11-Dec-2018

What's Shakin' in RF?

RF Group

- Dionis Kumbaro
  - Electron Guns
  - Linac RF Stations
- Robert Lindvall
  - BPM electronics
  - LLRF
  - RF Signal Diagnostics
- David McGinnis
  - Mode 0 damper
- Aleksandar Mitrovic
  - Ring Transmitters
  - Linac Drive Line
- David Olsson
  - Chopper Systems
  - B BB Feedback R1 & R3
  - Linac Structures & Sleds

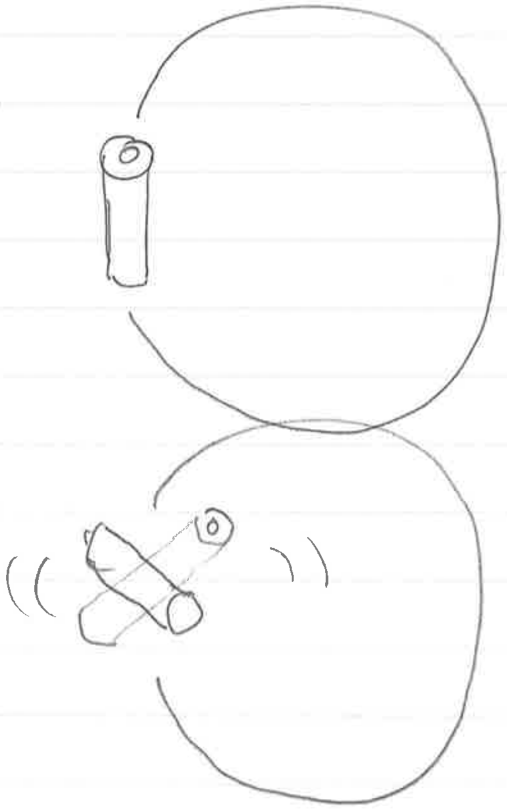
RF puts the "A" in Accelerator

Faraday's Law

$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

or

$$q\oint_c \vec{E}\cdot d\vec{l} = -q\frac{\partial}{\partial t}\int_s \vec{B}\cdot d\vec{S}$$



Bad

Good

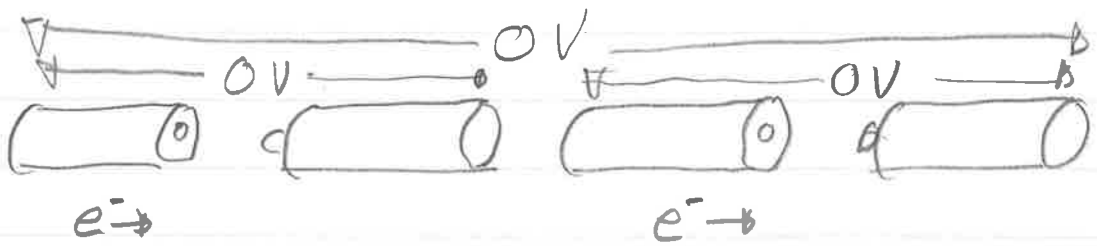
How to accelerate?

Max 1V Energy = 3 GeV

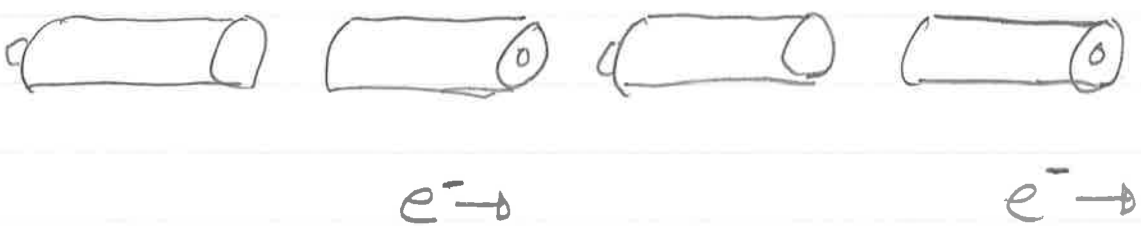
Max Electric field in air = 3 MV/m

Would need a kilometer of stand off just to keep Max 1V from sparking!!

Consider battery example



Now flip the batteries.



And so on!

We don't really use batteries ...

(you would need 100,000 km 1.5 V batteries to equal Max IV energy)

We use RF energy!

