An SRF Injector for the ILC

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Motivation

- RF electron guns can produce higher brightness beams than DC electron guns because of the field gradient at the cathode is higher
- A SRF electron gun may be capable of producing an electron beam with a small enough emittance to be accelerated in the ILC without a damping ring.
- Even if the damping ring can not be avoided a lower emittance injector might be advantageous.

ILC beam parameters at the entrance of the main linac

Parameter	**Nominal**	**Low charge**
Horizontal Emittance	8 µ	8 µ
Vertical Emittance	0.02 µ	0.02 µ
Energy spread	0.15 %	0.15 %
Bunch length	0.3 mm	0.2 mm
Bunch charge	3.2 nC	1.6 nC

What needs to be done

- **Simulation of beam transport including**
  - magnetized/flat beam
  - space charge
  - bunch shaping
- **Bunch shaping**
  - An ellipsoid distribution is necessary to reach the required emittances
  - A Beer can distribution gives a 4D emittance of 1.1 μ.
- **Survival of a GaAs cathode in an SRF gun**
  - The quantum efficiency of the cathode can be destroyed by electron and ion back-bombardment. Remedies are good vacuum and geometry.

Magnetization and round-to-flat conversion

4-D Emittance: $\varepsilon_{4D} = \beta\gamma \sqrt[4]{|\sigma|}$

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

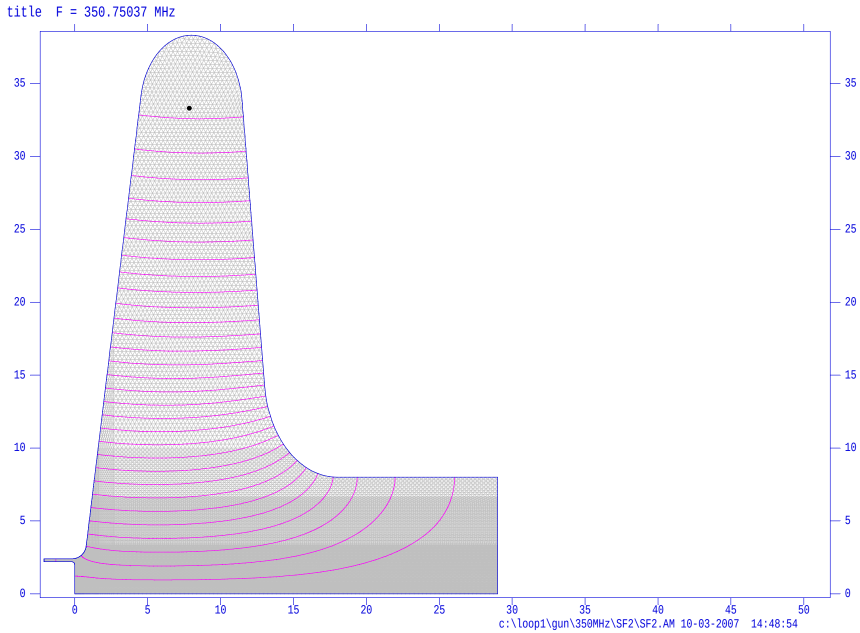
Magnetization: $M = \beta\gamma(<x \cdot y'> - <y \cdot x'>)$ with $L \equiv \frac{M}{2} = \frac{q \cdot B \cdot r_{cath}^2}{2m_e c}$

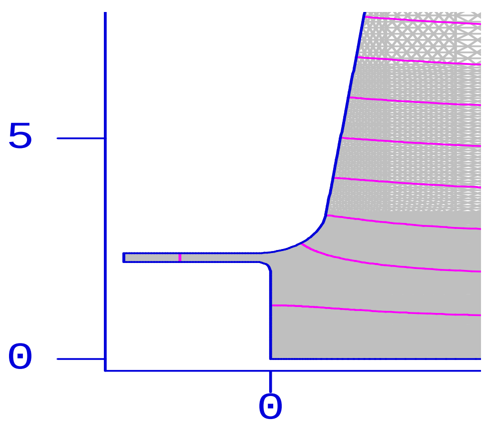
Round beam: $\varepsilon_{eff}^2 = \varepsilon_{4D}^2 + L^2$

Flat beam: $\varepsilon_x = \varepsilon_{eff} + L \approx M + \frac{2\varepsilon_{4D}^2}{M}$ $\quad \varepsilon_y = \varepsilon_{eff} - L \approx \frac{\varepsilon_{4D}^2}{M}$

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

SRF Gun

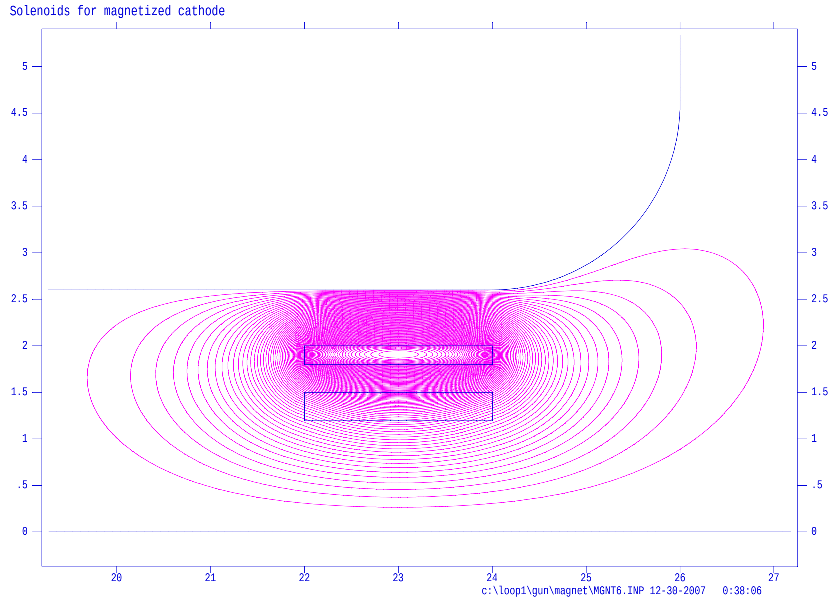


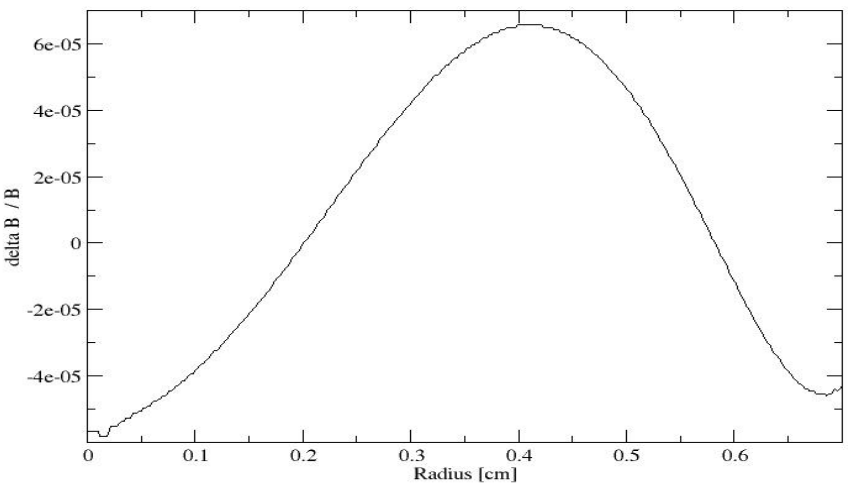


- **350 MHz**
- **Peak field on the cathode: 24.5 MV/m**
- **Peak field on the cavity walls: 43MV/m**
- **Beam energy at the exit of the gun: 5 MeV**

Cathode Magnet

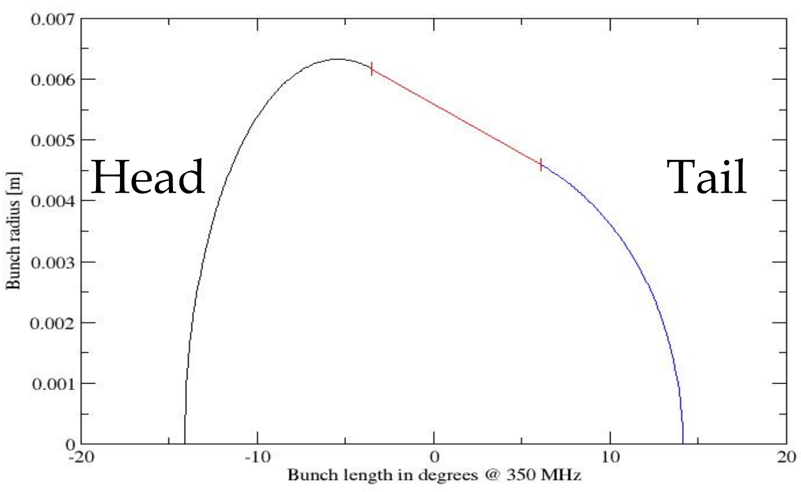
- Large cathode radius (6.5 mm) requires small field (11 Gauss)
- Two separate coils are used to produce a uniform field
- Magnets are turned on after cool-down, field does not penetrate Niobium



