The Polarized SRF Gun Experiment

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Abstract

RF electron guns are capable of producing electron bunches with high brightness, which outperform DC electron guns and may even be able to provide electron beams for the ILC without the need for a damping ring. However, all successful existing guns for polarized electrons are DC guns because the environment inside is RF gun is hostile to the GaAs cathode material necessary for polarization. While the typical vacuum pressure in a DC gun is better than 10^{-11} torr the vacuum in an RF gun is in the order of 10^{-9} torr. Experiments at BINP show that this leads to strong ion back-bombardment and generation of dark currents, which destroy the GaAS cathode in a short time.

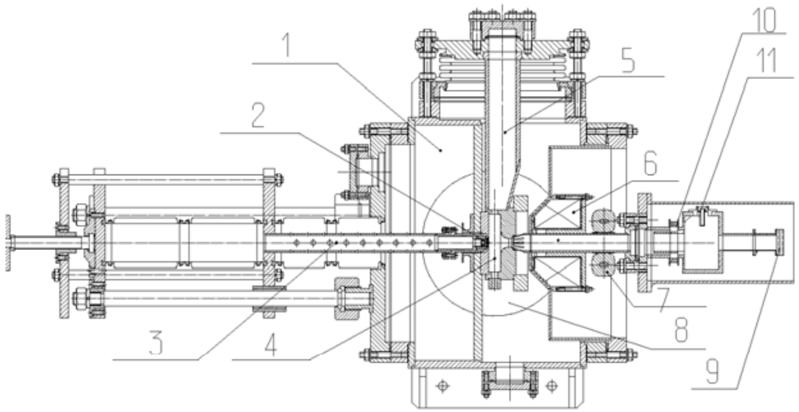
The situation might be much more favorable in a (super-conducting) SRF gun. The cryogenic pumping of the gun cavity walls may make it possible to maintain a vacuum close to 10^{-12} torr, solving the problem of ion bombardment and dark currents.

Of concern would be in this case contamination of the gun cavity by evaporating cathode material. This report describes an experiment that BNL (in collaboration with AES) is conducting to answer these questions.

Parmela simulations show promising results.

BINP experiment Aleksandrov, *et al.*

- **Normal conducting gun**
- **Pressure $2*10^{-10}$ torr at before RF is turned on.**
- **Large dark current cause by ion bombardment of NEA surface**
- **Quantum efficiency life time a few seconds**
- **RF field of 30 MV/m does no irreversible damage**



1 activation chamber,
2 photo-cathode assembly,
3 manipulator,
4 accelerating cavity,
5 wave guide,
6 focusing lens,
7 transverse corrector,
8 working chamber,
9 vacuum window for laser beam,
10 ceramic insulator,
11 the cavity for bunch length measurement.

How Many Ions Impact Cathode in RF Gun? (Ray Fliller at Snowmass)

- MAGIC predicts 2.8×10^7 ions/C, generated from beam, impacting the cathode at a partial pressure of 10^{-10} torr. Dark current produced a bombarding ion flux of 1.6×10^7 ions/C at 10^{-10} torr.
  - In contrast, a DC gun produces on the order of 3×10^7 ions/C striking the cathode at 10^{-11} torr .
- The RF gun seems to have an order of magnitude less in the number of ions impacting cathode at the same pressure.
  - However RF guns typically run in 10^{-9} torr range.
- In addition, the maximum ion energy is ~2keV in the RF gun. Dark current generated ions generally have energies less than 500eV.
  - Max ion energy in DC gun ~100keV
  - Higher mass of ions means they quickly slip relative to the RF phase, as opposed to the continual acceleration in a DC gun.
- An RF gun should be able to support an GaAs cathode at pressures higher then a DC gun, but lower than current RF guns.

Fermilab's cold RF gun (Ray Flliller at Snowmass)

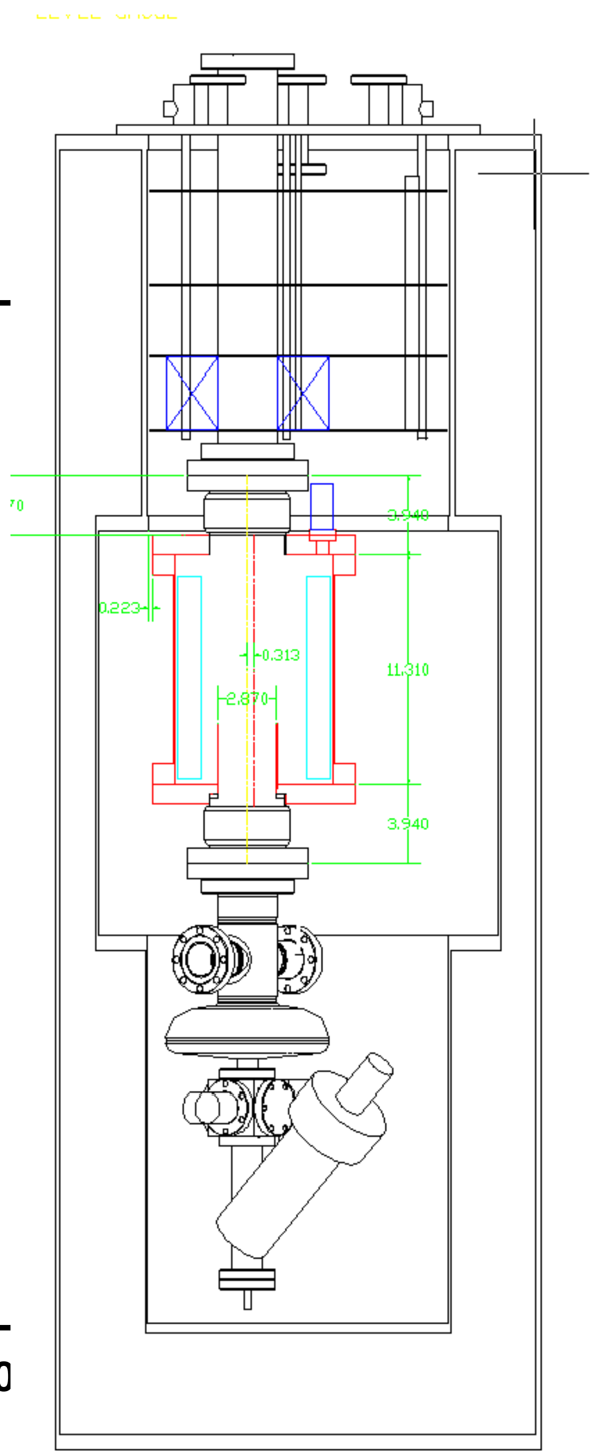
- **Liquid N_2 cooled**
- Base pressure of uncooled, no RF, gun is 3×10^{-10} torr
- When RF applied to uncooled gun, most gases show increased outgassing. Pressure increases to 1.6×10^{-9}.
- Cooling gun to 92K drops pressure by factor of 2.
- Applying RF to cooled gun increases pressure factor of 2, mostly due to methane out-gassing. Pressure slightly less than base pressure.

