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Cockcroft Institute

(Dept. Engineering, Lancaster University, UK)

June 2006

Overview

- The Cockcroft Institute
- Current Research
- Current Lancaster Research
  - Electron Reflection & Multipactor Discharge
- Future Research
  - MICE Cavity

Cockcroft Institute**,**
Accelerator Science and Technology Institute.

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Over 90 research staff from;

Lancaster	(Engineering, Physics)
Liverpool	(Physics)
Manchester	(Physics)
ASTeC	(Daresbury + RAL)

Current Research:
(Cockcroft)

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Specific and Generic RF-related projects

1. multipactor discharge in high power RF engineering
2. phase locked magnetrons
3. Radial Inductive Output Tube for improved RF power delivery
4. a high brightness gun for 4GLS RF stability of an energy recovery linac (ERL)
5. Beam breakup in energy recovery linac for 4GLS

Contributions to the CERN "beam-beam acceleration" project CLIC (CTF3)

1. CLIC drive beam RF source using a multi-beam klystron
2. Coherent synchrotron radiation effects in the CTF3 combiner ring

Design and prototyping of aspects of the ILC

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1. beam delivery system optics design for beam monitoring and diagnostics and for beam extraction

2. wake-field evaluation of beam delivery collimation design

3. interaction region beam dumps

4. positron source using helical undulator and target technology

5. robust delivery of design luminosity with spin polarisation to the interaction region

6. crab cavity design

7. dipole-mode, wake-field simulations for the cavities in the main ILC linacs

8. wake-field evaluation of the design for the proposed Accelerator Test Facility ATF2 at KEK, Japan

9. damping ring design and optimisation including ILC Global Design Effort

1. LHC machine performance, in particular beam delivery, for the operation of small detectors adjacent to the LHC beam

Theoretical work

1. stability analysis of magnetically focussed, non-planar, particle trajectories

2. global field analysis of accelerator beams based on a new approach to the solution of the fundamental equations for a charged fluid in the ultra-relativistic limit

3. the development of a full theoretical treatment of nanometre bunch-bunch effects

4. development of a theoretical understanding and treatment of the fundamental processes for laser-driven plasma-wave acceleration (protons and electrons)

Current Research:
Dept Engineering (Lancaster)

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- High Power PBG structures (just awarded $1.5M)
- Generic Klystron
- High Brightness gun
- Multipactor Discharge\Suppression
- Multi Beam Klystron
- Radial IOT (200 – 500 MHz, ~ 0.5 MW)
- ILC Crab Cavity
- Phase Locked Magnetrons
- Beam breakup in ERL for 4GLS

Multipactor Discharge:

Role of Election Reflection

What is Multipactor ?

Considered a parasitic resonant electron phenomena occurring in generic RF vacuum systems

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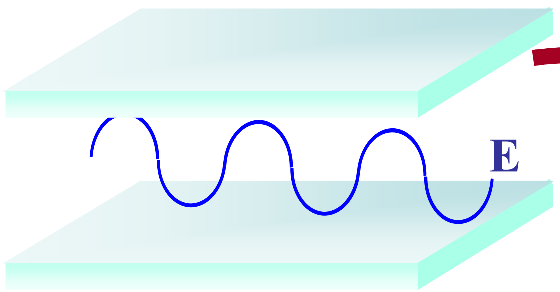
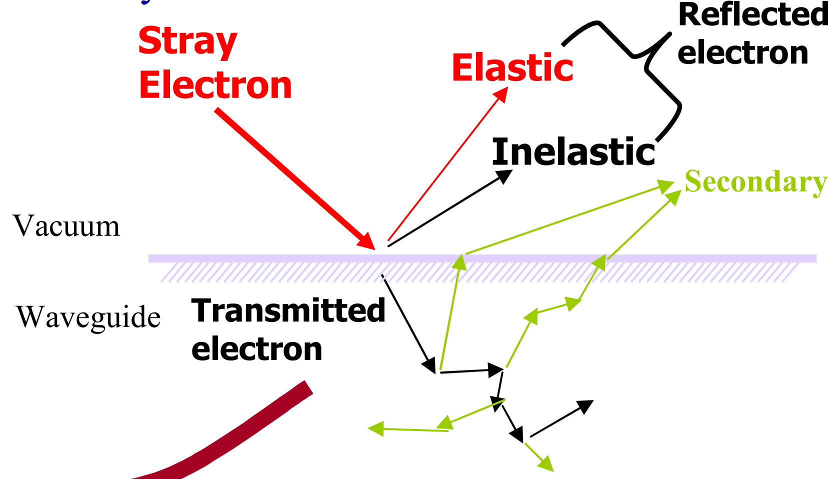
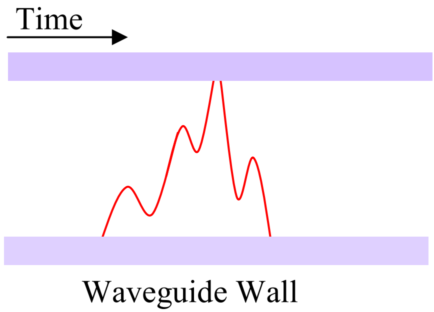
Consider an Electromagnetic wave Propagating between two parallel plates.



Stray electrons are accelerated by the wave, and collide with the walls generating secondary electrons.



The secondary electrons are accelerated by the wave, colliding with the walls and generating more secondary electrons.



The secondary electrons can *lock* with the RF field so electrons are produced at a phase to repeat this process.

If the number of electrons produced by each impact is > 1 then the electron population grows very quickly

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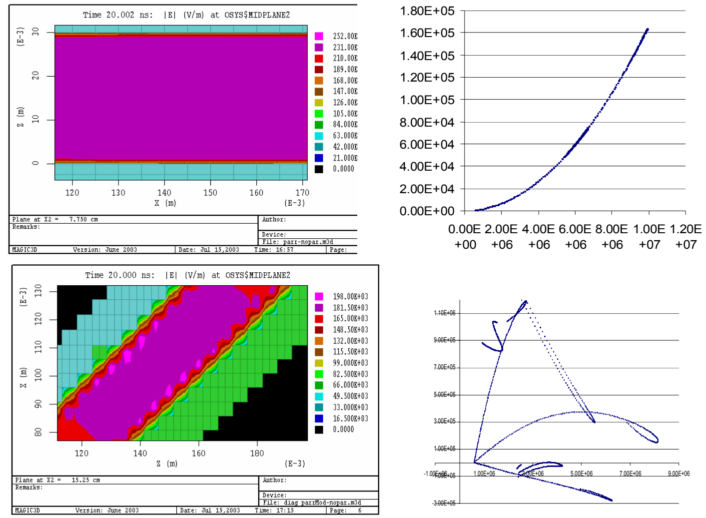
A number of codes used for Multipactor prediction, but none work for arbitrary structures.

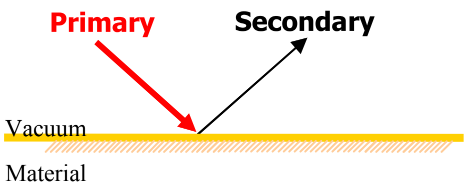
Two Key problems,

- Poor Field description near the surface

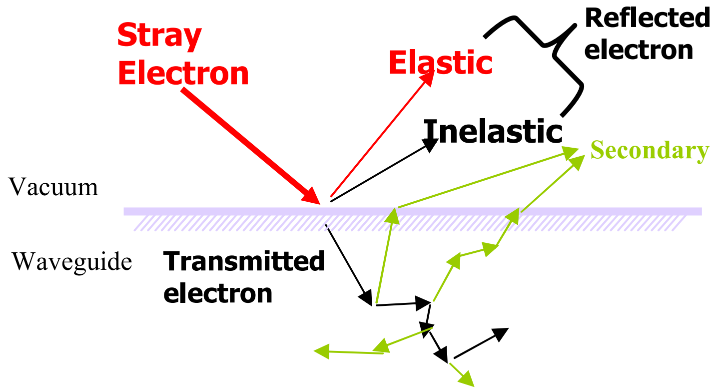
- Poor description of electron impact with surface

Phase Space

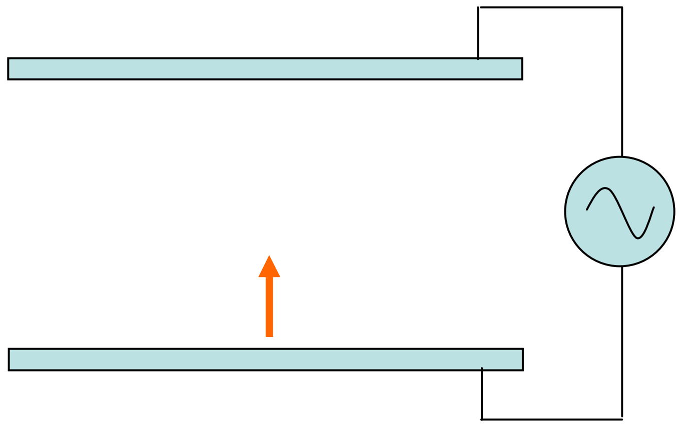




Usual Model



Scattering Approach



$$E = E_o \sin(\omega t)$$

10 Seed electrons with 1eV each degree of 1st RF cycle

SEY Model

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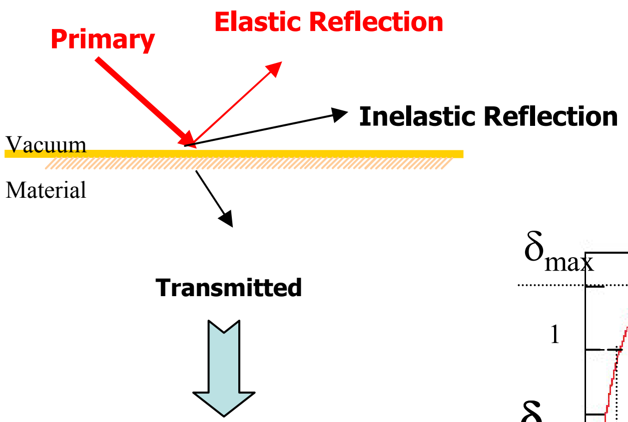
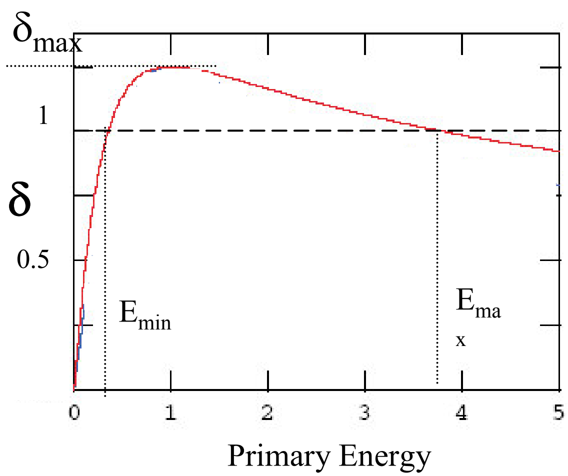
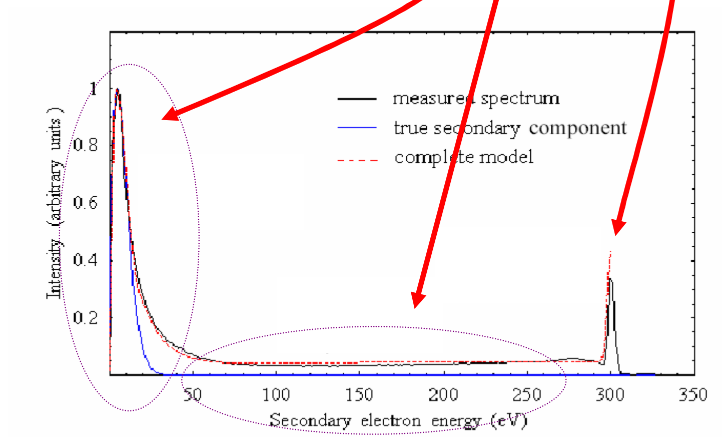
$$1 = R_{elastic} + R_{inelastic} + T$$