RF means Radio Frequency

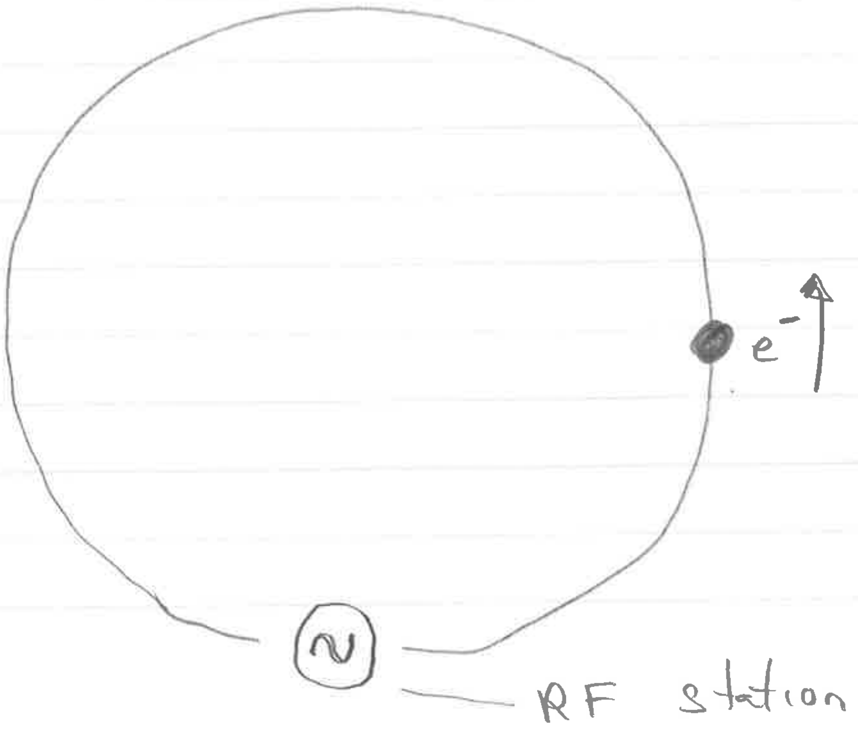
or

Time changing electromagnetic fields

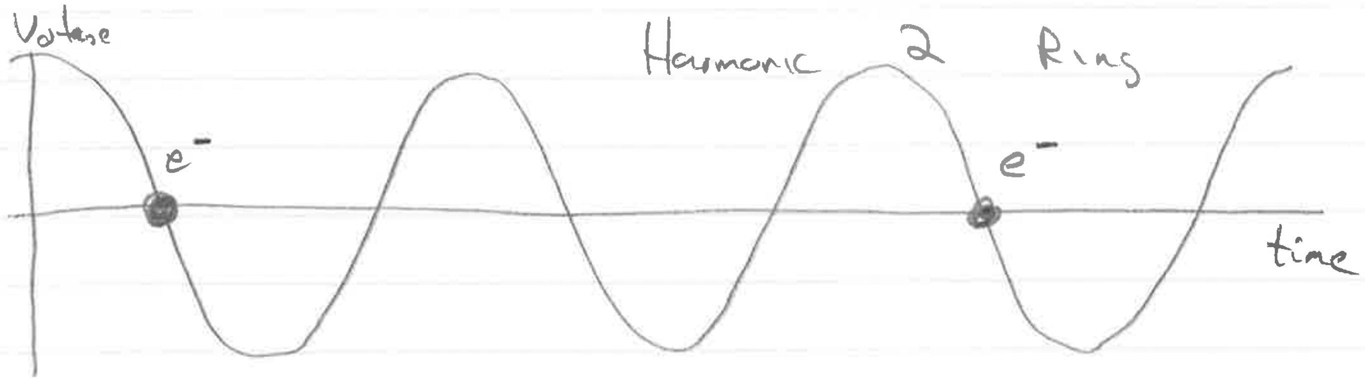
at

Radio Frequencies (1 MHz - 100 GHz)

Consider our battery analogy



Look at the voltage at the RF station and forget about synchrotron radiation for a moment.



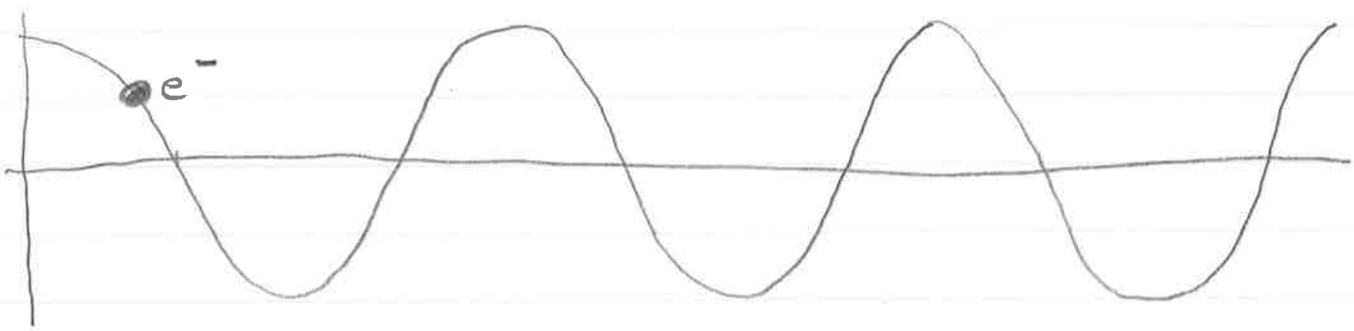
If the revolution period is an integer multiple of the RF period, the beam stays nicely put.