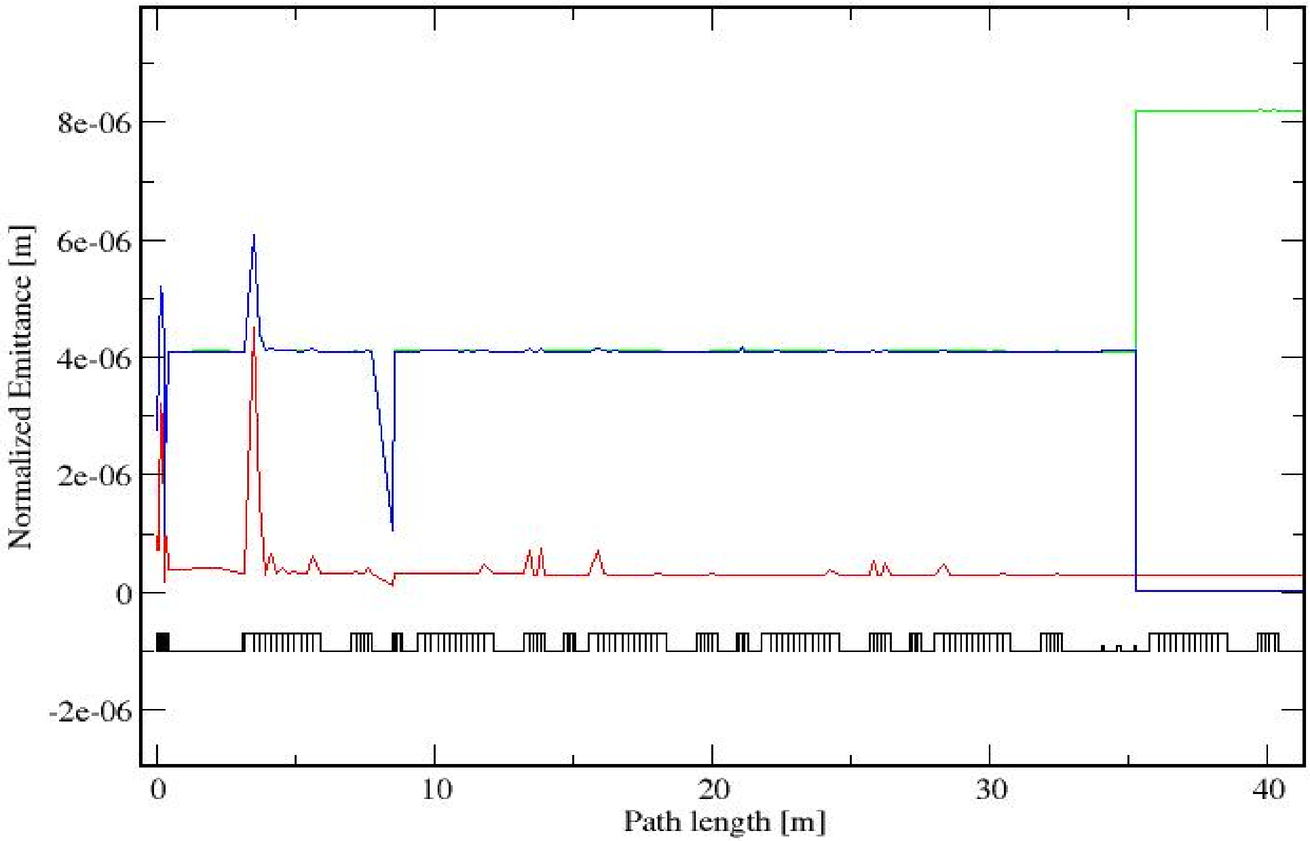


Bunch Shaping

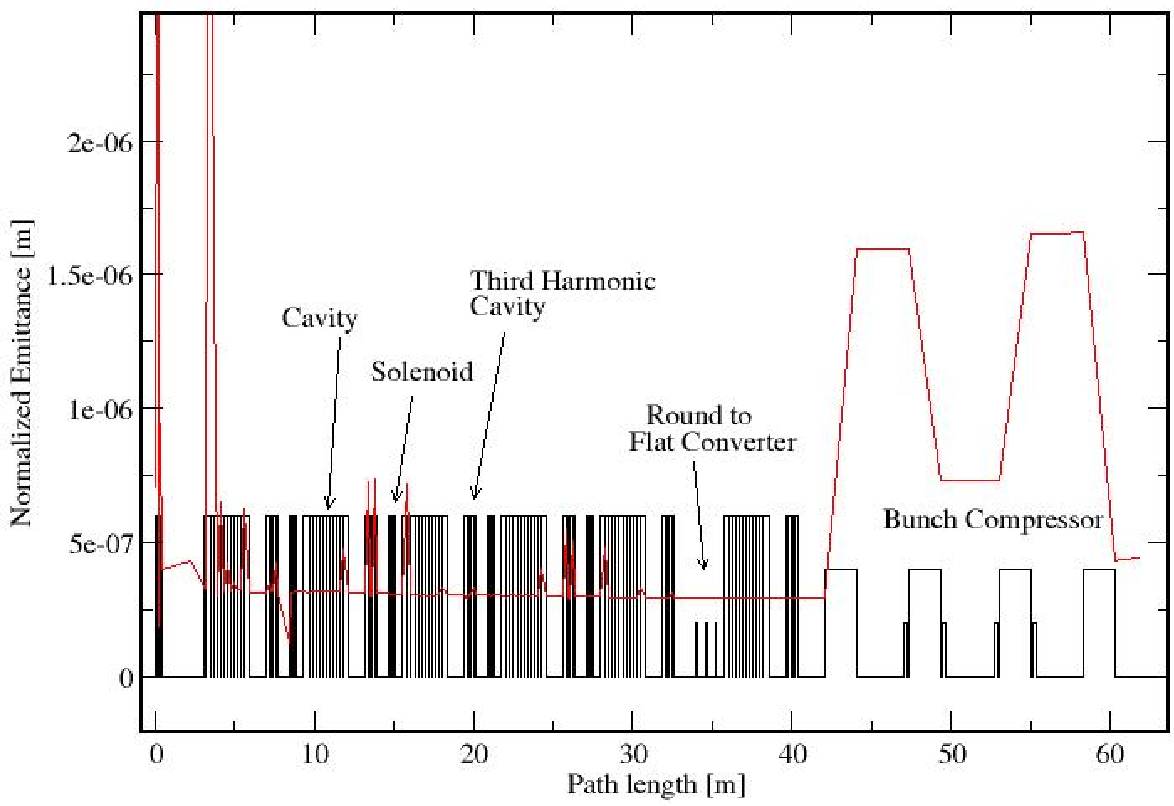
- **Deviation from ellipsoid shape compensates space charge asymmetry of space charge forces during emission**
- **A thermal emittace of 0.03 eV is assumed for a GaAs cathode at 80^{o} K (liquid nitrogen temperature)**



Emittances



$$\varepsilon_{4D} = 0.3\mu$$

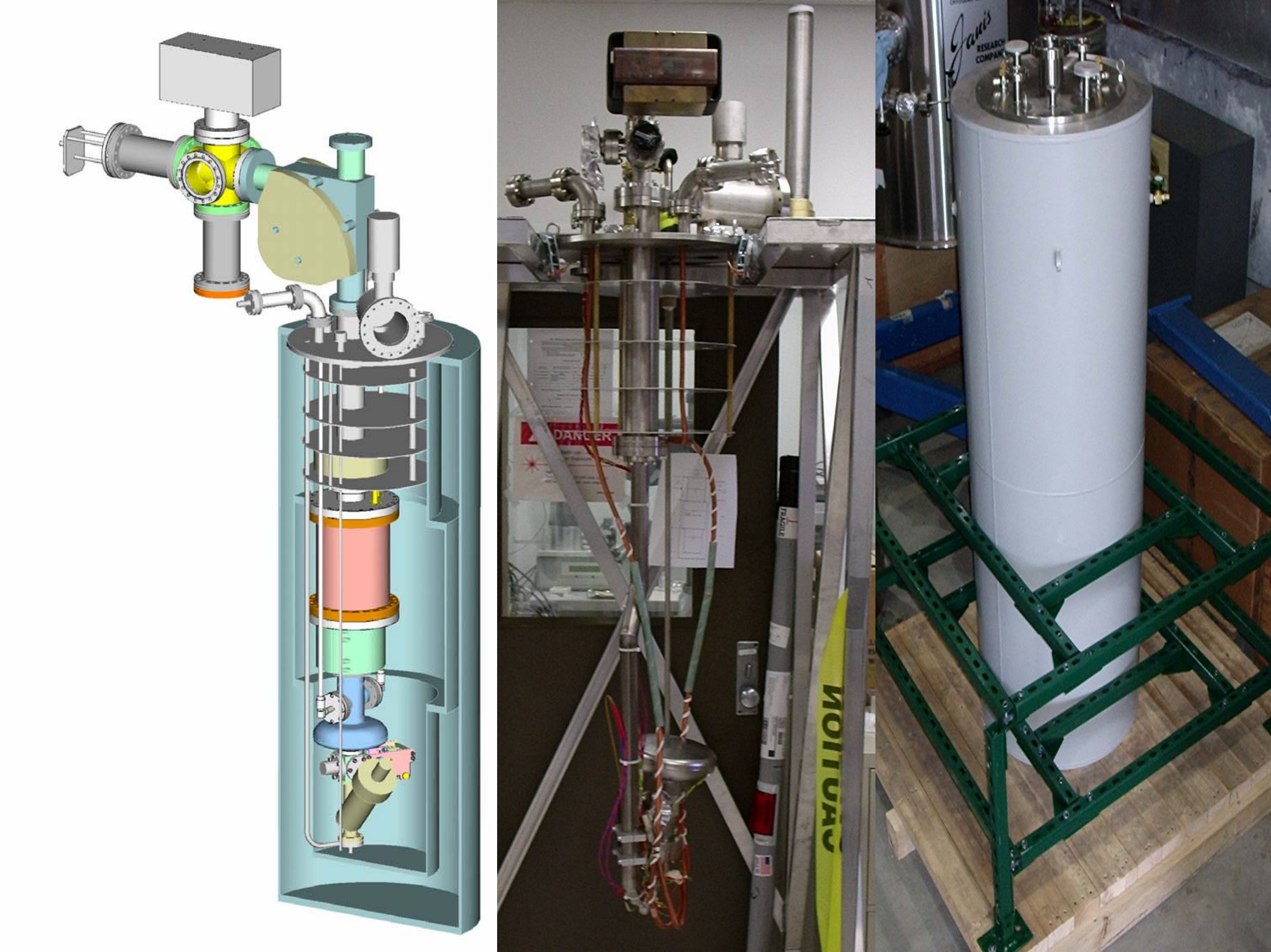

Normalized Emittance [m]
2e-06
1.5e-06
1e-06
5e-07
0
Cavity
Solenoid
Third Harmonic
Cavity
Round to
Flat Converter
Bunch Compressor
0
10
20
30
40
50
60
Path length [m]