If $E_{min} \leq E_T \leq E_{max}$ then
$(1 \leq n \leq \delta_{max})$ secondaries

	|E|	Energy Distribution
Elastic Reflection	$E_R = E_P$	
Inelastic reflection	$E_R = 20\% \leq E_P \leq 99\%$	Uniform
Secondaries	$E_R = 0\% \leq E_P \leq 20\%$	Gaussian





Comparison of SEY model

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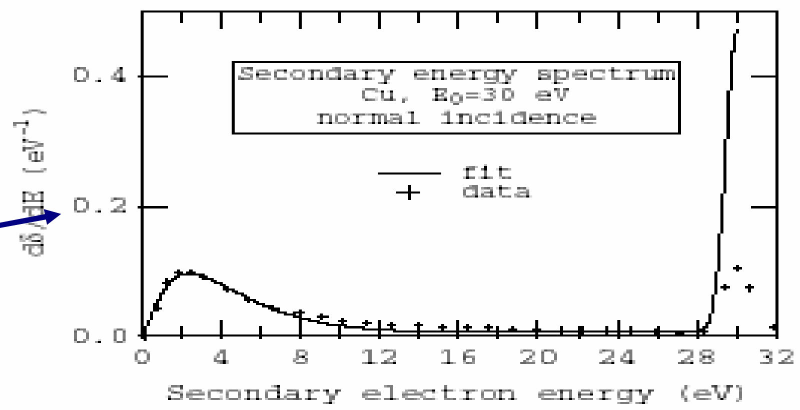
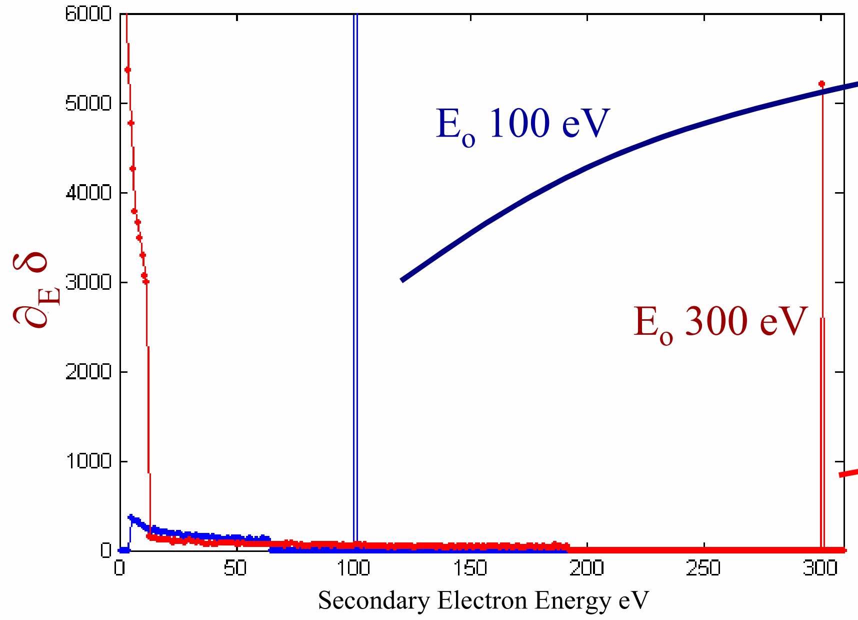
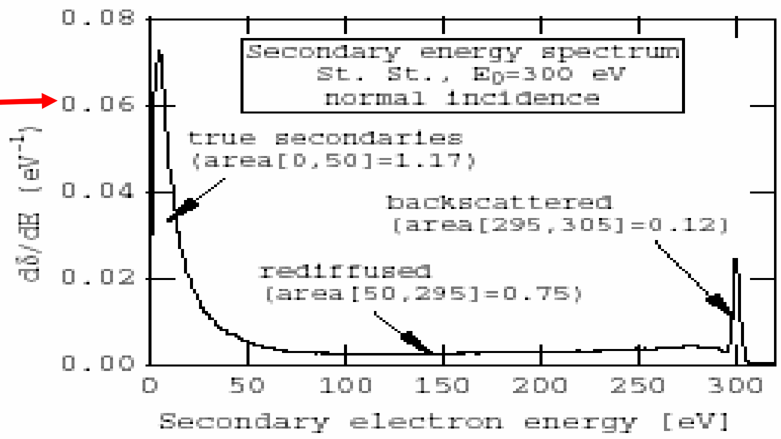
Taken from Furman (2002)



Simulation results for electron yields





Comparison of SEY model

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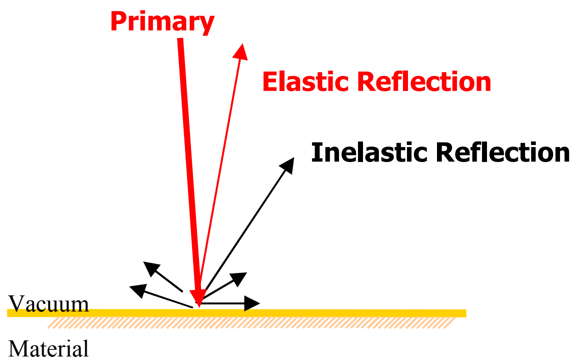
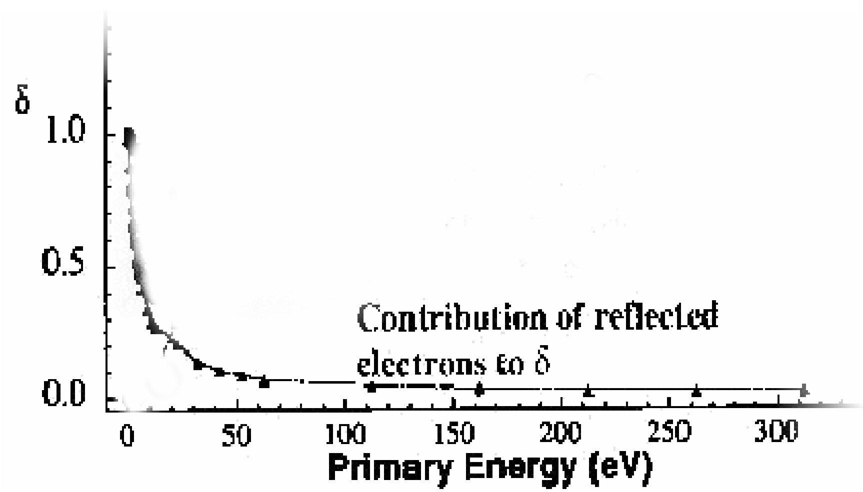
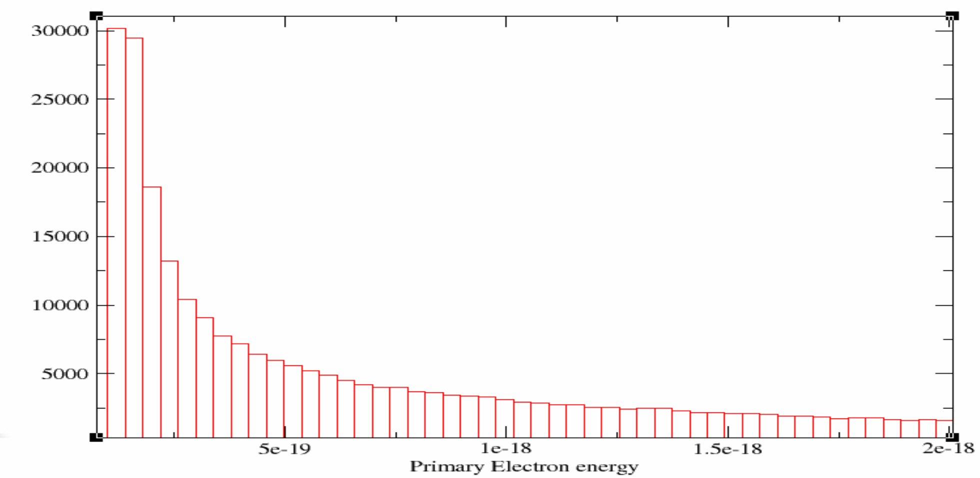
Contribution of reflected electrons to total electron yields



Experimental results, Cimino (2004)



