A Polarized Electron PWT Photoinjector for the ILC

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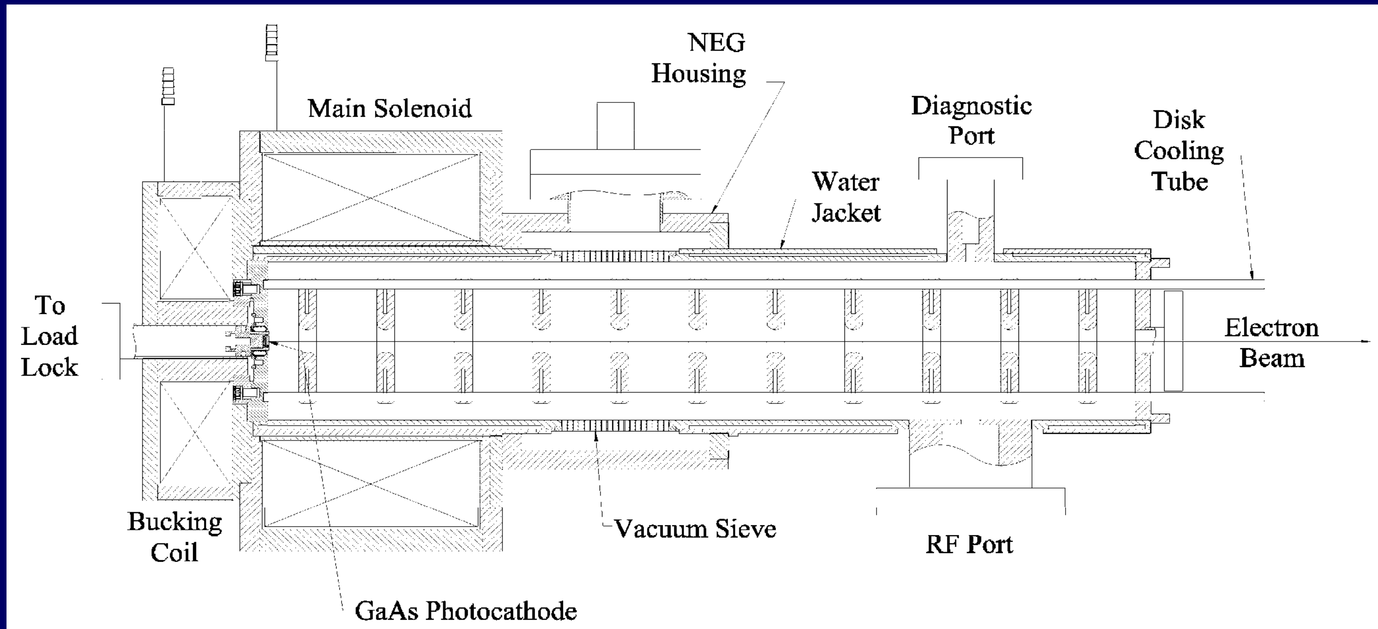
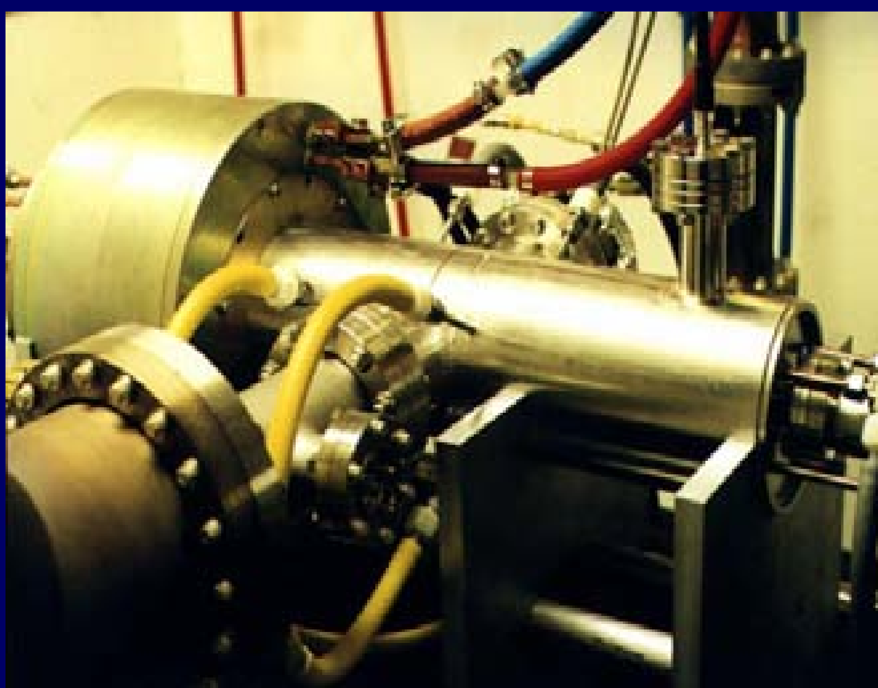
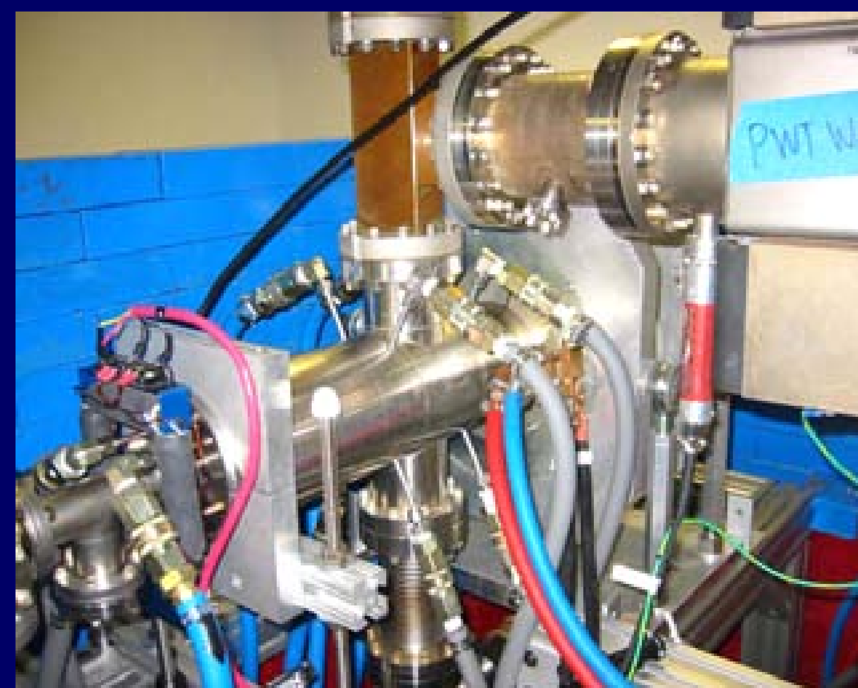

NEG
Housing
Main Solenoid
Diagnostic
Port
Disk
Cooling
Tube
Water
Jacket
To
Load
Lock
Electron
Beam
Bucking
Coil
Vacuum Sieve
RF Port
GaAs Photocathode





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Assigned to: DULY Research Inc.

