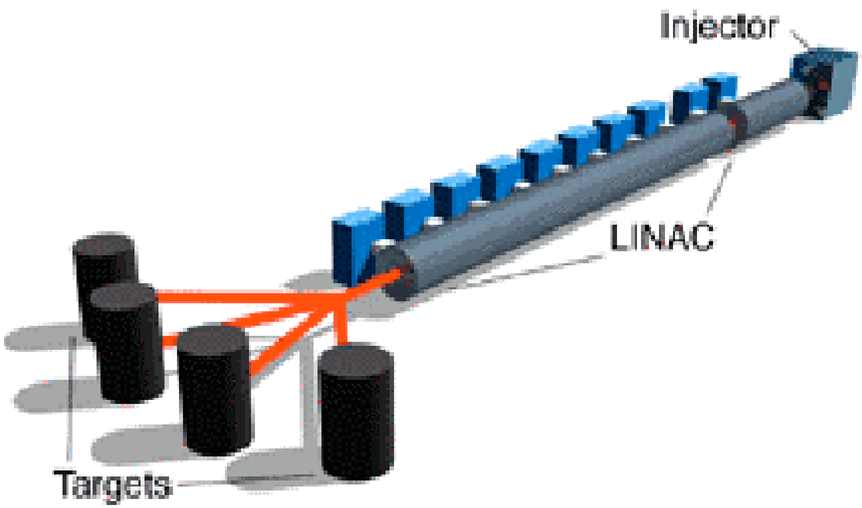
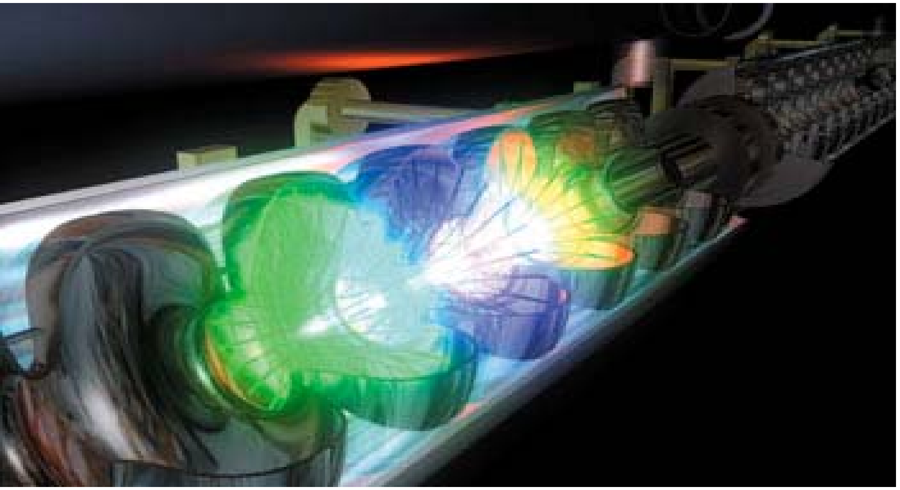
PREPARATION STUDIES FOR THE SECONDARY ELECTRON EMISSION EXPERIMENTS ON SUPERCONDUCTING NIOBIUM

ANOOP GEORGE & ROBERT A. SCHILL, Jr.

Department of Electrical and Computer Enginering
University of Nevada, Las Vegas
4505, Maryland Parkway
Las Vegas, Nevada 89154-4026

PURPOSE & MOTIVATION





- Accelerator driven Transmutation of Nuclear Waste
- Major Component- Linac (LANL)
  - Superconducting Radio-Frequency (SC RF) Accelerator
  - Multi-cell niobium cavities in superconducting state
- Concern - Multipacting
  - A physical phenomenon limits the amount of power that can be supplied to the cavity.