“Getting cold” is not enough (R. Flliler at Snowmass)

- True cryopumping involves
  - Gas molecules freezing to chamber walls
  - A reduction in gas vapor pressure below total pressure
- Only CH_4, C_2H_4, CO_2 and H_2O are frozen at 92K.
- Other gases merely collect in the cold volume, forming a lower pressure, higher density gas than exists in the warm section.
- Vapor pressures of the gases involved to not reach 10^{-10}-10^{-11} torr until 20-30K.
- Cooling with Liquid He is necessary!

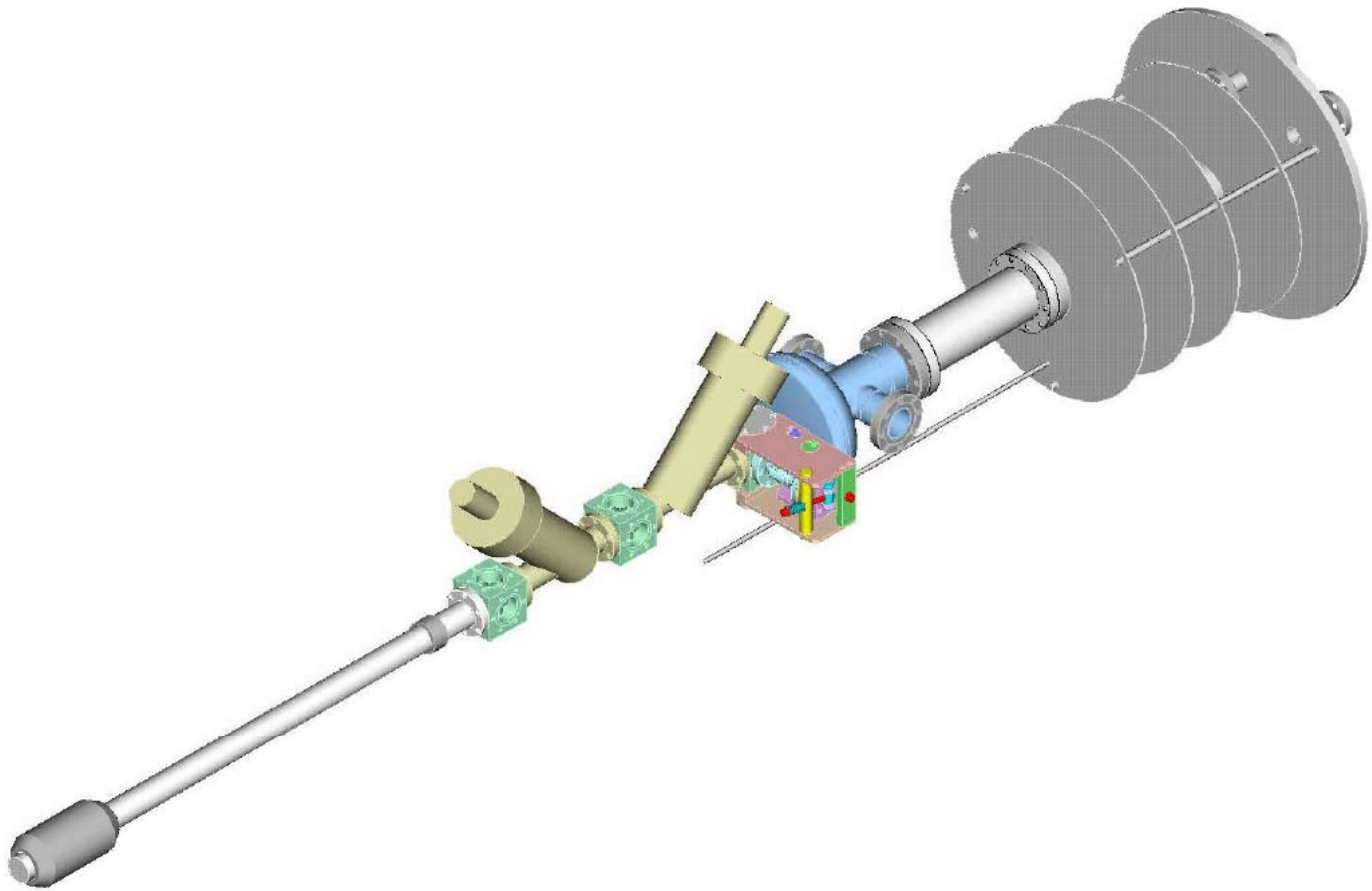
Our Experiment

- Superconducting ½ cell 1.3 GHz gun
- Beam energy 0.8 MeV, current 10 μA, limited by availbale RF power
- Removable NEA bulk GaAs cathode, 1 mm diameter.
- 100 liter cryostat, helium lasts about 24 hours
- Beam exits to on top, is bend 90 degrees into a Faraday cup
- Focusing with permanent magnet solenoids
- NEG pumps inside the cryostat, close to the gun, expected vacuum close to 10^{-12} torr.