David U. L. Yu, James E. Clendenin, Robert E. Kirby
Photoelectron Linear Accelerator for Producing a Low Emittance Polarized Electron Beam

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Linear Collider Requirements for a Polarized Electron Source

- High polarization (NEA GaAs photocathode)
- High peak brightness (high charge, short pulse length, low emittance – 800-nm laser, rf gun)
- Long rf pulse and high beam bunch rep rate (effective cooling required to remove heat)
- Long GaAs life and Good QE (low dark current–ultra high vacuum, surface preparation; low gradient)
- L-band normal-conducting PWT injector for ILC

PWT Features and Benefits

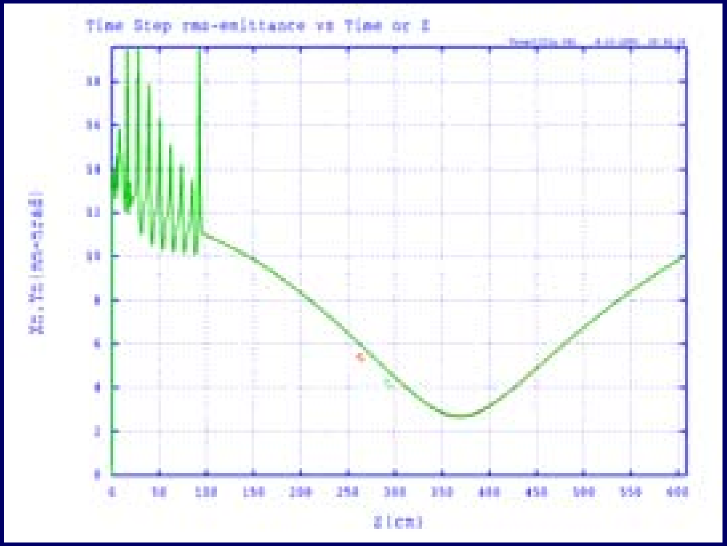
Feature	Methodology	Benefit
Low emittance, achieved with a low peak field.	Emittance compensation, with solenoids close to the cathode.	Simplify damping ring design; flat beam possible.
Mitigation of back-scattered electrons on photocathode; no backscattered ions	Low rf peak field (20 MV/m at L band); surface cleaning and coating.	Suppress dark current; help survivability of semiconductor photocathode.
Ultra high vacuum	Large vacuum conductance; massive NEG pumping, low outgassing rate.	GaAs cathode has long life with good quantum efficiency.

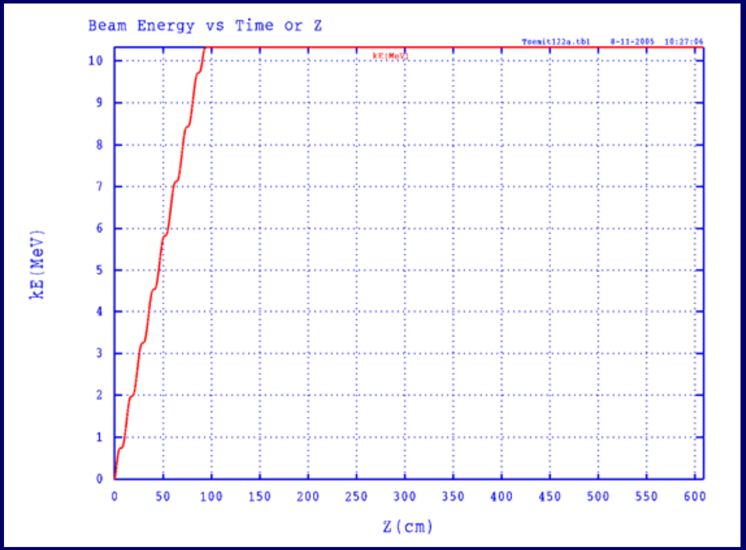
Parameters of an L-Band PWT Polarized Electron Gun

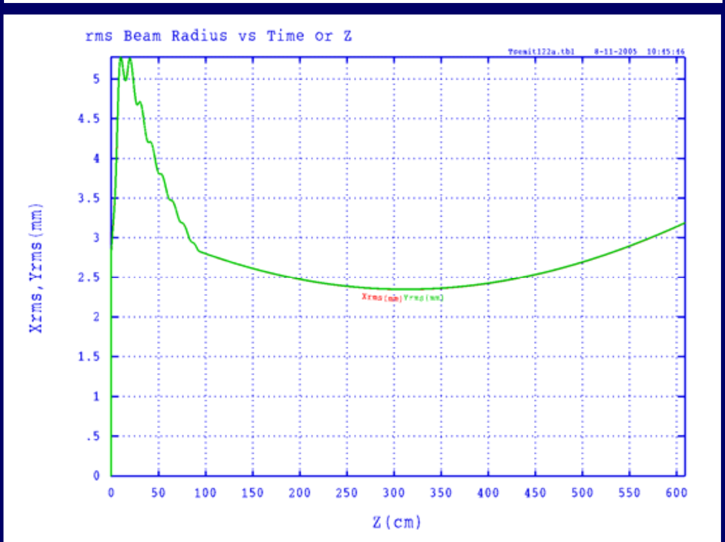
Charge per Bunch (nC)	3.7
Frequency (MHz)	1300
Energy (MeV)	10.3
Normalized RMS Emittance (mm-mrad, incl. thermal emittance)	2.7
Energy Spread (%)	0.3
Bunch Length (rms, ps)	6.5
Peak Current (A)	164
Linac Length (cm)	98.7
Beam Size (rms, mm)	2.35
Peak Magnetic Field (Gauss)	638
Peak Electric Field (MV/m)	20
Peak Brightness (10^{13} A/m^2-rad^2)	4.5

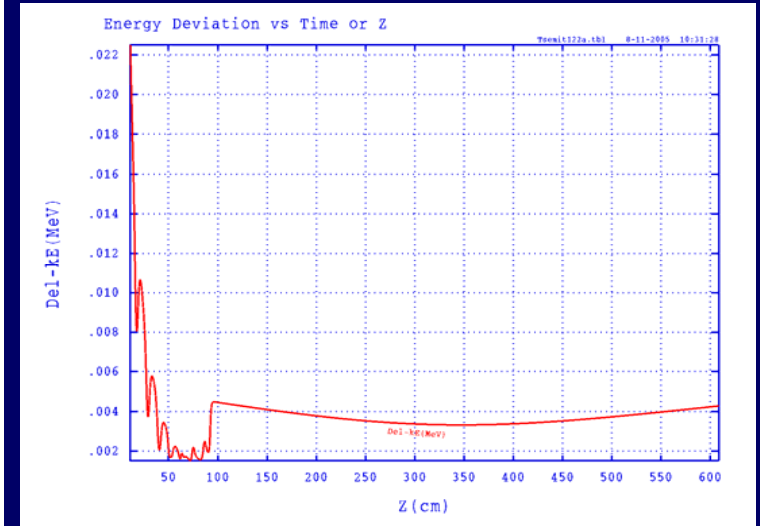
PARMELA Simulation Results

Peak Electric field = 20 MV/m, Bunch Charge = 3.7 nC,
Initial Beam Size = 5.7 mm, Magnetic Field = 638 Gauss.