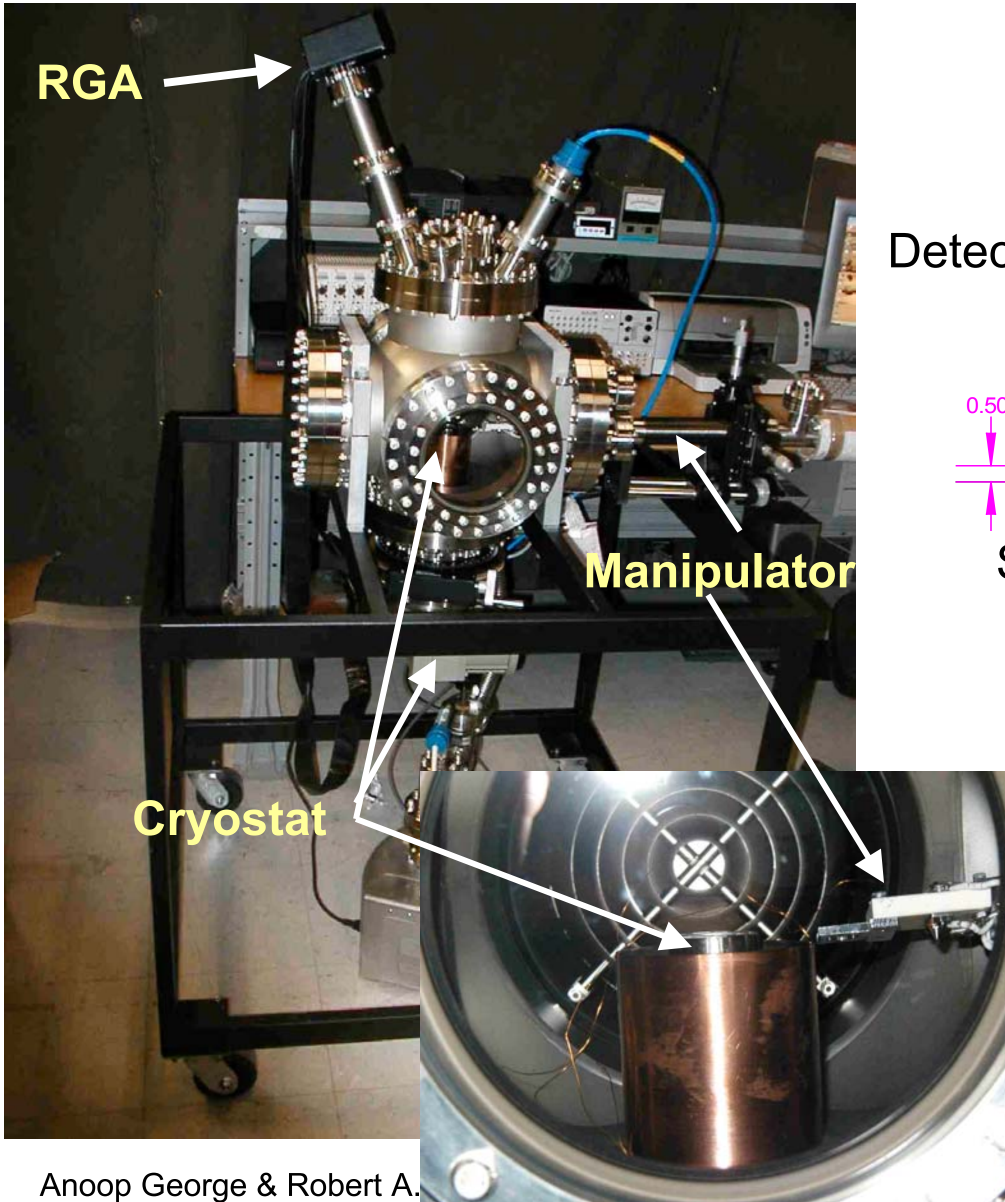
MULTIPACTING

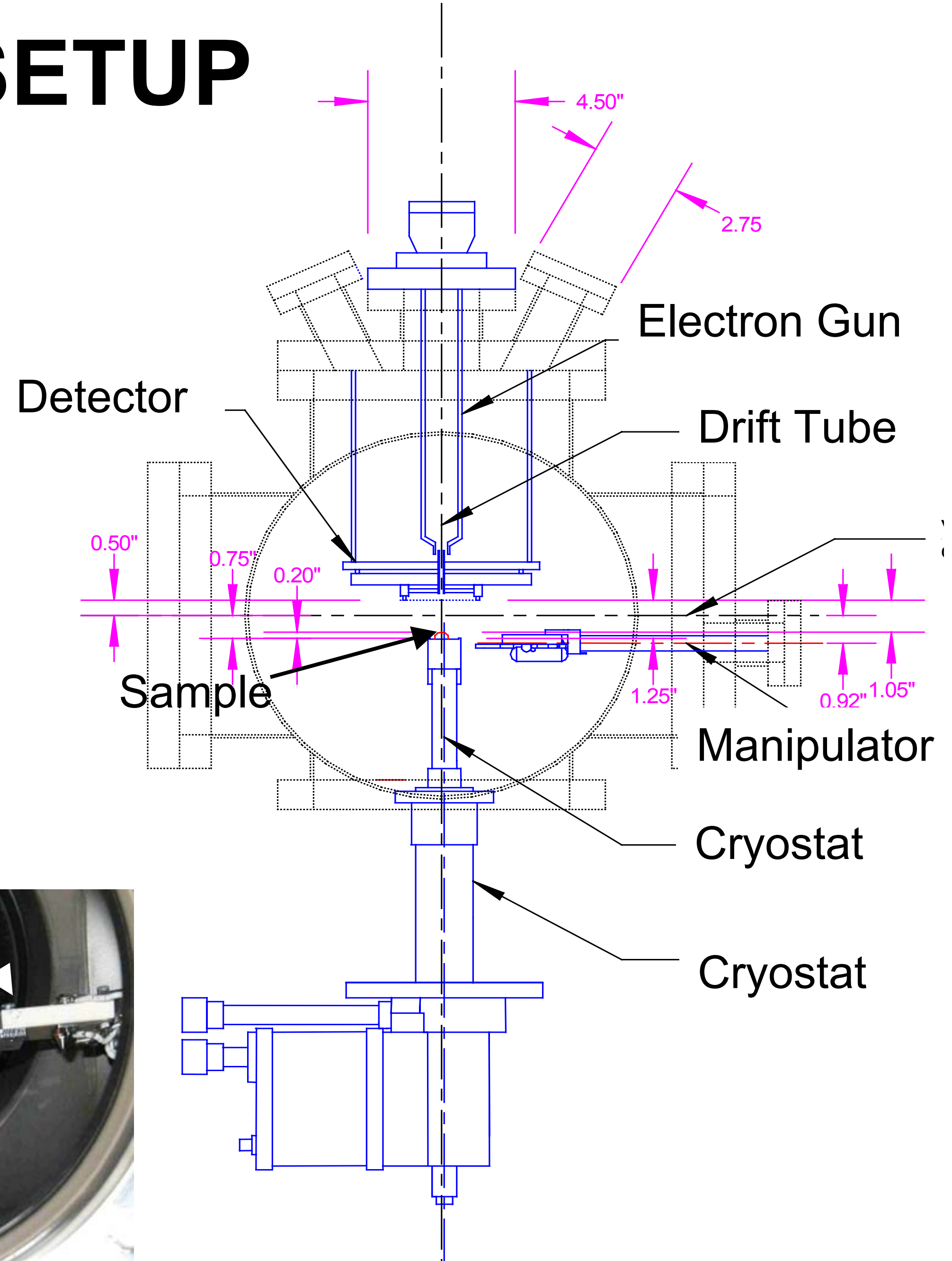
- Localized resonant current resulting from multiple impacts of electrons leading to an electron avalanche condition
- Multipacting reduces the quality factor of the cavities by
  - Breakdown of superconductivity
  - Cavity structural damage
  - Degradation of cavity vacuum
- Major factors that induce multipacting
  - Cavity shape
  - Cavity surface finish and conditioning
  - **Secondary electron yield of the cavity material**
- Current work
  - Study secondary electrons form LANL surface conditioned niobium samples
  - Experimental results will be incorporated in LANL multipacting codes