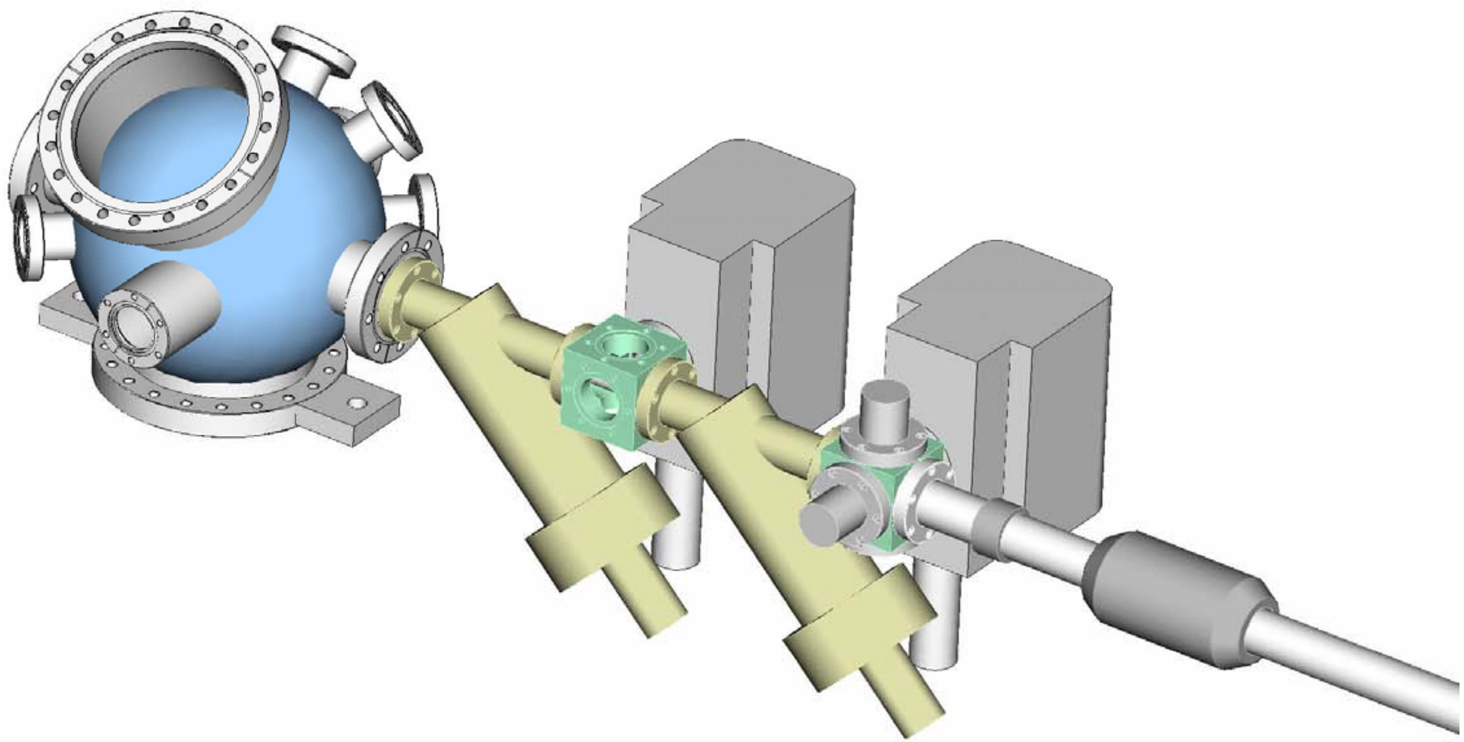



CRYOFAB

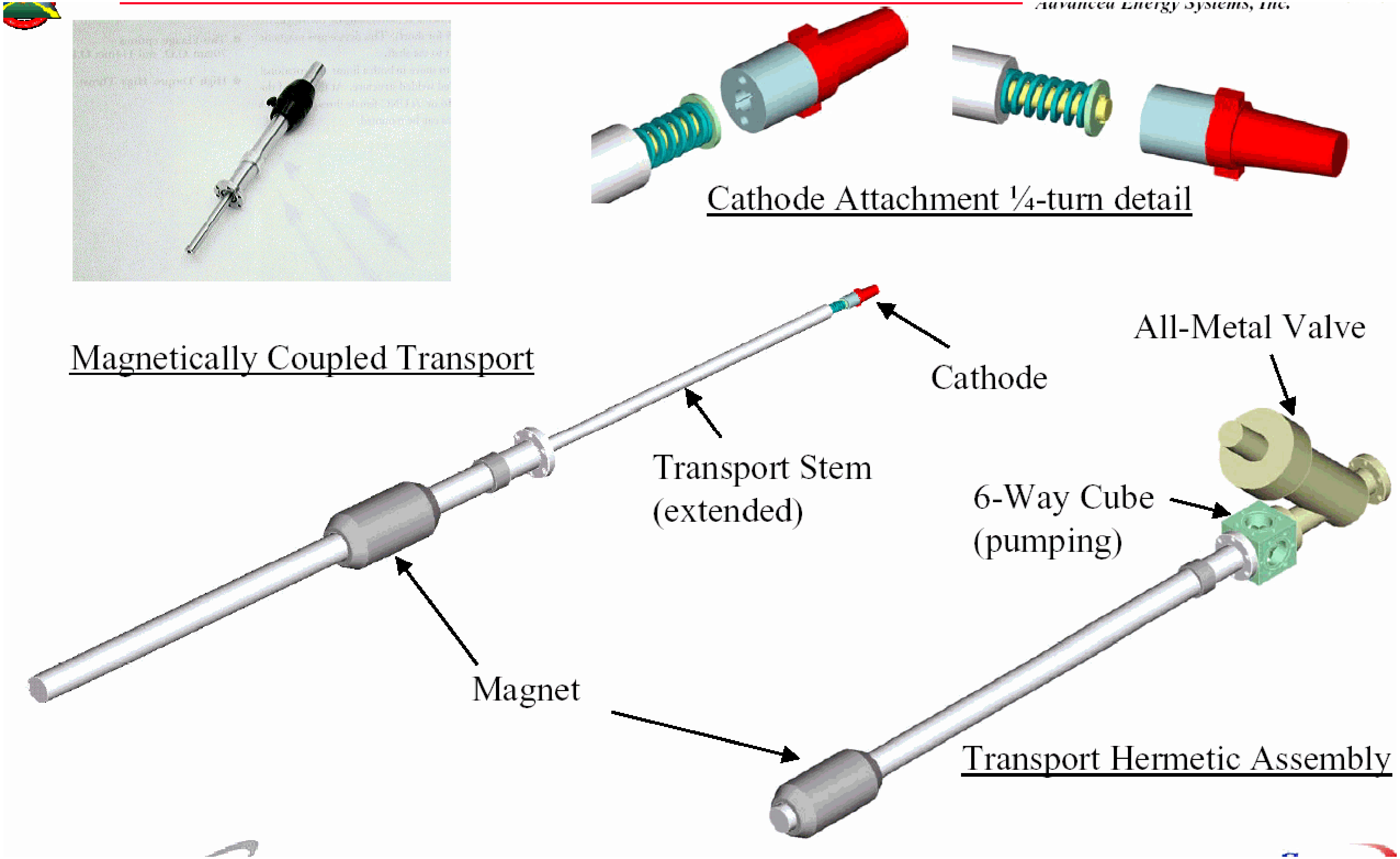
