

# Progress on using a GaAs Photocathode in an RF gun

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# Outline

- Introduction and Motivation
- Ion Bombardment Simulations
- Vacuum Measurements in liquid N<sub>2</sub> cooled gun
- Future R&D Plans
- Conclusions



# Collaboration

## Fermilab

- Helen Edwards
- Terry Anderson
- Marcus Heuning  
(now DESY)

## AES

- Hans Bluem
- Tom Schultheiss
- Tony Ambrosio

## Cornell

- Charles Sinclair

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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.



# Advantages 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 rejuvenated if  $E_{\text{cath}} < 30 \text{ MV/m}$ .
  - 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

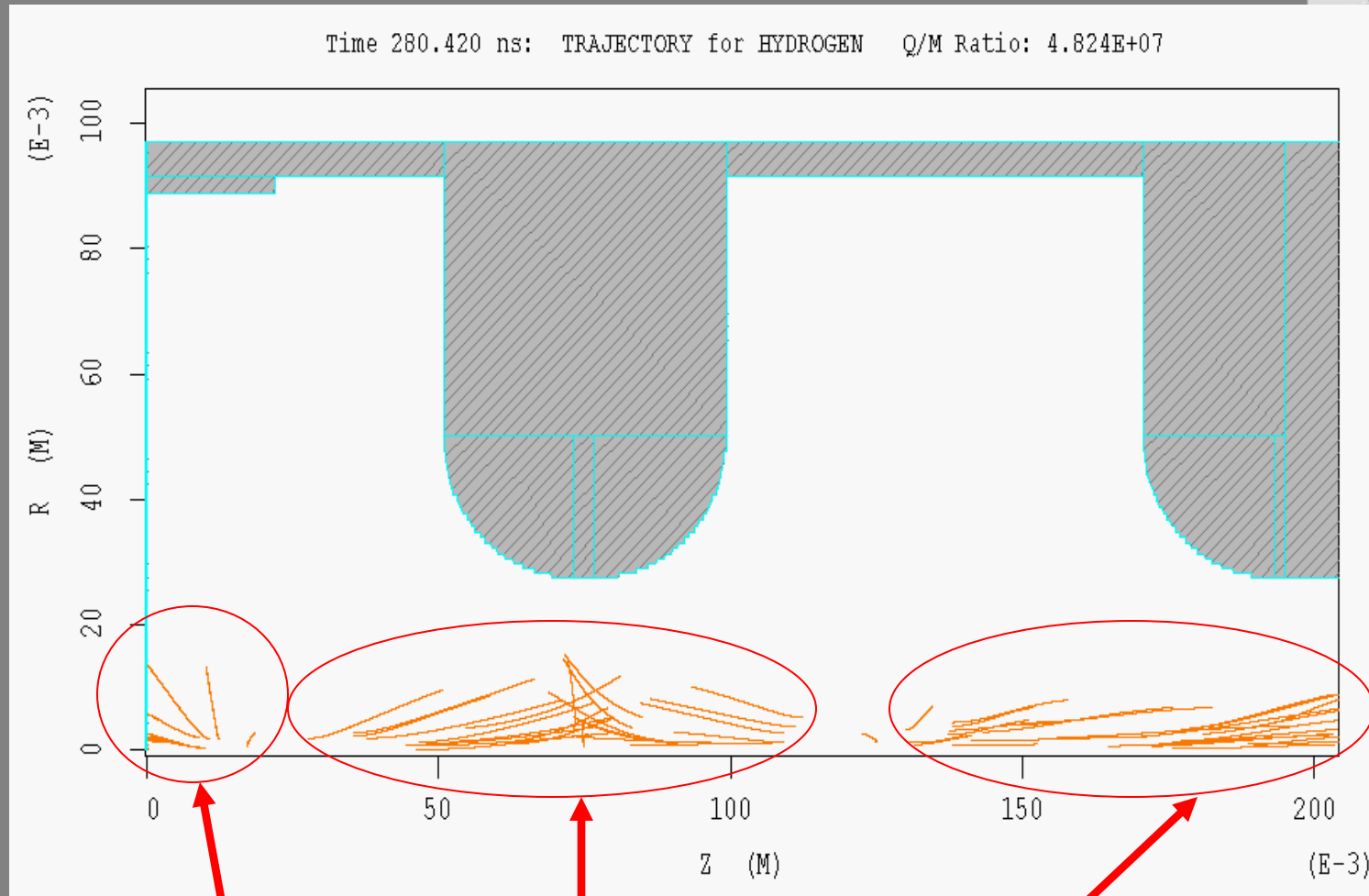


# Ion Back Bombardment Simulations

- 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<sub>2</sub> background gas
  - H<sub>2</sub> 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