UNIQUENESS OF EXPERIMENT

- Single particle position and timing detector
  - Study the spatial distribution and yield of secondary electrons emitted from niobium
- Exp. Environment - cryogenic temp. (< 8.5 ^{o}K)
  - Emulate LANL niobium cavity in superconducting state
  - Secondary electron yields obtained from a material (niobium) ***in a superconducting state***
- UHV with pressures ~ 10^{-8} to 10^{-9} Torr
  - Emulate the LANL RF cavity environment
- *In situ* Cleaning Techniques
  - Sputter cleaning - desorb carbons and hydrocarbons
  - Monolayer heating - water

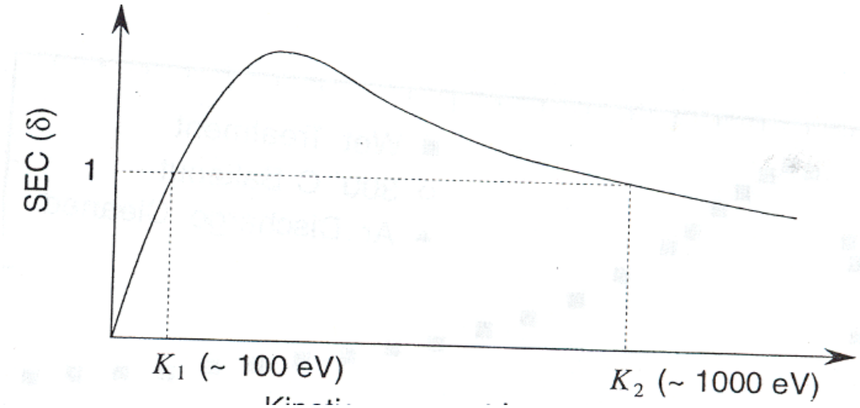
EXPERIMENTAL SETUP

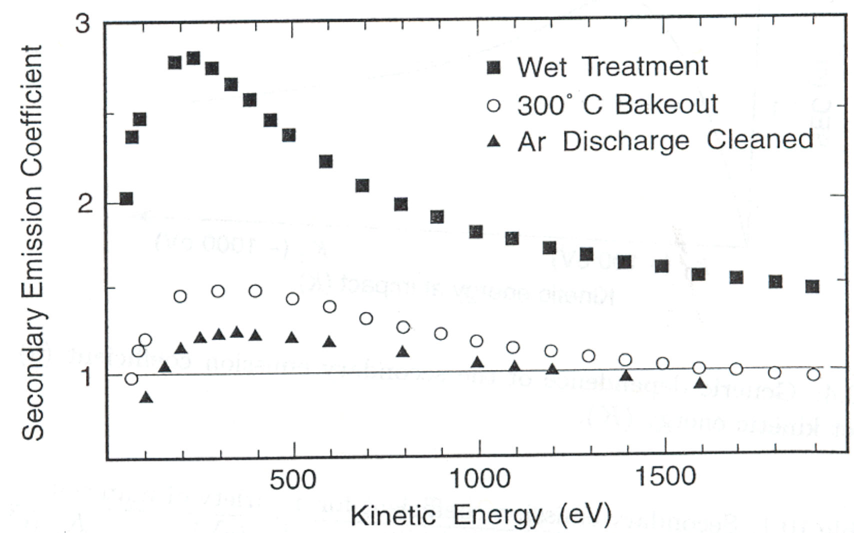




SECONDARY ELECTRON (SE) YIELD OF NIOBIUM

- SE – Energies from 1 eV-20 eV
- Secondary Electron Coefficient (SEC)
  - Number of SE per incident primary electron (PE)
  - SEC > 1, for PE energies betw. 150 eV & 1050 eV
  - SEC peaks to ~2 for a PE energy of 375 eV
  - SEC altered by surface preparations & conditioning