Gun with cathode transporter



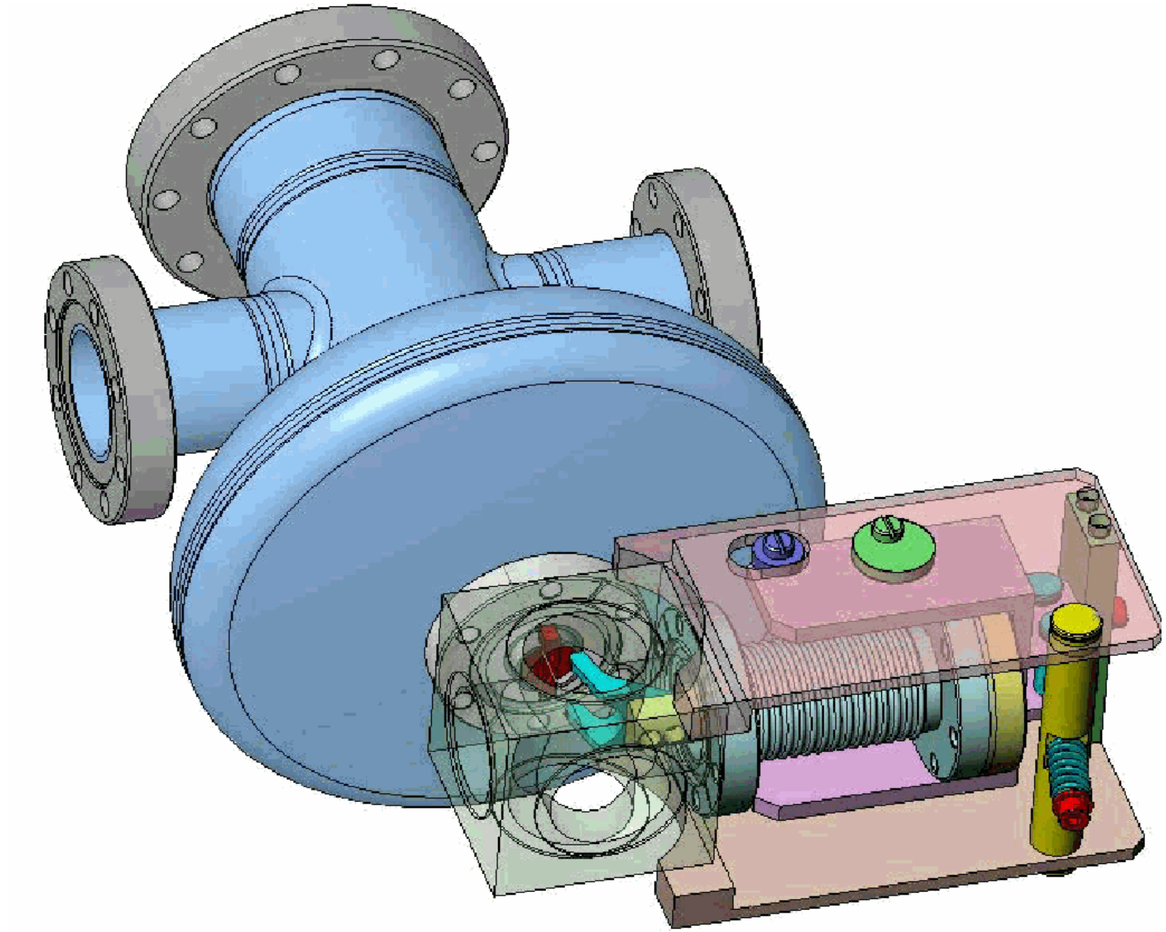
Cathode connected to the preparation chamber