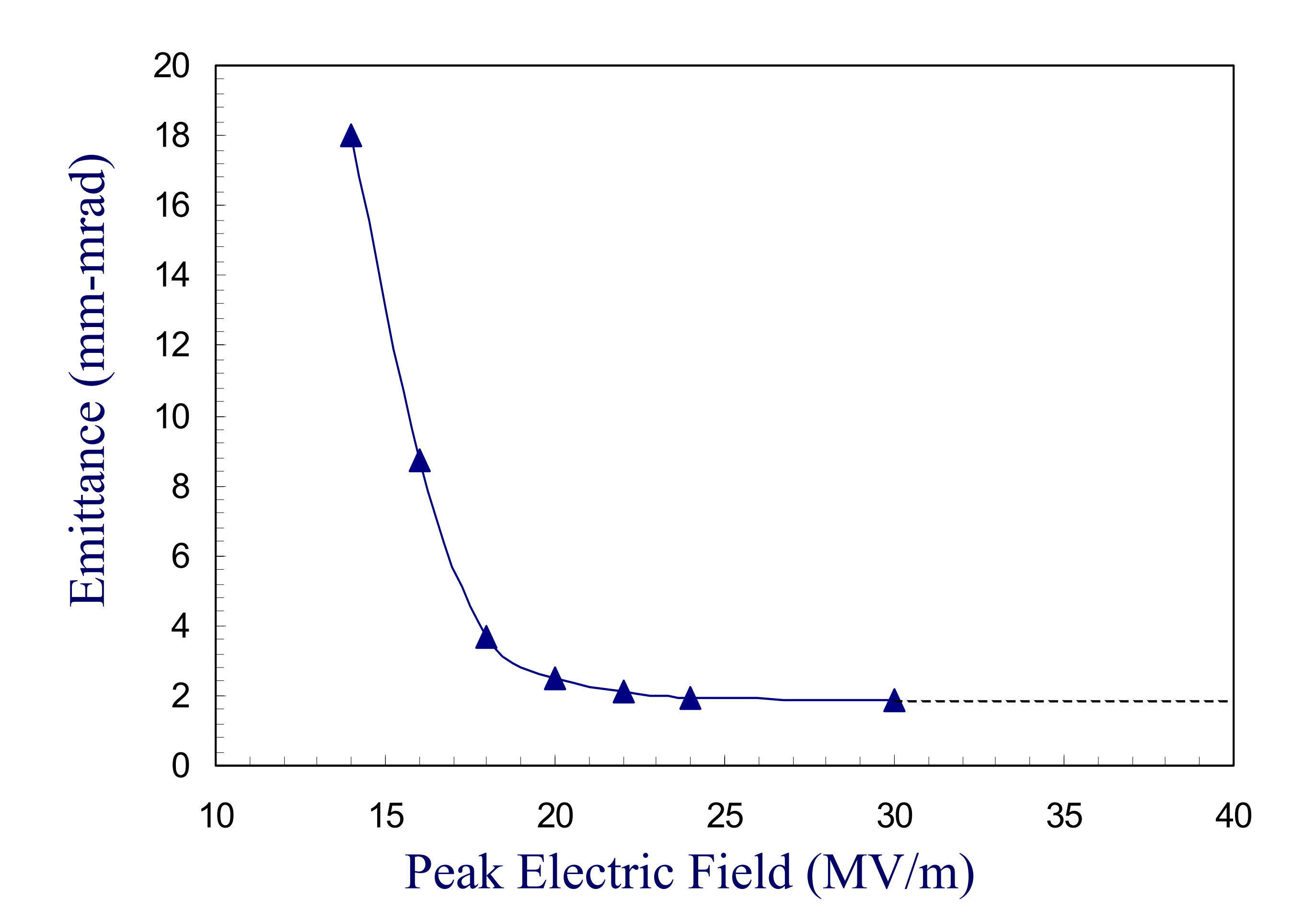




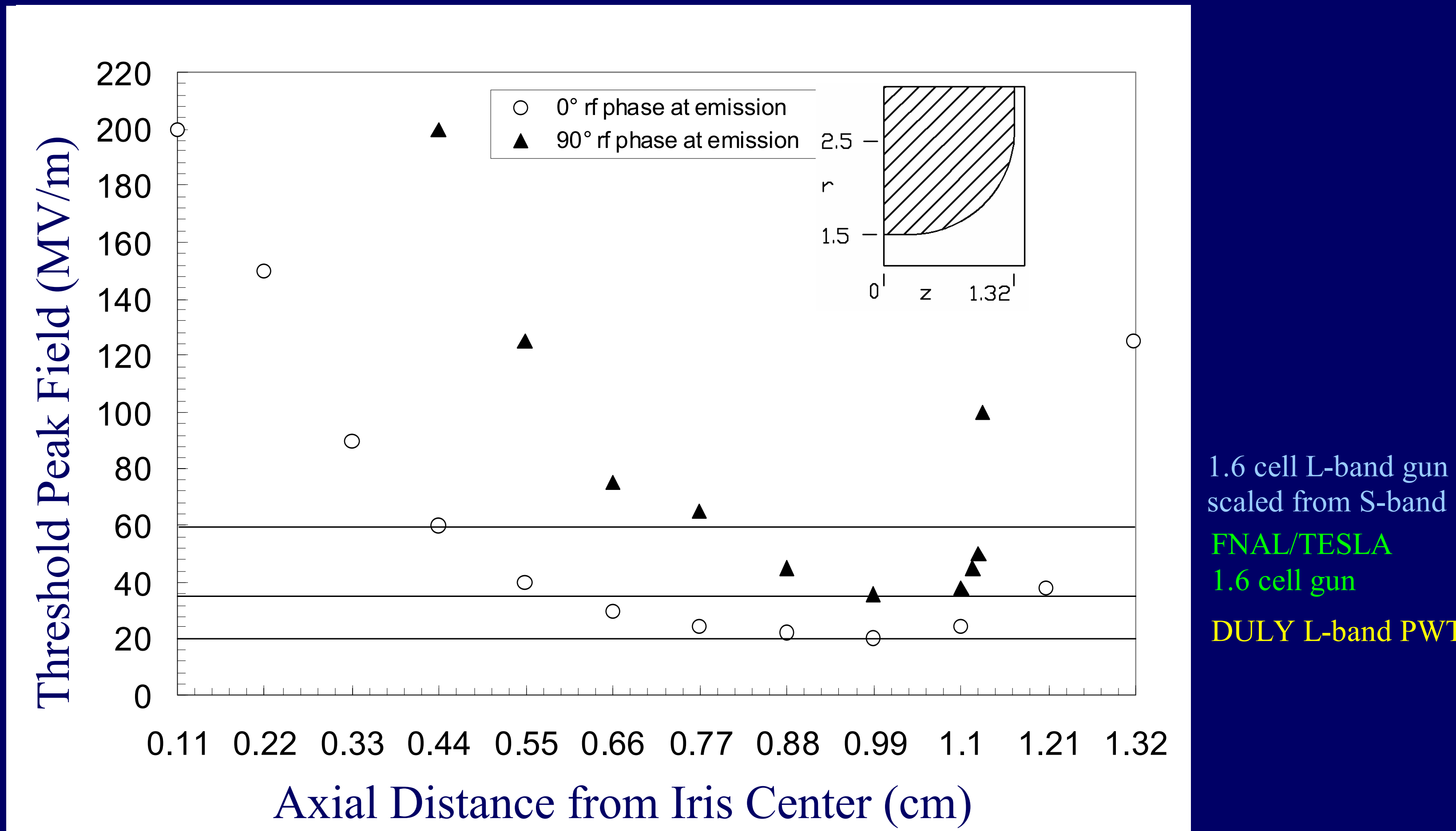


L-band PWT Normalized Transverse Emittance vs Peak Field at Photocathode

Initial electron beam parameters:
charge = 3.7 nC, bunch length = 15 ps, radius = 5.7 mm

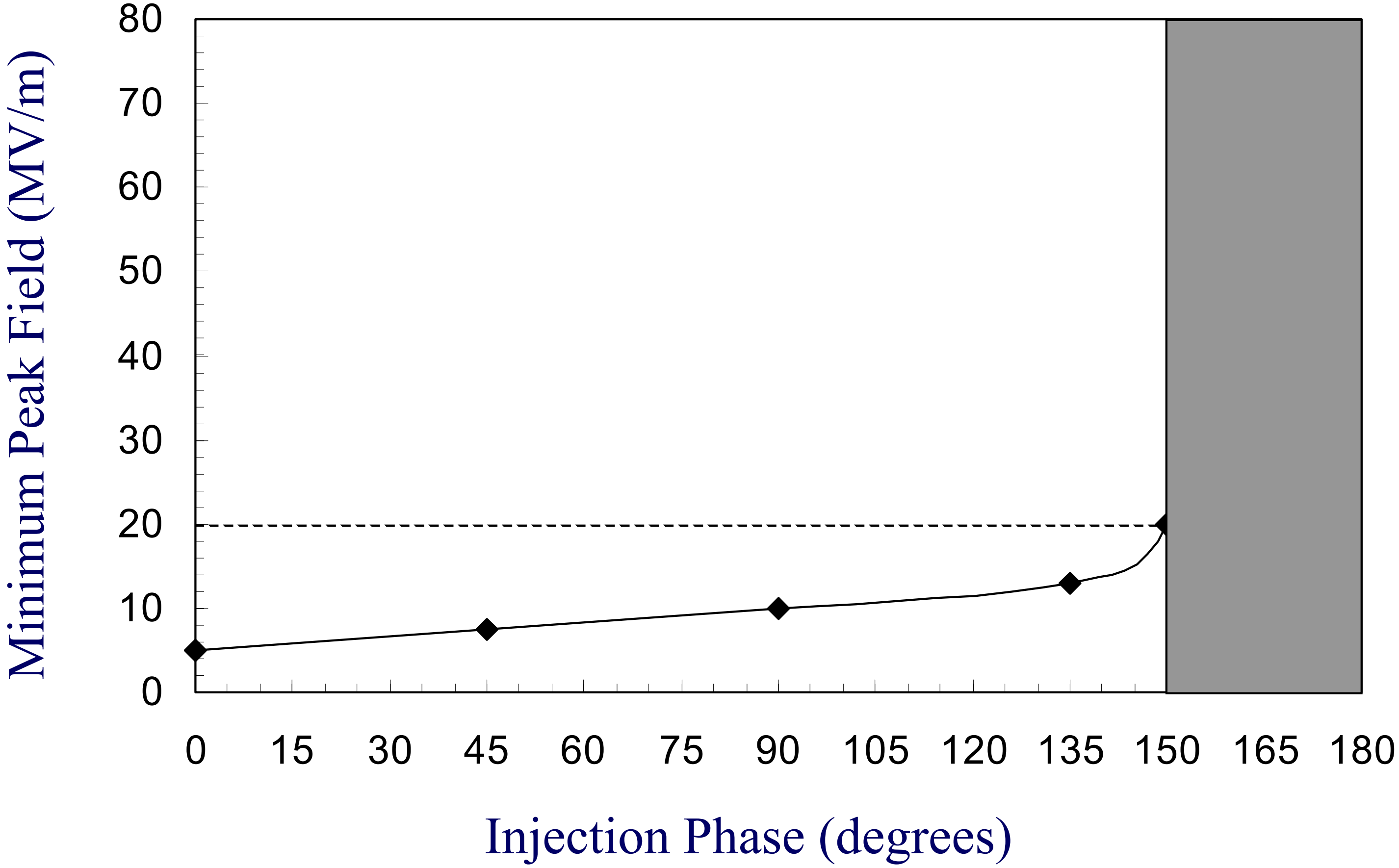


Dark Current Suppression at Low Peak Field