Simulation results, of reflected electron yields



Hatch Diagram

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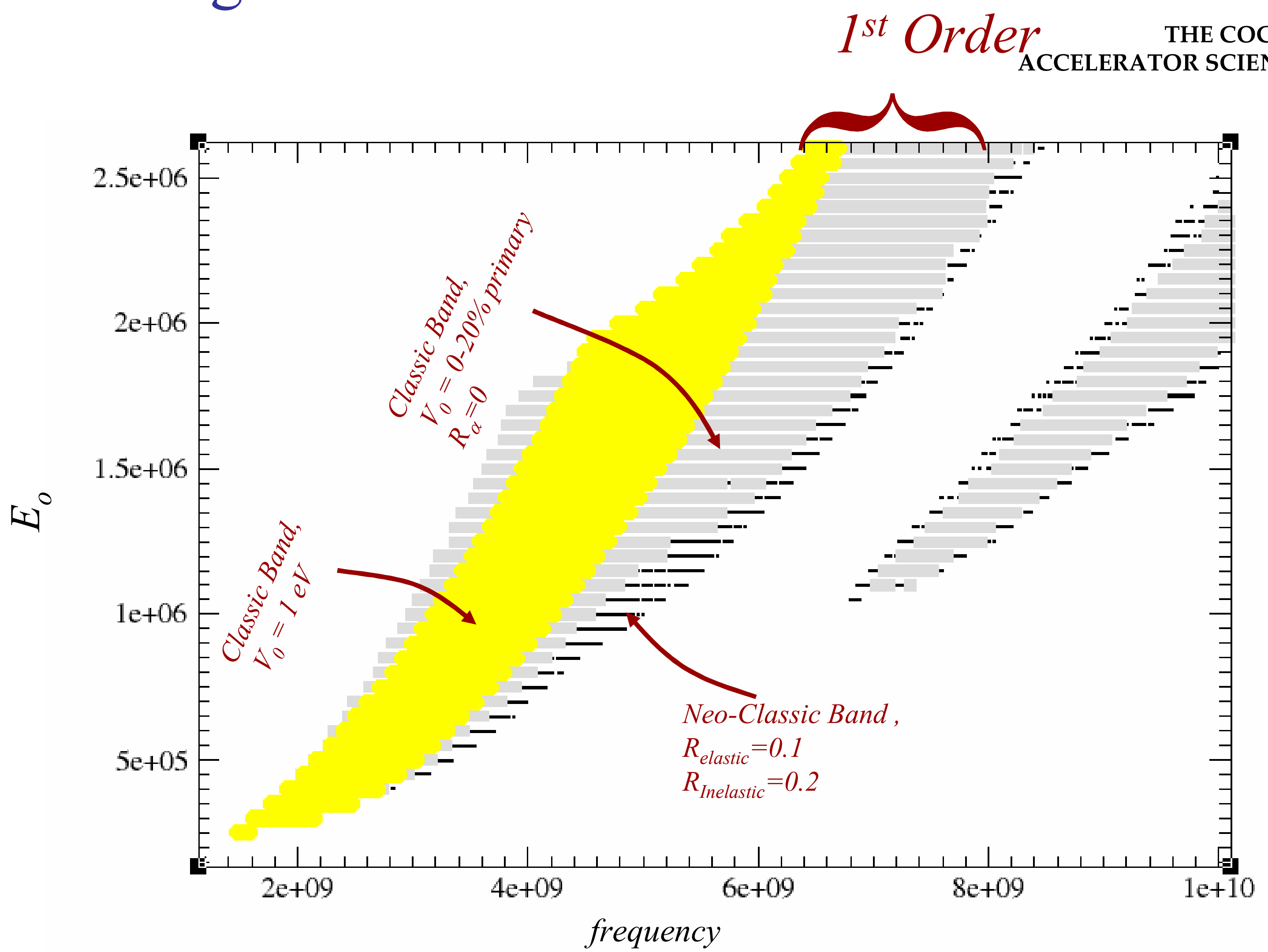
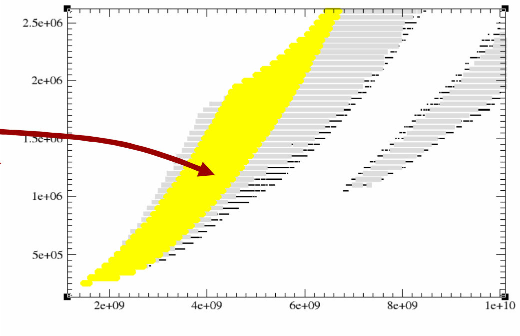
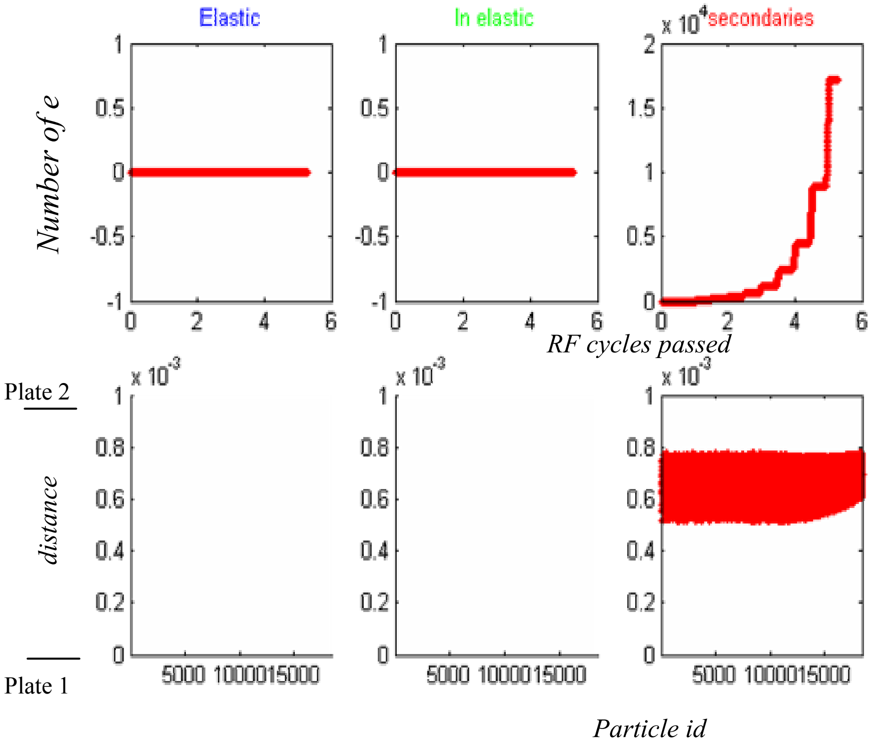


Classic Mid band point

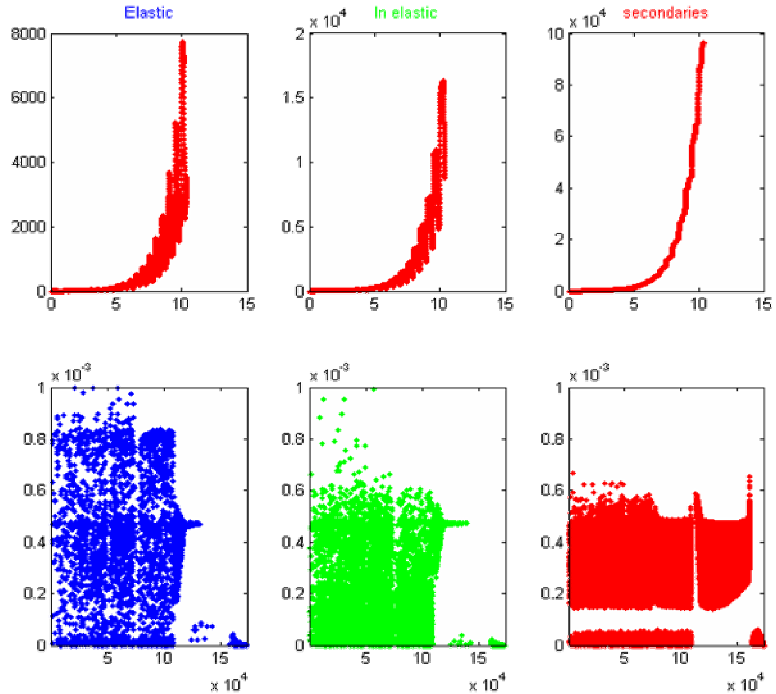
$E_o = 10^6$
$f = 4$ GHz



$R_e = 0, R_i = 0$



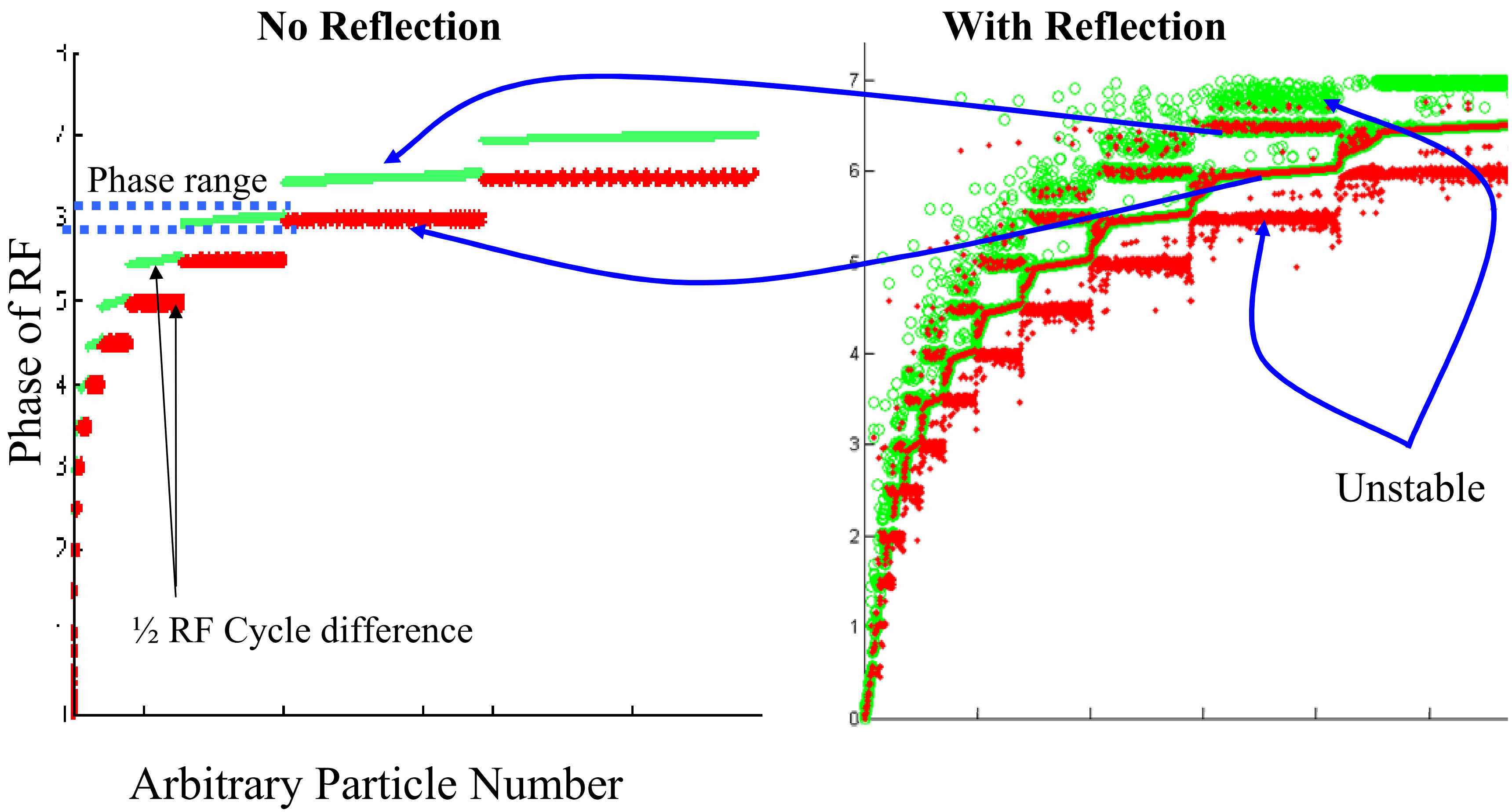
$R_e = 0.1$, $R_i = 0.2$



- 76% of impacts capable of e creation
- Ignoring reflection 75% of impacts capable of e creation.