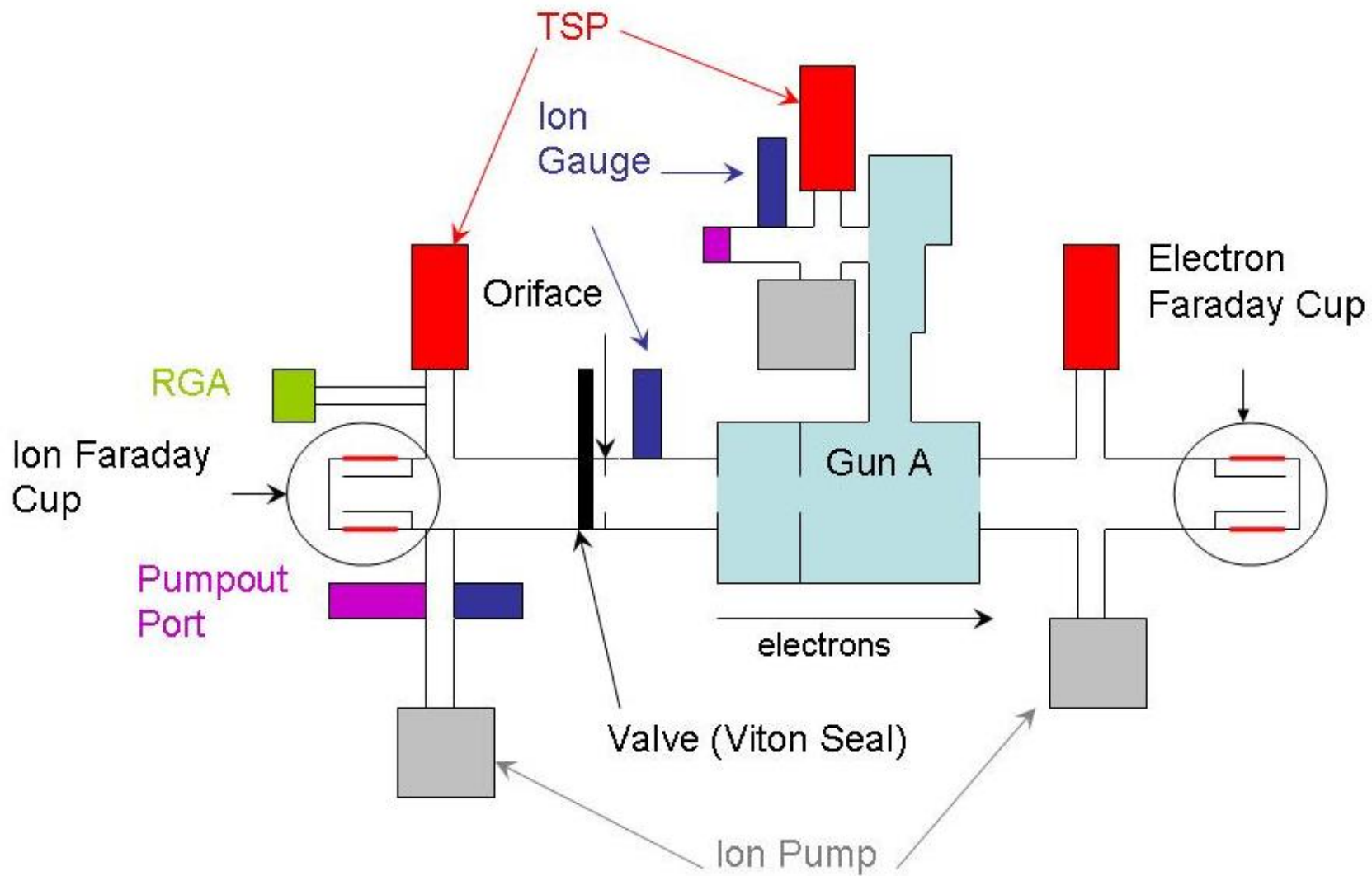
- Ions generated near the cathode strike the cathode.
- Otherwise they collect at the irises.

