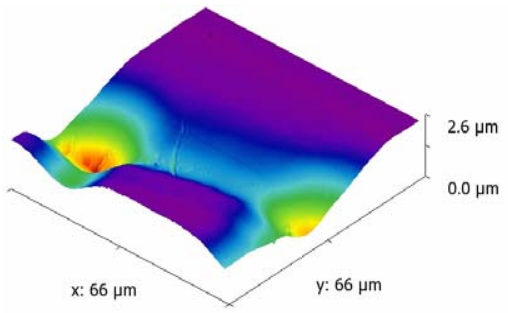
Laser shaping of diamonds

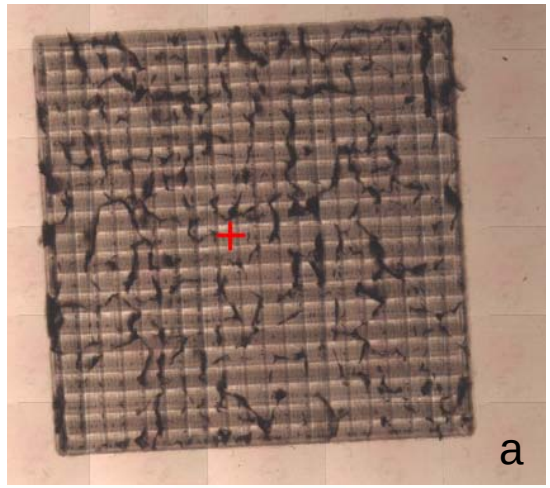
Good laser ablation rates have been achieved using the193 nm excimer



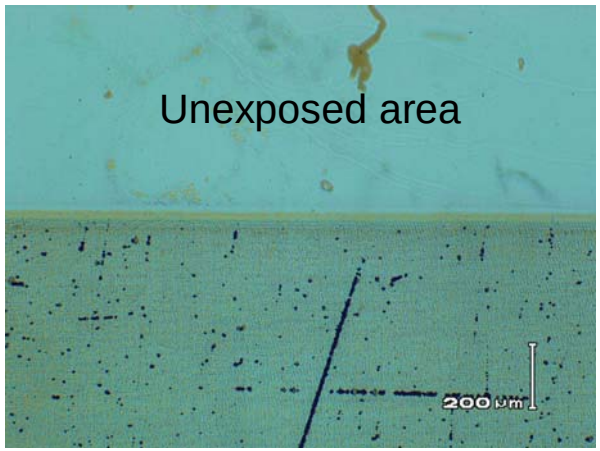
Polycrystalline diamond



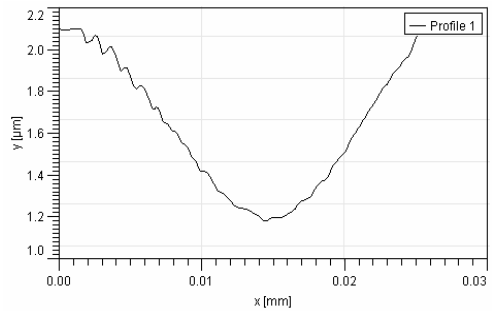
AFM depth profile



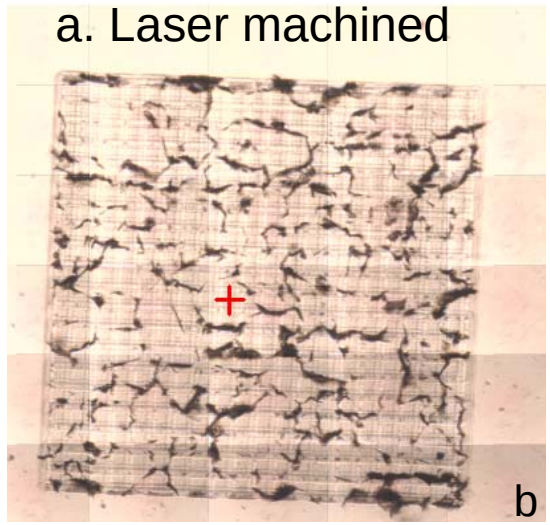
a. Laser machined



Single crystal diamond



UV ps laser shaping gives best surface.