Operating the L-band PWT at a low peak field helps prevent backstreaming electrons emitted from the first PWT iris from reaching the photocathode.

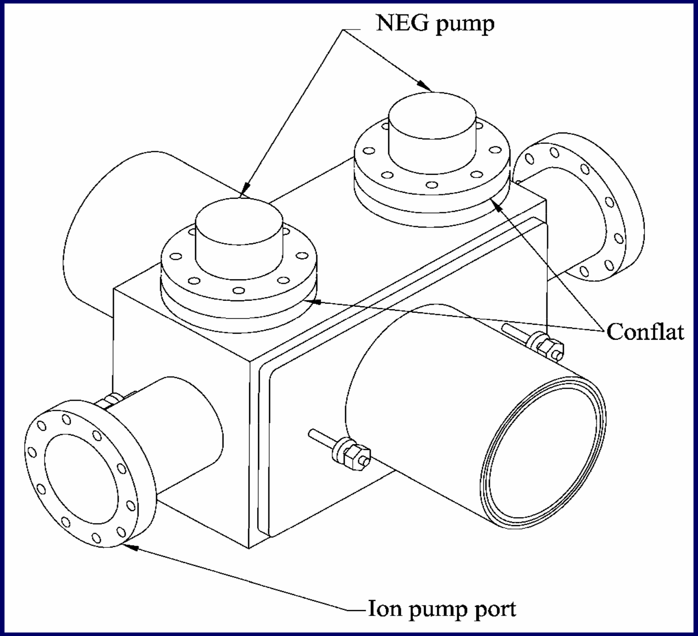
Minimum Peak Field vs Injection Phase for Electrons Emitted from the Cathode Holder to Avoid Backstreaming to the Cathode



