Progress on using a GaAs Photocathode in an RF gun

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Fermilab

Advanced Energy Systems, Inc.

Outline

- Introduction and Motivation
- Ion Bombardment Simulations
- Vacuum Measurements in liquid N_2 cooled gun
- Future R&D Plans
- Conclusions

Collaboration

Fermilab

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Polarized RF Gun Electron Source

- Our goal is to **produce an RF gun capable of supporting a strained GaAs cathode for polarized e$^-$ production** as a possible source for ILC **by using gun walls as a source of cryopumping to achieve the necessary vacuum.**

Advantanges of RF Guns

- Higher source energy (few MeV vs. 100’s keV).
- Shorter bunch lengths possible.
- Simpler injection system – inject directly to LINAC structure.
- Normal conducting RF guns allow magnetic emittance compensation and flat beam production.

Issues with NEA GaAs Cathodes

- Cathode surface sensitive to oxidation effects from O_2, CO_2, CO, H_2O.
  - SLAC DC gun partial pressures on order 10^{-13} torr or less for these species
  - RF guns operate 2 orders of magnitude higher in pressure for these species
- Ion and electron bombardment.
  - H^+ dominant ion species.

Both of these serve to reduce the quantum efficiency lifetime of the cathode.

By reducing the vacuum pressure, both of these effects can be minimized.