Max IV R3 $\quad T_{Rev} = 176\, T_{RF}$

$$T_{RF} = 10\ nS$$

$$f_{RF} = 100\ MHz \quad \text{(FM Radio!)}$$

Now look at the case if an electron is a little early



If the electron is a little early wrt to the RF, it will get an positive energy kick.

At Max IV, the electron energy is so high that the electrons are very relativistic

$$m_0 c^2 = 511 \text{ keV}$$

$$\gamma m_0 c^2 = 3{,}000{,}000 \text{ keV}$$

$$\gamma = 5870 \, !$$

$$v = 99.999999 \, c$$

So giving electrons extra energy can't make them go faster.

Instead the electrons get more mass.

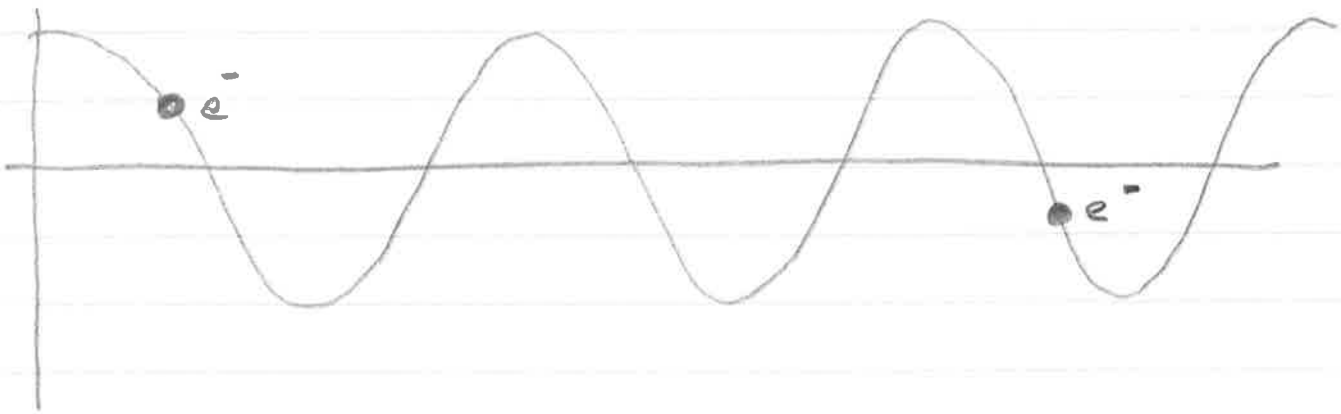
* 1 gram of electrons at rest have a mass of almost 6 kg in R3.

* At 200 mA, the mass of all the electrons in Max IV is 60 pico grams

In R3, we can deliver 1 MV/turn

so we can change the mass of the electron by 0.03 % each turn

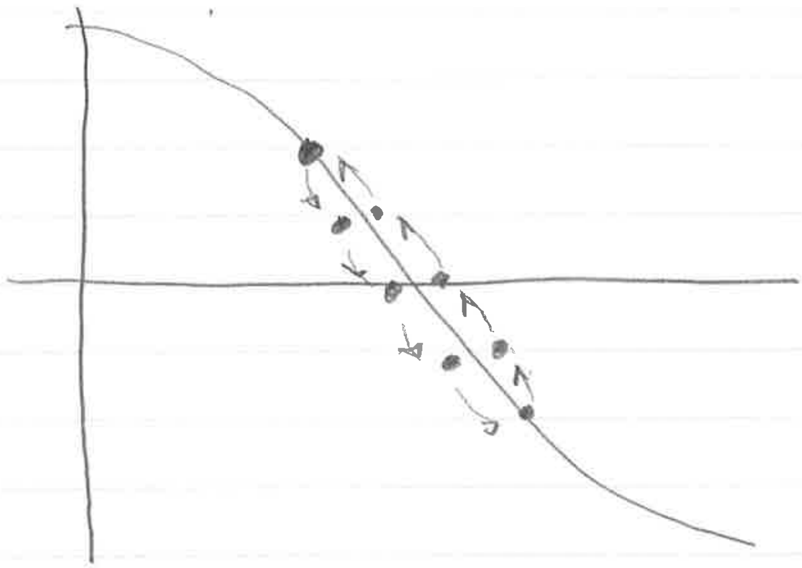
Just like a gravitationly gifted kid on a merry-go-round, the more massive electrons will ride on the out side of the machine and since the speeds are the same, the more massive electron will take a longer time to go around and come later to the RF station



Now it has arrived too late and will get a negative energy kick

so it will become less massive and arrive earlier the next time around.