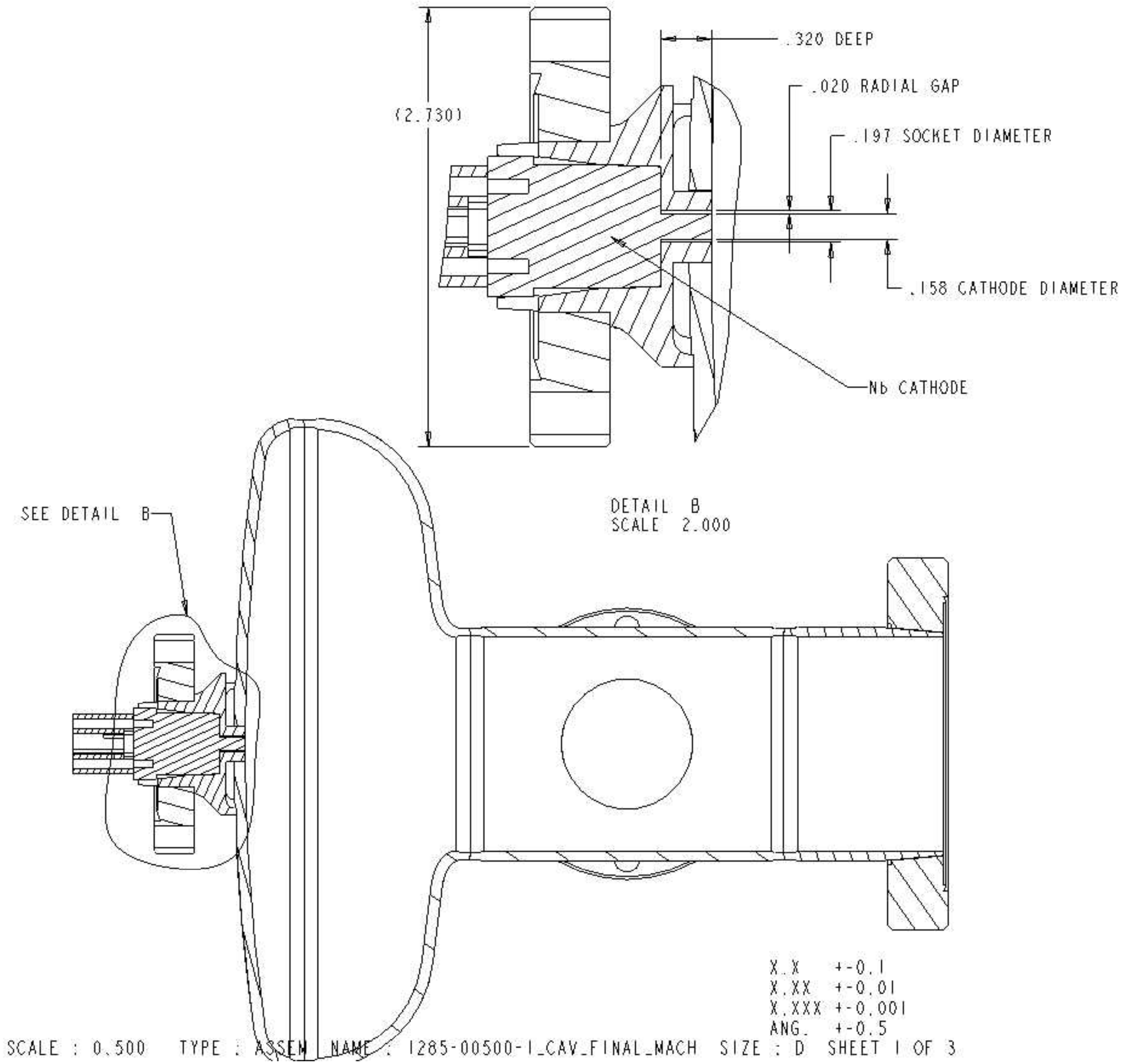
Cathode transporter



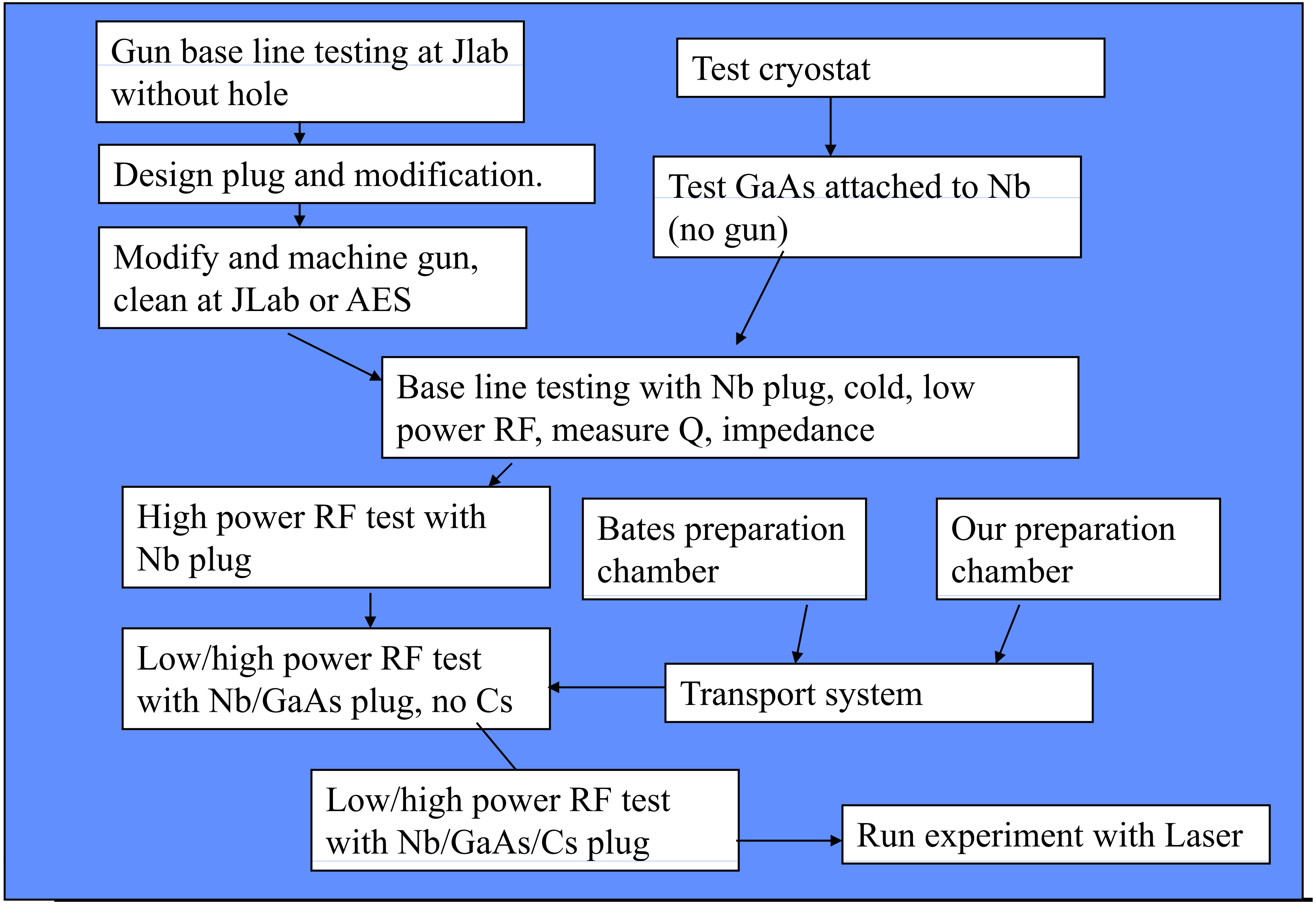
Clamping the cathode to the gun



Cathode plug



Tasks


Gun base line testing at Jlab without hole
Design plug and modification.
Modify and machine gun, clean at JLab or AES
Test cryostat
Test GaAs attached to Nb (no gun)
Base line testing with Nb plug, cold, low power RF, measure Q, impedance
High power RF test with Nb plug
Bates preparation chamber
Our preparation chamber
Low/high power RF test with Nb/GaAs plug, no Cs
Transport system
Low/high power RF test with Nb/GaAs/Cs plug
Run experiment with Laser

Magnetization

- We define the magnetization generated by the magnetic field on the cathode as: $M = \beta\gamma(< x \cdot y' > - < y \cdot x' >)$ $L \equiv \frac{M}{2} = \frac{q \cdot B \cdot r_{cath}^2}{2 m_e c}$

  The angled brackets indicate the average over all electrons. According to Busch's Theorem the magnetization is a constant of motion outside longitudinal fields when only axial symmetric fields are present.

- We also define the 4D emittance as the forth root of the determinate of the sigma matrix: $\varepsilon_{4D} = \beta\gamma\sqrt[4]{|\sigma|}$

  with

$$|\sigma| = \begin{vmatrix} < x^2 > & < xx' > & < xy > & < xy' > \\ < xx' > & < x'^2 > & < yx' > & < x'y' > \\ < xy > & < x'y > & < y^2 > & < yy' > \\ < xy' > & < x'y' > & < yy' > & < y'^2 > \end{vmatrix}$$