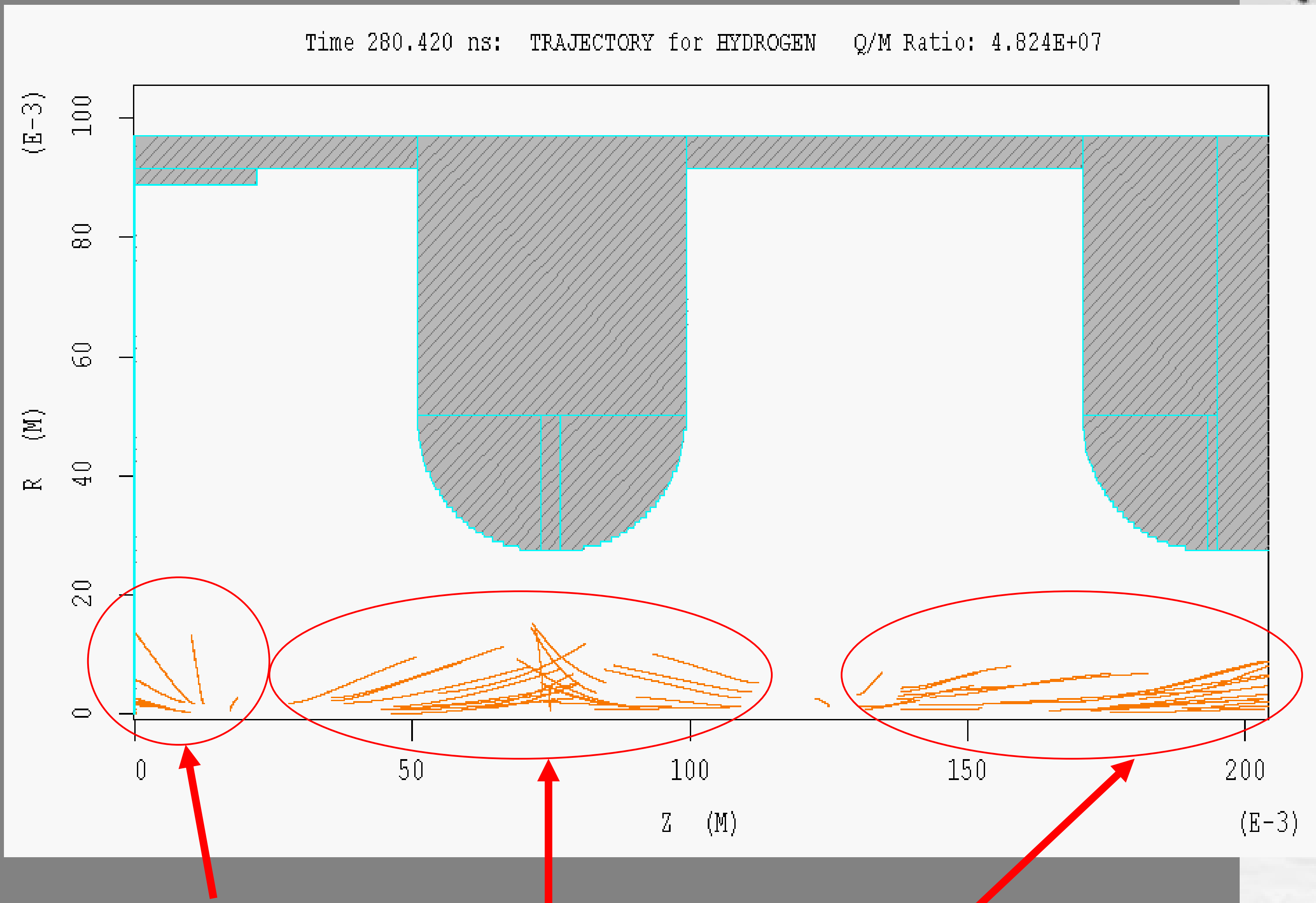
Past Experience in RF Guns

- Aleksandrov, *et al.,* achieved a few second lifetime with NEA GaAs cathode in RF gun.
  - Ion back bombardment from residual gas blamed
- Cathode could be rejuvinated if E_{cath}<30 MV/m.
  - Irreversible damage seen above this
- NEA cathodes had 2-3 orders of magnitude higher dark current than PEA cathodes.
  - Ion back bombardment combined with large secondary electron coefficient in NEA cathodes

Ion Back Bombardment Simulations

- Ion bombardment of cathode studied using MAGIC
  - MAGIC is a 2.5D plasma physics PIC code developed by RTK MRC
- Simulation ran 360 RF periods
- Built-in electron beam induced ionization model was used
- Modeled effects using only H_2 background gas
  - H_2 should be the dominant gas in the gun vacuum
  - Heavier gases would result in very low impact energies
- Artificially high gas pressure was used in order to obtain reasonable statistics
- No solenoidal magnetic field in gun