The electron "surfs" on the RF wave



- The side of the sine-wave where the electrons surf is called the "RF Bucket"

The rate at which the electrons surf around the bucket is called the "synchrotron frequency"

Now what is needed is a "wave pool" for the electrons to surf and a "wave machine" to make the waves for the "pool".

Problem! Our current transmitters can only provide 2500 Volts per transmitter and with 5 transmitters we can only develop 12 kV total!

But the transmitters can source 50 Amps of RF current each.

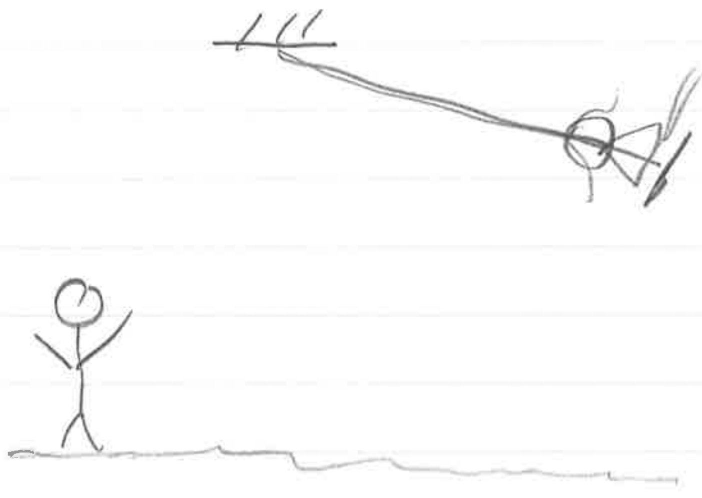
We only have 200-500 mA of beam circulating in the machine.

We need to build an RF transformer!

Consider a swing

The dad can only push the swing by the length of his arms.

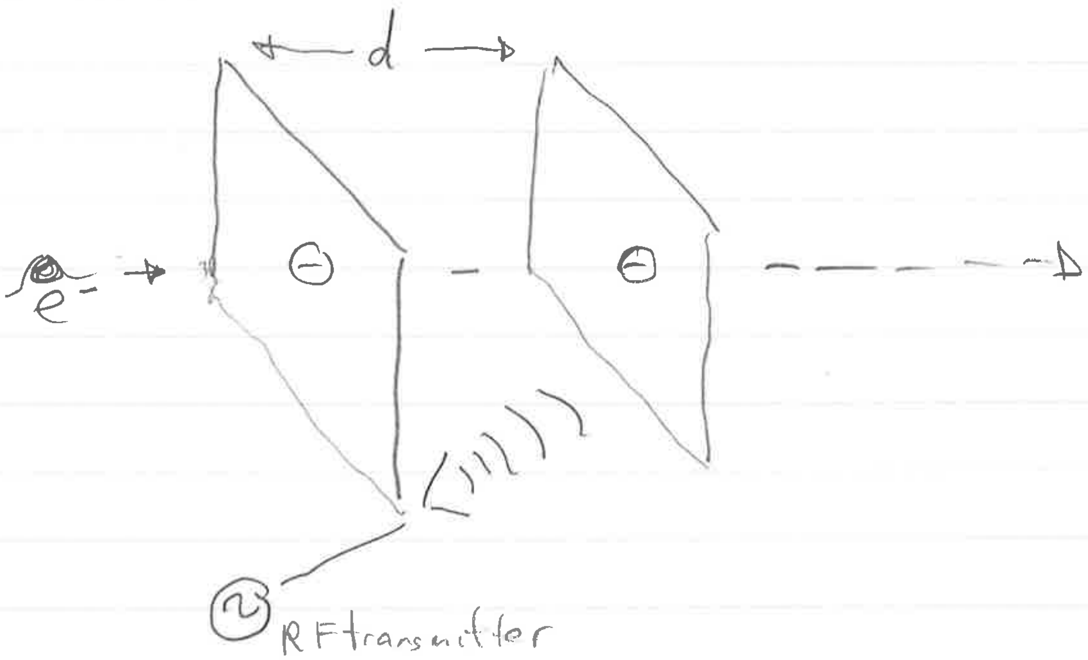
But if he pushes the swing synchronous to the period of the swing, he can make the swing go higher.



As long as there is not to much friction in the swing set

(or Jr. does not drag her feet a.k.a. synchrotron radiation).

