Multipacting

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Basic facts

- Multipacting is a Resonant Electron Discharge with Electron Multplication.
- To have multipacting you need the occurrence of two conditions

1) ***electron synchronization with the RF Field.***
2) ***Electron multiplication via Secondary electron reemission.***

electron synchronization with the RF Field.

- The time between two electron impacts on the cavity wall is ~ an integer number of half RF cycles.
- This condition force the starting condition for the electrons reemitted at each impact to be always the same

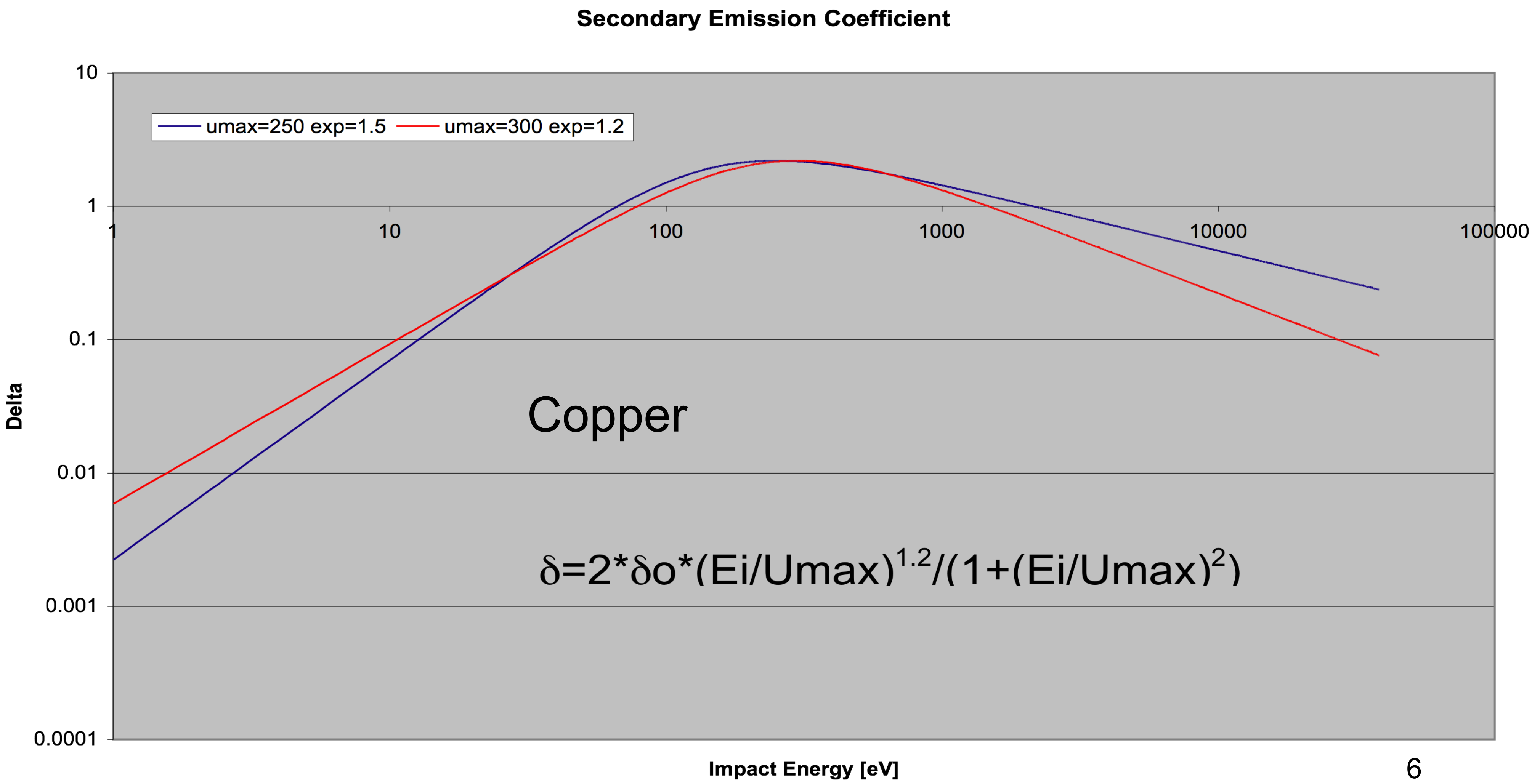
Electron multiplication via secondaries

- This condition set the mechanism for a runaway discharge depleting the energy stored in the cavity.
- The Secondary emission coefficient δ need to be >1. (even slightly)
- To fulfil this multiplication condition the impact energy U of the electrons is usually in the range 50~1500 eV (for metals)
- Secondary emitted electron Energy ~ 2eV