CHOICE OF THE SE DETECTOR

- Crucial parameters
  - Type
  - Size
  - Spatial resolution
  - Temporal resolution
  - The distance from sample
  - Grid effects
  - Central hole & drift tube
- Types studied
  - Scintillating photomultiplier detector
  - LEED type detector
  - Gas electron multiplier detector
  - Micro-channel plate (MCP) / Delay line detector (DLD)
- Reason for MCP/DLD choice
  - Single particle detection
  - Time resolution of ~ 1 ns
  - Large active area (45 mm dia.)
  - Position resolution of 250 μm
  - Multi-hit capability
  - UHV compatibility

PRELIMINARY DETECTOR STUDIES

- Governing Eq. of Motion

$$\ddot{r} - r\dot{\theta}^2 - r\dot{\phi}^2 \sin^2\theta = K / r^2$$

$$2\dot{r}\dot{\theta} + r\ddot{\theta} - r\dot{\phi}^2 \sin\theta\cos\theta = 0$$

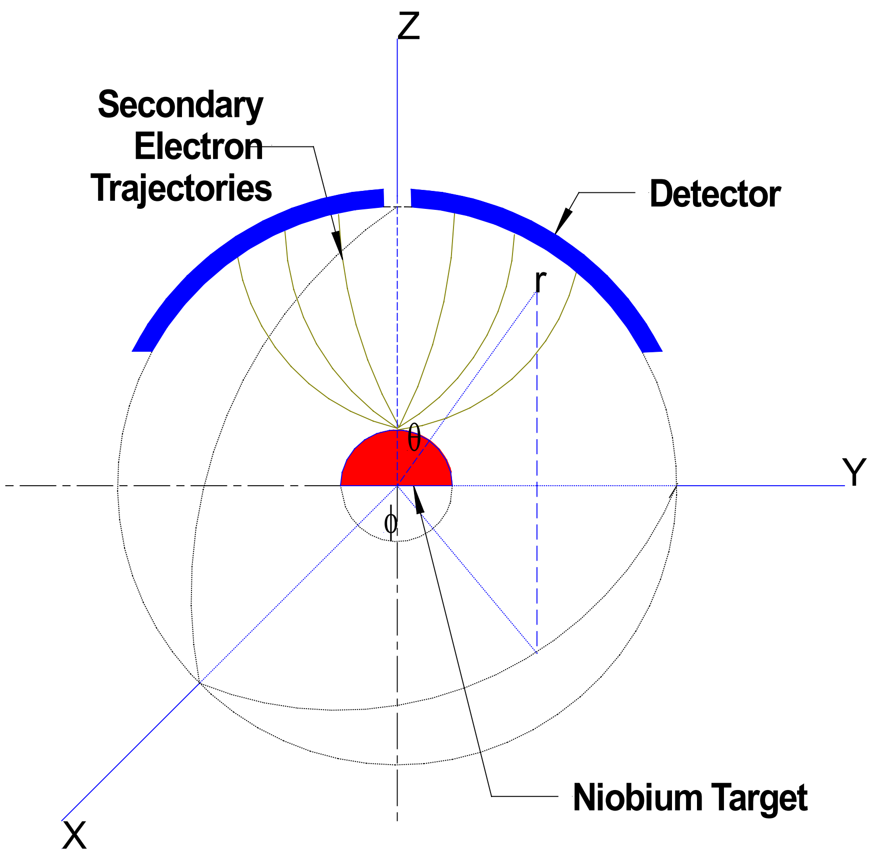
$$2\dot{r}\dot{\phi}\sin\theta + 2r\dot{\theta}\dot{\phi}\cos\theta + r\ddot{\phi}\sin\theta = 0$$

- Azimuthal Motion Constraint

$$\ddot{\phi} = \dot{\phi} = 0$$

- Constant of Motion

$$C_0 = r\dot{\theta}/2$$



- Normalization
  - Distances normalized w.r.t. radius of spherical detector, $r = \tilde{r}R_2$
  - Energies normalized w.r.t. the front MCP voltage, $\mathrm{E}_0 = \tilde{\mathrm{E}}_0 q V_s$