Consider two parellel plates with a hole for the beam



The wave from the RF transmitter will ⊛ bounce off the right plate, ⊛ travel to the left plate,

⊗ bounce off the left plate and travel to the right plate

If $$f_{RF} = \frac{v_{wave}}{2d}$$

then the reflected waves will keep adding up with the transmitted wave.

The number of bounces the wave will make on its own before dying out is called the Q of the cavity →

how "shiny" the cavity is.

Building Blocks of an RF System

① A well defined RF wave maker LLRF

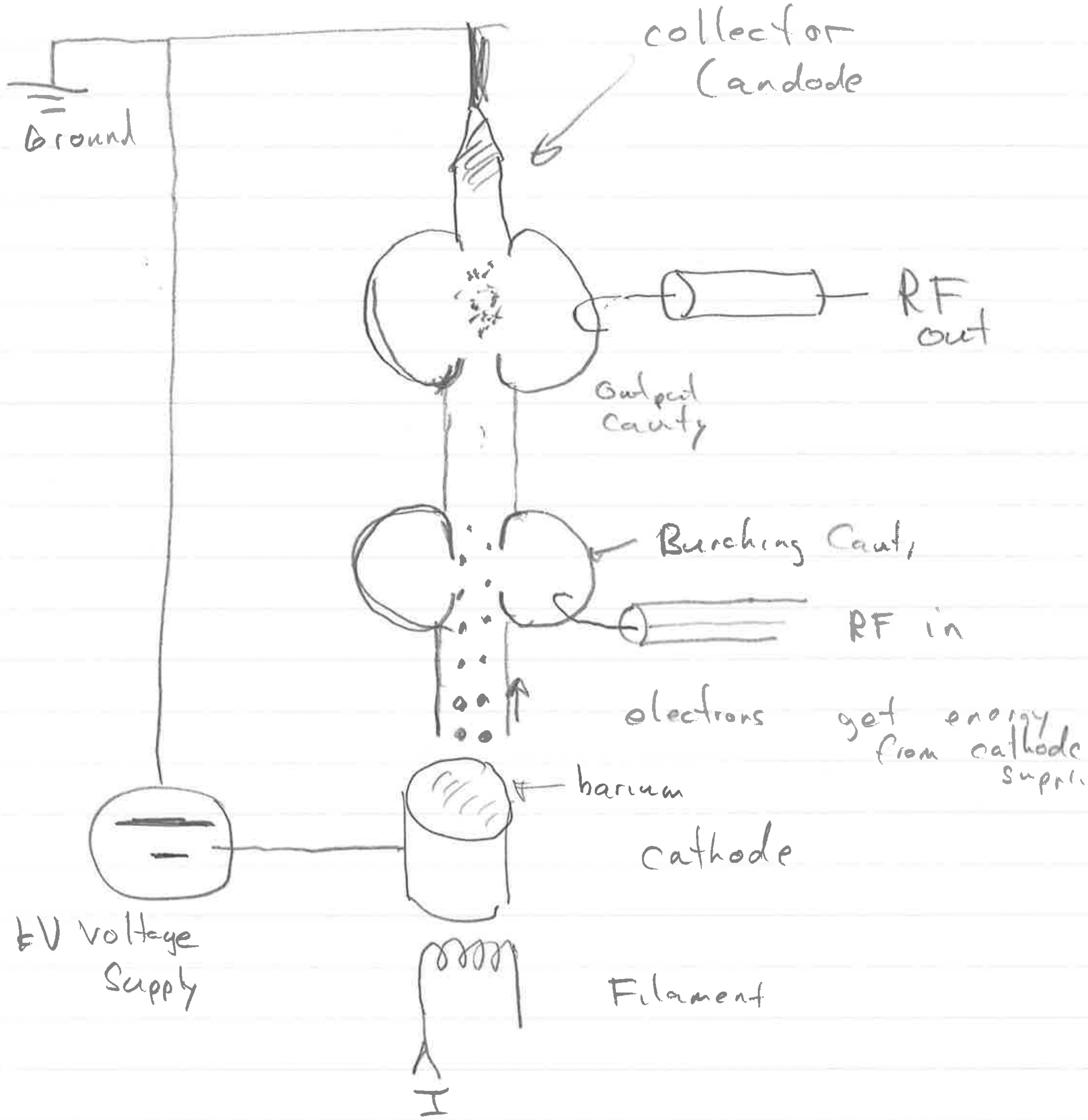
② An amplifier for increasing the energy of the wave

③ A distribution system to get the RF wave into the tunnel

④ A cavity to transform the voltage to the beam

RF Amplifier – Klystron.