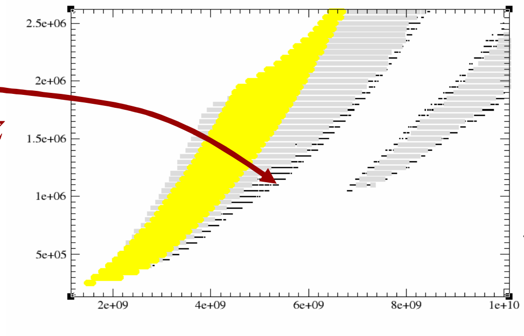
RF Phase at which new electron was created

RF Phase of the electron that created the new electron



Neo band point

$E_o = 10^6$
$f = 5$ GHz



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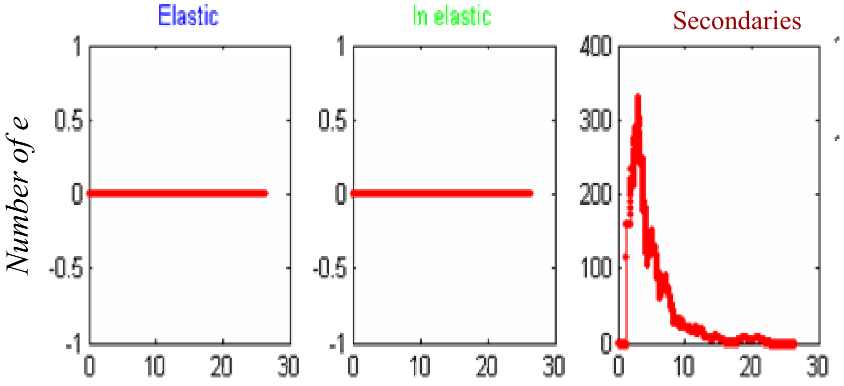
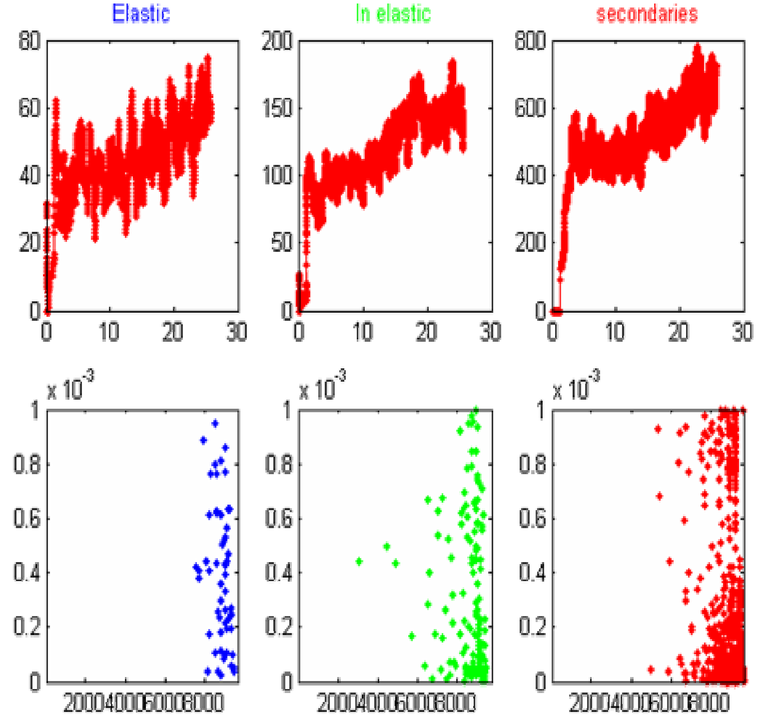
$R_e = 0, R_i = 0$



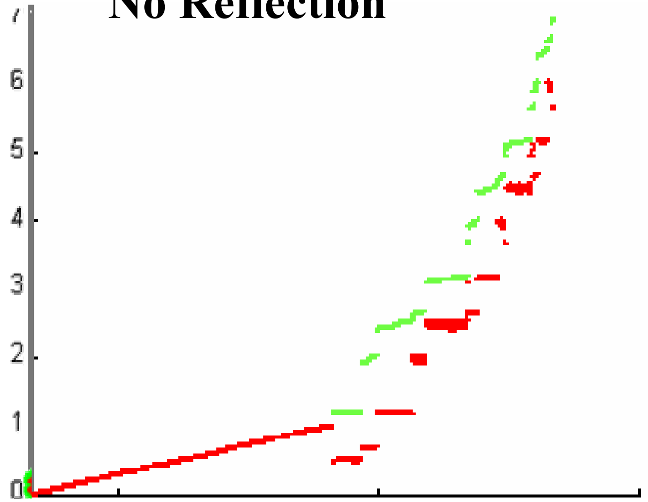
RF cycles passed

$R_e = 0.1, R_i = 0.2$

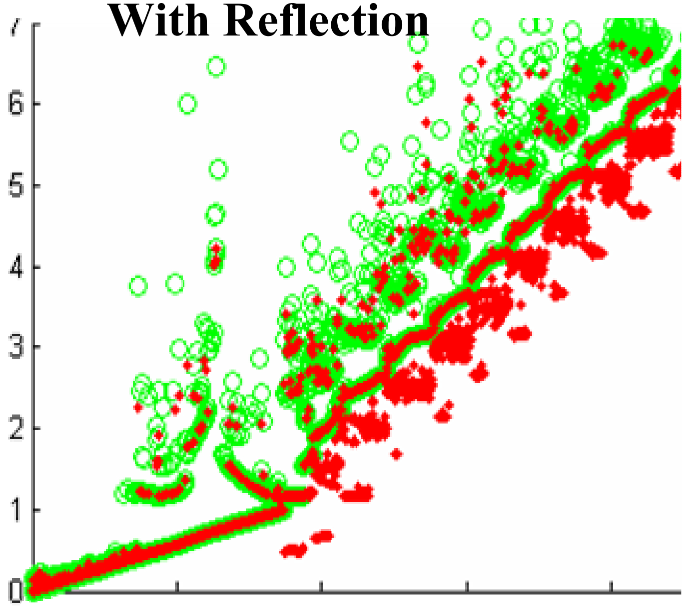


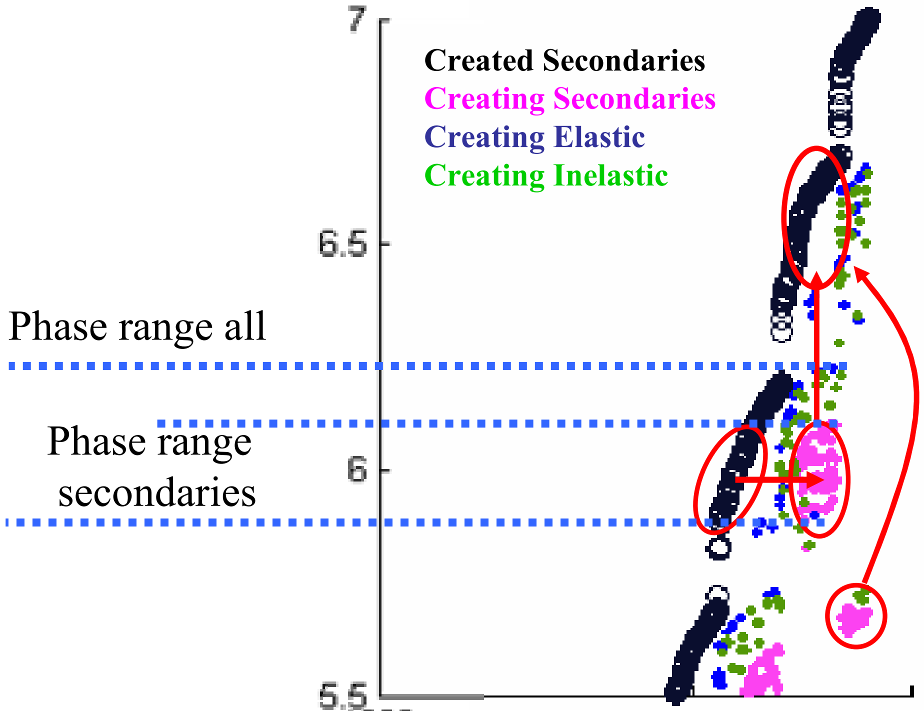
- 52% of impacts capable of *e* creation
- Ignoring reflection 43% of impacts capable of *e* creation.

No Reflection



With Reflection





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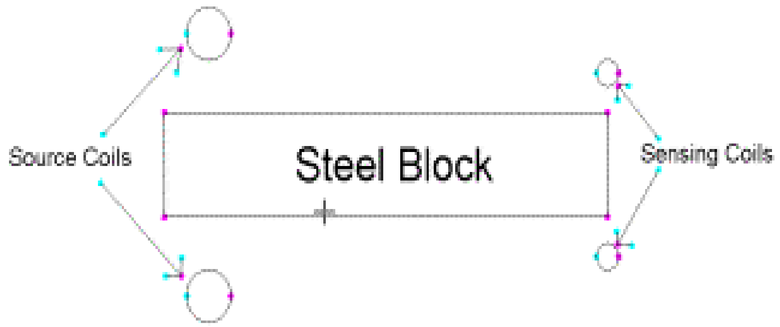
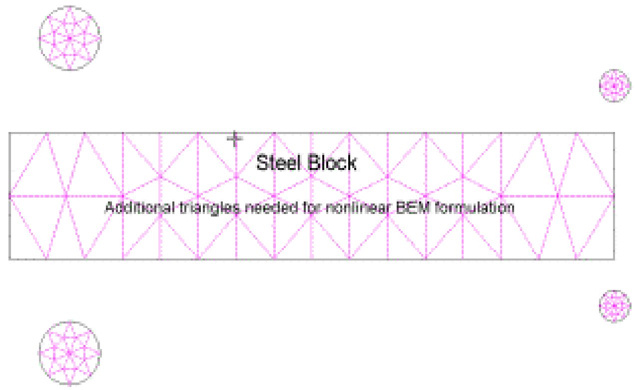
Hybrid Solve : Combined FE/BI Field Solver *Lorentz*

The hybrid approach combines the boundary element and finite element methods to solve a specific problem. The idea is, of course, to take advantage of the strengths of each method for a specific problem.

The approach is straightforward but the implementation is difficult. First decide which method to use in each volume (FE or BI). The two methods are then tied together by enforcing the continuity conditions on either ***E/B*** at the boundaries. In general the strategy is to use the boundary elements in all linear regions and finite elements in all nonlinear regions. In some instances, however, it is desirable to use finite elements in linear regions as well.





Electron surface interactions: 2 models,

- Scattering model
- Furman & Pivi semi empirical model

Predicting multipactor in CESR cavity (using Lorentz-HF)