Unfortunately

- Good metallic conductors used for RF accelerating structures (Copper, Silver and Niobium) already have δ greather than ONE!
- Titanium, Stainless steel have δ lower than one
- The Secondary Emission Coefficient strongly depends on the surface conditions (oxidation increases δ, carbon layers decreases)

Secondary Emission Coefficient

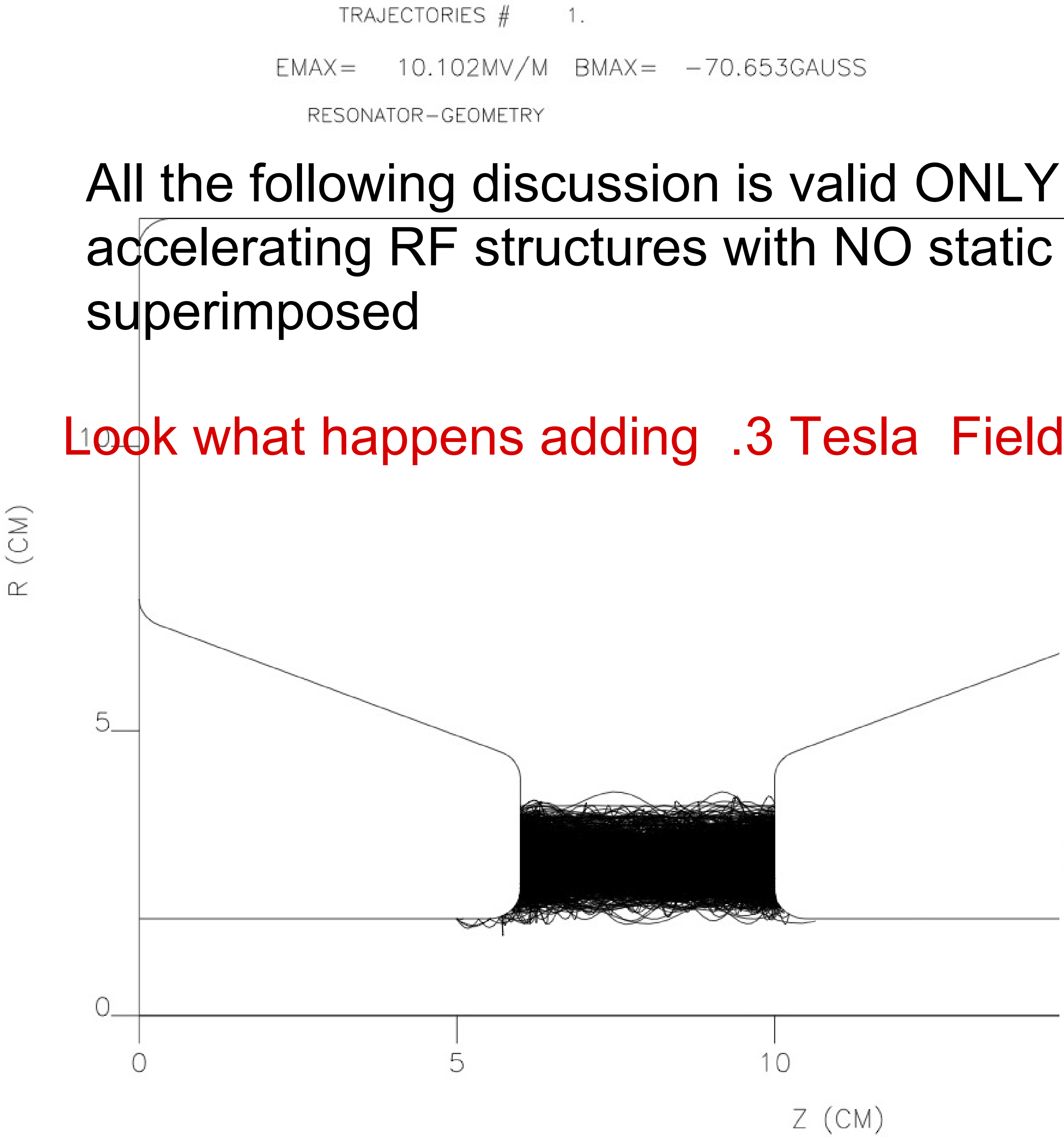


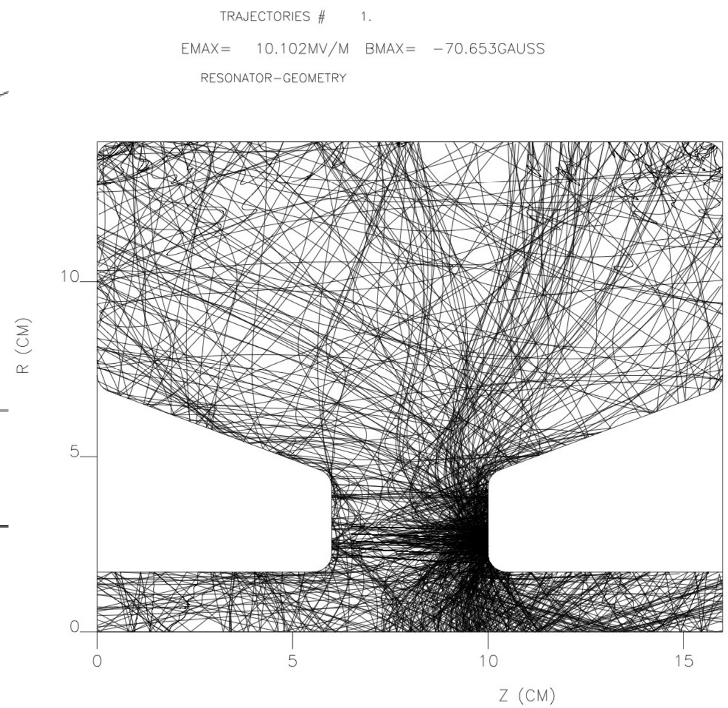
Two Point MP

- Occurs when electrons impacts cavity regions with fields of opposite sign
- Synchronization is obtained for time of flight ~ an integer number of Half RF cycles.
- Multiplication is achieved if the impact energy is in the range 50 to 1500 eV

All the following discussion is valid ONLY for axial-symmetric accelerating RF structures with NO static Magnetic Field superimposed