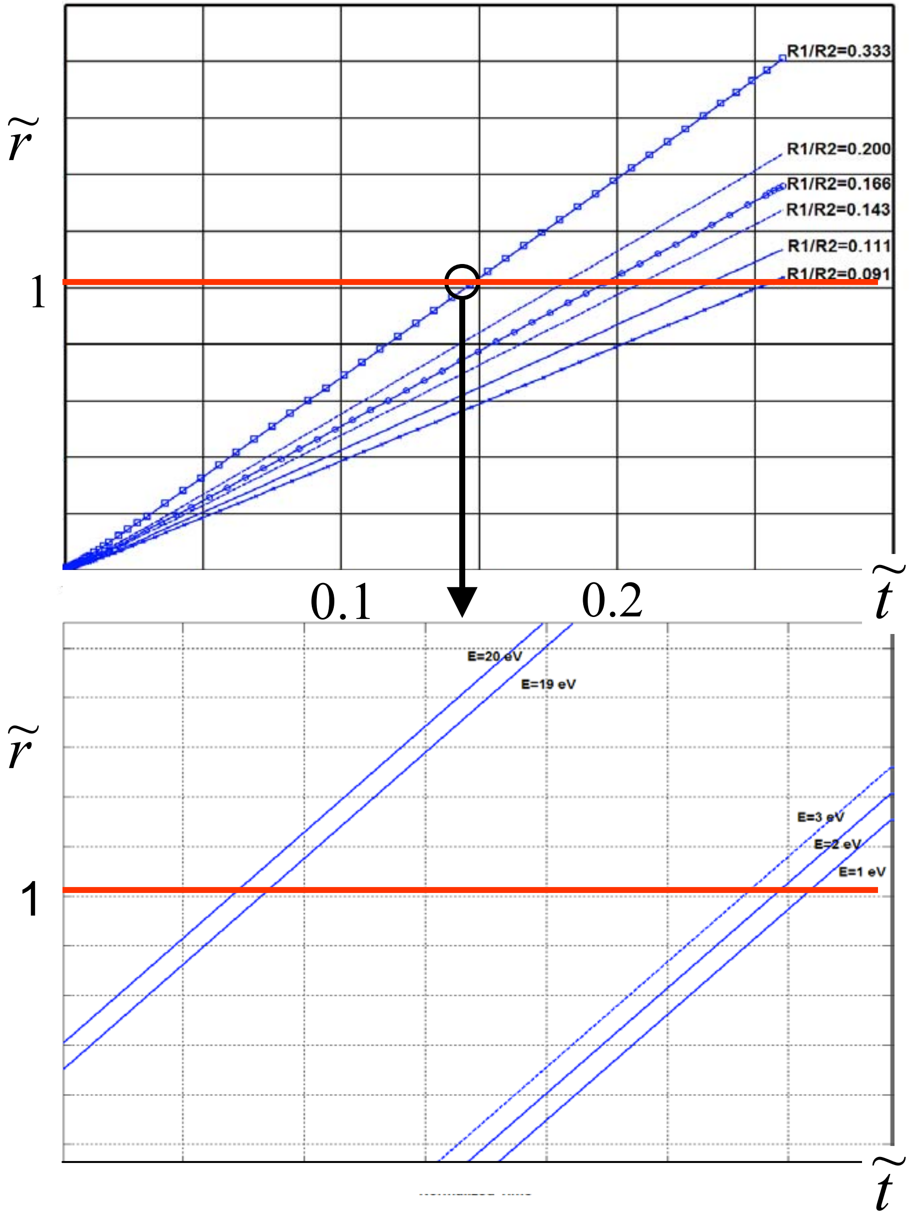
PRELIMINARY DETECTOR STUDIES [CONTINUED]

- Normalized Eqs. of Motion

$$\frac{d^2\tilde{r}}{d\tilde{t}^2} = \frac{\tilde{R}_1}{\tilde{r}^2\left(\tilde{R}_1 + 1\right)} + 2\frac{\tilde{E}_o - \tilde{v}_{ro}^2}{\tilde{r}}$$

$$\frac{d\theta}{d\tilde{t}} = \frac{\left[2\left(\tilde{E}_o - \tilde{v}_{ro}^2\right)\right]^{1/2}}{\tilde{r}}$$

- Plot drawn for $\tilde{r}$ vs $\tilde{t}$
  - For various values of R_1 / R_2 and $\tilde{E}_0$
- Normalized time for SE to reach detector surface – intersection of the curve with $\tilde{r} = 1$ line.



DETECTOR SIZE & RESOLUTION STUDY

- Normalized distance, $\Delta\widetilde{D} = \Delta D / R_2$, on the spherical detector between any two SE impact points is

$$\Delta\widetilde{D} = (\theta_2 - \theta_1)$$

- This distance projected onto a flat surface normal to the z-axis is

$$\Delta\widetilde{D}_{flat} = \cos\theta_1 \left(\tan\theta_2 - \tan\theta_1\right)$$

- Ex: R_2=3cm & V_s=1000V
  - R_1=0.5 cm
  - E_o=20 eV
  - t= 433 ns
  - D_{flat}= 1.5 mm