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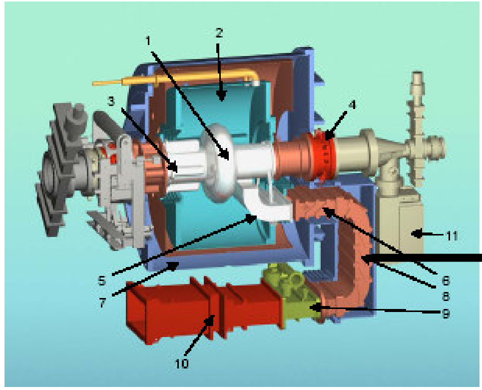
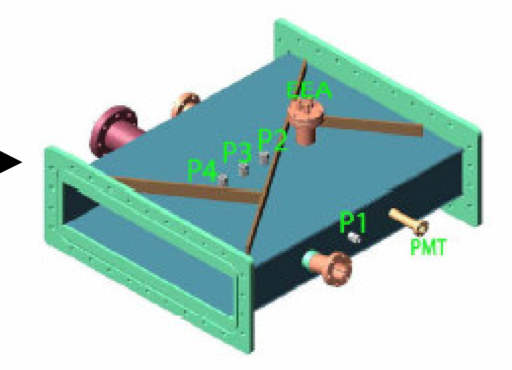
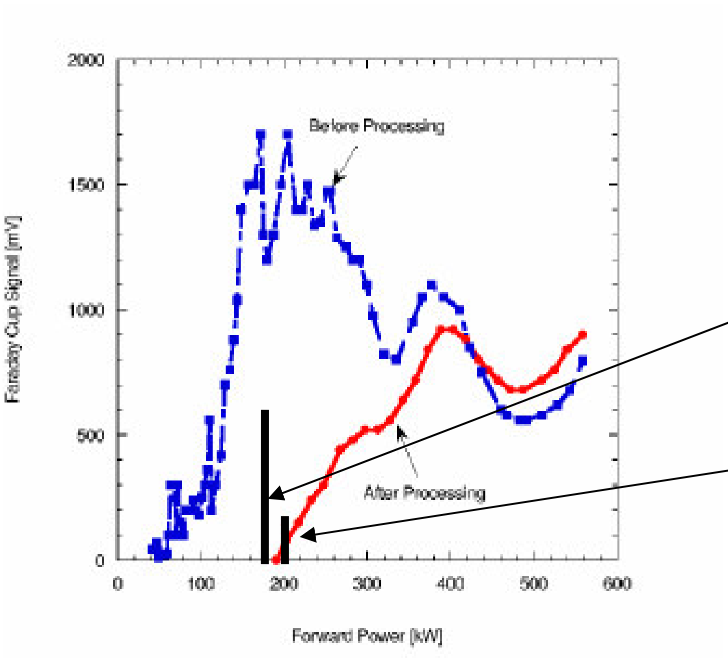
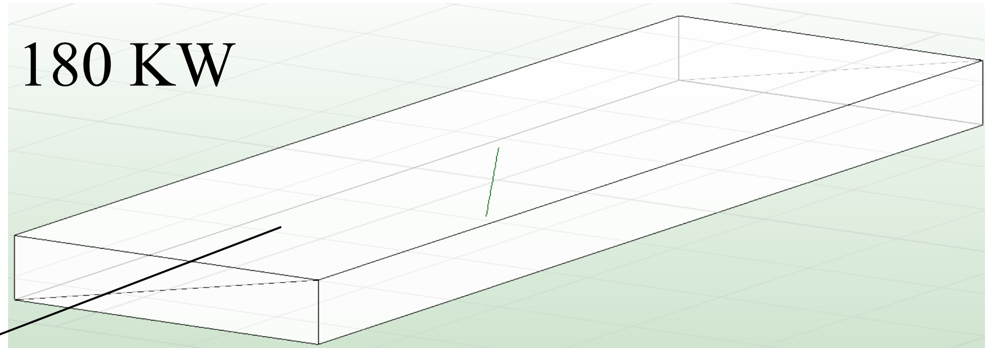
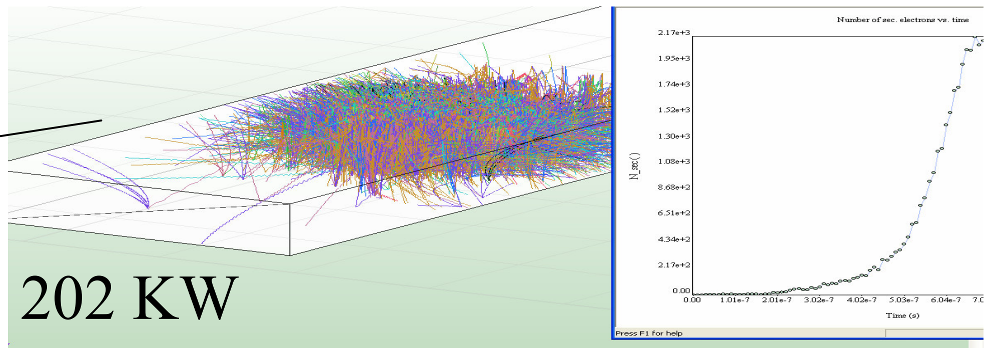


Previous simulations failed to predict the onset of multipactor

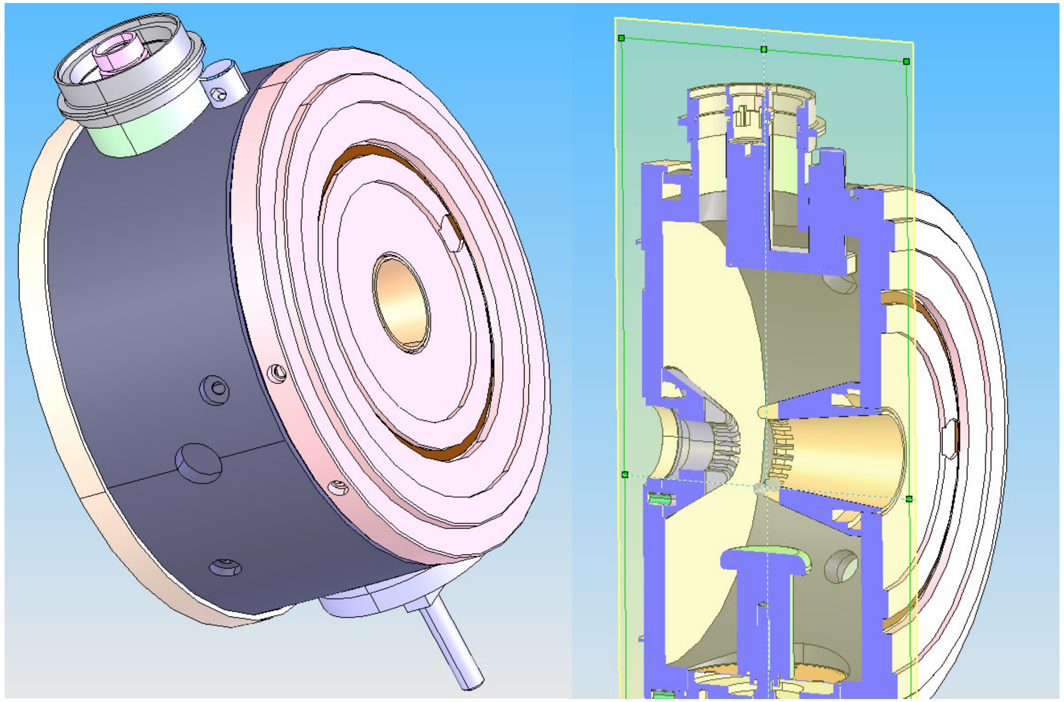




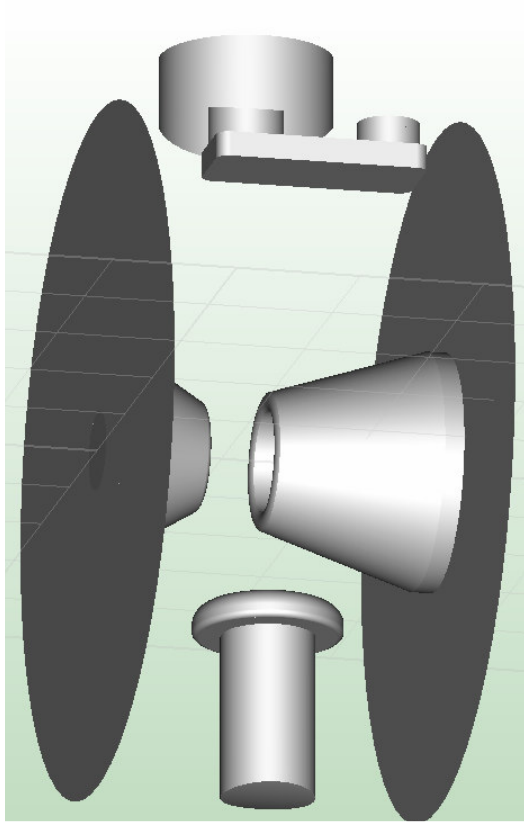




A more complicated structure : 1.3 GHz IOT Cavity (E2V)



- Cu Cavity
- Without castellation structure Multipacts
- With Castellation Multipactor suppressed



Modelled with Lorentz-HF

- Modelled without castellation
- Modelled with castellation
- Assumed Perfect Cu
  - 0.05 probability of Elastic Reflection
  - 0.25 probability of Inelastic Reflection

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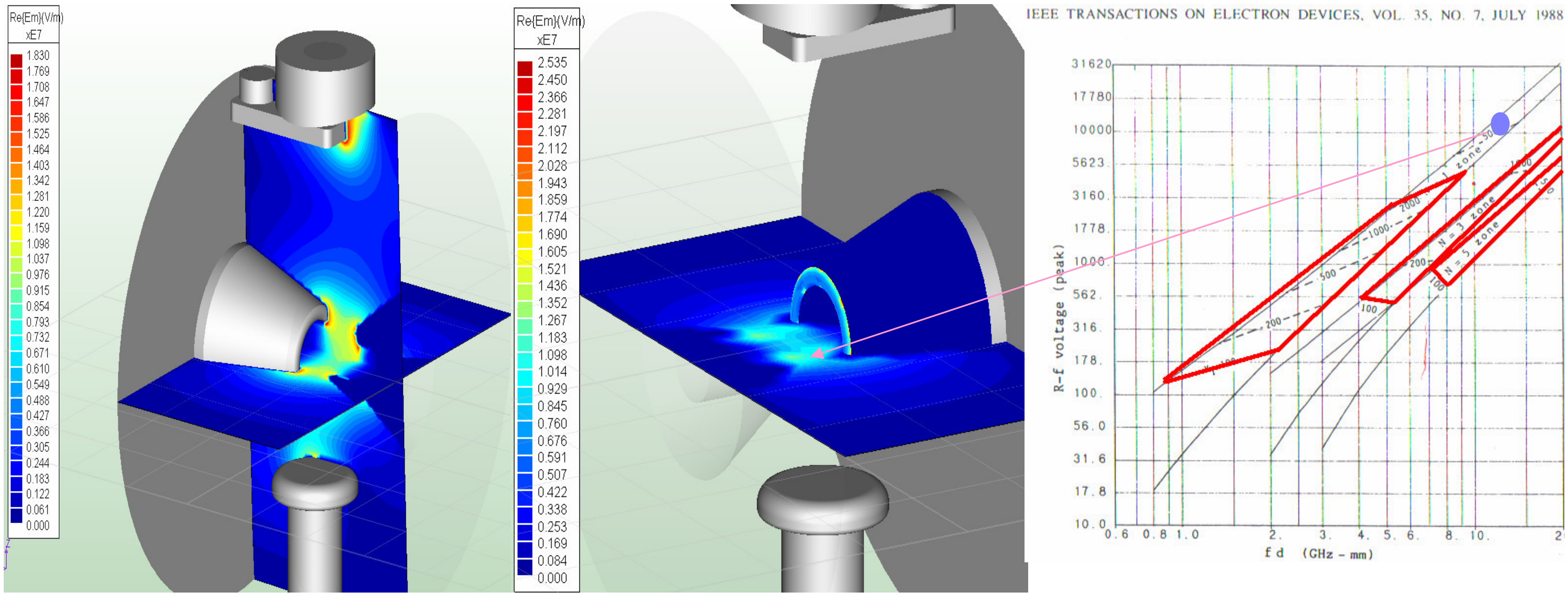
No castellations