# How Many Ions Impact Cathode in RF Gun?

- MAGIC predicts  $2.8 \times 10^7$  ions/C, generated from beam, impacting the cathode at a partial pressure of  $10^{-10}$  torr. Dark current produced a bombarding ion flux of  $1.6 \times 10^7$  ions/C at  $10^{-10}$  torr.
  - In contrast, a DC gun produces on the order of  $3 \times 10^7$  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 than a DC gun, but lower than current RF guns.



# Vacuum Test Stand



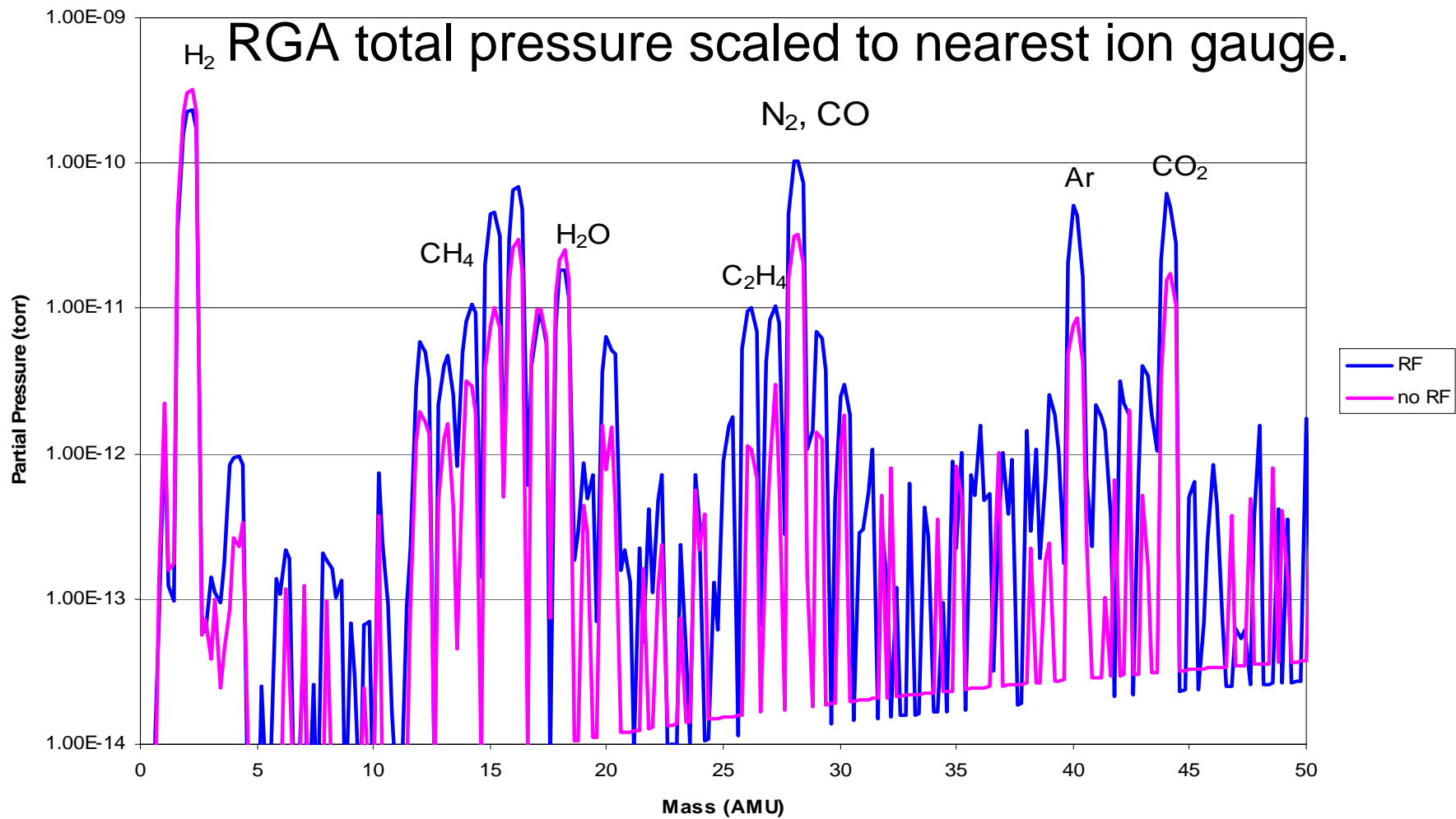
- Gun is 1.6 cell L band RF gun almost identical to one used at FNPL
- No cathode installed.
- Liquid N<sub>2</sub> flowed through water cooling lines.