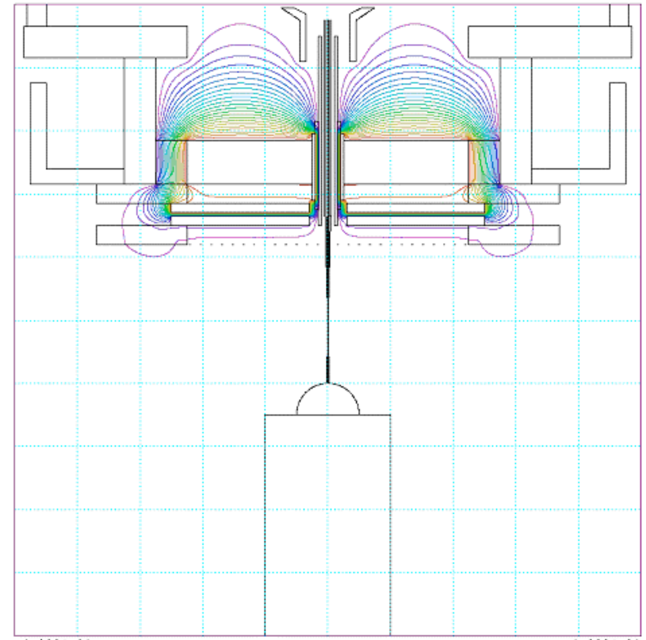
$\widetilde{R}_1$	$\widetilde{E}_o$	$\widetilde{t}$	θ [mrad.]	$\widetilde{D}_{flat}$
0.333	0.001	0.14497	6.48	.00065
	0.02	0.14457	28.9	.029
0.2	0.001	0.17748	7.94	0.0079
	0.02	0.17673	35.3	.035
0.166	0.001	0.19204	8.56	0.0085
	0.02	**0.19180**	**38.36**	**0.038**
0.143	0.001	0.20481	9.15	0.0091
	0.02	0.20369	40.7	.041
0.111	0.001	0.22920	10.25	0.010
	0.02	0.22757	45.55	0.046
0.091	0.001	0.25082	11.22	0.011
	0.02	0.24873	49.77	0.050

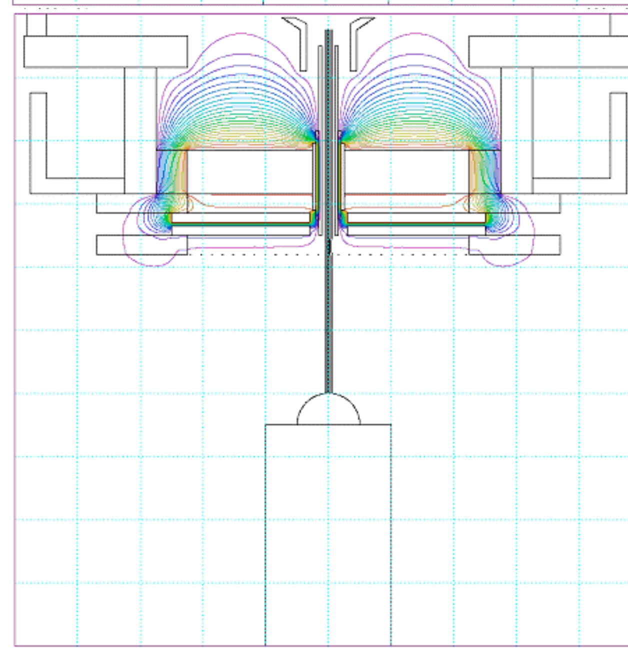
PRELIMINARY RESULTS

- Provides ballpark values for the spatial resolution and the size of the detector for a fixed distance between the sample and the detector.
    - The detector size required was estimated to be ~ 6 mm at worst case scenario. (MCP face potential of 200 V)
    - The detector spatial resolution required was estimated to be ~ 90 μm for 1000 V on the MCP and ~200 μm for an MCP voltage of 200V.
    - The estimates were obtained for a sample to detector distance of 25mm.
- Validation test for future secondary electron trajectory simulations.

SIMULATION STUDIES - EXPERIMENTAL SETUP

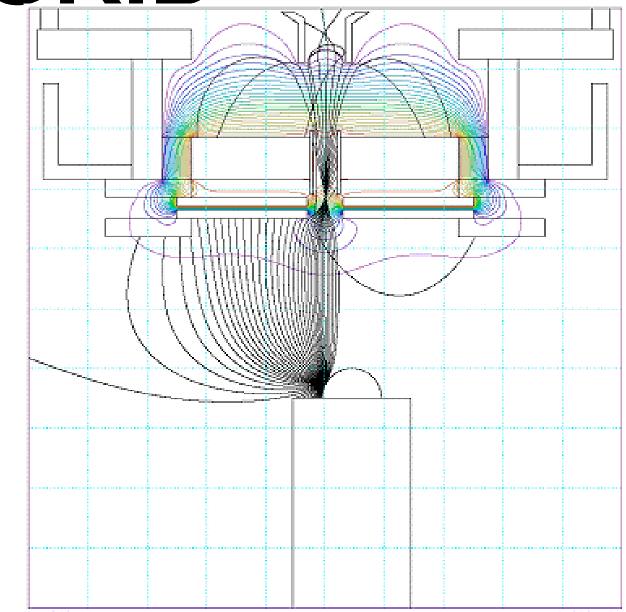
- Detector active area - 45 mm dia.
- Detector central hole - 6 mm dia.
- Electron drift tube through central hole - 30 mm long & 2 mm ID
- Hemispherical niobium sample - 10 mm spherical diameter
- Cylindrical cryostat 20 mm dia.
- Optimum distance between the niobium sample and the front face of the detector - 25 mm.
- A drift tube at chamber potential inserted in the detector's central hole was deemed necessary to provide a field free path through the detector.