Look what happens adding .3 Tesla Field along Z



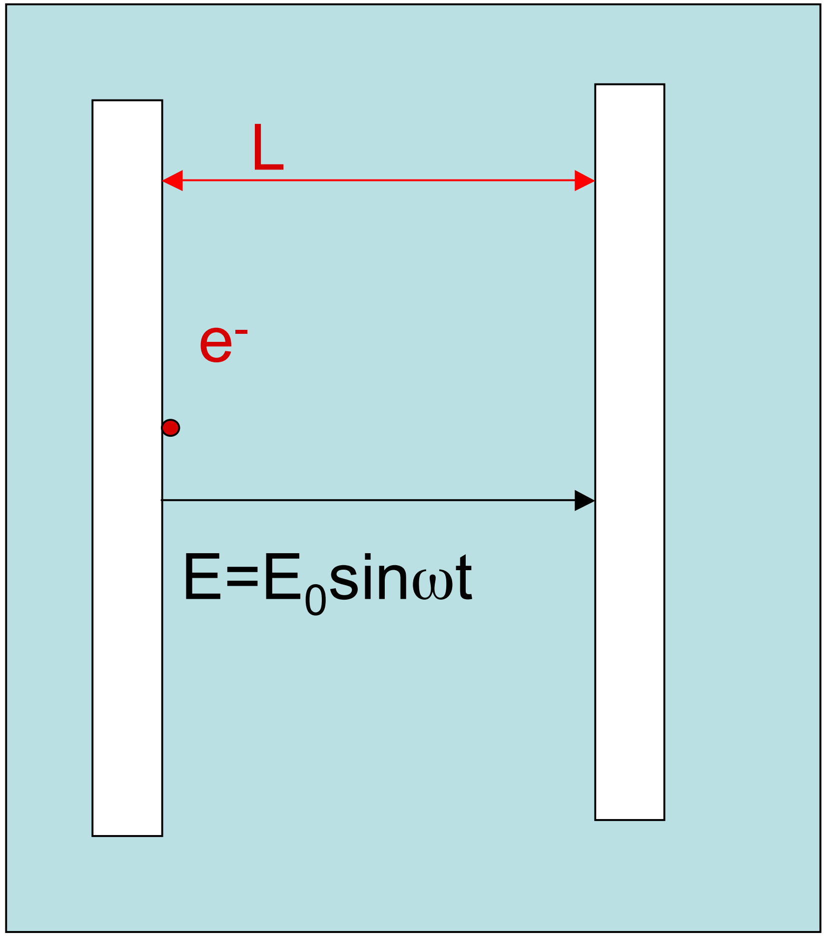


- A typical example is MP in short gap Cavities as:
- low beta cavities (heavy ions, buncher, catcher)
- semi lumped cavities like to one used in the old time storage rings as ADONE.
- Approximating (if possible) the gap with a parallel plate capacitor it is possible to analytically solve the motion equation and obtain a reasonable guess of the MP discharge field.

RF capacitor MP discharge

Starting condition

1) An electron start at rest on the capacitor plate
2) The electron strikes the opposite plate after an integer number of half RF Cycles.



- Solving the motion equations (C.Kittel,Berkley Physics Course Vol.1 pag102,McGraw-Hill) and imposing the starting condition we get the value for the gap voltage at the nth resonance

$$\mathbf{E \times L = V = 4 * \pi * m_o c^2 * (L/\lambda)^2 * 1/(2n-1)}$$

- And the corresponding value for he impact energy