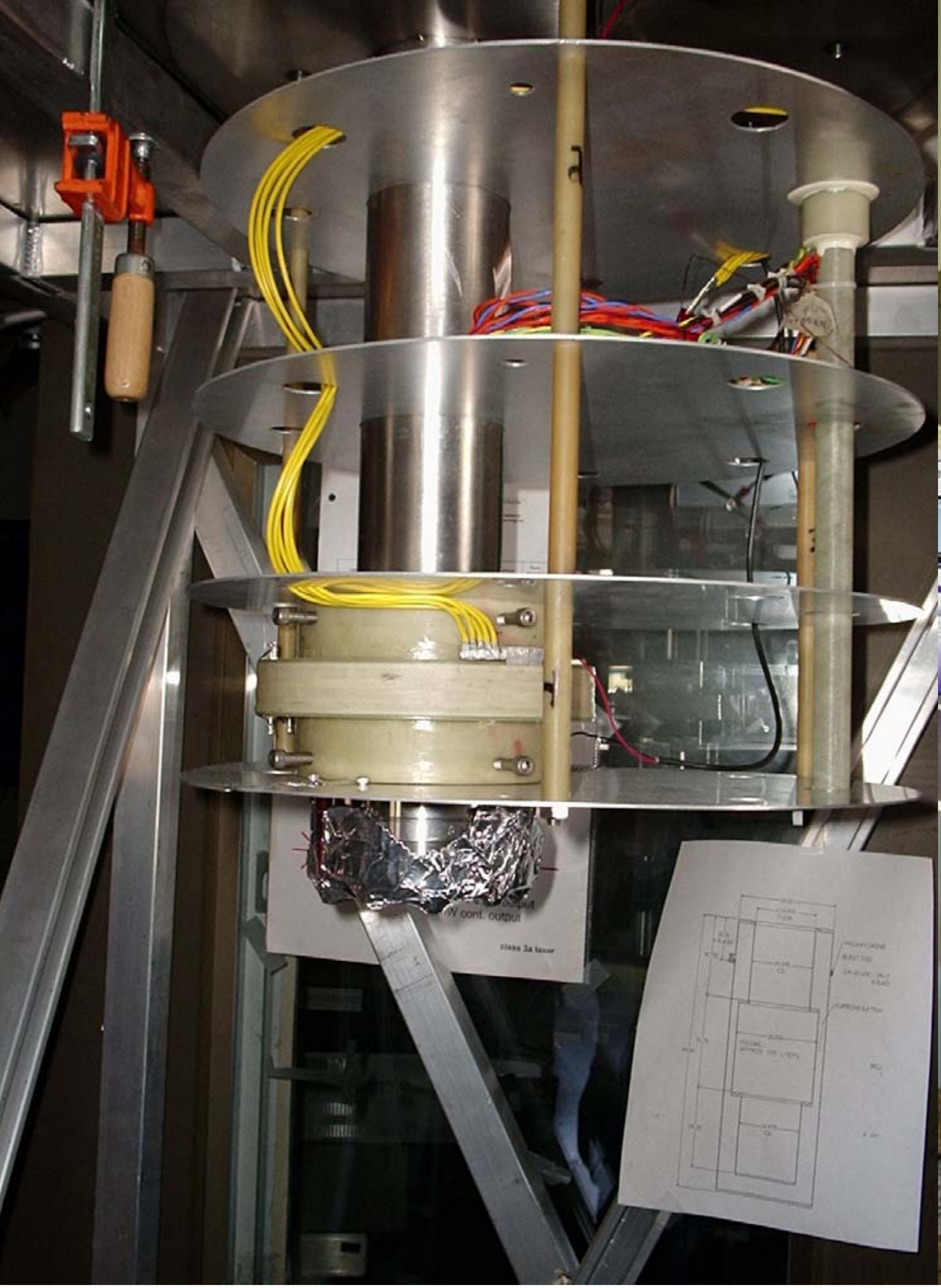
GaAs cathodes in RF guns

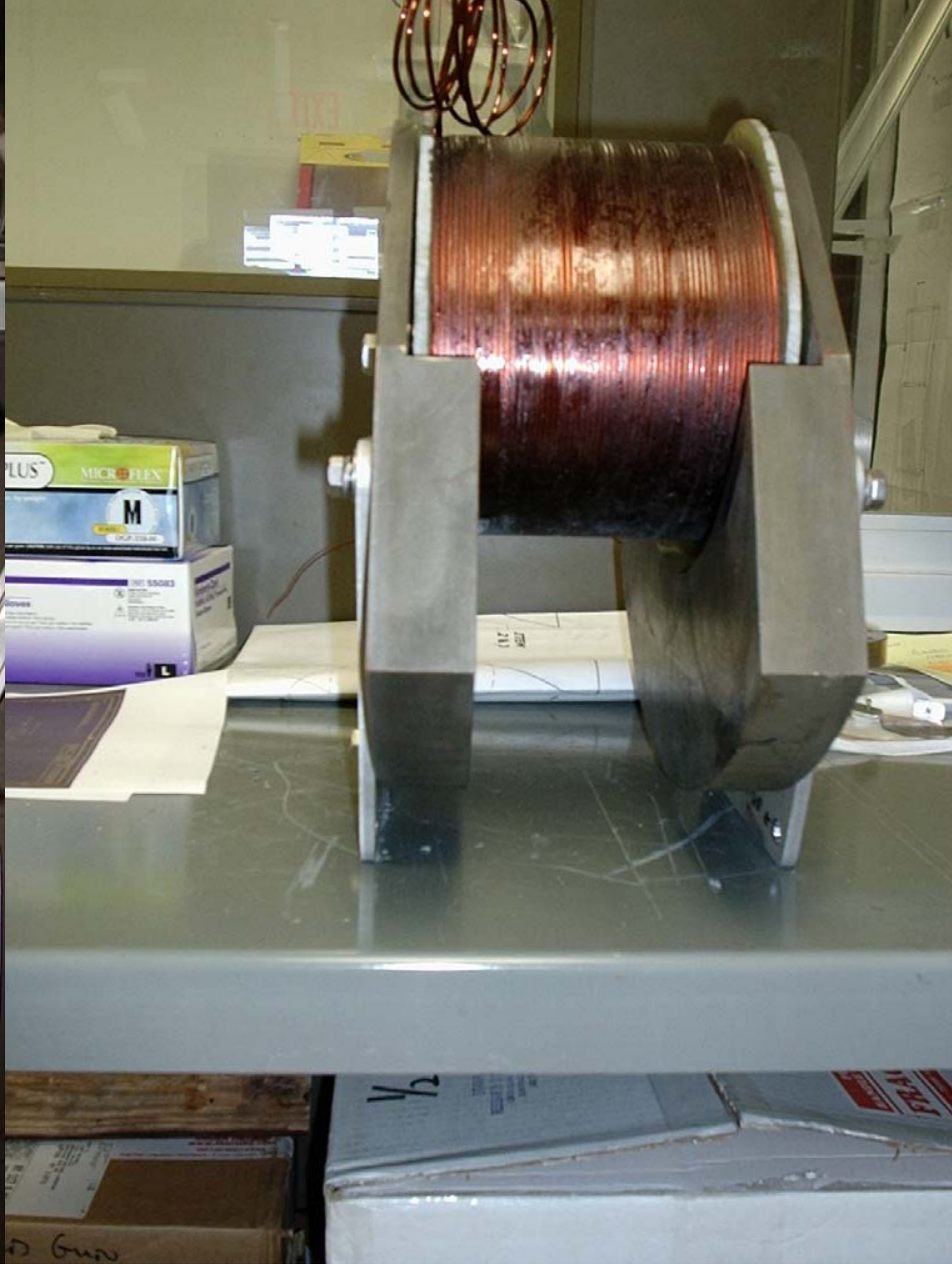
- The quantum efficiency of GaAs cathodes is destroyed by ion back-bombardment. All successful GaAs guns are DC guns with a vacuum level of 10^{-11} torr.
- Normal conducting RF guns have 10^{-9} torr due to out-gassing caused by the RF field. Quantum efficiency life times of 10 seconds have been measured.
- Superconducting RF guns can have a vacuum of better than 10^{-11} torr due to cryo-pumping.
- Only ions created close to the cathode will hit the cathode with energies ~ 2 keV (E. Pozdeyev, PRST-AB).
- Little electron bombardment from field emission electrons. SRF cavity treatment reduces dark currents.
- The SRF gun may be poisoned by boiled off cesium. We believe this effect is negligible, but it will be measured.