b. UV lamp cleaned

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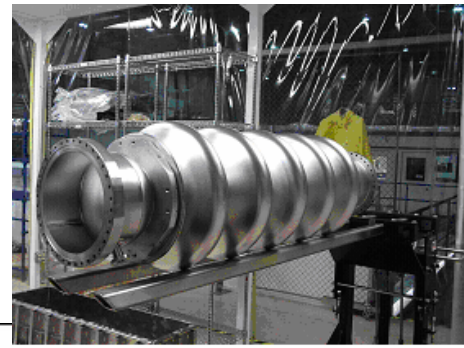
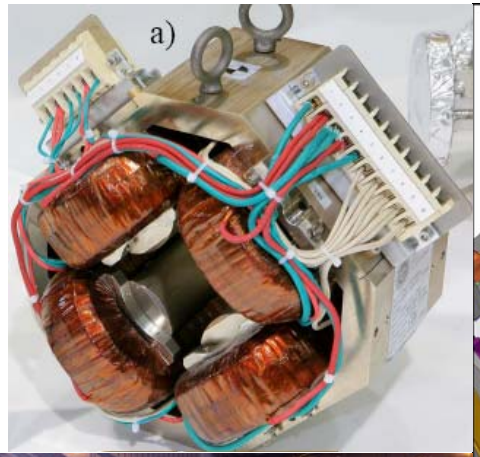
R&D Energy Recovery Linac

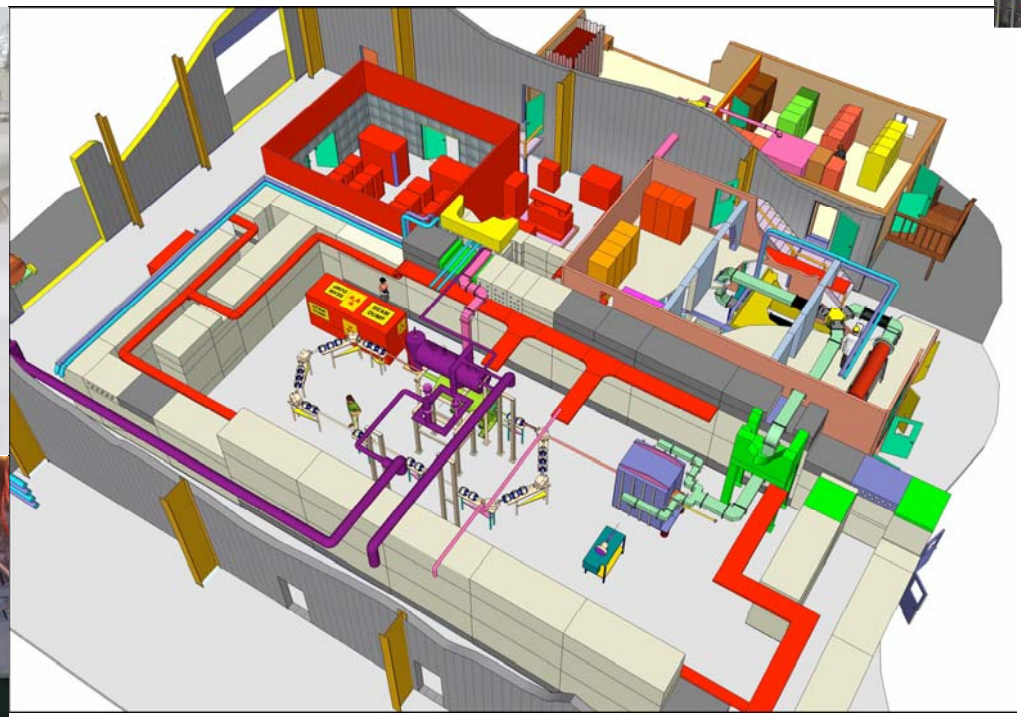
Near future plans

0.5 A @ 20 MeV under construction

Commissioning start 2/09







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Additional information:

R. Calaga, I. Ben-Zvi, M. Blaskiewicz, X. Chang, D. Kayran and V. Litvinenko, High current superconducting gun at 703.75 MHz , Physica C: Superconductivity, **441**, 159, (2006)

I. Ben-Zvi, Review of various approaches to address high currents in SRF electron linacs, 12th International Workshop on RF Superconductivity, Cornell University, Ithaca, NY USA, July 10-15, 2005. Physica C: Superconductivity, **441**, 21, (2006)

T. Rao, I. Abdel, I. Ben-Zvi, X. Chang, J. Grimes, R. Grover, J. Smedley, R. Todd, J. Warren, Q. Wu, J. Bohon, D. Fischer, D. Dimitrov, Status of Diamond Secondary Emission Enhanced Photocathode, Proceedings, 2007 ERL Workshop, Daresbury UK May 21-25, 2007.

Thank you for your attention

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