Ion Trajectories

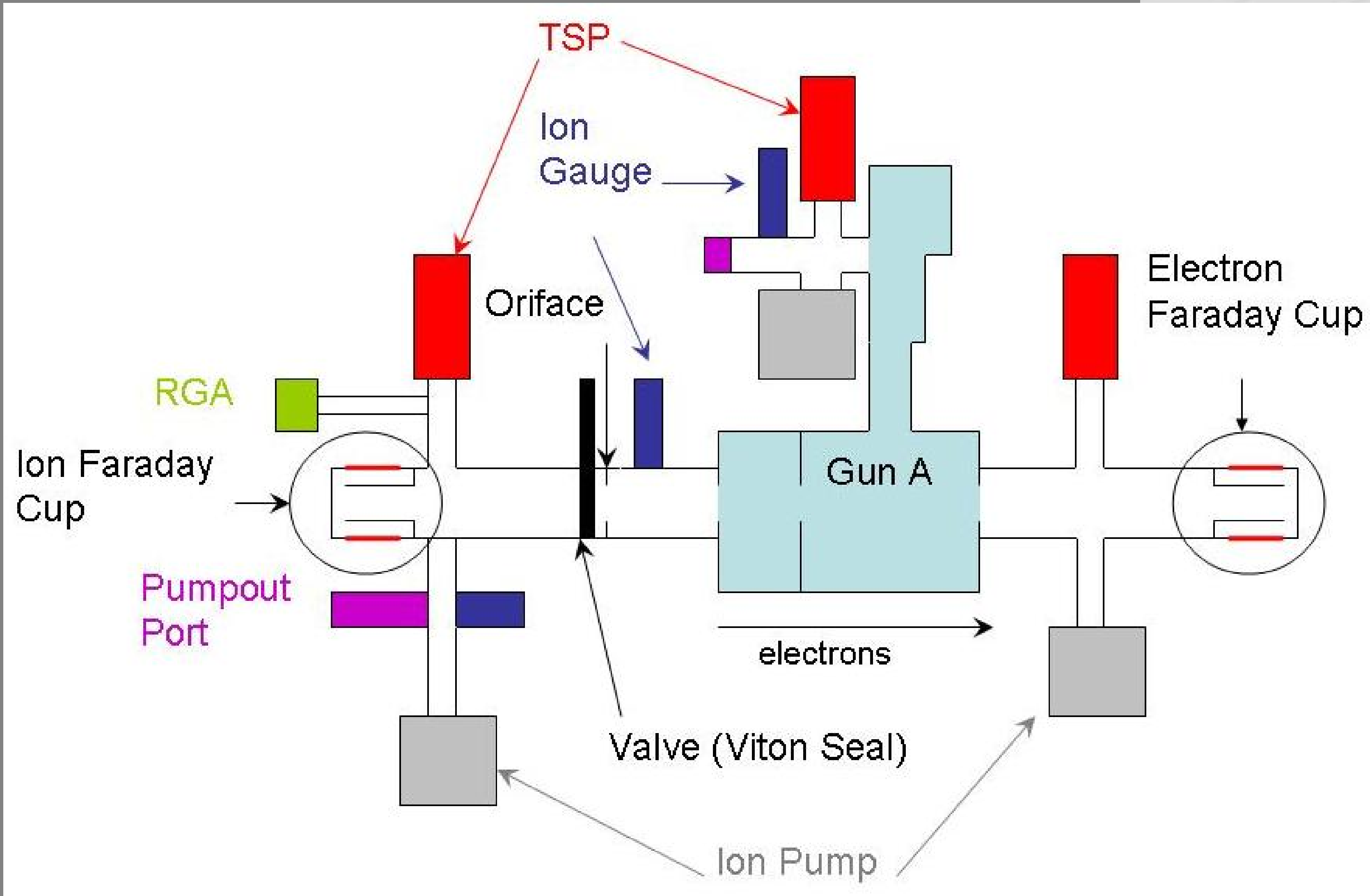


- Ions generated near the cathode strike the cathode.
- Otherwise they collect at the irises.

How Many Ions Impact Cathode in RF Gun?

- 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 evergies less than 500keV.
  - 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.