Requirements for the Experiment

- Good vacuum (10^{-11} torr) before cool-down.
- High current density (10 μA from a 1mm ∅ cathode). Ions will hit close to the center of the cathode.
- High gradient (15-20 MV/m) for realistic field emissions.
- Easy removal of the cathode without loss of vacuum.
- Preparation chamber for the regeneration of cathodes. Preparation includes heating of the cathode (exact temperature) and replenishment of the cesium layer.
- Radiation protection (200 rad/h @ 1 m distance).
- We will not measure the spin polarization.

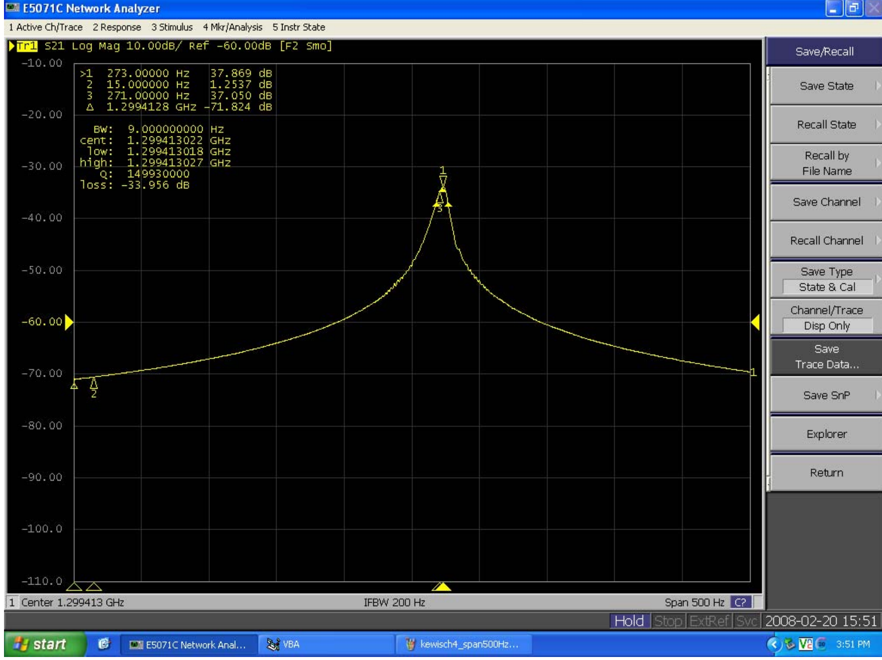

DANGER
Janis

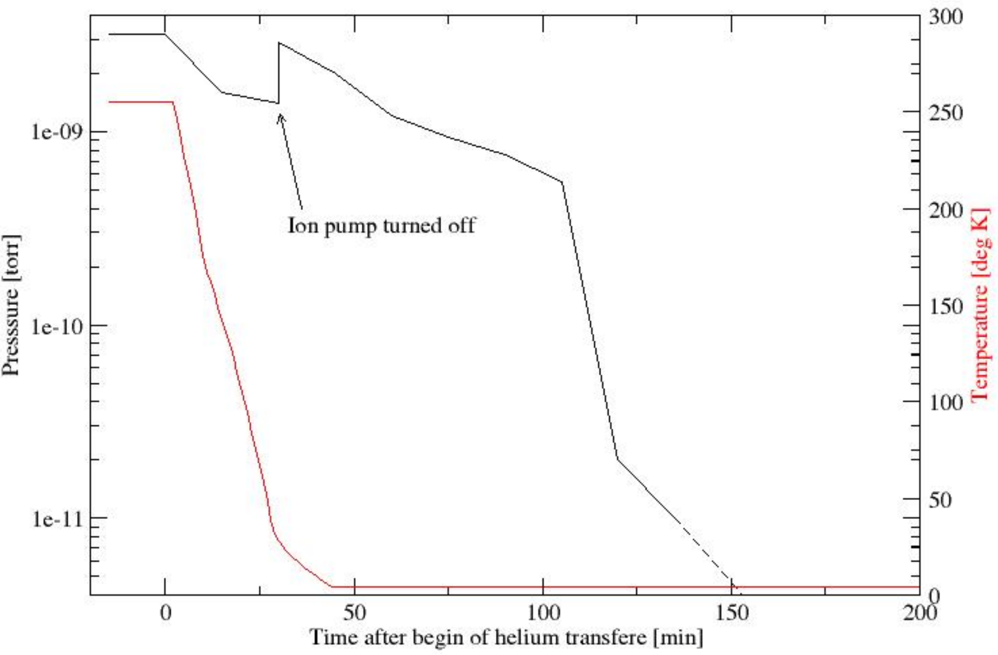


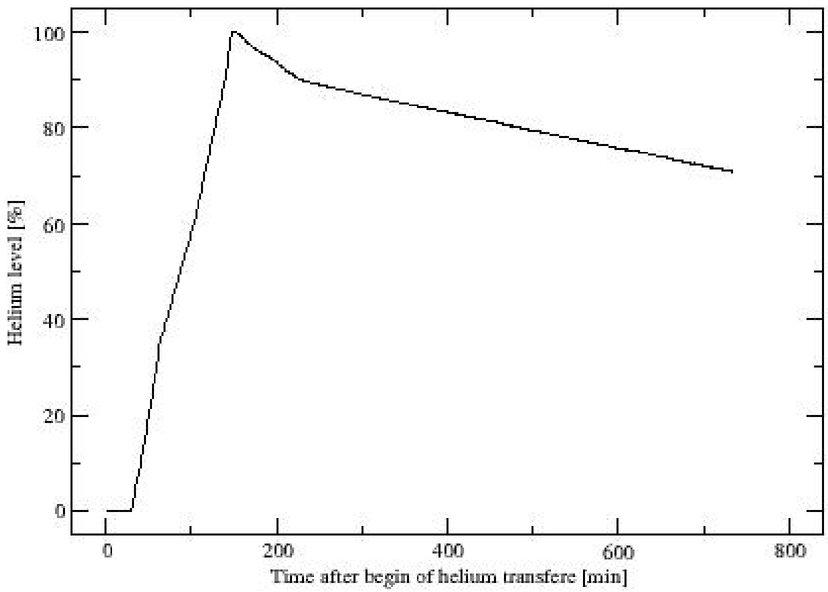


Test results

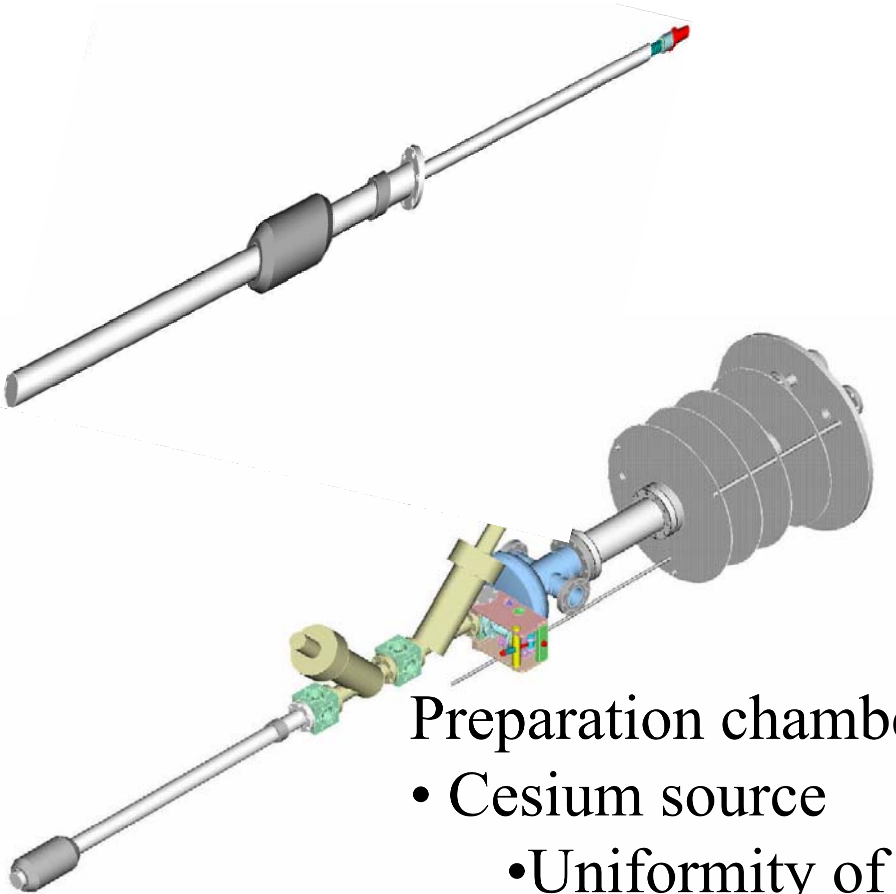
- $Q=1.5\cdot10^{8}$ @4.2 deg K.
- Heat load 5 W.
- Vacuum with cryo-pumping < 10^{-11} torr.