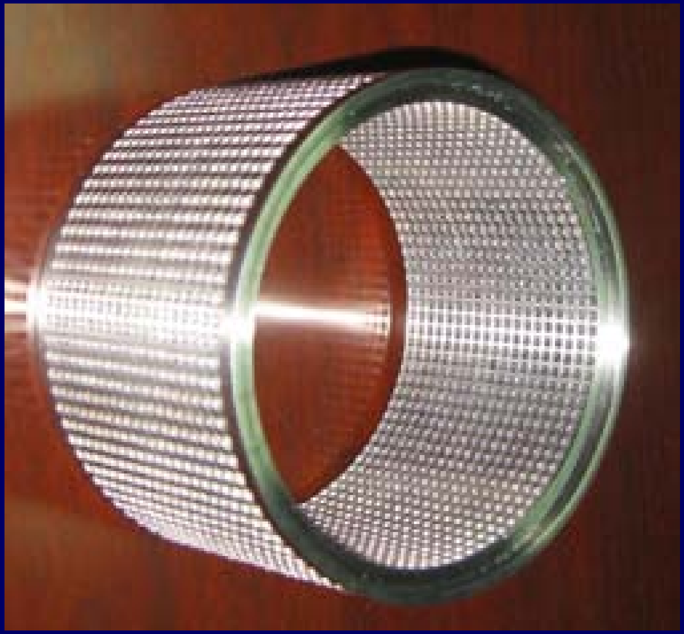
How to achieve UHV better than 10^{-11} Torr required by the GaAs photocathode?

- Open PWT structure (large vacuum conductance)
- Material (SS tank, Class 1 OFHC copper)
- Cleaning (diamond machining + high pressure rinsing for Cu parts; electropolishing for SS)
- Bake out (250°C for 20 hrs: 6.3×10^{-12} Torr l/s cm^2 for SS
  500°C for 40 hrs: 8.0×10^{-16} Torr l/s cm^2 outgassing)
- Coating inner surface of pressure vessel with TiZrV
- Removable SNEG strips + ion pump
- Load lock for activated GaAs cathode
- Cooling the pressure vessel to reduce outgassing(?)

- NEG coating of the PWT tank and large arrays of replaceable SNEG strips plus an ion pump provide effective pumping.
- Large vacuum conductance is limited by the perforated section of PWT tank inside the pumping box.

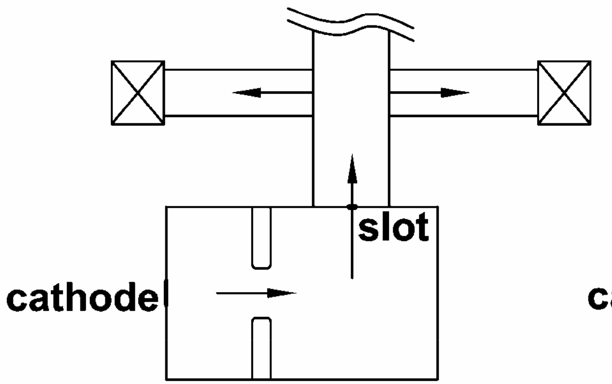


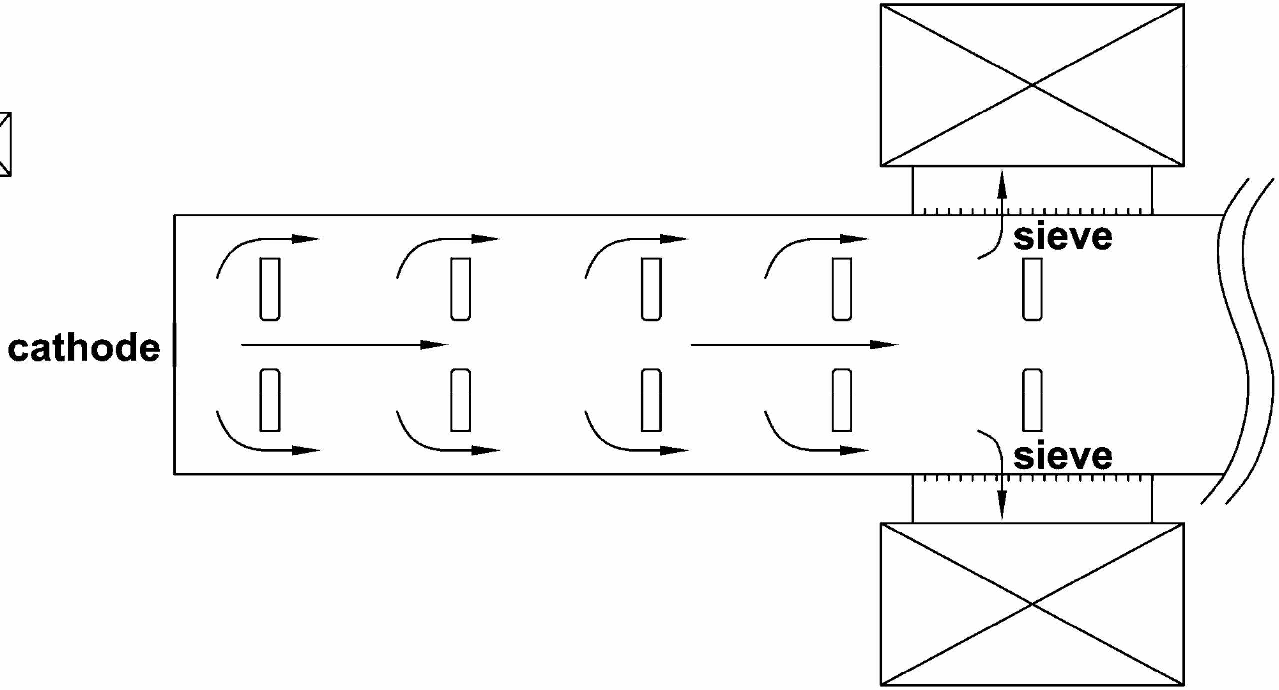
Pumping box with Conflat design



PWT tank sieve section inside the pumping box

Pumping diagrams of 1.6-cell GTF gun (left) and PWT (right)