Vacuum Test Stand

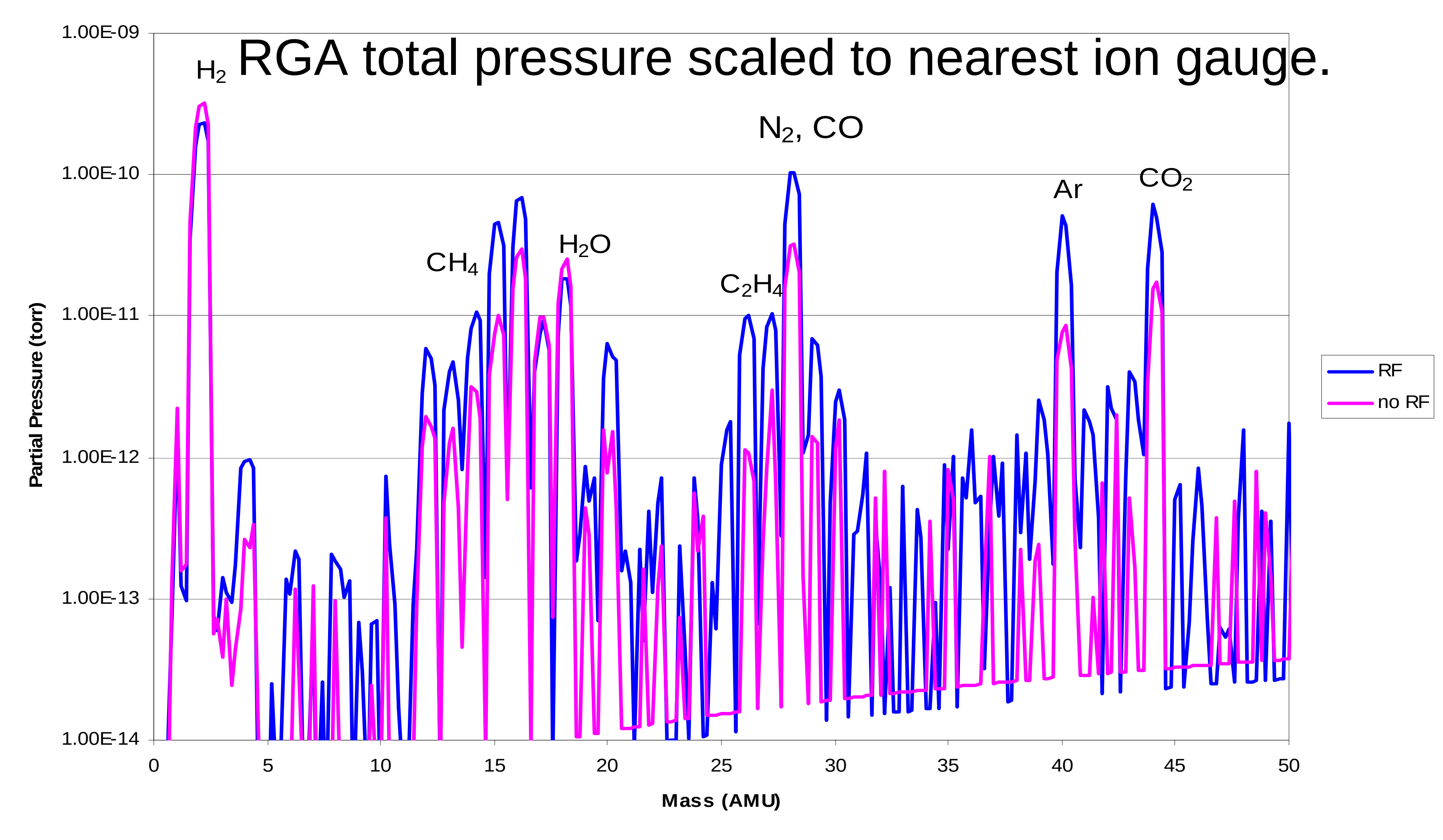


- Gun is 1.6 cell L band RF gun almost identical to one used at FNPL
- No cathode installed.
- Liquid N_2 flowed through water cooling lines.

Vacuum Measurements

- Warm outgassing rate
- Pumping speed of pumping stations
- Base pressure cold
- Outgassing with RF applied, warm and cold
- Cryopumping Characterized
- Dark Current measurements warm and cold