$$\mathbf{U = 8 * m_o c^2 * (L/\lambda)^2 * 1/(2n-1)^2}$$

One Point MP

- Occurs when electrons impacts cavity allways in the same place
- Synchronization is obtained for time of flight ~ an integer number of RF periods.
- Multiplication is again achieved if the impact energy is in the range 50 to 1500 eV

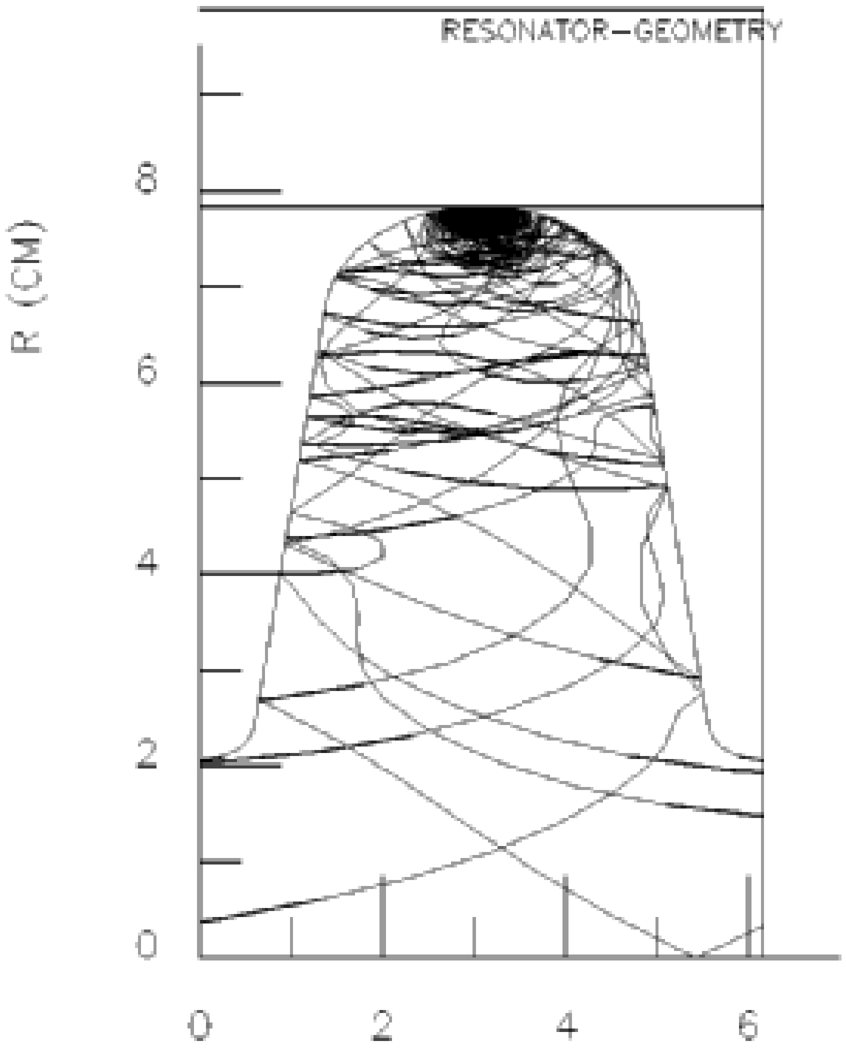
- In Axial-Symmetric accelerating TM_{01} cavities this resonant discharge happens at the equatorial region where the magnetic field is high (and the electric field is quite low).
- The secondary electrons are trapped by the strong magnetic field in a Cyclotron-like orbit. Landing fairly in the takeoff place after an integral number of RF Cycles.
- The energy gain due to the electric field is quite low, (the electric field in a pure Pill_Box accelerating cavity is ZERO at the equator.) and gives the rigth amount of energy 50-1500eV leading to multiplication via secondary emission.