Invented in 1936 by
Varian bröderna



1) Filament heats up the cathode
2) Electrons boil off the cathode
3) Electrons are accelerated towards the anode

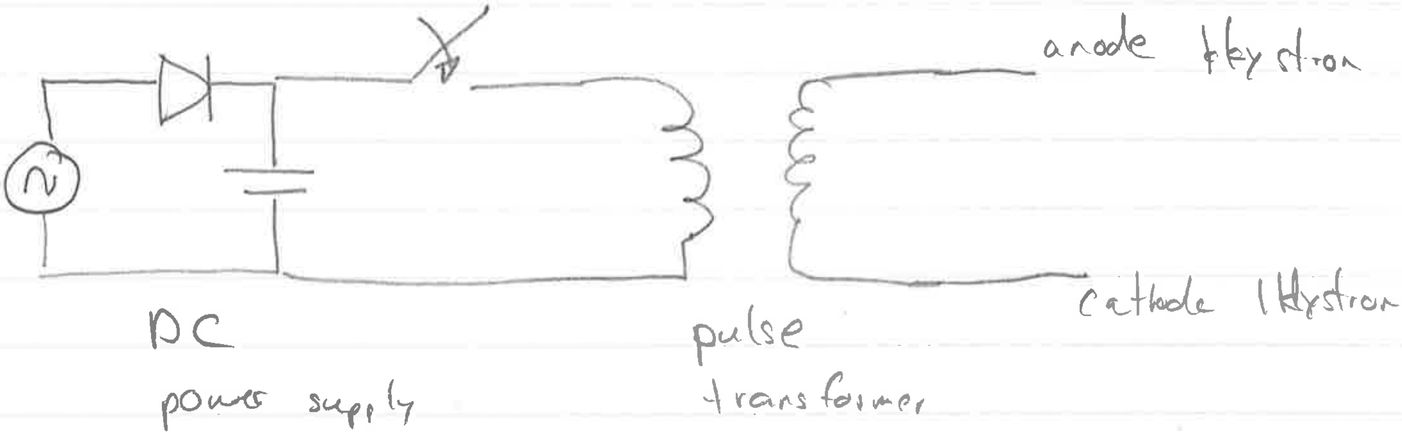
4) Electrons get velocity modulated in the bunching cavity. Some electrons are sped up, some are slowed down.

5) The fast electrons catch up to the slow electrons and the beam bunches up in the out put cavity.

6) The bunched electrons leave an electro magnetic wake in the out put cavity.

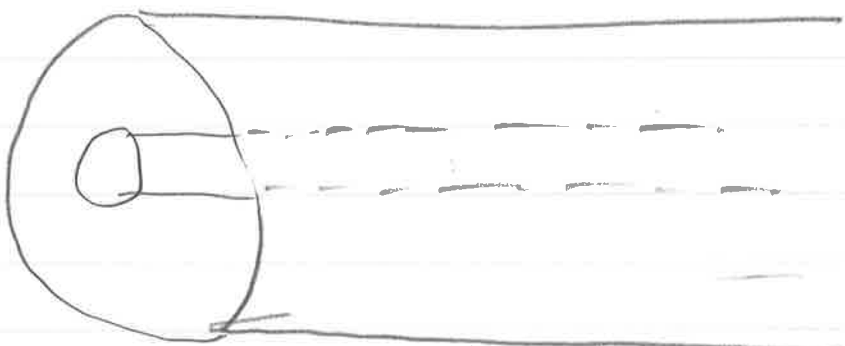
Max IV klystrons
37 MW
5 us Pulse
2 Hz Rep rate
10×10^{-6} Duty factor
370 Watts average power
Pulse Compressor 5 x
+
50% efficient