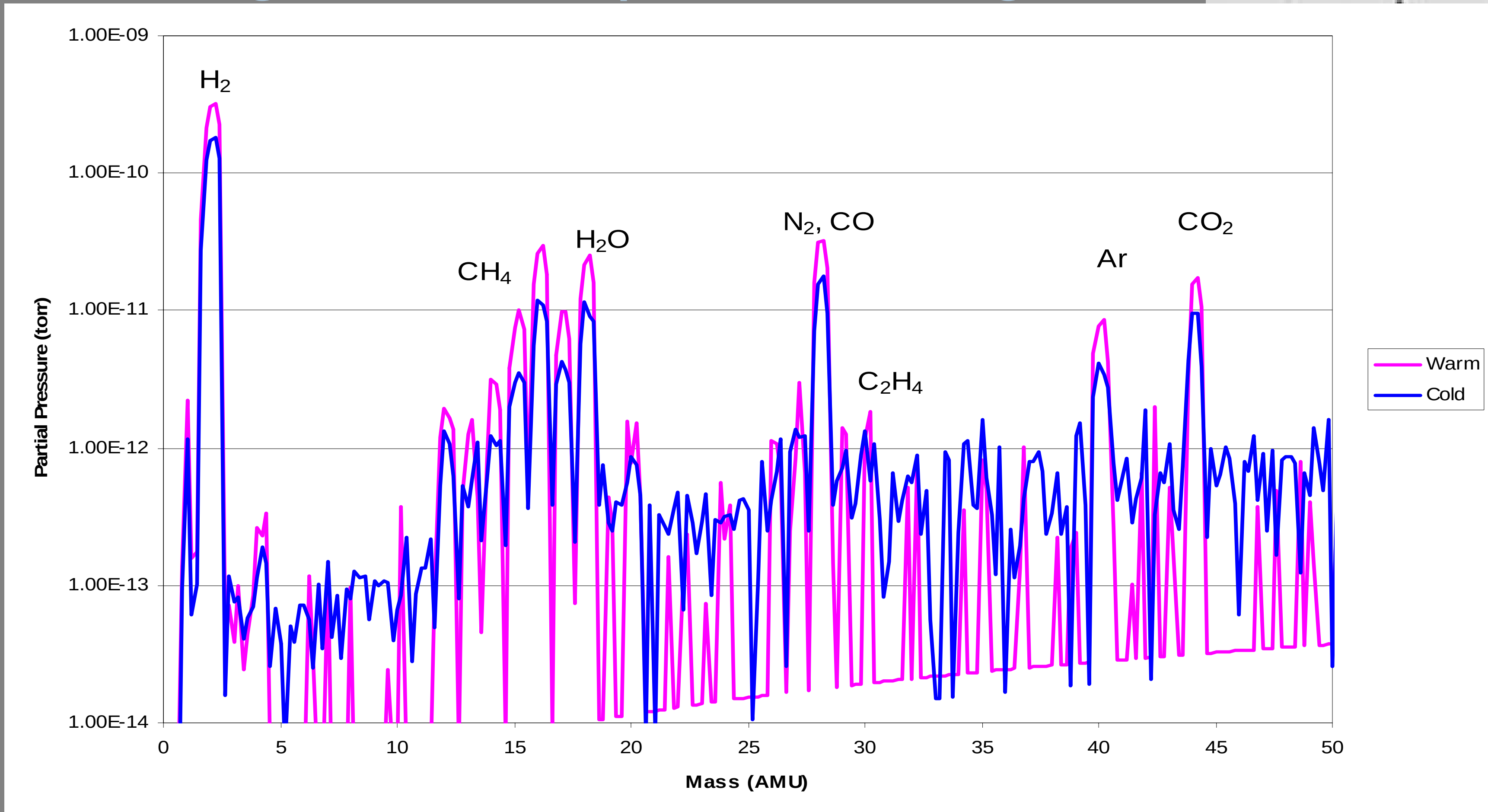
Effect of RF on gun vacuum



•Gun pressure increases factor of 5 from $3x10^{-10}$ torr to $1.6x10^{-9}$ torr with RF applied