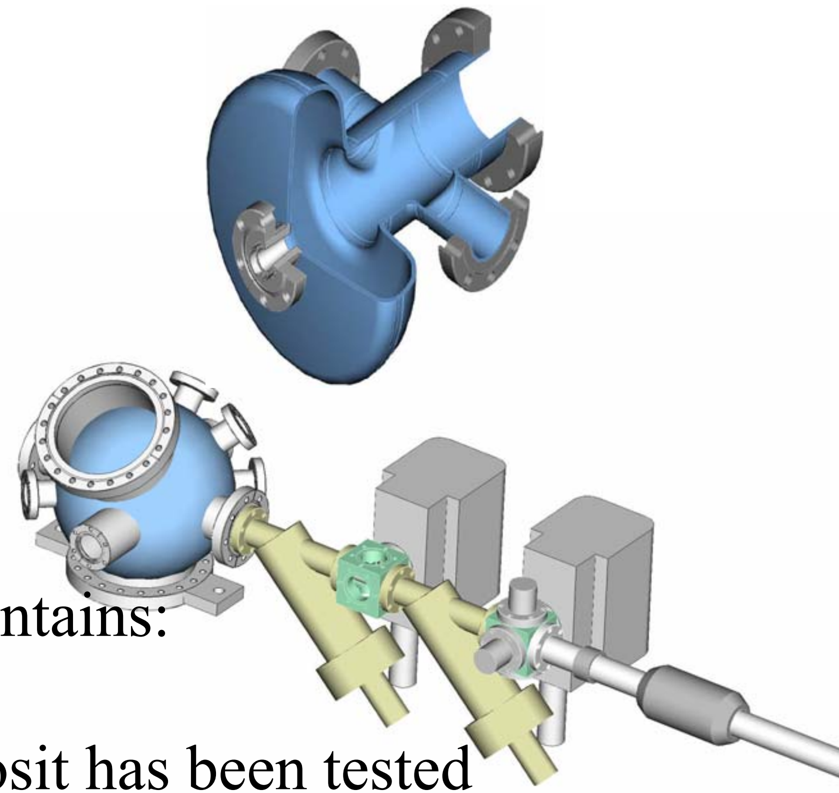






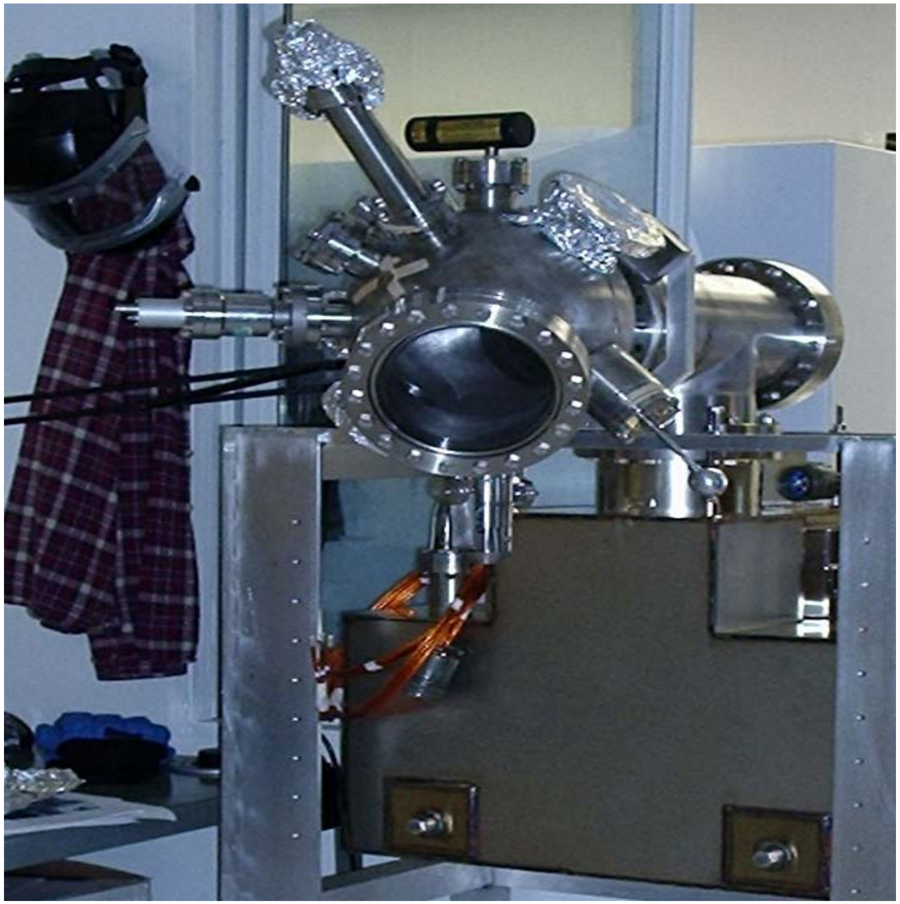
Transporter Mechanism and Preparation Chamber

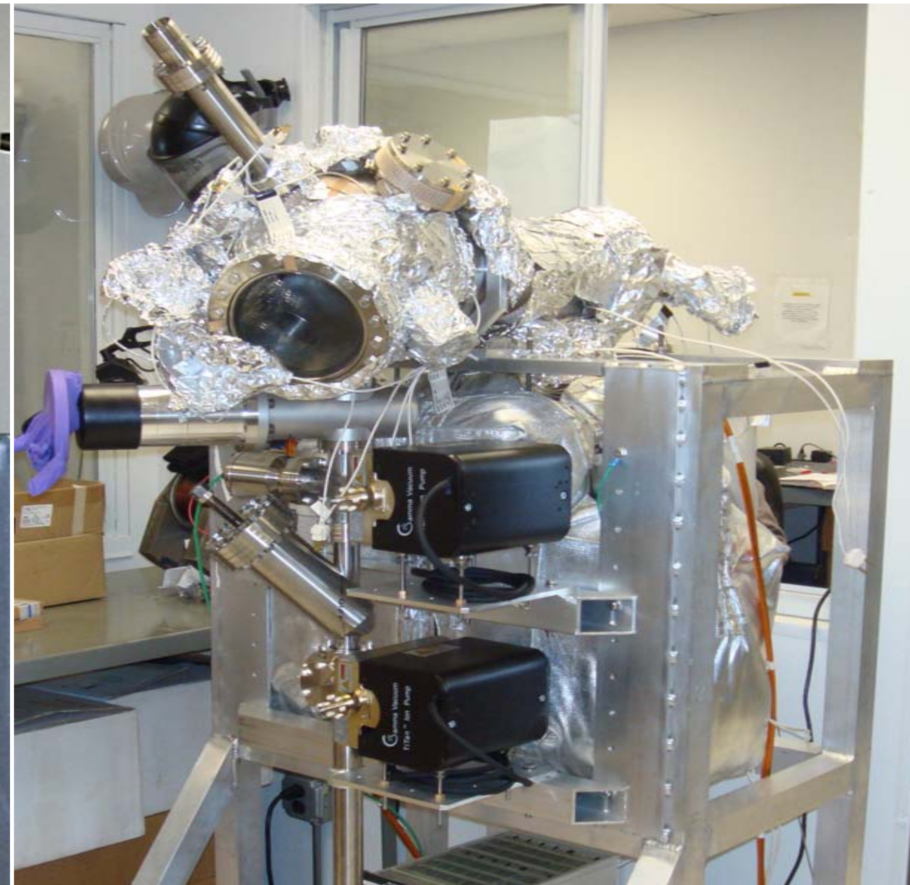




Preparation chamber contains:
- Cesium source
  - Uniformity of deposit has been tested
- Heating mechanism 560^{o}C
- Quantum efficiency measurement