Power convertor

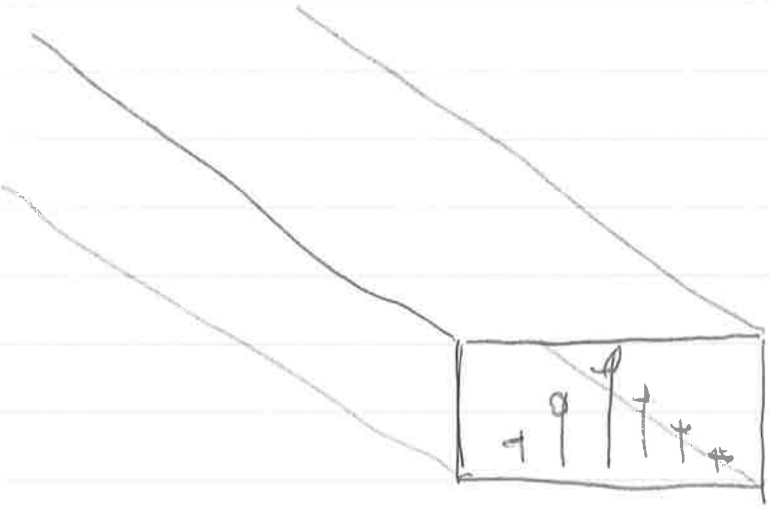


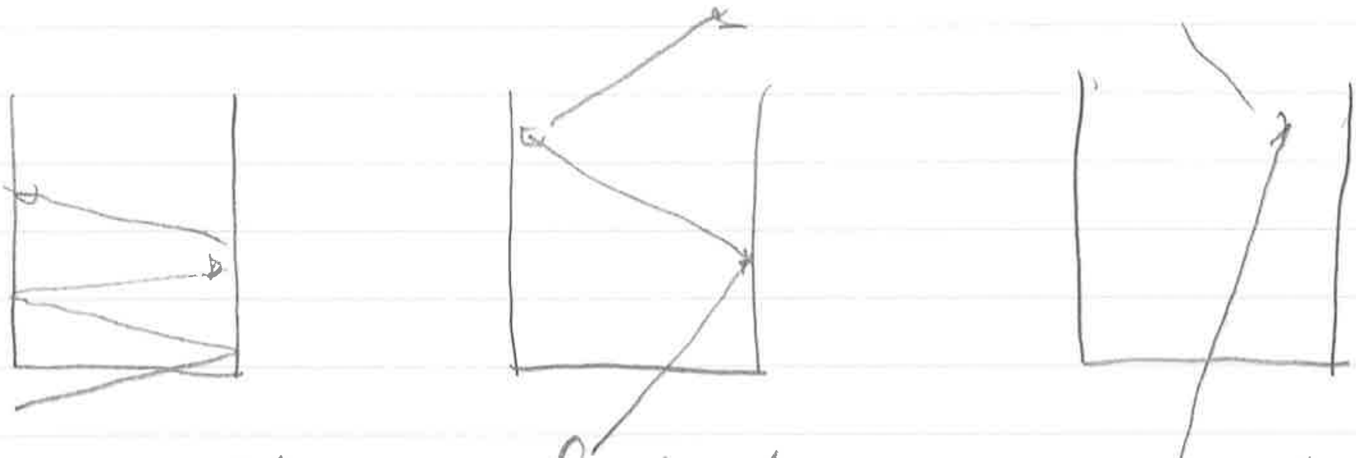
Waveguides

Twisted pair:
too low voltage (arcing)
too high current resistive loss



Used in R3.
Okay at freq < 1GHz
& voltages ≲ 10kV





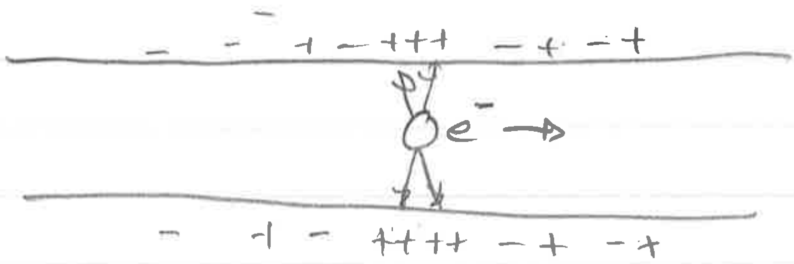
near cutoff

Perpendicular

High above cutoff

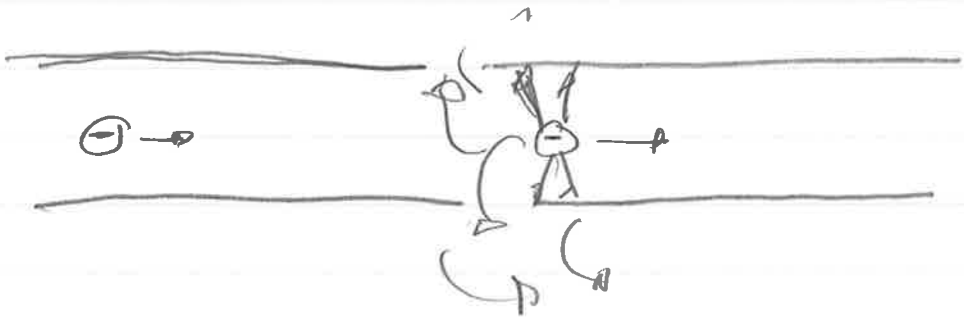
Beam Stability

Charge particles leave an electromagnetic wake as the travel through space



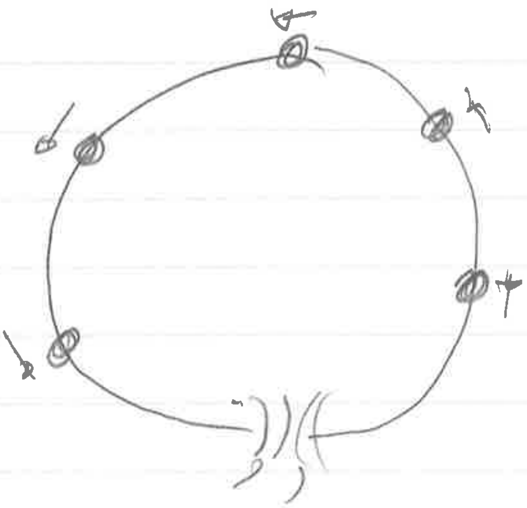
This wake affects the free charge in the beam pipe