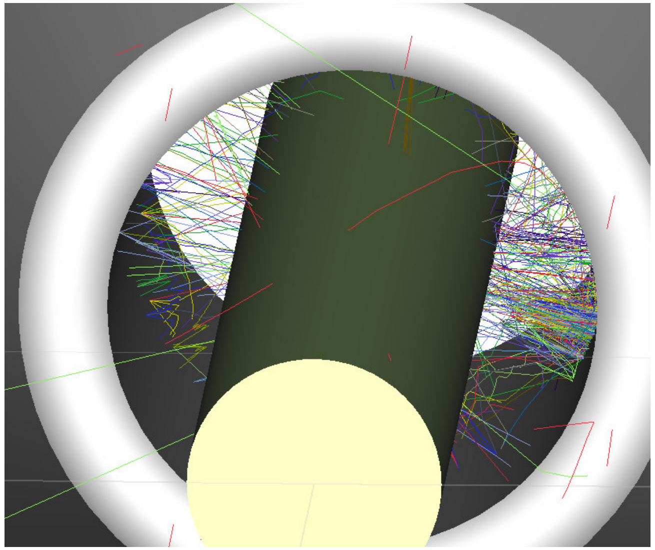
Crudely approximating to a parallel plate

Nose separation 10mm, at 5 % efficiency → $E_{peek} = 1.2 \times 10^7$

$RF_{peek} = 120000$, $fd = 13$

Multipactor Not Possible

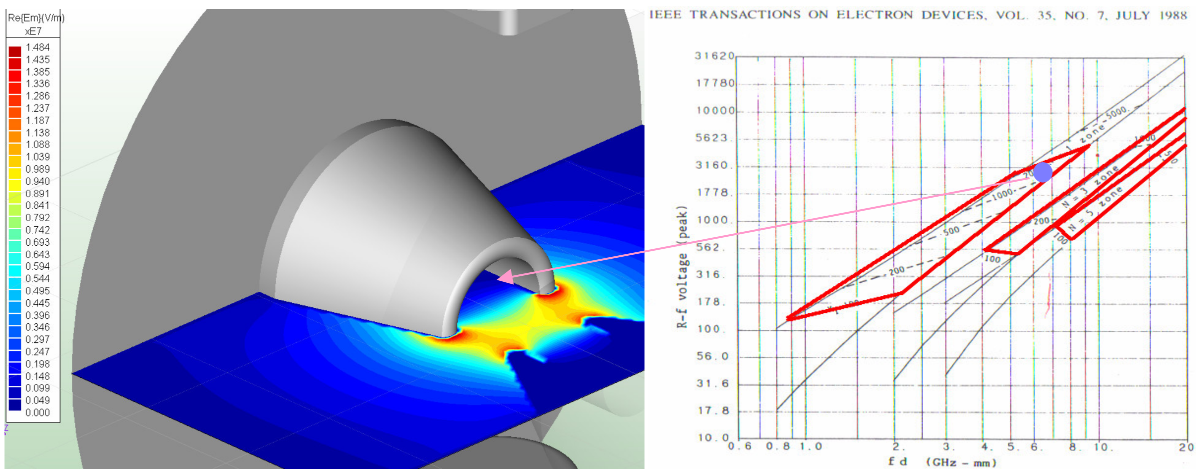


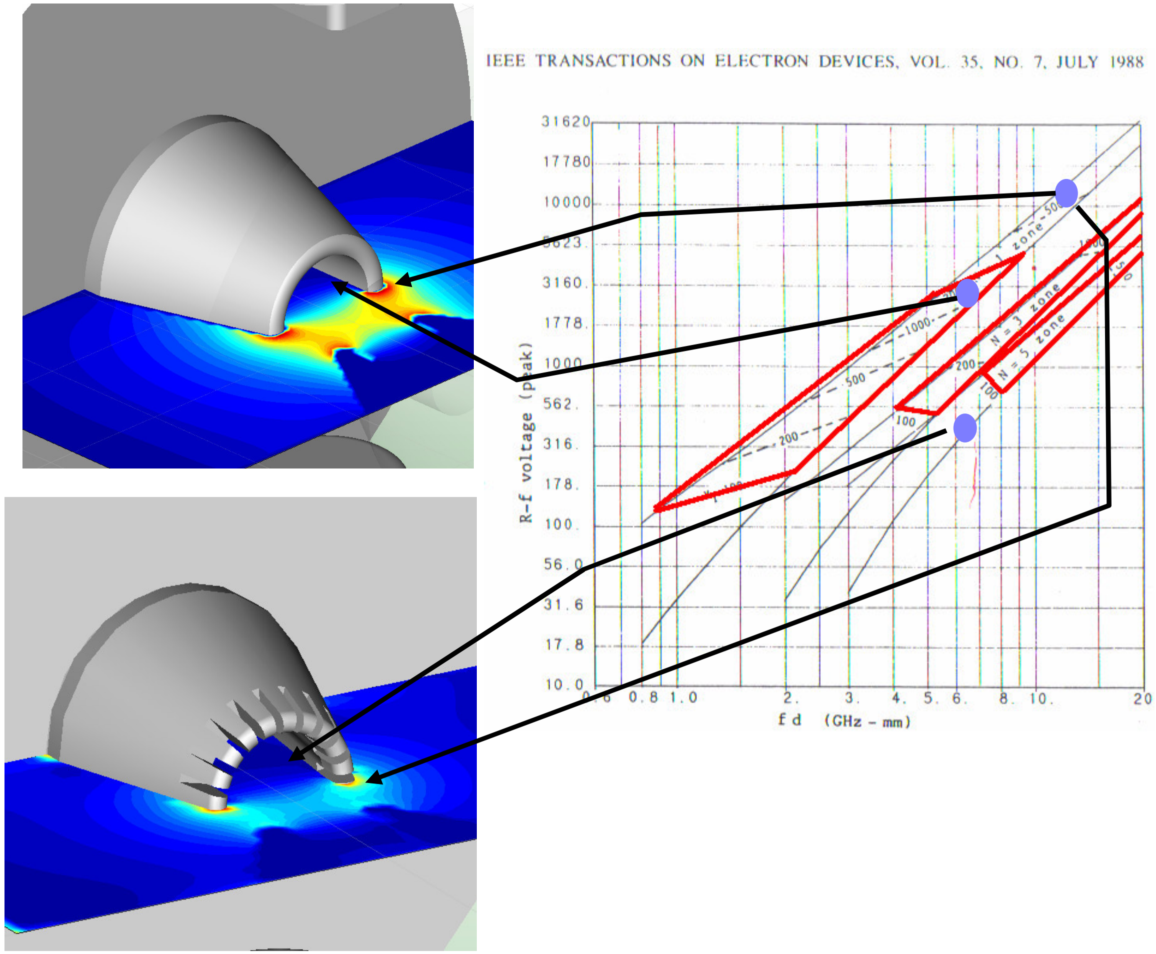


Crudely approximating to a parallel plate
Impact point separation 5mm
at 5 % efficiency → E_{peek} = 0.048 x 10^7

RF_{peek} = 2400,   fd = 6.5

1st order Multipactor




IEEE TRANSACTIONS ON ELECTRON DEVICES, VOL. 35, NO. 7, JULY 1988
31620
17780
10000
5623
3160
1778
1000
562
316
178
100
56.0
31.6
17.8
10.0
R-f voltage (peak)
0.6
0.8
1.0
2.
3.
4.
5.
6.
8.
10.
20
f d (GHz - mm)
N = 3 zone
N = 5 zone
1000
500
200
100

MICE Cavity

Research Program

(proposed)

Motivation for RF cavity program

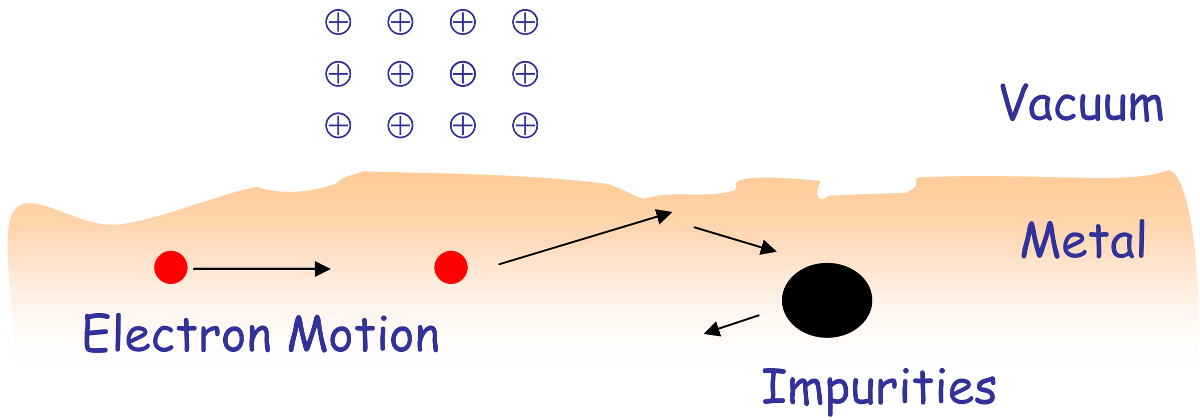
- Current accelerating gradients lower than maximums
- Poor reproducibility
- Current EP based techniques a *black art*.
- UK capacity building
- Complement USA program

Motivation

We propose to conduct a systematic review of each stage of manufacture.

Investigating the effect each stage has on the surface topology and chemical composition of the surfaces, and ultimately the effect on cavity performance.

Electric field ⇔ Magnetic field ⇔ Surface currents



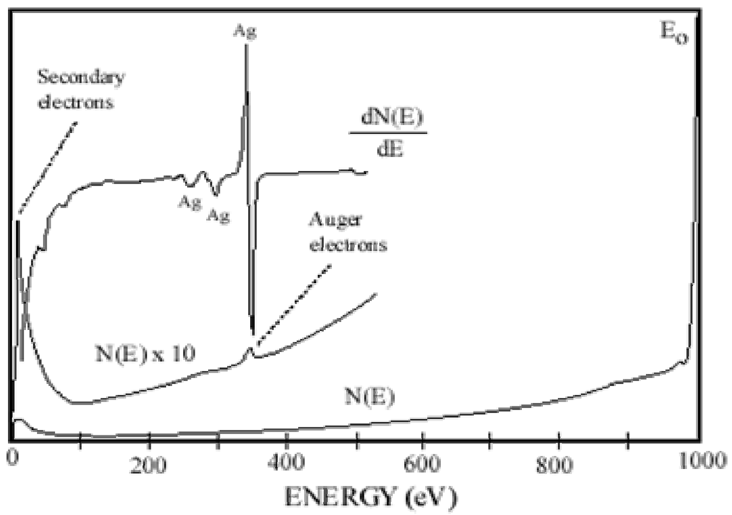
Scattering causes losses
➔ limits current
➔ limits RF
➔ limits acceleration

Surface Chemistry: Auger spectroscopy

Auger spectroscopy probes the chemistry of a surface by measuring the energy of electrons emitted from that surface when it is irradiated with electron of energy in the range 2–50 keV.

The incident electrons can remove a electron from a core state. This core state can be filled by an outer shell electron from the same atom, in which case the electron moves to a lower energy state.

Excess energy is released by ejecting a second outer shell electron from the atom.