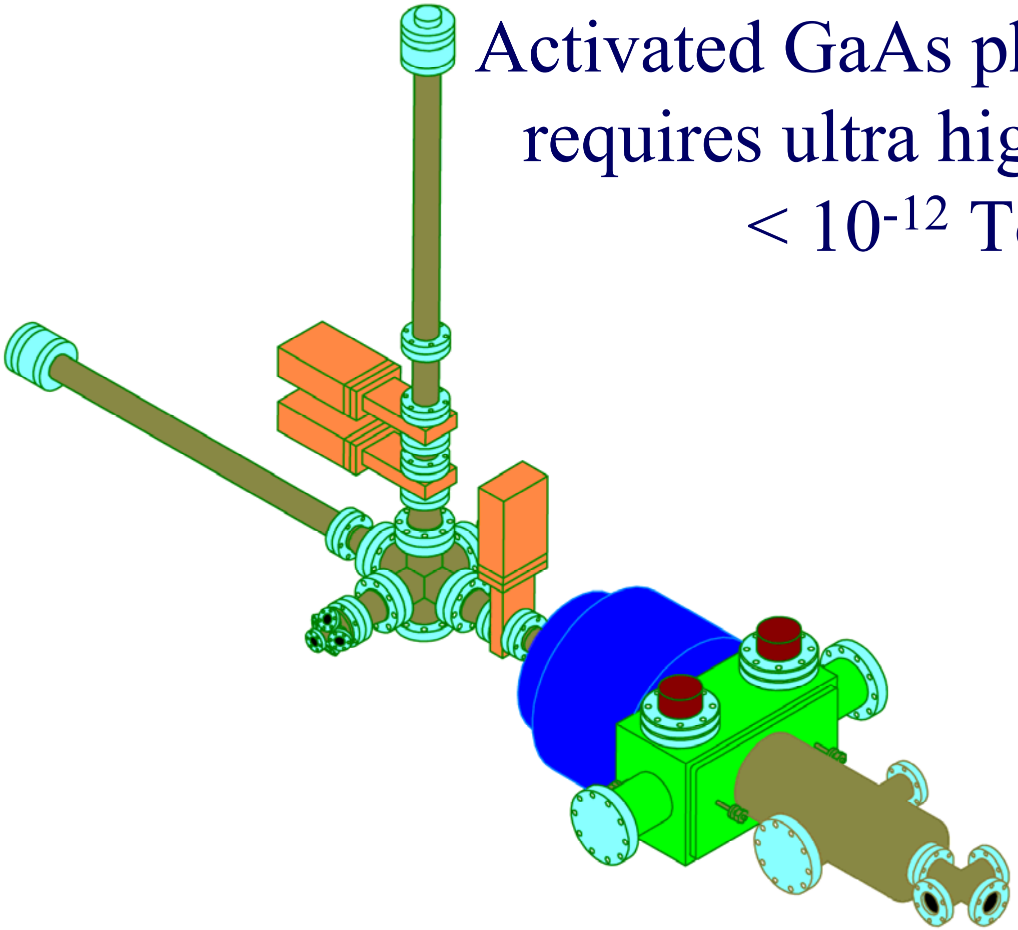
Comparison of vacuum conductance, outgassing rate and pressure at cathode for 1.6-cell GTF gun, S-PWT and L-PWT

	Conductance(l/s)			Outgassing Rate (10^{-9}Torr-l/s) Q	Pump Speed (l/s, at 10^{-10} Torr) S_1	Pumping Speed at cathode (l/s) S_2	Pressure at Cathode (10^{-11} Torr) Q/S_2
	Sieve or Slot F_1	Cathode to pump except F_1	Total Cond F				
1.6 cell S-band Gun	9.2 (thru slot)	3.9	2.7	6 (with Cu wall)	2 x 4=8 (ion pumps)	2	**294**
S-band PWT	248 (900 holes)	56	46	12 (with Cu tank)	200 (NEG pumps)	37	**32**
L-band PWT	3104 (1710 holes)	780	623	12 (with SS tank)	800 (not including NEG film)	350	**3**

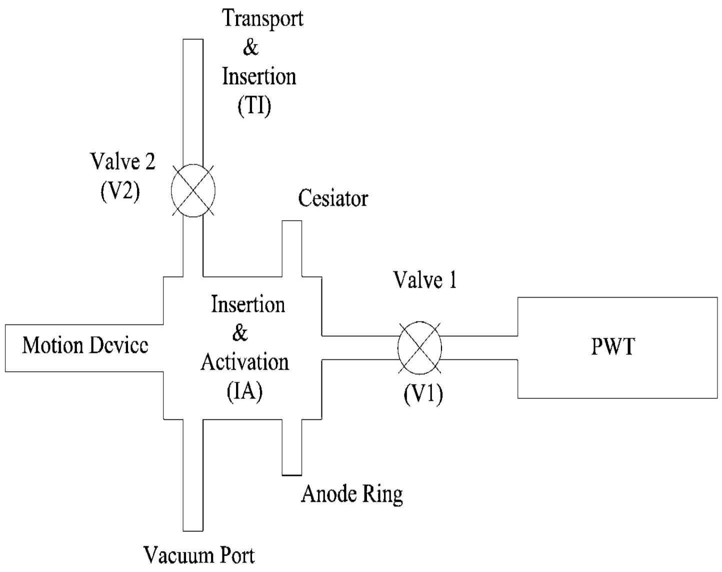
Outgassing rate and cathode pressure can be further reduced by more than two orders with high-temperature bake out (400-500°C for 40 hrs)!