Although for this particular kind of MP discharge no simplified analytical model is possible, nevertheless a POOR MAN estimation is possible for the kinematic condition.

- *Let consider the motion of the electron in a sinusoidal RF magnetic field .*
- *the trajectories are roughly cyclotron orbits and the syncronus motion condition is given by the approximated expression:*

$$f/N = \frac{eB_0}{2\pi m_0}$$

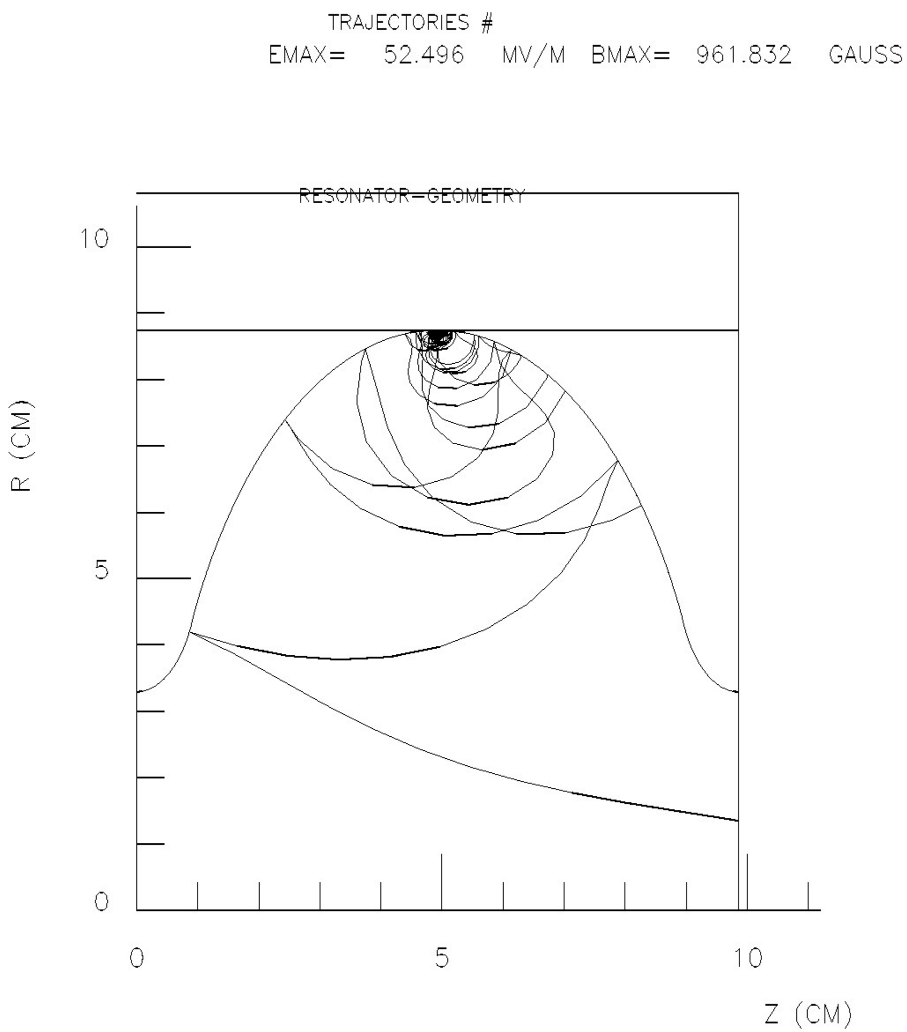
This gives us 28 mT per GHz for the Highest level using a first order correction for the effective field seen by the flying electron