Cathode Preparation Chamber

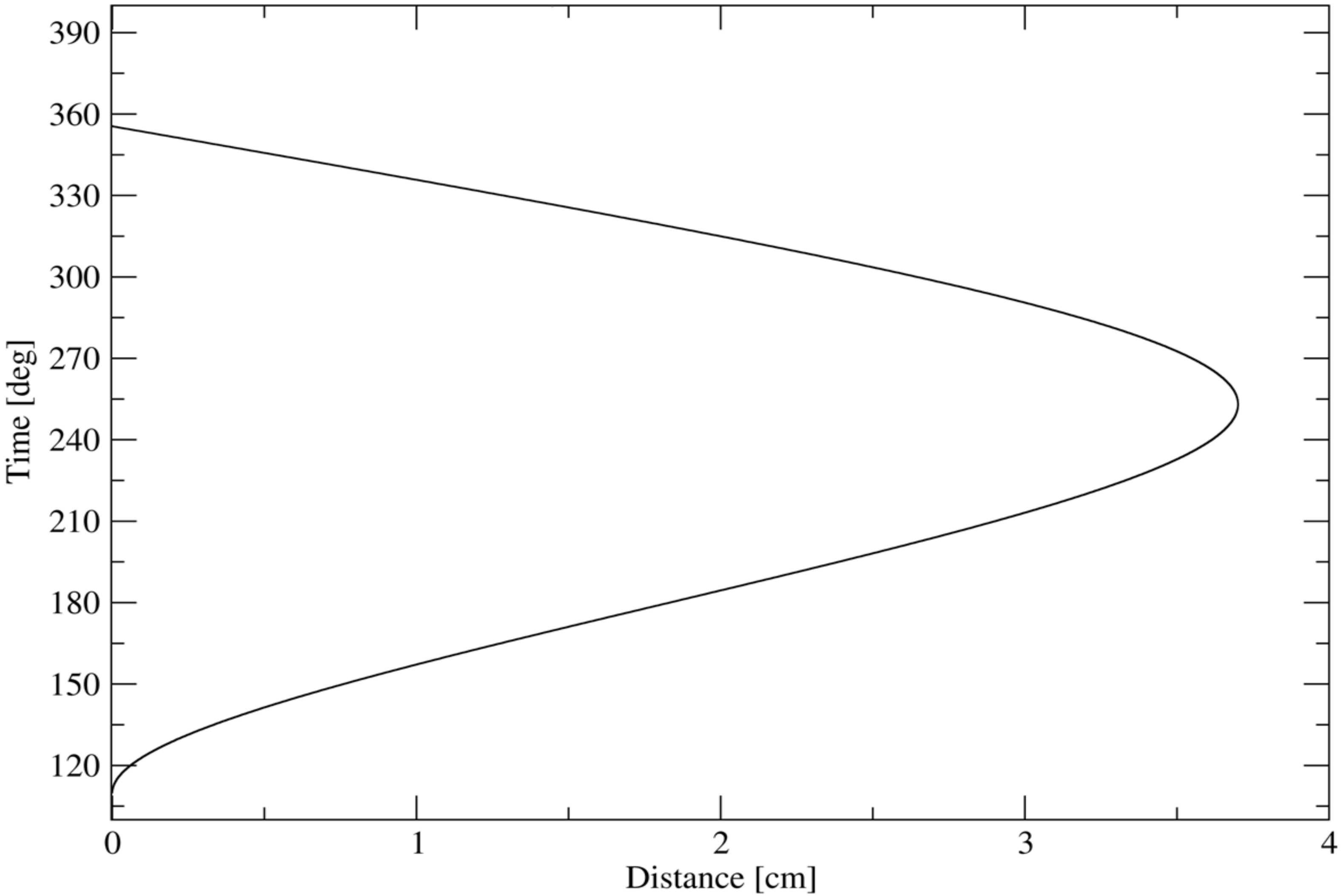




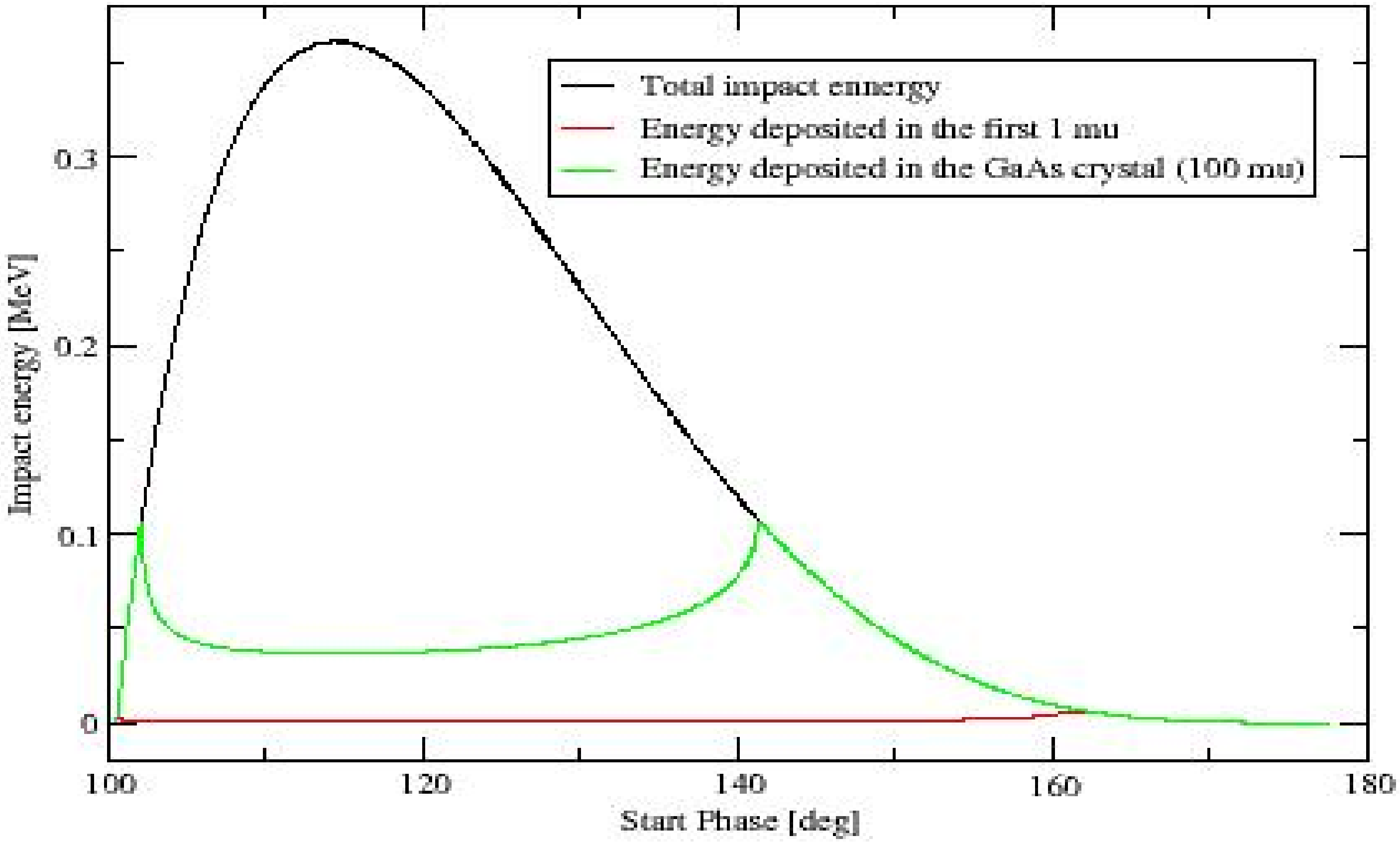
Electron bombardment

- Experiment at BINP measures 10 seconds life time
- Bad vacuum does not explain short life time
- Dark currents from field emission are small (H. Bluem, AES)
- Aleksandrov (BINP) suggests bad lifetime is caused by electron bombardment with electrons emitted from the cathode