# 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

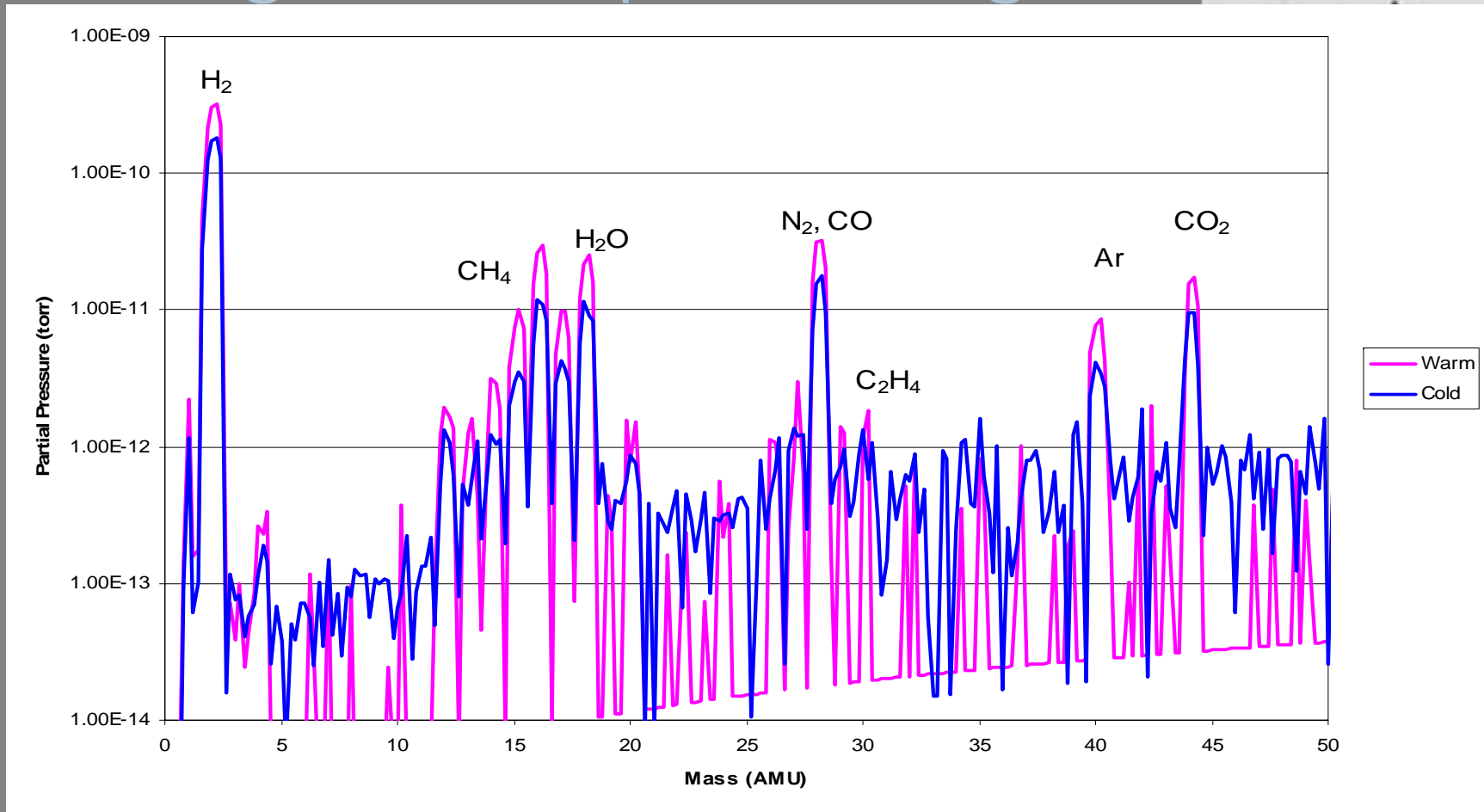


# Effect of RF on gun vacuum



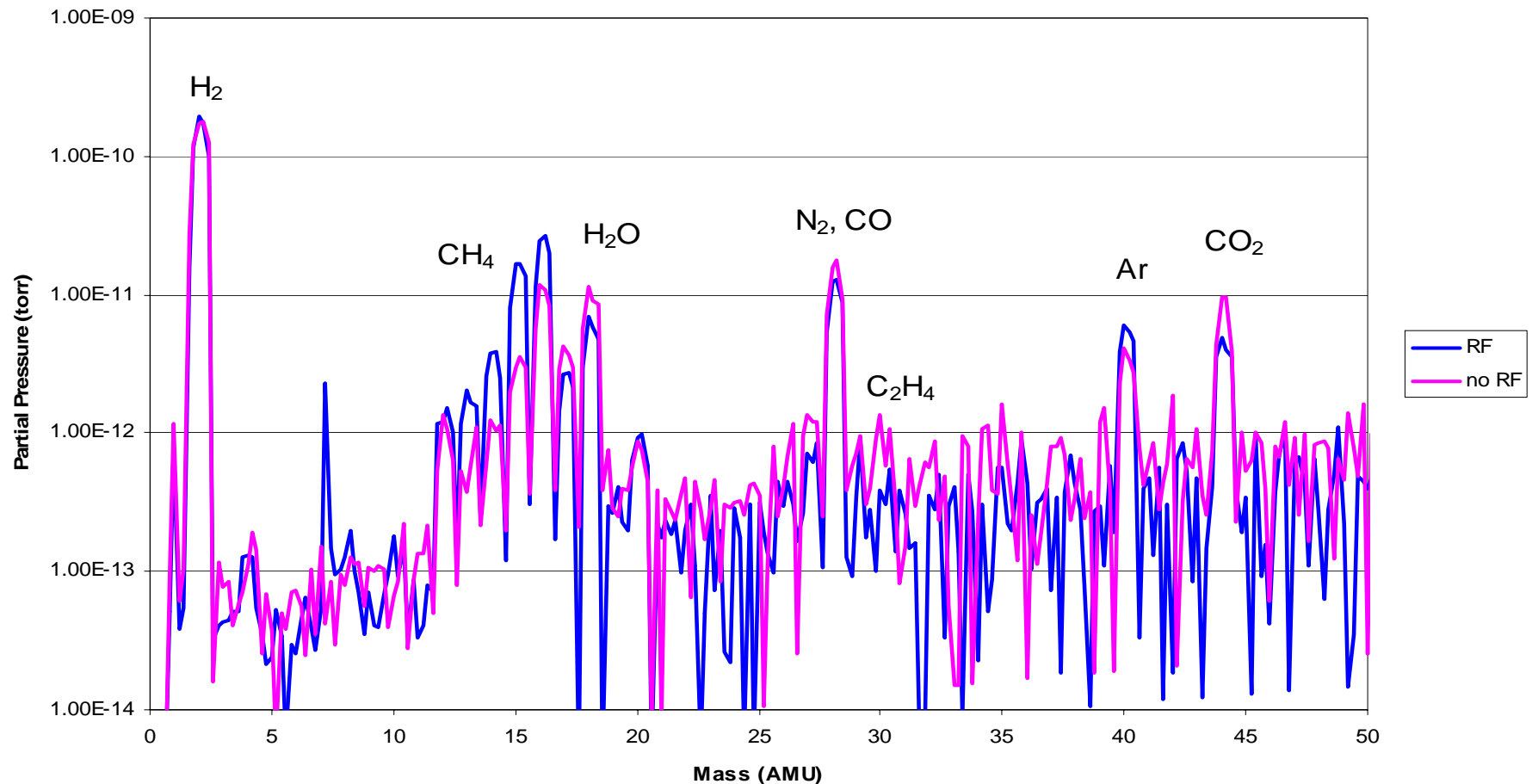
- Gun pressure increases factor of 5 from  $3 \times 10^{-10}$  torr to  $1.6 \times 10^{-9}$  torr with RF applied
- All gases except  $H_2O$  and  $H_2$  show increased levels

# Cooling with Liquid Nitrogen



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

# 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  $3 \times 10^{-10}$  torr
- When RF applied to uncooled gun, most gases show increased outgassing. Pressure increases to  $1.6 \times 10^{-9}$ .
- Cooling gun to 92K drops pressure by factor of 2.
- Applying RF to cooled gun increases pressure factor of 2, mostly due to methane 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