Last, at the cavity equator is still possible a 2 point discharge with the electrons flying across the cavity mid_plane

$$f/(2N-1) = \frac{eB_0}{2\pi m_0}$$

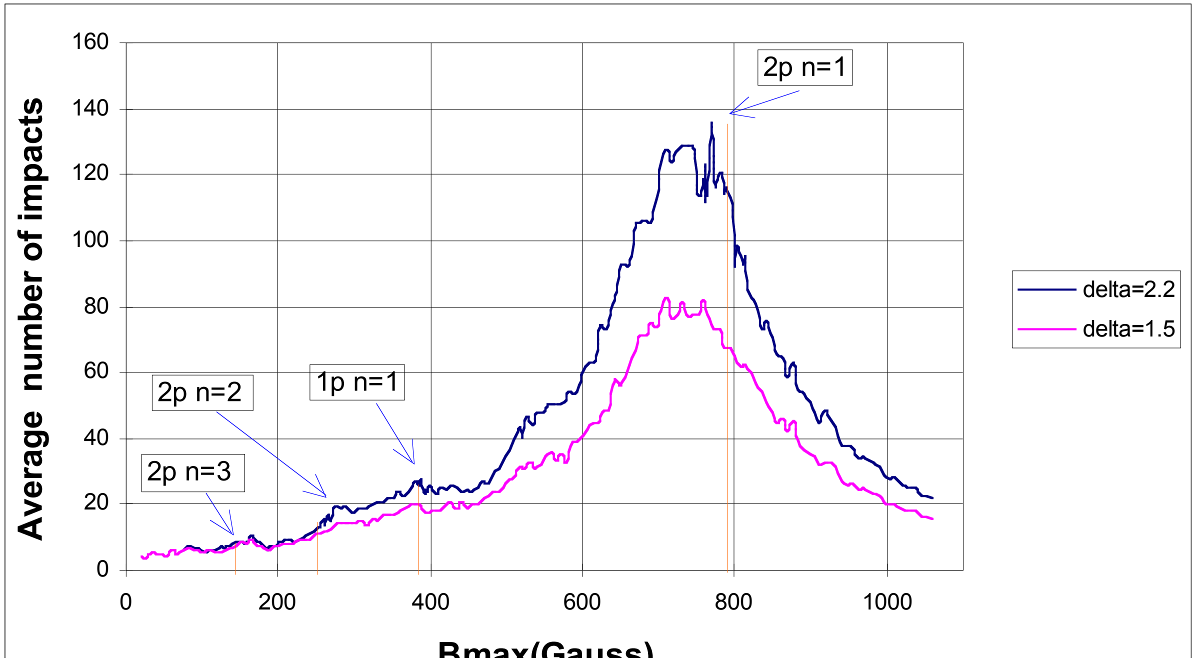
- **This gives us 56 mT per GHz for the Highest level using the usual first order correction for the effective field seen by the flying electron**



- For all the MP discharge at the equator the Poor Man Rules give only an Hint about the field levels to loog at for MP related problems.
- The full detail can only be found numerically by solving the motion equation in the real geometry, using a detailed and realistic implementation of the reemission process.
- Any way computer simulations and experimental measurement have shown the reliability of the POOR MAN estimation for MP barriers.

Electron Yield in a 1.4Ghz cavity

(computer simulation)



B field (Gauss)

From synchronization condition

Level order	MP 1pt	MP 2pt
1	392	784
2	196	261
3	131	157
4	98	112

How to avoid MP discharges?