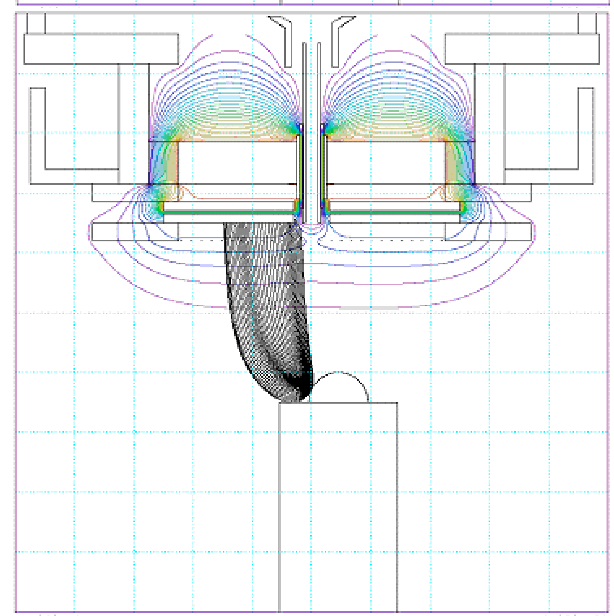




SIMULATION STUDIES - GRID

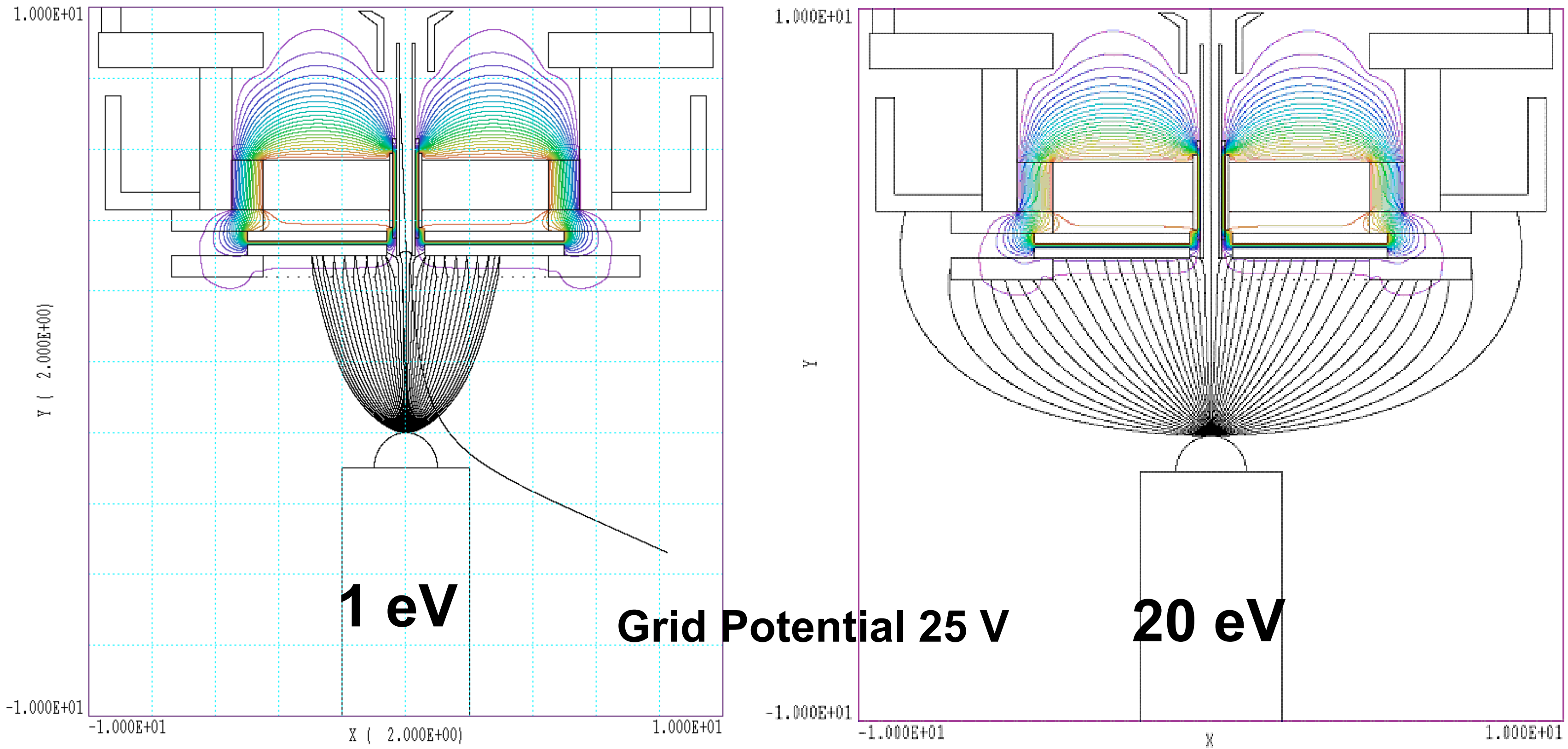
- High energy SE and low energy SE with large initial angle of trajectory are not captured by the detector.
- A controlling grid in front of the detector was essential in creating a variable field region in between the sample and the detector.
- For oblique PE incidence - Using a grid SE are drawn to the detector by creating a higher field region in between the sample and the detector.
- For normal PE incidence - Using a grid SE are drawn to the detector (instead of passing through the hole) by creating a zero field region in between the sample and the detector.