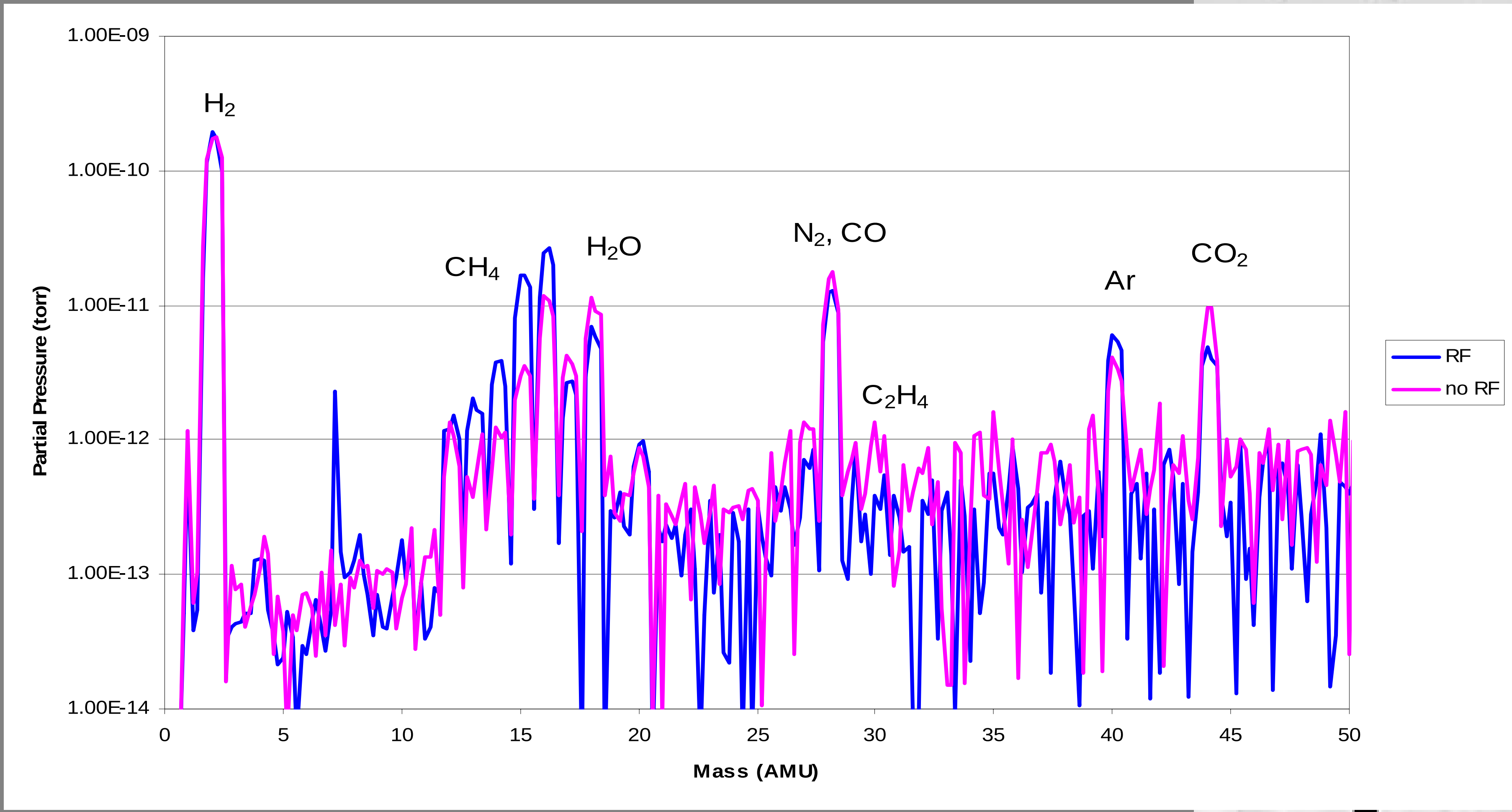
•All gases except H_20 and H_2 show increased levels

Cooling with Liquid Nitrogen



- Cooling with liquid nitrogen reduces temperature to 92K
- Pressure reduced by factor of 2 to 1.7×10^{-10} torr
- Pressure change proportional to $\sqrt{T_c/T_h} \approx 0.55$

Effect of RF in a cooled gun



- Cooled gun pressure increases a factor of 2 with RF, less deterioration than when warm
- Pressure cold with RF slightly less than pressure warm without RF.
- Only methane shows significant increase

Summary of Vacuum Measurements

- Base pressure of uncooled, no RF gun is $3x10^{-10}$ torr
- When RF applied to uncooled gun, most gases show increased outgassing. Pressure increases to $1.6x10^{-9}$.
- Cooling gun to 92K drops pressure by factor of 2.
- Applying RF to cooled gun increases pressure factor of 2, mostly due to methane outgassing. Pressure slightly less than base pressure.

Why is liquid N_2 cooling not very effective?
How is outgassing in N_2 cooled gun explained?