Ultra High Vacuum Design

Activated GaAs photocathode requires ultra high vacuum $< 10^{-12}$ Torr



Isometric view of polarized electron PWT gun with load lock



Block diagram of major components of the PWT load lock

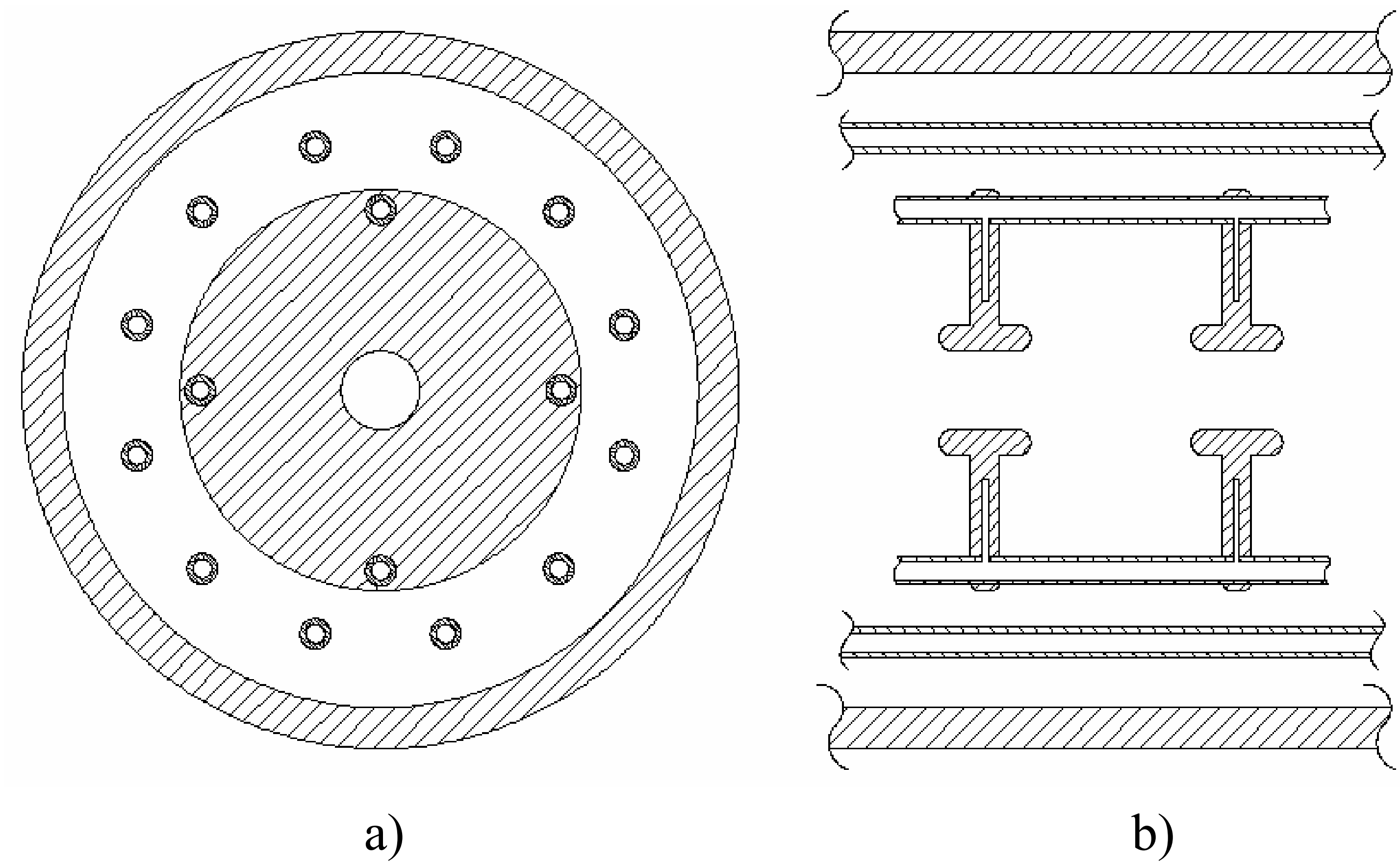
RF Design of an L-band PWT Photoinjector

1) Two Klystrons Design: 20MW, 5Hz, 1.37ms (137kW)

PWT Structure	Heat load (kW)					r, MΩ/m for 8 periods	E_{ampl}, MV/m
	SS cyl. tank	Cu end-plates	Copper rods		Cu disks		
			periphery	supporting			
6rods	64.2	8.8	0	29	35.2	17.1	19.2
4+12rods	31.2	9.2	30	24.2	42	23.1	22.4
4+12rods reentrant	33.8	8.4	26.4	18.64	50	31.8	26.2

2) One Klystron Design: 10MW, 5Hz, 1.37ms (68.5kW)

PWT Structure	Heat load (kW)					r, MΩ/m for 8 periods	E_{ampl}, MV/m
	SS cyl. tank	Cu end-plates	Copper rods		Cu disks		
			periphery	supporting			
6rods	32.1	4.4	0	14.5	17.6	17.1	13.6
4+12rods	15.6	4.6	15	12.1	21	23.1	15.8
4+12rods reentrant	16.9	4.2	13.2	9.32	25	31.8	18.6



(a) PWT designs with 12 peripheral rods and 4 cooling/supporting rods between disks. (b) Cut-away view showing a re-entrant cavity with an optimized nose on each PWT iris.

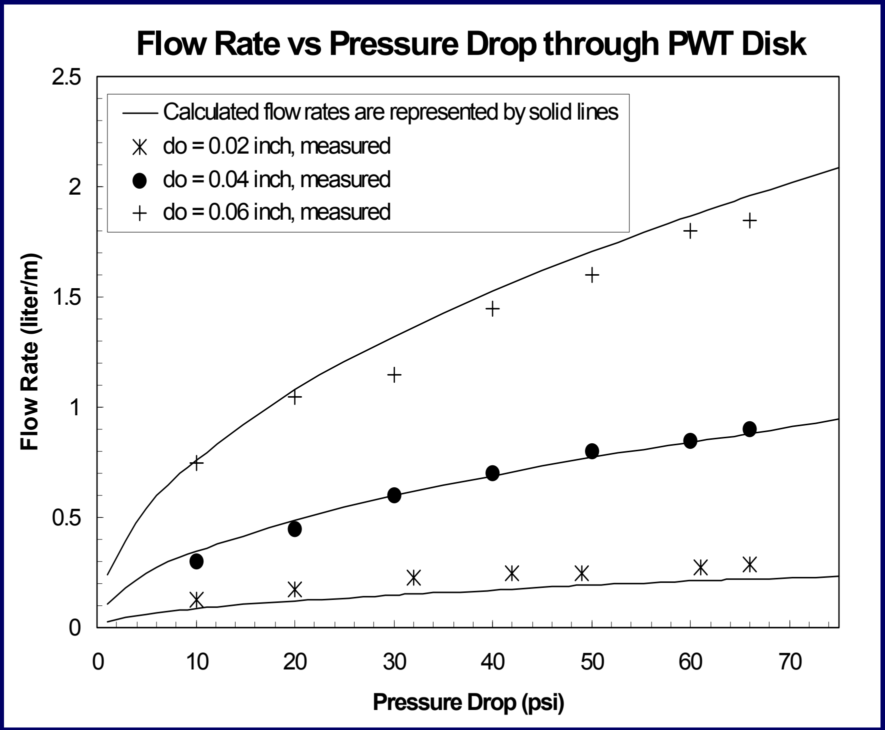
L-band PWT Thermal Hydraulic Design

- ILC parameters: 5-Hz, 1370 microsecond-long rf pulses, 2x10-MW peak power at L band; **136 kW** total.
- In a PWT structure with 8 copper disks, 6 rods and a SS tank, 35.2 kW goes into the 8 disks (4.4 kW per disk) and 29 kW into the 6 rods (3.6 kW per section between disks).
- Heat in disk and rod (0.43" ID) is removed by water flow through hollow rods and disk internal channels. Required flow in each disk is 20 lpm at $\Delta T=10°C$.
- Use 3 parallel cooling circuits (3/3/2 disks each), with a variable orifice size (0.238" to 0.4") for each disk to account for line pressure drop.
- Required external pressure head is **76 psi** for a total flow of **80 lpm** through the inlet/outlet pipes.