Round to Flat conversion

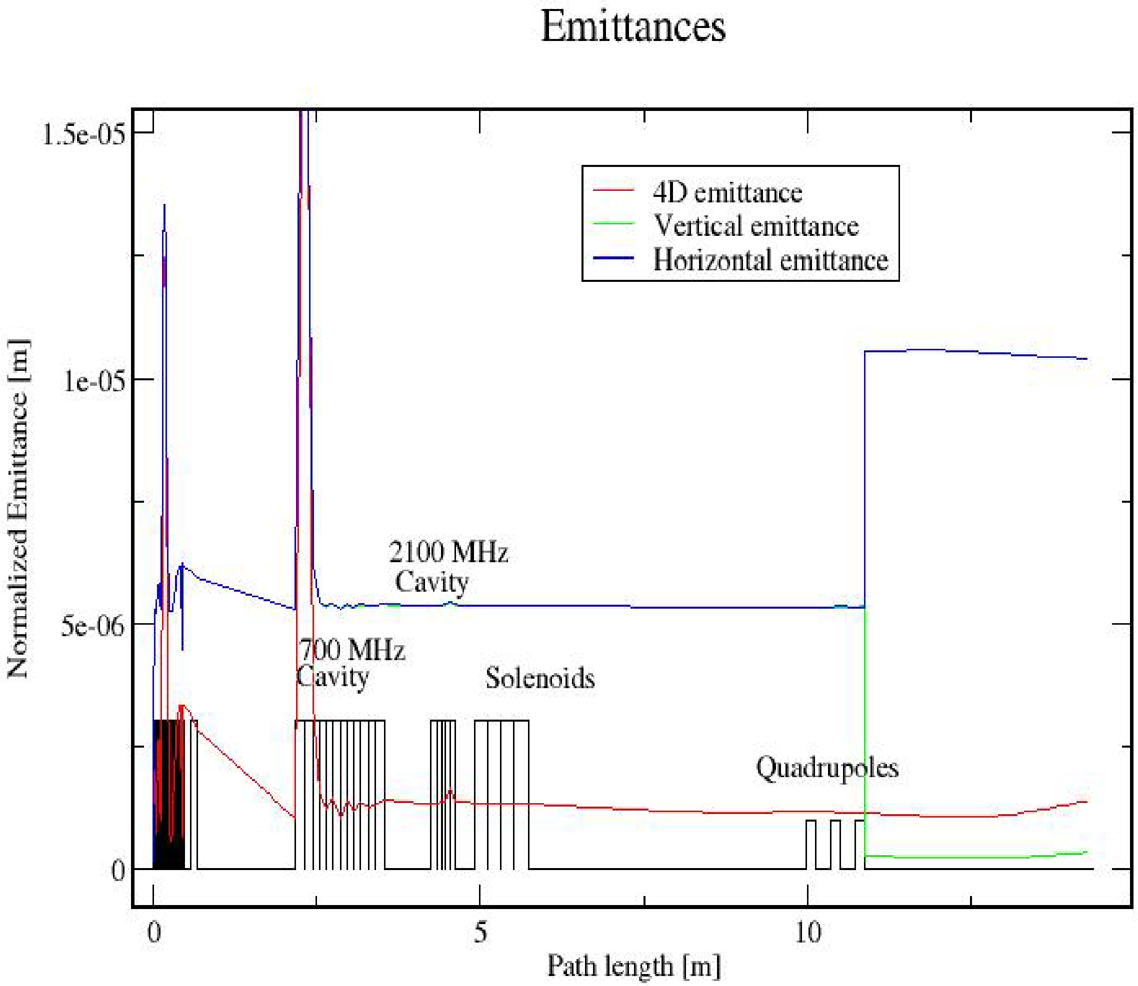
- **The beam will then have an effective emittance of:** $\varepsilon_{eff}^2 = \varepsilon_{4D}^2 + L^2$
- **After the round-to-flat converter the beam has the horizontal and vertical emittances of:** $\varepsilon_x = \varepsilon_{eff} + L \approx M + \frac{2\varepsilon_{4D}^2}{M}$ **and** $\varepsilon_y = \varepsilon_{eff} - L \approx \frac{\varepsilon_{4D}^2}{M}$
- **Given those equations we calculate the necessary 4D emittance and magnetization for an ILC injector:**

$\varepsilon_{4D} = \sqrt{\varepsilon_x \cdot \varepsilon_y} = 0.4\mu$ **and** $M = \varepsilon_x - \varepsilon_y = 8\mu$

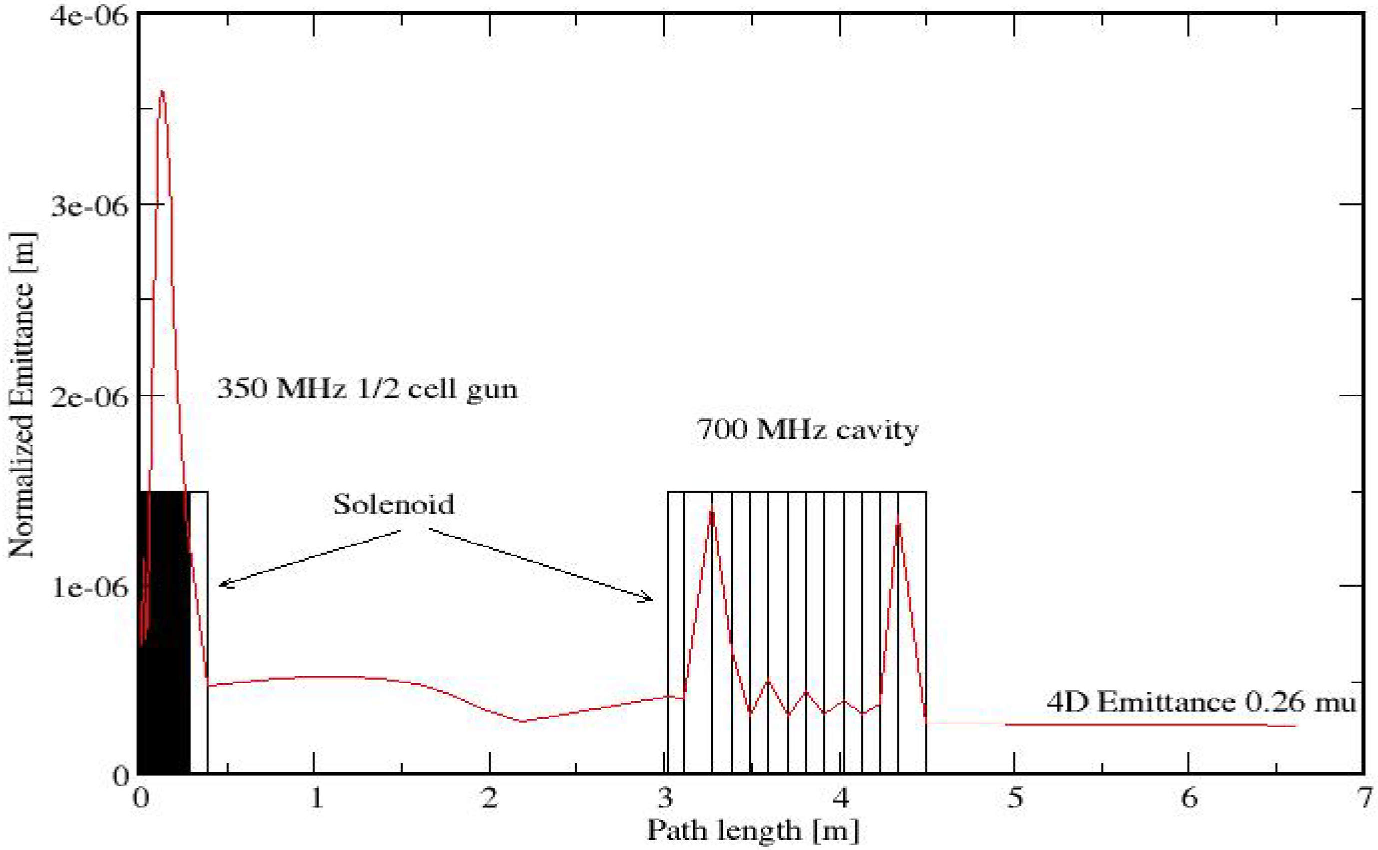
Kwang-Je Kim: Round-to-flat transformation of angular-momentum-dominated beams. Phys. Rev.ST, 6, 104002