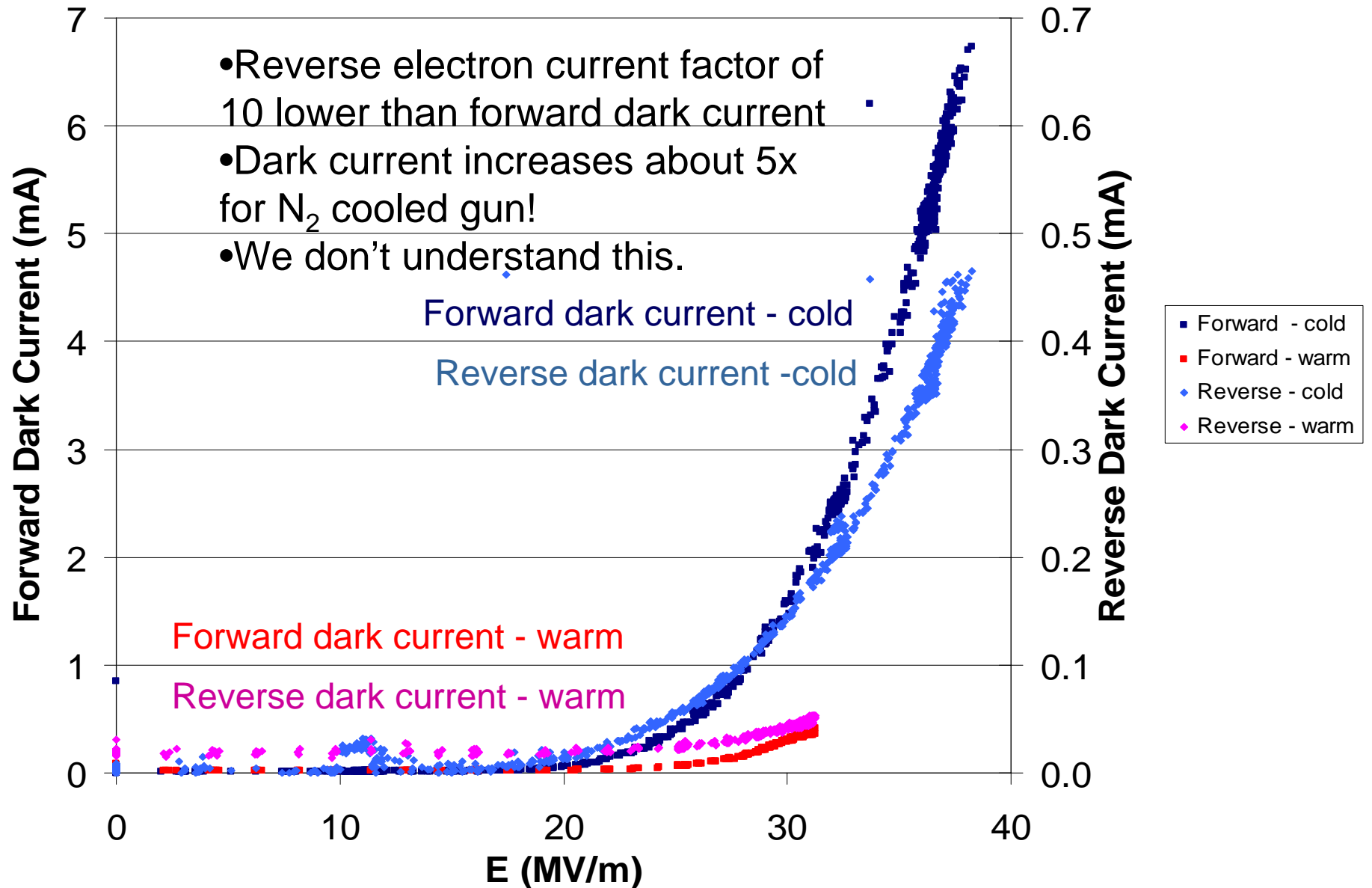
- “Getting cold” is not enough
- True cryopumping involves
  - Gas molecules freezing to chamber walls
  - A reduction in gas vapor pressure below total pressure
- Only  $\text{CH}_4$ ,  $\text{C}_2\text{H}_4$ ,  $\text{CO}_2$  and  $\text{H}_2\text{O}$  are frozen at 92K.
- Other gases merely collect in the cold volume, forming a lower pressure, higher density gas than exists in the warm section.