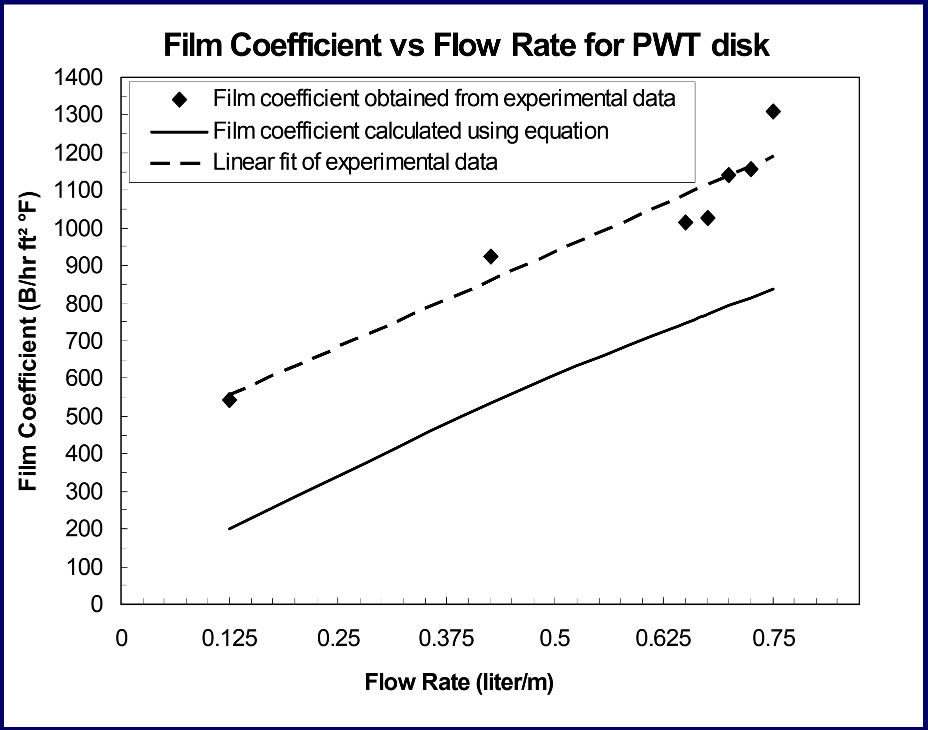
PWT Disk Thermal Hydraulic Study

- Microcomputer measurements
- Cooling fluid flow control
- Temperature monitoring
- Closed loop temperature feedback control

Comparison of Measurements with MathCad Calculations



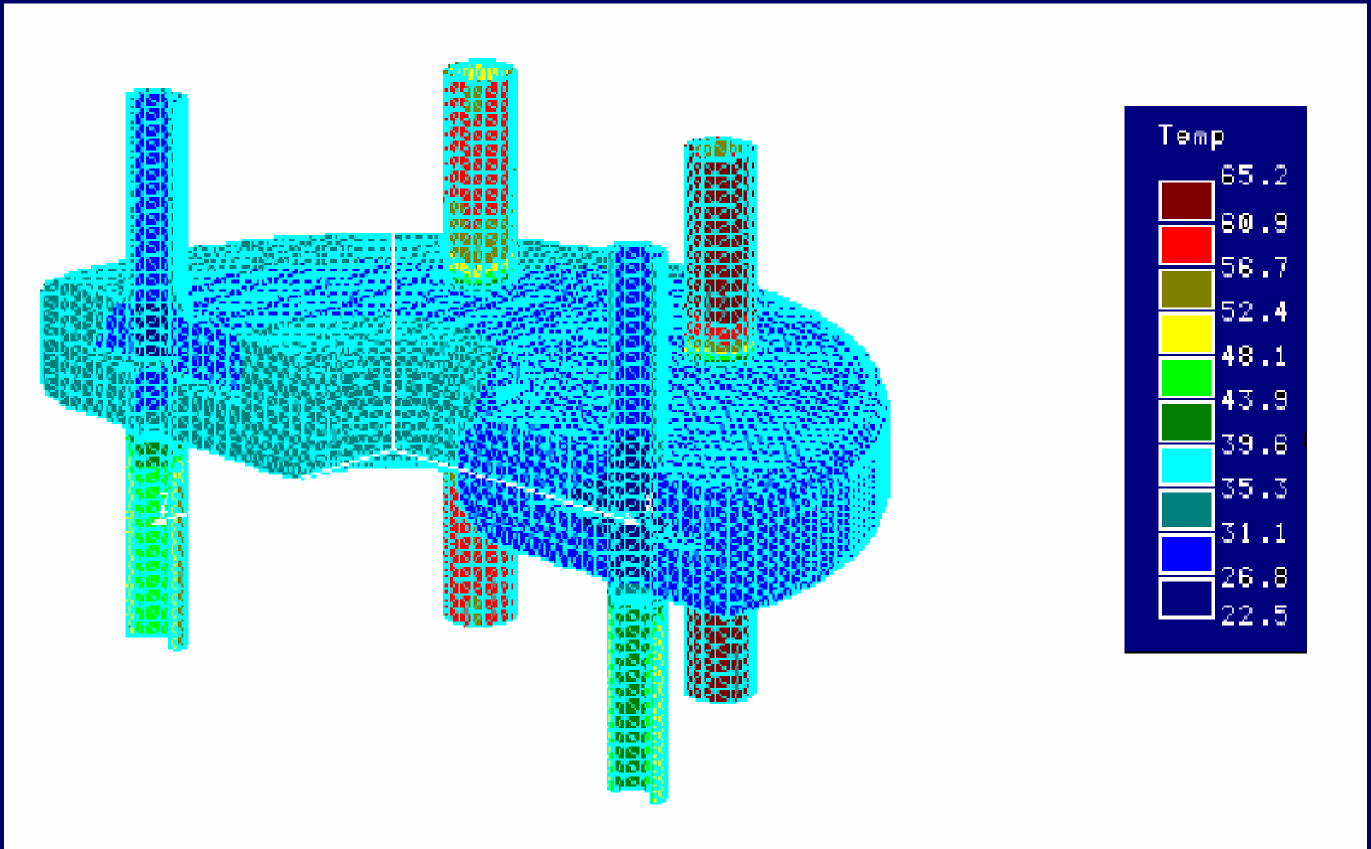
Disk flow rate vs pressure drop, measurements vs calculations



Disk channel film coefficients, measurements vs calculations

3D Finite Element Model

max disk temp rise = 7.5°C, disk-to-disk var. < 10 °C



Conclusions

- Electromagnetic, vacuum, thermal-hydraulic, and mechanical designs have been performed by DULY Research Inc. for an S-band and an L-band polarized electron PWT photoinjector.
- L-band PWT photoinjector has a low transverse emittance, which may help simplify the damping ring design for the ILC.
- L-band PWT photoinjector offers ultra high vacuum and excellent cooling to meet the ILC requirements for a polarized electron source.
- Simulations show that backscattered electrons are suppressed at the low PWT operating field, important for the GaAs survivability.