Proof of principle

- 700 MHz gun and linac
- $M=10\mu$, $\varepsilon_{4d}=1\mu$
- Conversion at 20 MeV
- Energy spread $3.6*10^{-3}$
- Space charge still importatnt

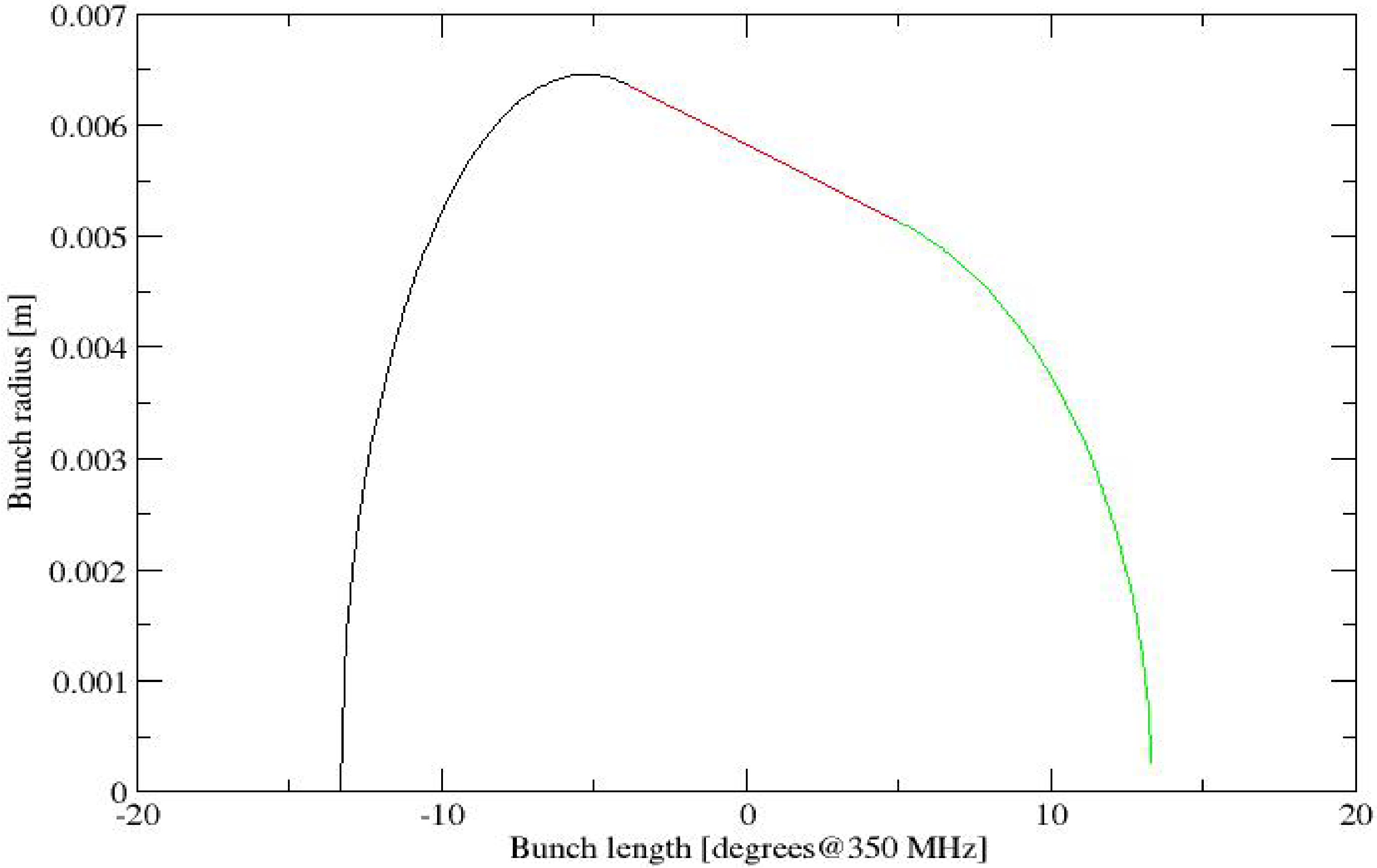


Best so far

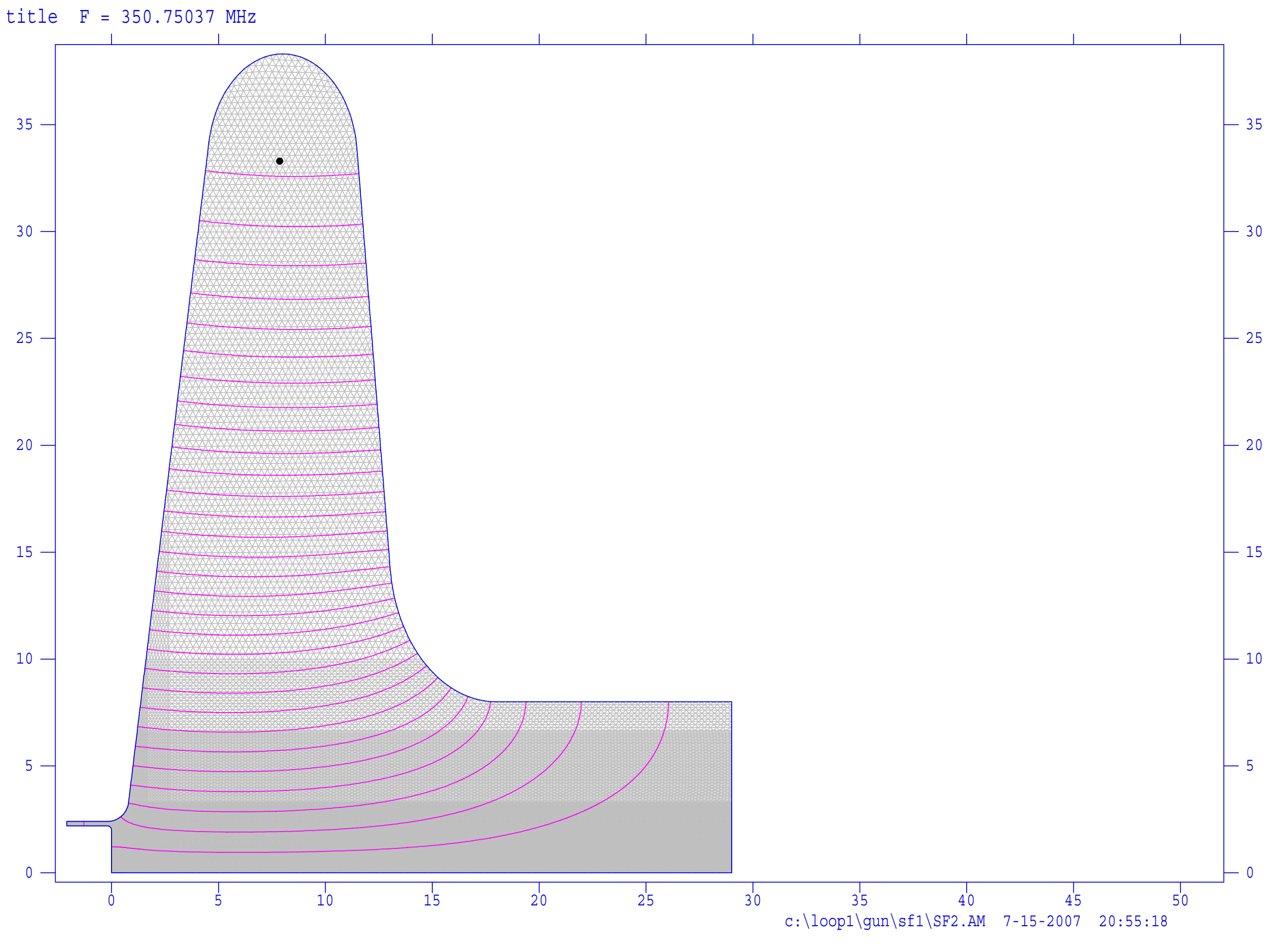


4e-06
3e-06
2e-06
1e-06
0
Normalized Emittance [m]
350 MHz 1/2 cell gun
700 MHz cavity
Solenoid
4D Emittance 0.26 mu
0
1
2
3
4
5
6
7
Path length [m]

Bunch shape



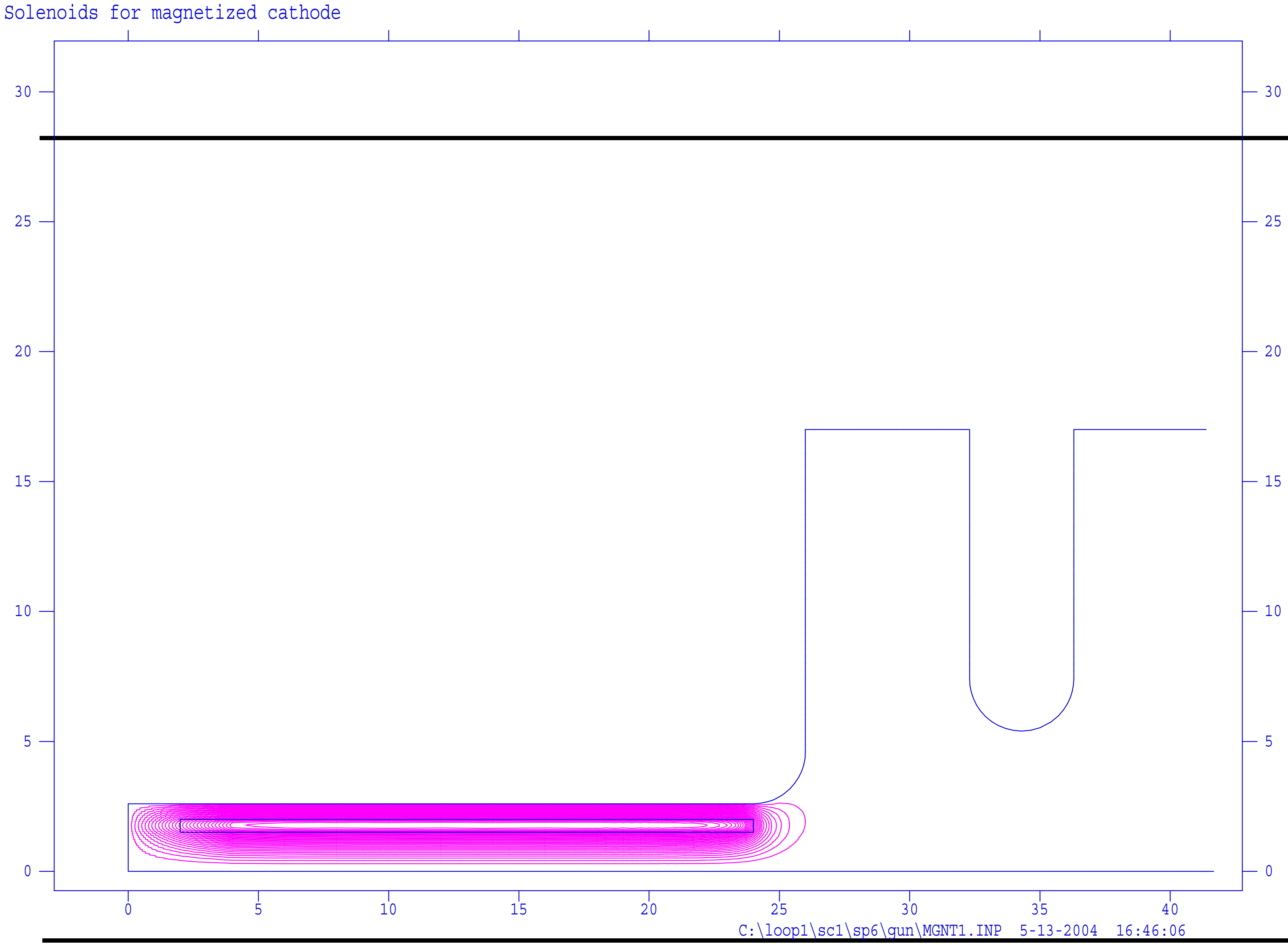
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
Bunch radius [m]
-20
-10
0
10
20
Bunch length [degrees@350 MHz]


title F = 350.75037 MHz
35
30
25
20
15
10
5
0
0
5
10
15
20
25
30
35
40
45
50
c:\loop1\gun\sf1\SF2.AM 7-15-2007 20:55:18

Parameters

- Gun frequency: 350 MHz
- Linac Frequency 700 MHz (working on 350 MHz)
- Bunch length: ± 13.3 degrees
- Cathode radius: 6.3 mm
- Transverse temperature on the cathode: 0.03 eV (this corresponds to a cathode temperature of 80 deg K. The expected temperature in our experiment is about 3 deg K.
- Field on the cathode: 11.2 Gauss
- Magnetization 5 μ (not much increase expected for 8 μ)
- Energy at the exit of the gun: 5 MeV
- Further optimization possible (gun shape, frequency, linac)

Including a Solenoid in the gun



Conclusion

- Promising simulations indicate better than required 4D-emittance, leaving budget for the real world.
- Expectation that the experiment proves the feasability of GaAs SRF guns.
- Experiment progressing on a shoe-string budget