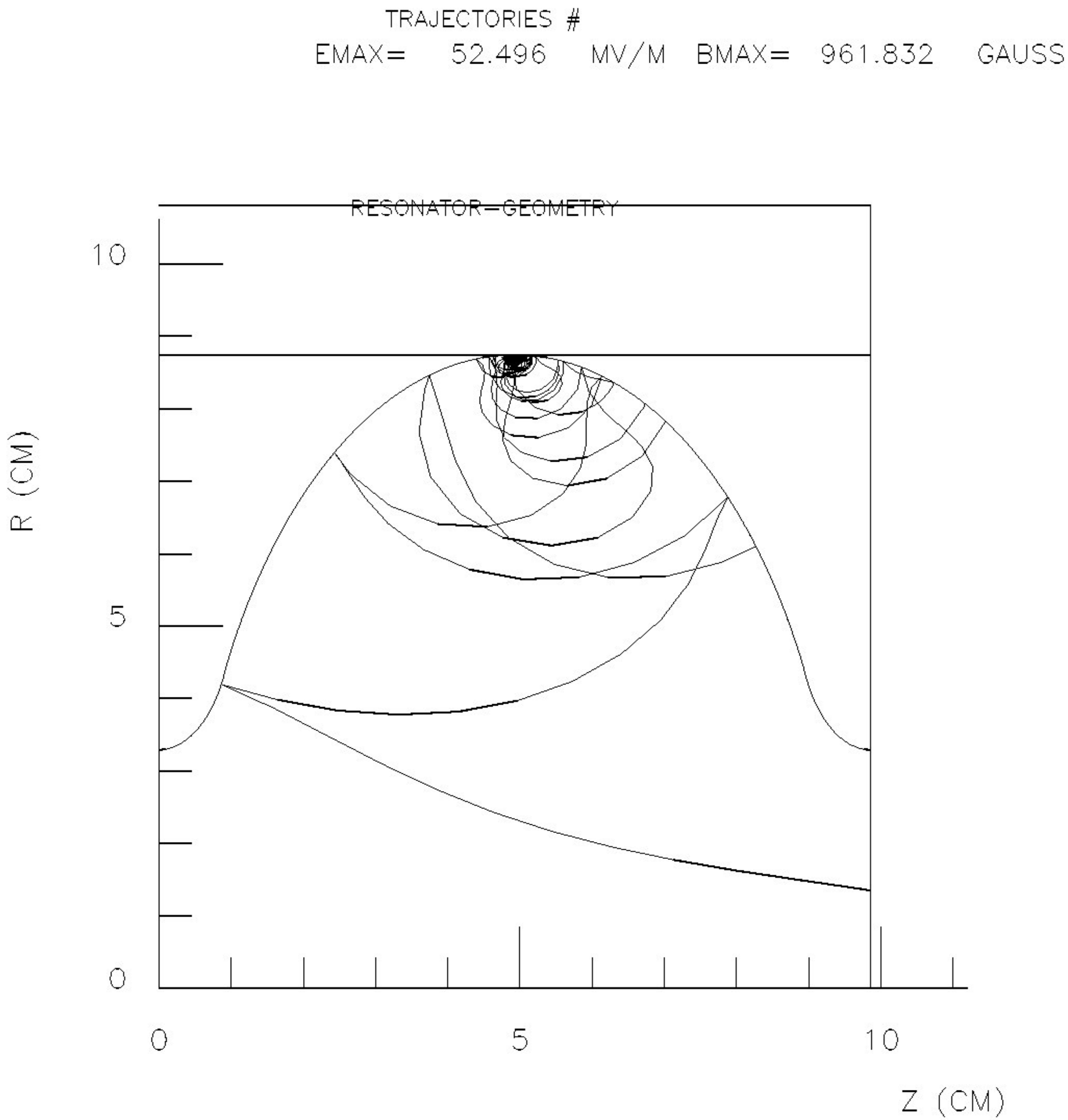
Reduce Electron multiplication

- **Use materials with a low secondary yield to avoid electron multiplication**.

  Unfortunately good conductors and superconductors have Secondary Yelds > 1
- **Use thin coating (*d*<< of the skin depth) of low secondary Yield materials in the critical regions of the accelerating structures.**

Avoid spatial focusing of the electrons in critical regions.

- This was done in SRF cavities choosing the rounded shape in the equator region in the late seventies (see IEEE Trans on Magnetics, Mag-15.pag.25 January 1979)
- With this trick we always have a force (due to the E_z component of the field on the cavity surface) seeping the reemitted electrons away from the emission point.
- Only at te equator the E_z is ZERO, as the E_r component and (if you are lucky) the electrons loose the syncronization with the RF field and the discharge stop.


TRAJECTORIES #
EMAX= 52.496 MV/M BMAX= 961.832 GAUSS
RESONATOR=GEOMETRY
R (CM)
Z (CM)
0
5
10
0
5
10