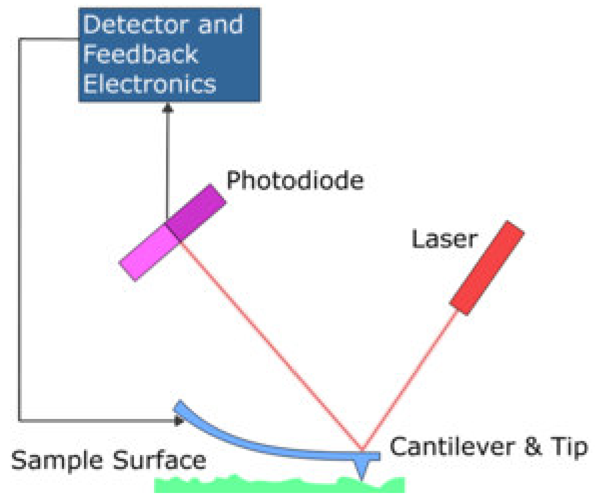
Surface Topology: Atomic Force Microscopy

Operate by measuring attractive or repulsive forces between a tip and sample.

• Contact mode, tip at the end of a cantilever touches the sample (force on sample <10^{-9} N). raster-scan drags the tip over the sample, measuring the vertical deflection of the cantilever, which indicates the local sample height. Thus, in contact mode the AFM measures hard-sphere repulsion forces between the tip and sample

• Noncontact mode, the AFM derives topographic images from measurements of attractive forces.

• AFMs can achieve a resolution of 10 pm



In situ measurements: AFM & Auger spectroscopy

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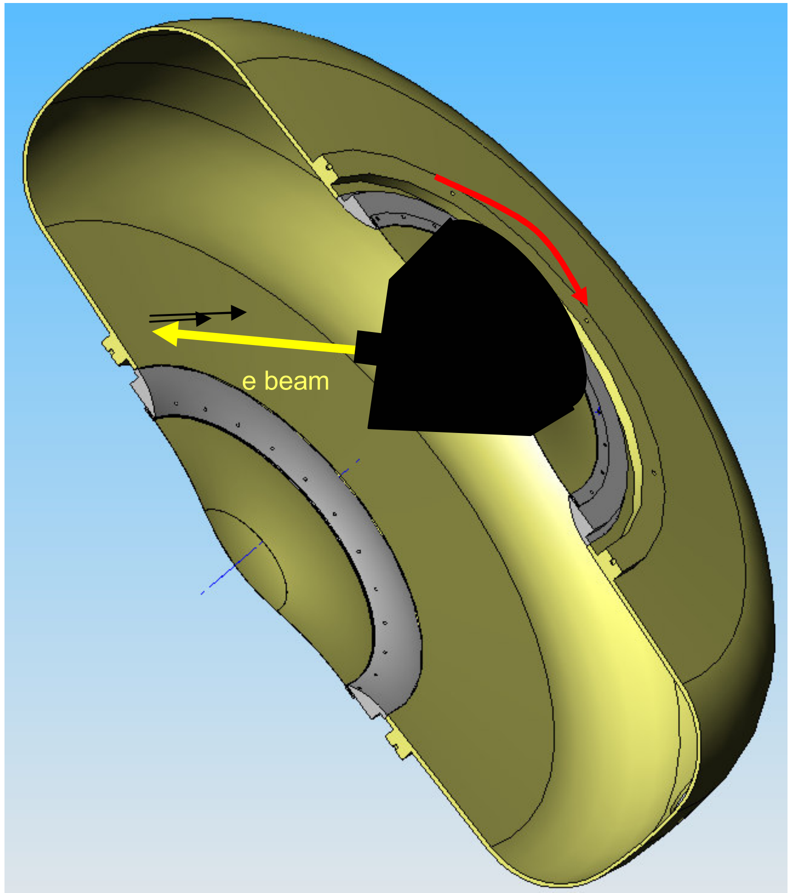

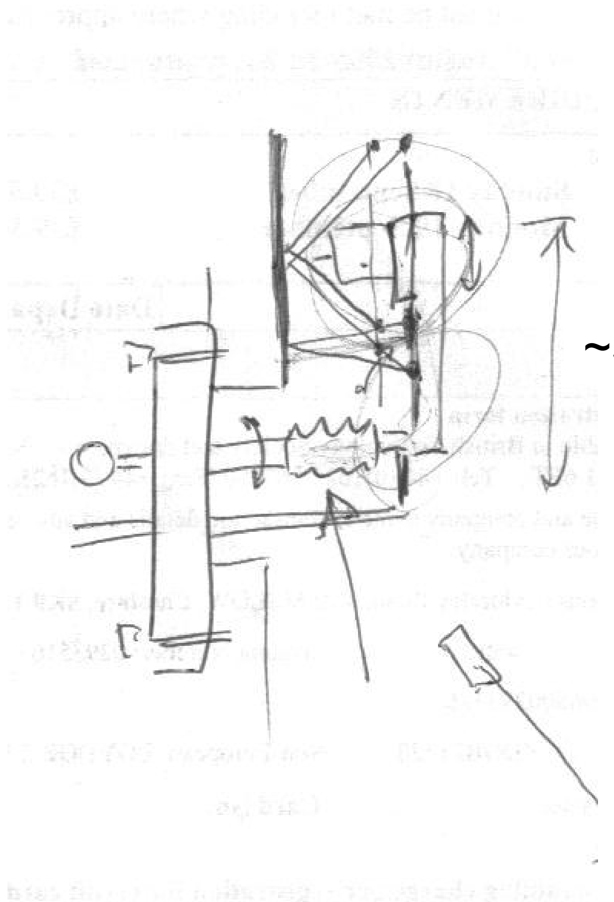

Cavity Forming

- Cavity Spinning
    - Auger on plate sample
    - AFM before/after spinning
- Weld
- Mechanical checks
    - leak test
    - weld inspect
    - eccentricity
    - frequency tuning
    - Auger & AFM

Surface Preparation

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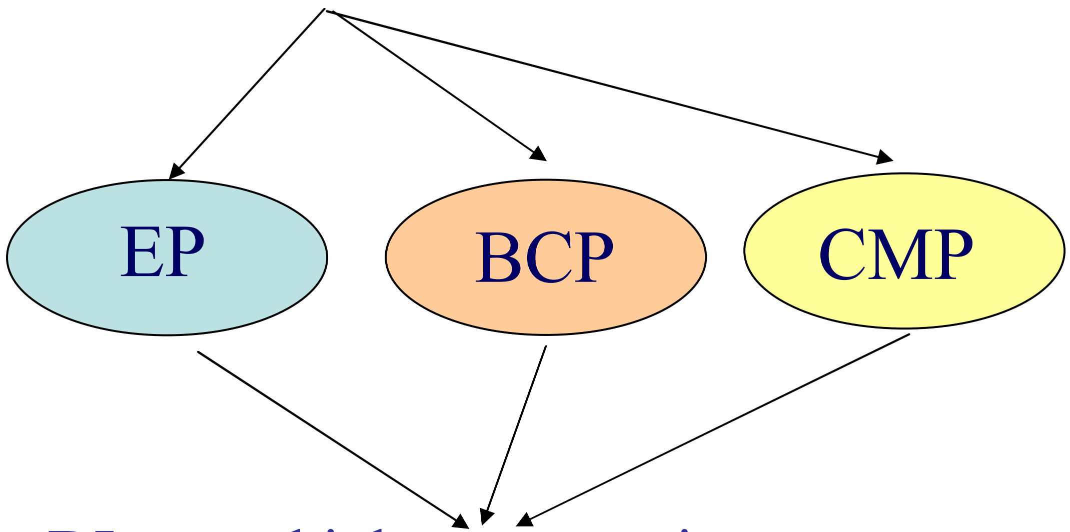
After each Step Auger & AFM

- Mechanical polish (graded sandpaper)
- Ultrasonic cleaning
- Deoxidation/etch,



Will use simple pill box cavity to evaluate different cleaning regimes. Use best identified to treat Cavity.

- DI water high-pressure rinse

Dependent upon resource will look to test at MTA / Daresbury

CMP

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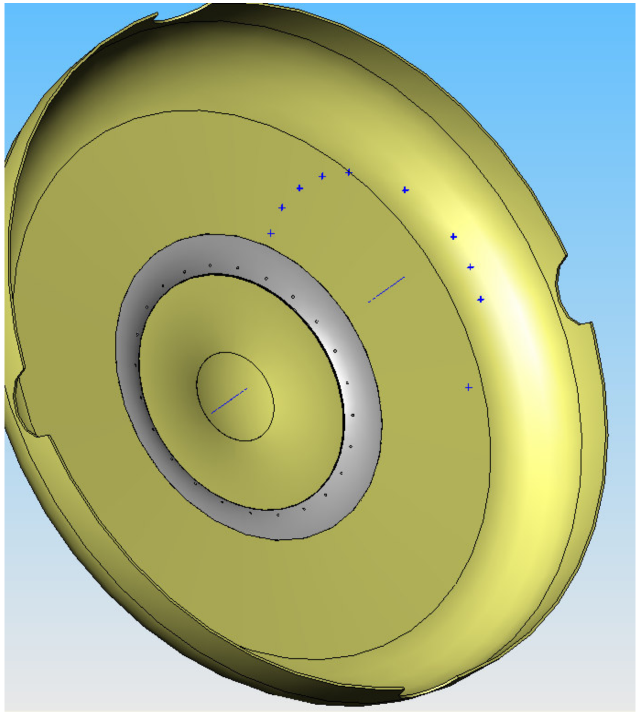
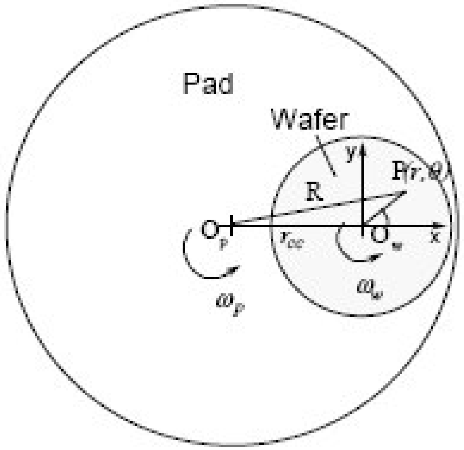
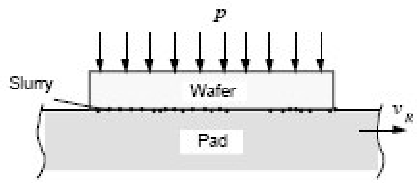


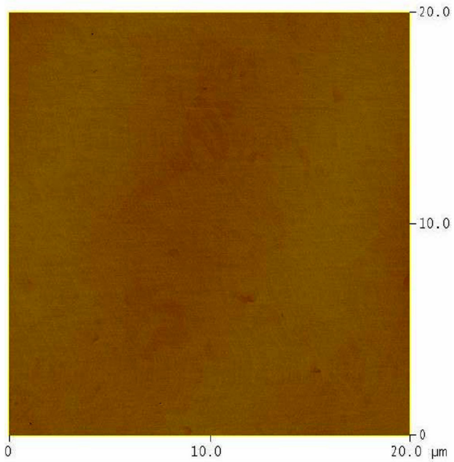




Al_2O_3 suspended in PH7 Solution.

CMP cheaper & less hazardous than EP.