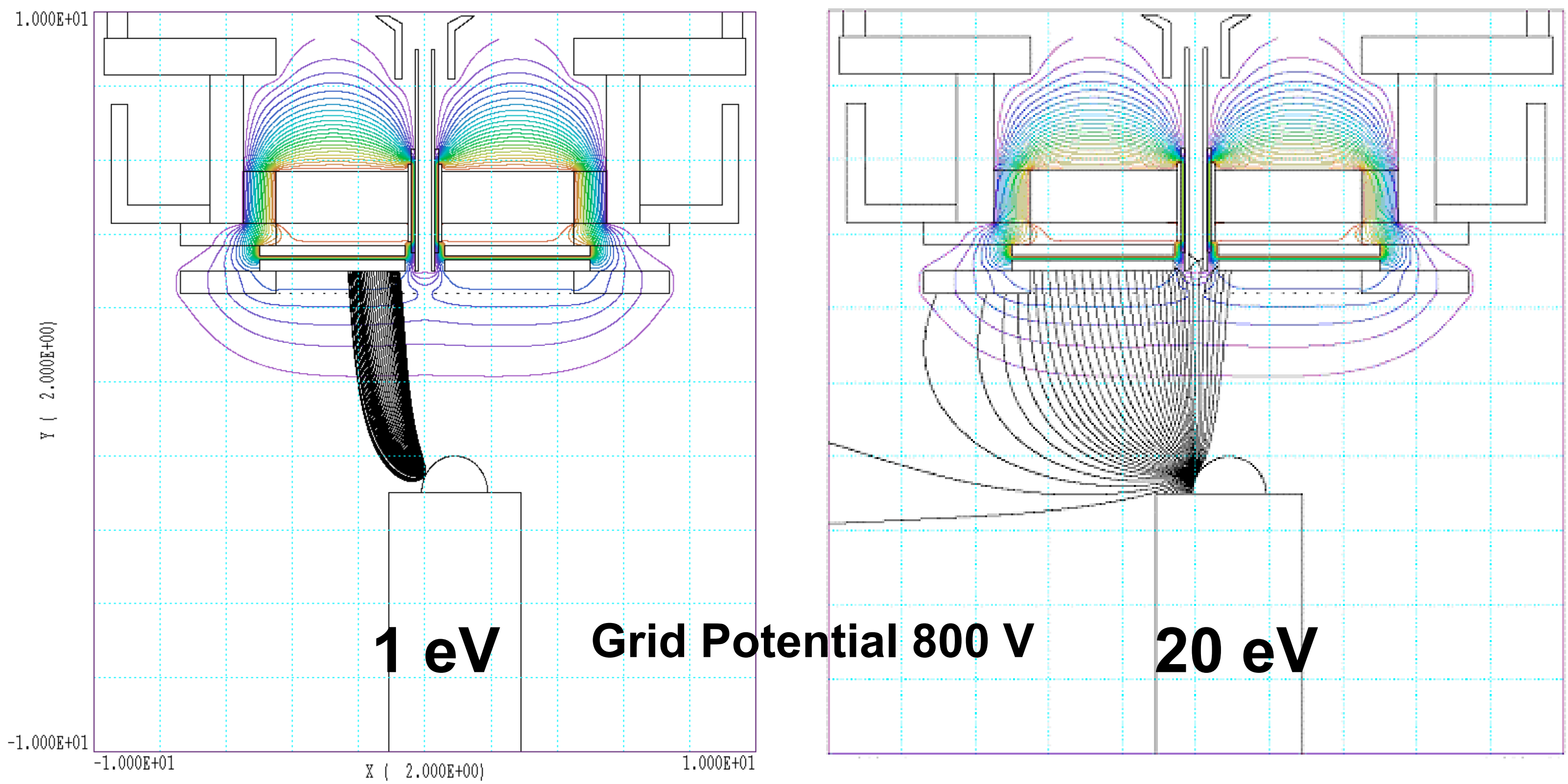
SIMULATION STUDIES - SE TRACKING WITH SAMPLE ON BEAM AXIS

- Secondary electrons launch with initial launch angles between -90 and 90 degrees with increments 4.5 degrees
- Initial secondary electron energies 1eV and 20 eV



SIMULATION STUDIES - SE TRACKING WITH SAMPLE OFF BEAM AXIS

- 4 mm lateral shift of the sample
- Angular incidence - 60^0 to the surface normal



CONCLUSION

- Analytical studies on the secondary electron motion were performed which provided a reasonable range of detector sizes, detector resolutions and distances from sample to detector.

- Particle tracking simulations provided a complementary in-depth study of these parameters.

- It was determined that a 4.5 cm diameter detector with 250 μm resolution positioned 2.5 cm from the sample allows for an optimal collection of secondary electrons.

THANK YOU