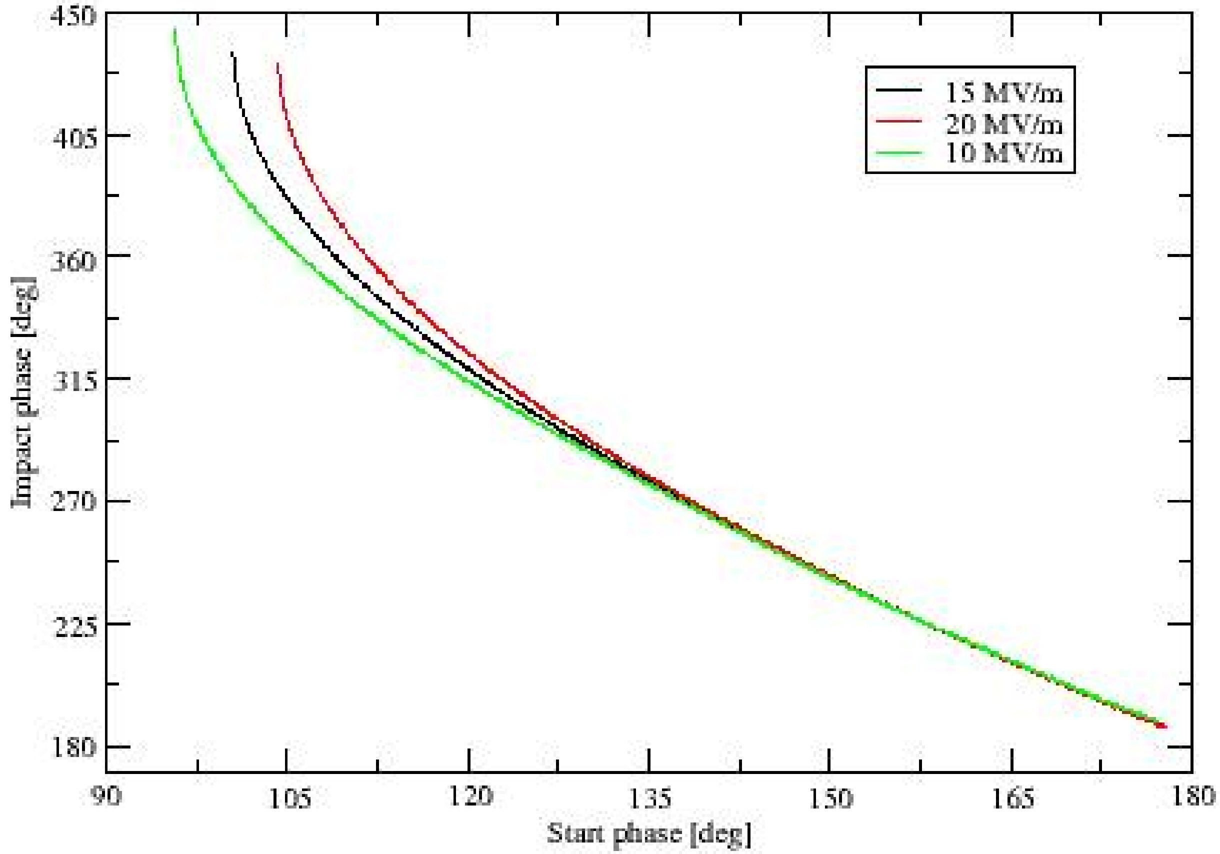
Electron trajectory on axis



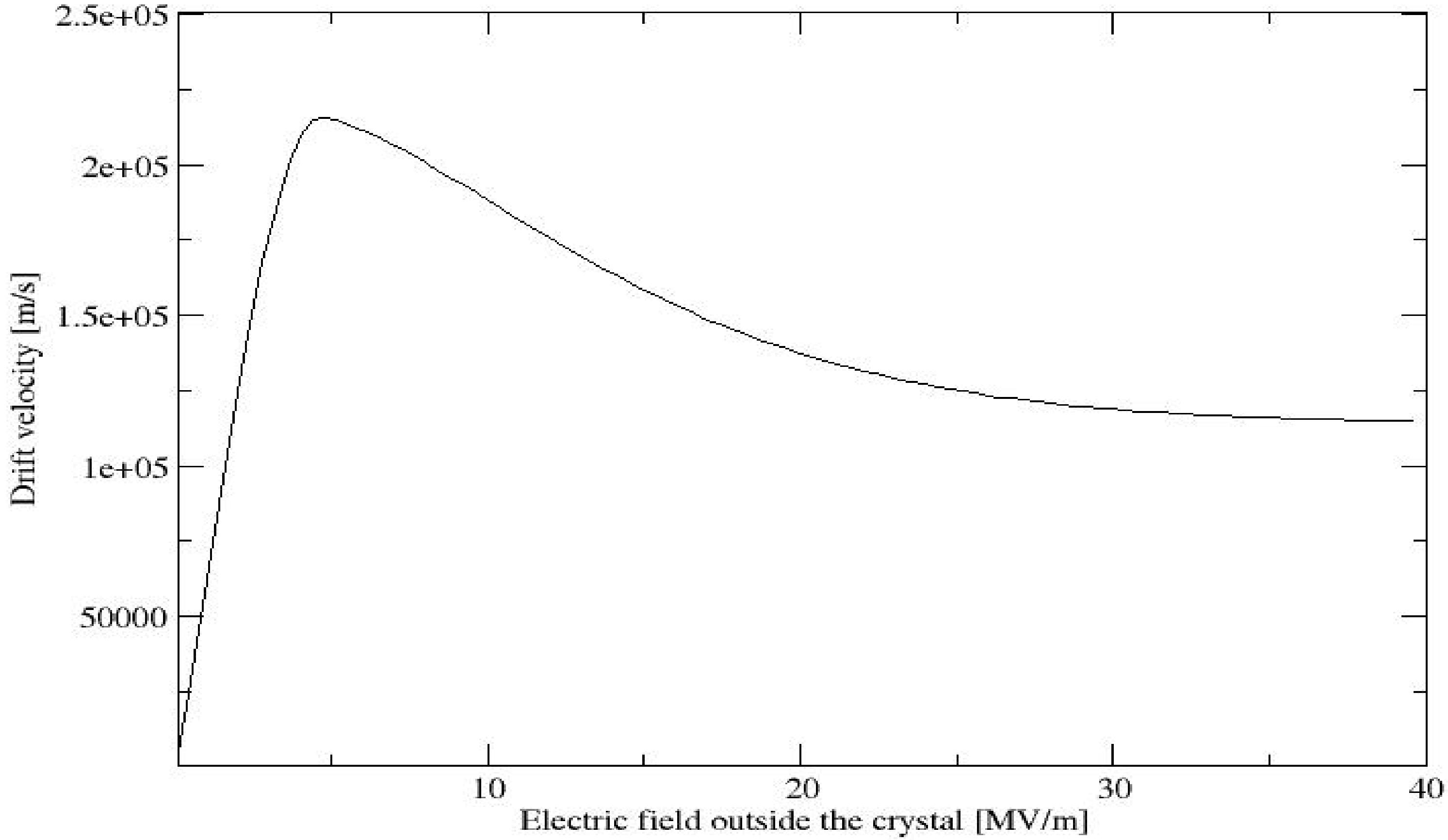
Energy deposited by electrons



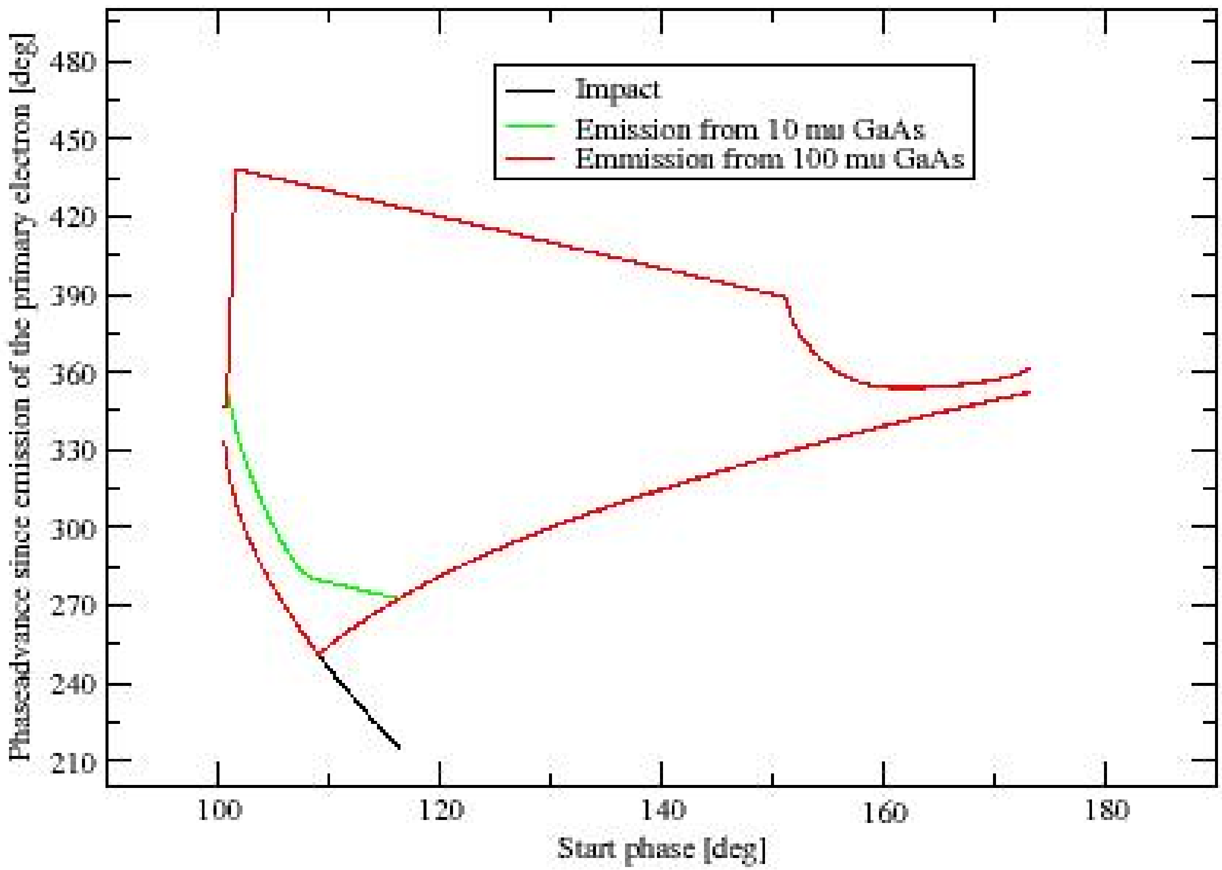
Impact phase vs. start phase

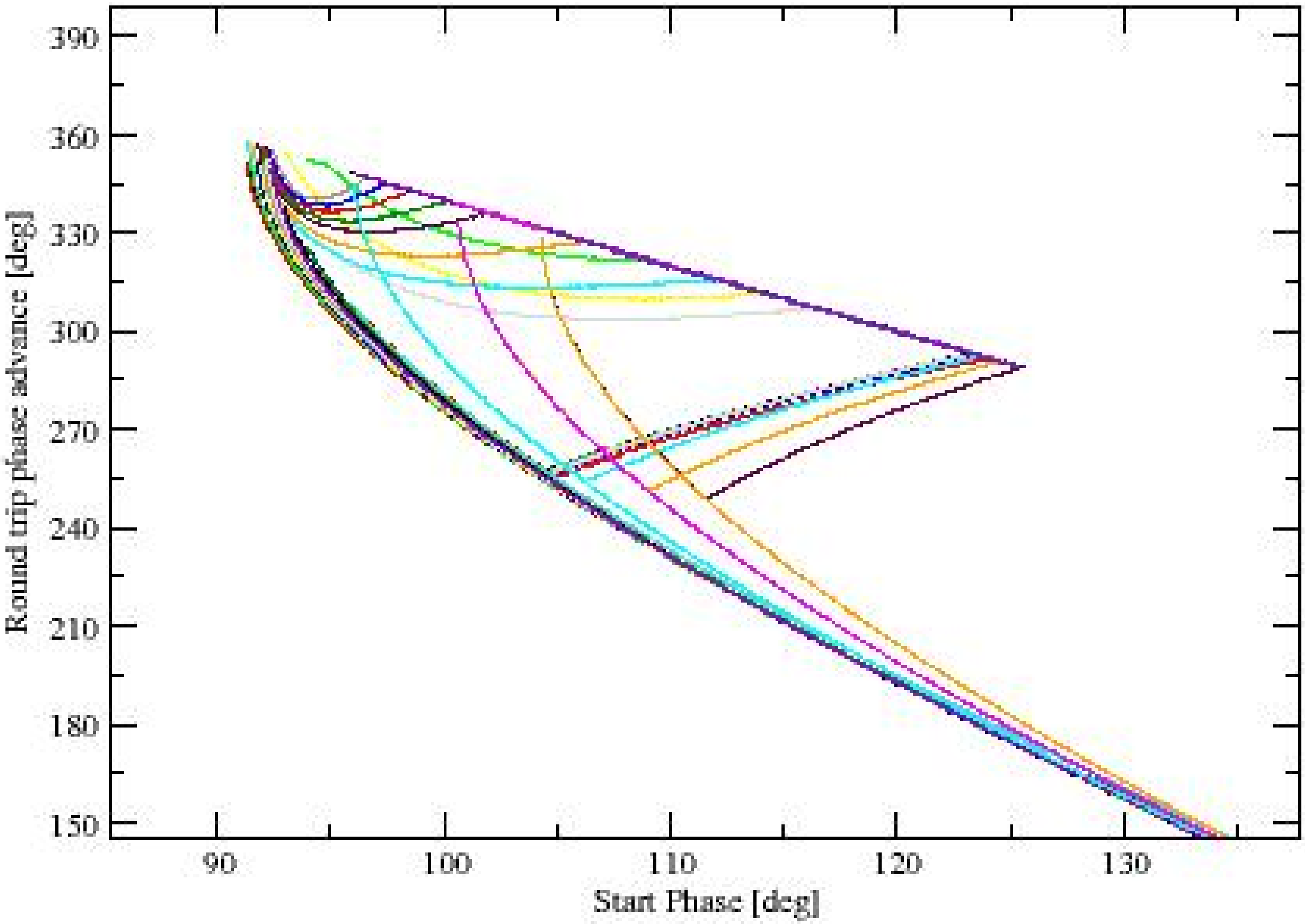


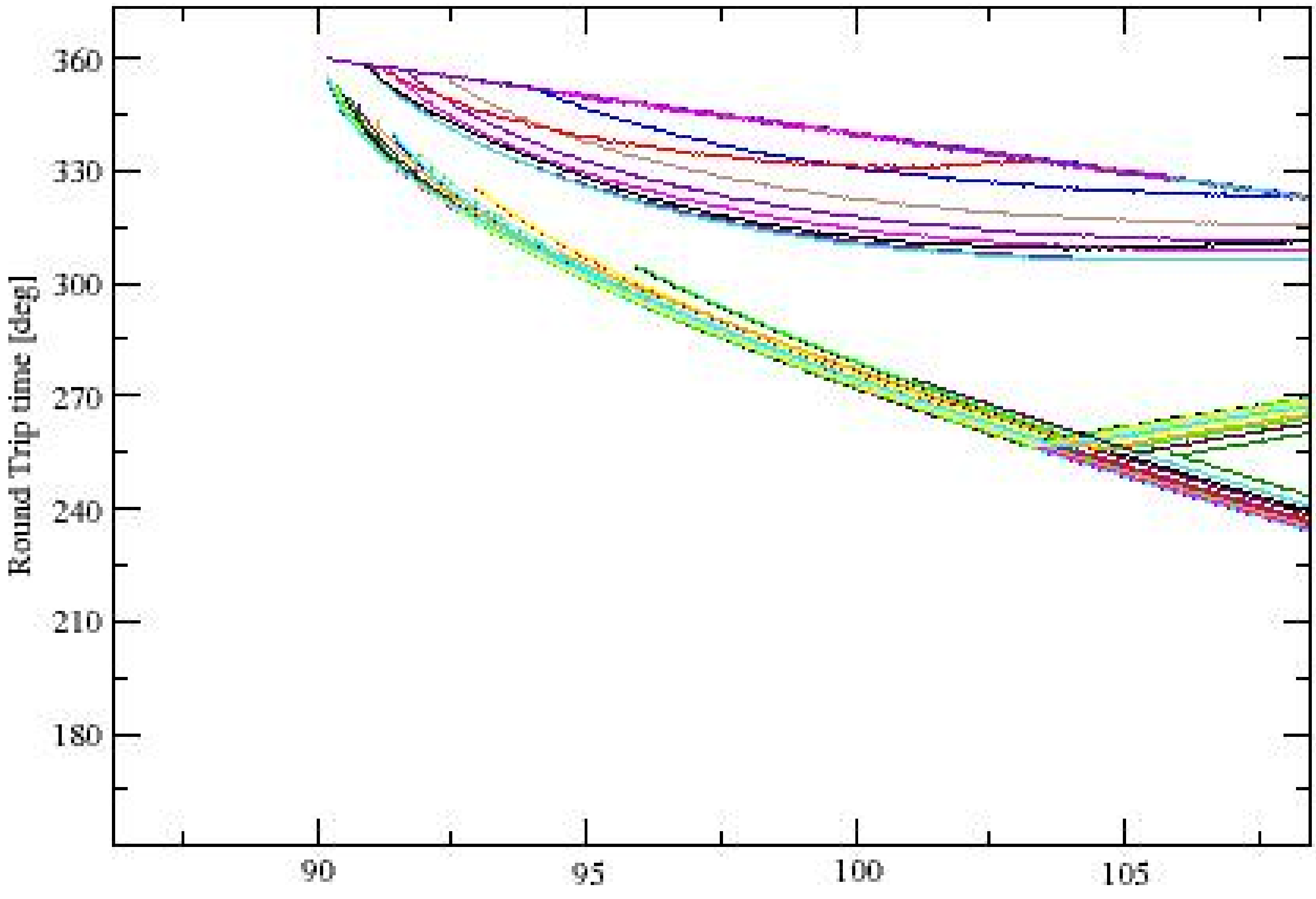
Drift Velocity in GaAs



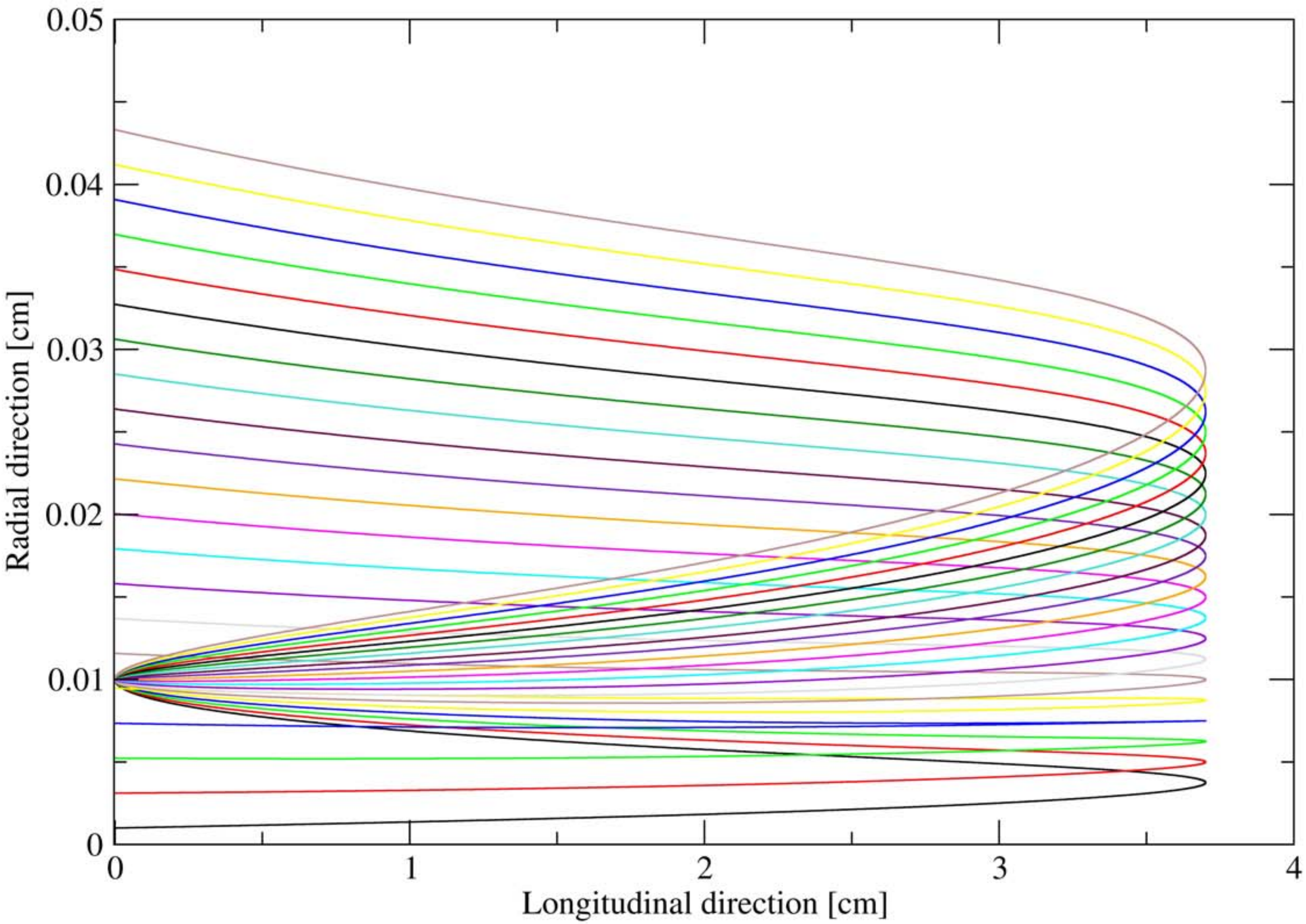
Emission range of secondary electrons due to the delay caused by drifting inside the cathode material.




390
360
330
300
270
240
210
180
150
Round trip phase advance [deg]
90
100
110
120
130
Start Phase [deg]



360
330
300
270
240
210
180
Round Trip time [deg]
90
95
100
105


0.05
0.04
0.03
0.02
0.01
0
Radial direction [cm]
0
1
2
3
4
Longitudinal direction [cm]

Conclusion

- **Measurement of cathode life time scheduled for summer 2009.**
- **Ion bombardment damage should be less severe than in a DC gun.**
- **Electron bombardment with up to 350 keV electrons**
- **Multipacting can be avoided using a thin GaAs crystal and/or low frequency guns .**