Only useful on flat areas



Img. Rms (Rq)	0.581 nm
Img. Ra	0.464 nm
Img. Rmax	8.753 nm

(Rohm and Haas Electronic Materials)

Examine surface conductance numerically

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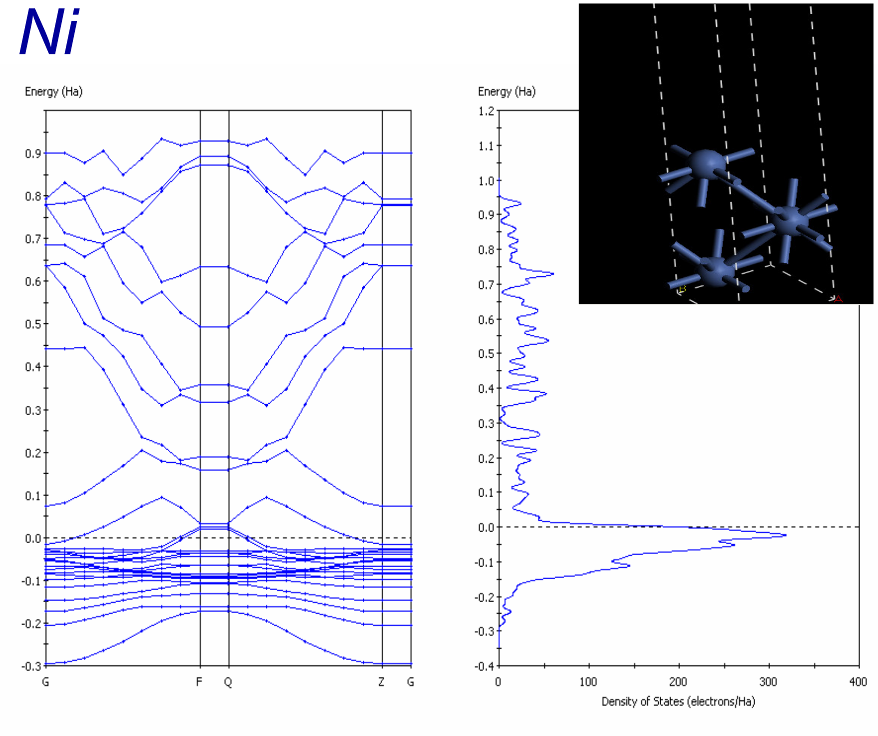
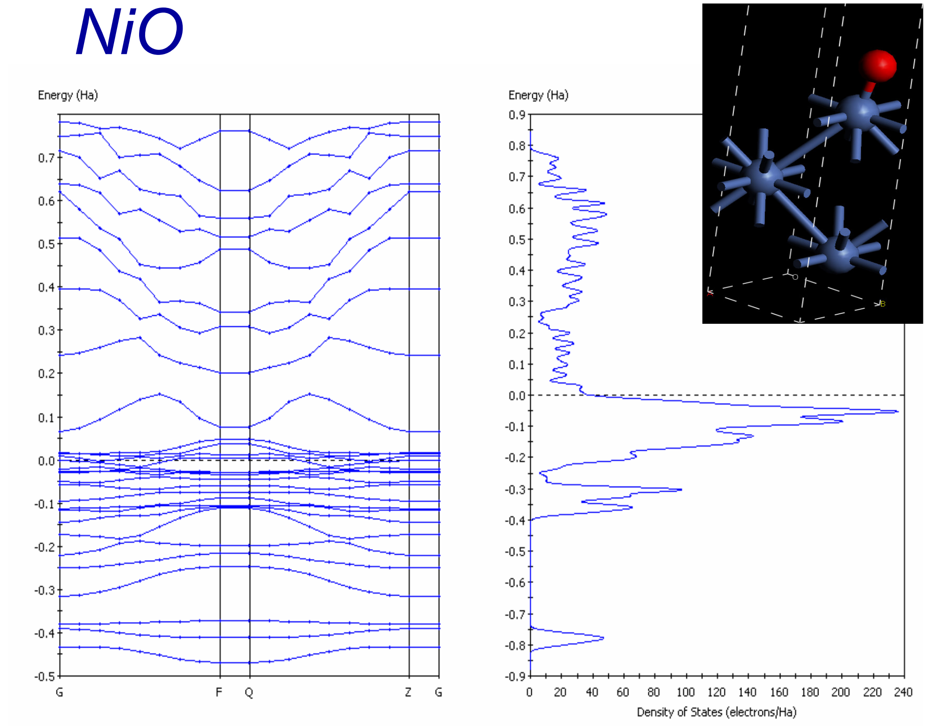
Ni



NiO



Use DFT codes to determine band structure/DOS

Use transport codes developed by C. Lambert (Lancaster) to determine conductance of surfaces. Use this to compare to experimental data.

As an aside we are starting to examine use to predict SEY

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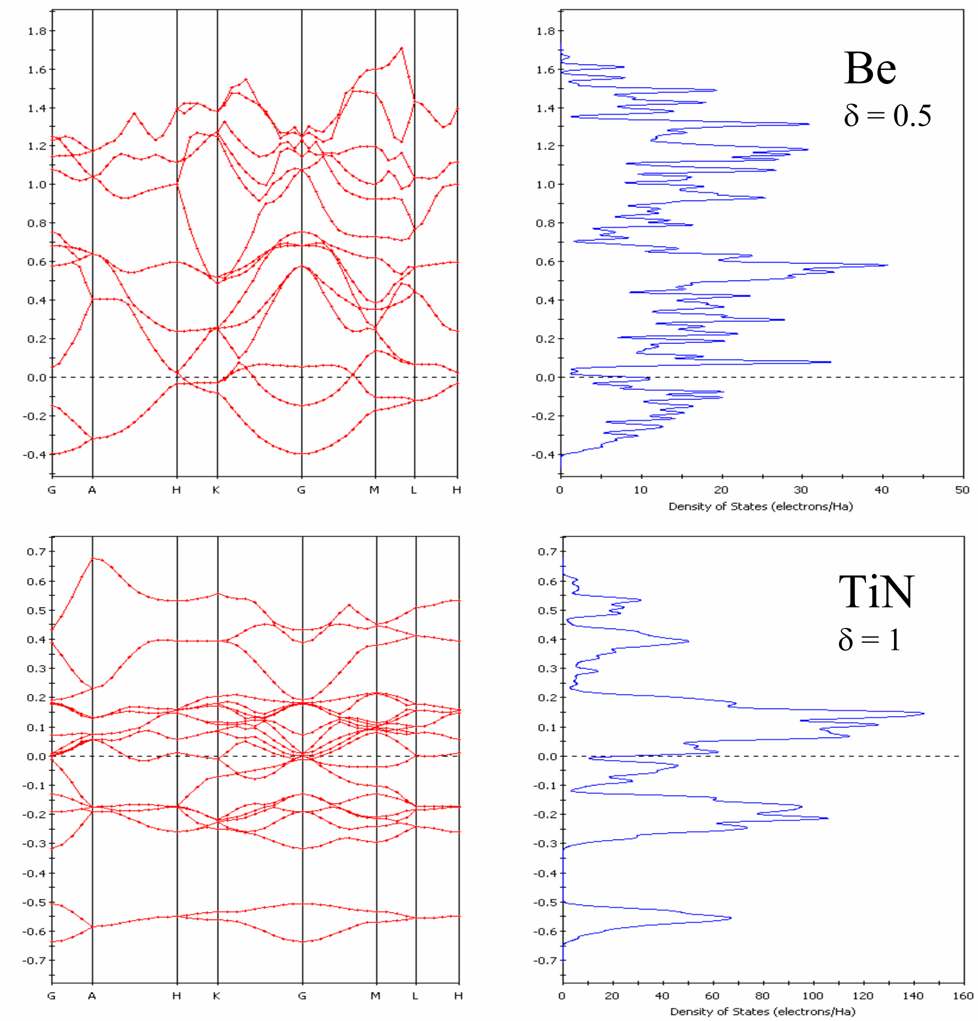
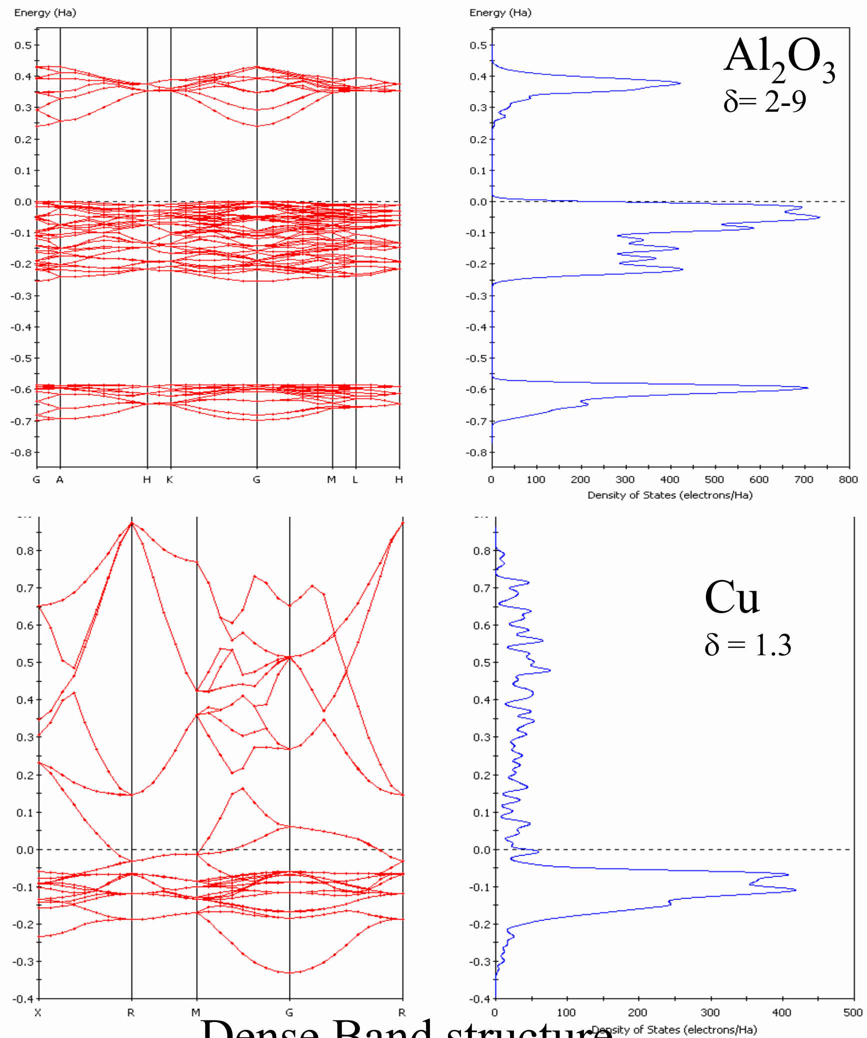
Low Yield



Dispersed Band structure
Relatively low Number of states

High Yield



Dense Band structure
Relatively Large Number of states

Conclusion

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• Use in situ Auger & AFM to determine how each step in the cavity manufacture effects surface topology and chemistry.

• Using test pill box for a variety of cleaning regimes.

• Use numerical study to determine how surface structure/chemistry effects transport and hence cavity performance, Compare with experimental results.

• Evaluating each for reproducibility & performance

• Complement US RF Cavity research programme

• Produce a cavity for MICE

• Infrastructure development will enable UK to participate more in accelerator research programmes