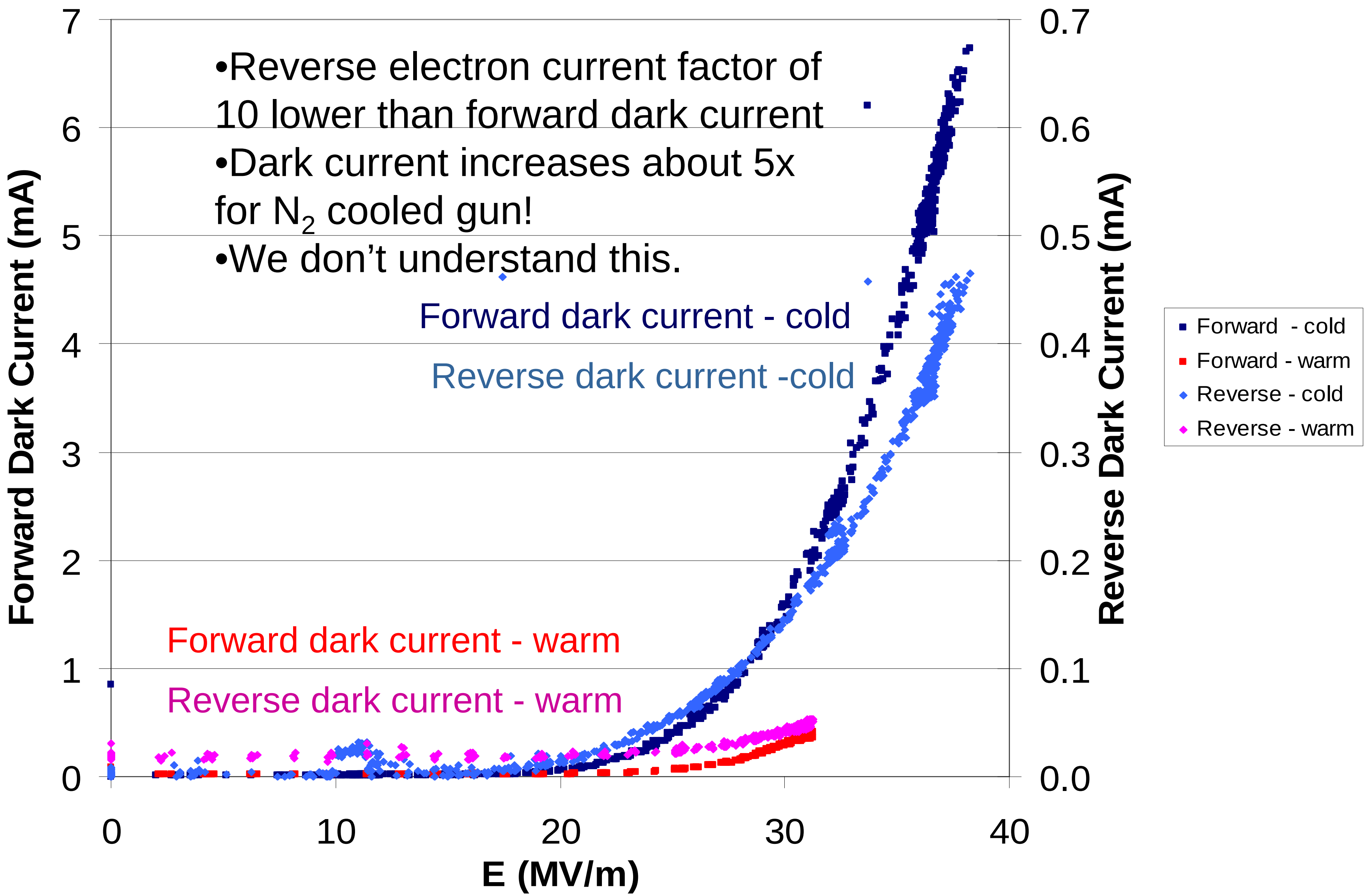
Understanding Cryopumping

- “Getting cold” is not enough
- 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.