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

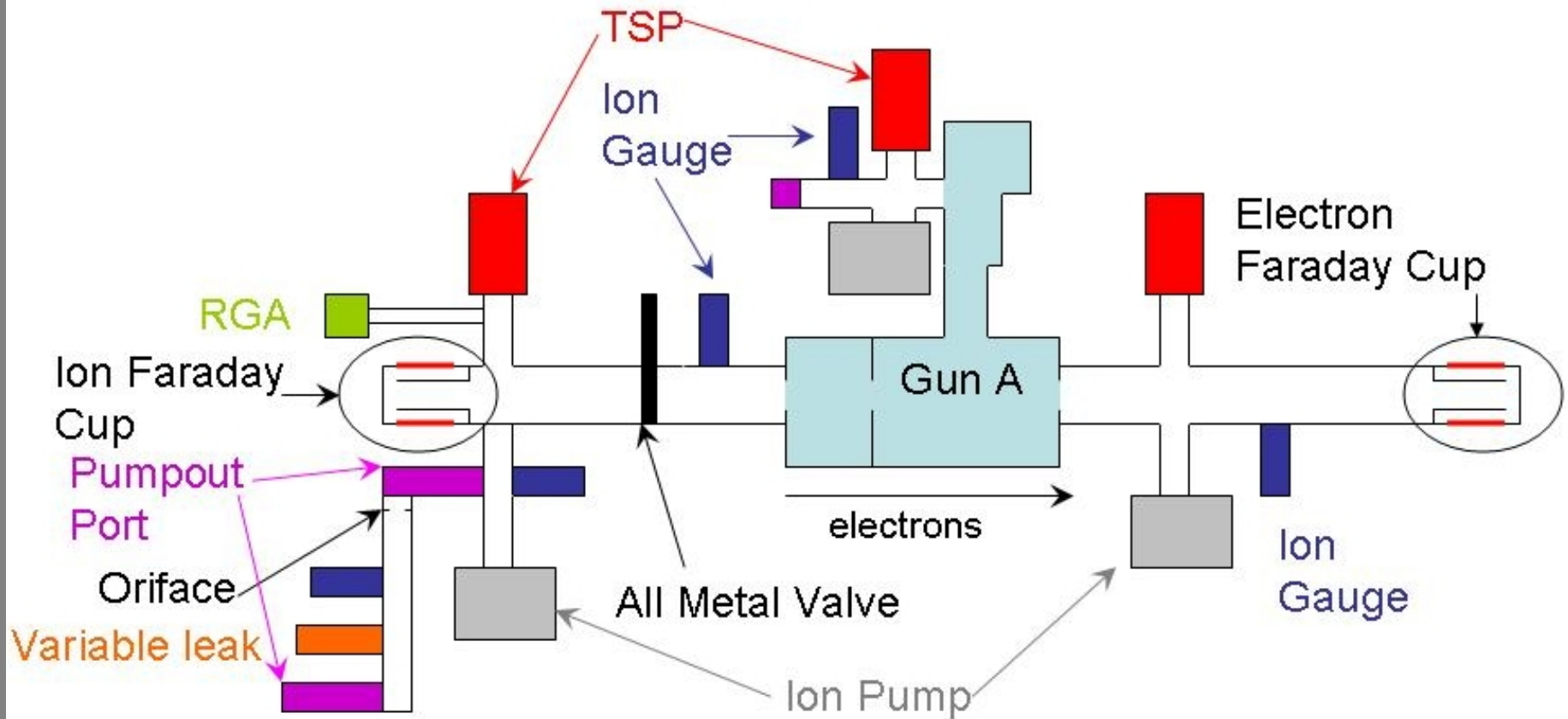
- Vapor pressures of the gases involved to not reach  $10^{-10}$ - $10^{-11}$  torr until 20-30K.
  - Cooling with Liquid He is necessary!



# 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<sub>2</sub> cooling is not sufficient, He cooling necessary.
- Vacuum with RF does not deteriorate as much when N<sub>2</sub> cooled – **this is encouraging!!!**
- Larger dark current in N<sub>2</sub> 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.