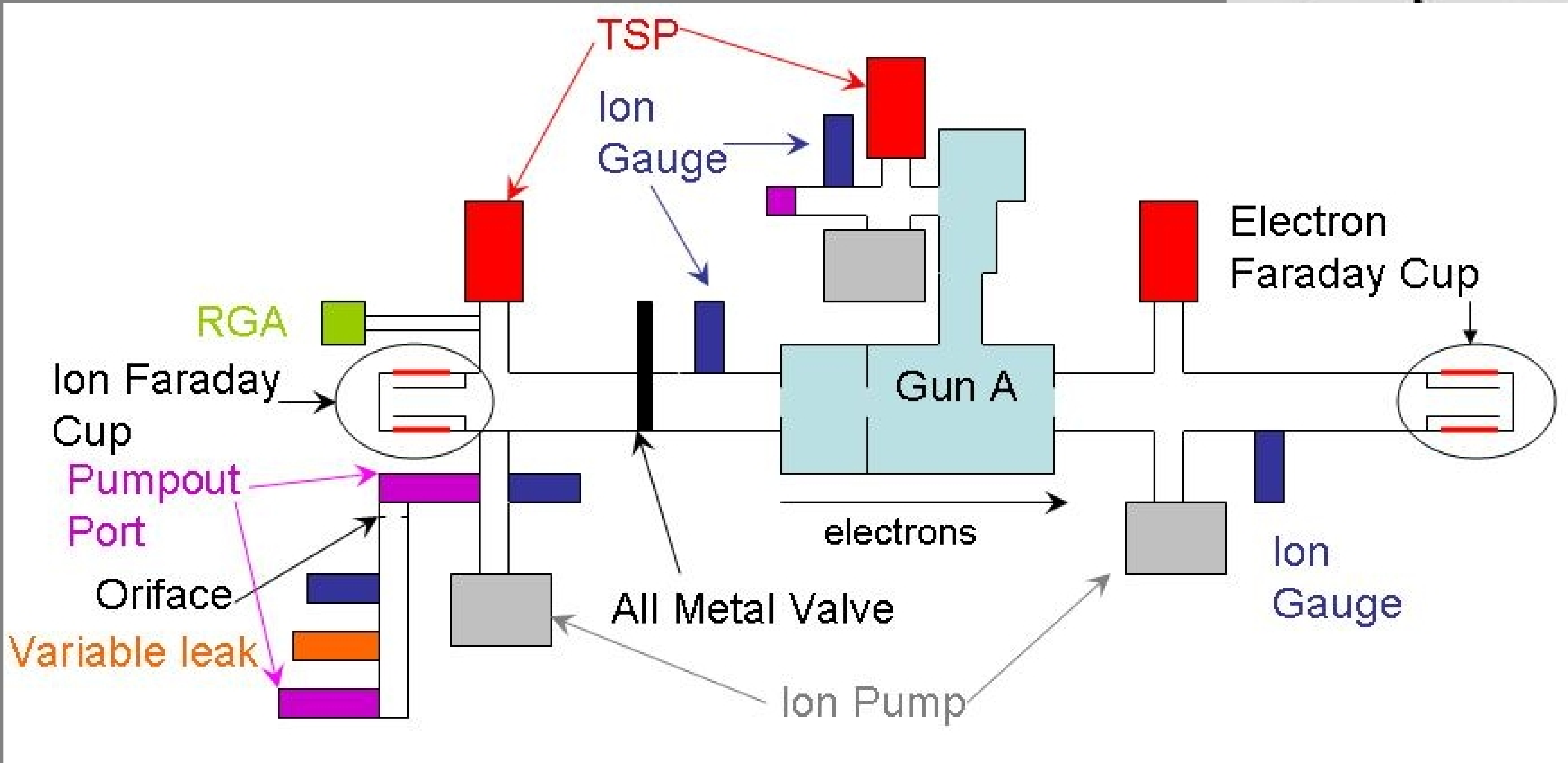
$$p_c / p_h \propto \sqrt{T_c / T_h}$$

- Vapor pressures of the gases involved to not reach 10^{-10}-10^{-11} torr until 20-30K.
  - Cooling with Liquid He is necessary!

Dark Current in Cold Gun



New Test Stand



Major improvements:

- inclusion of variable leak section and oriface that can be isolated from the remainder of the vacuum.
- Also inclusion of All Metal Valve
- Extra ion gauge.

- All allow for better vacuum and measurements.

Immediate and Long Term Plans

- Bake parts @ 450C for 3 days to reduce outgassing.
- Cross calibrate Ion Gauges, RGA
- Perform previous tests
- Cool with Helium and measure vacuum, dark current
- Ion back bombardment measurement
- Build cathode prep chamber (arrived at Fermi last week) in parallel
- Prepare and test cesiated GaAs cathode in gun

Summary

- Using GaAs cathodes in an RF gun has proven problematic in the past.
- Ion bombardment simulations show that ion backbombardment should be better in an RF gun vs. a DC gun, with equivalent vacuum.
- Initial vacuum tests show N_2 cooling is not sufficient, He cooling necessary.
- Vacuum with RF does not deteriorate as much when N_2 cooled – this is encouraging!!!
- Larger dark current in N_2 cooled gun, not understood.
- Continuing to proceed with R&D to produce an RF gun capable of supporting a GaAs photocathode to meet the requirements for the ILC electron source.