When the wake passes over a discontinuty, large wakefields can occur



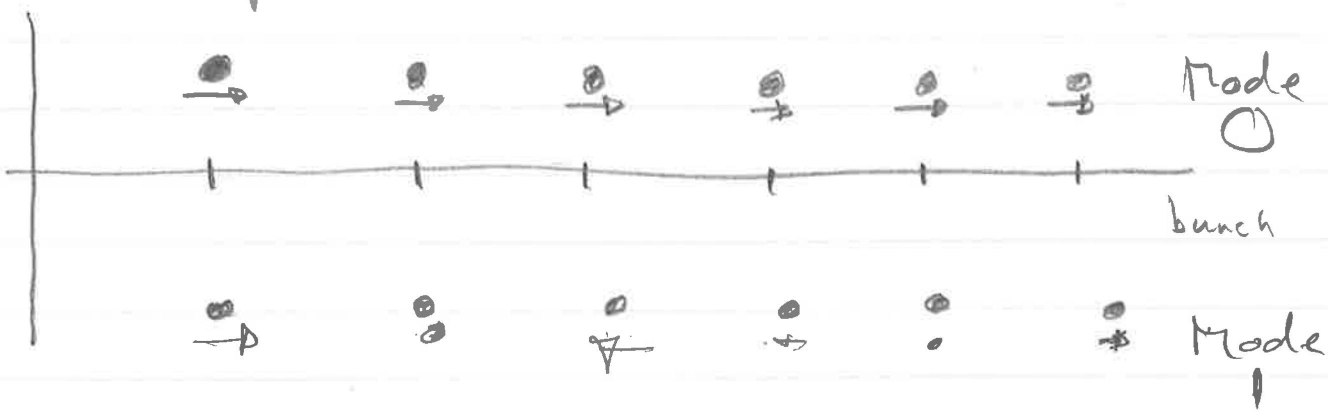
These wakes can influence electrons traveling behind, which in turn influences more electrons behind.

When you have a ring, then resonances can build up



The resonances can then start moving the beam. If the resonance buildup gets large enough, the beam gets torn apart.

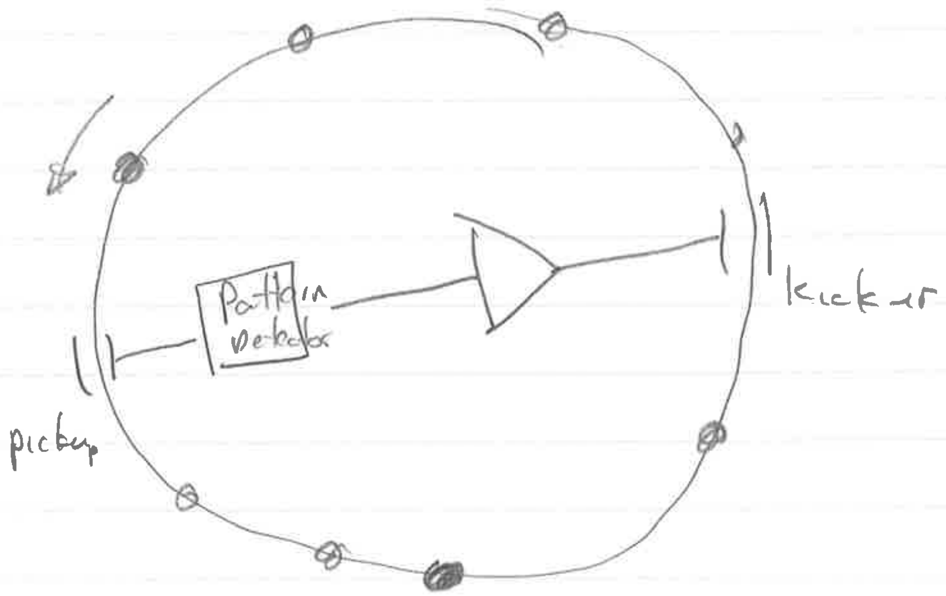
Since the beam is in a ring, the beam motion must be periodic



Because of Nyquist sampling there are $\frac{N}{2}$ modes in the beam

88 for R3

To fix this you need a negative wave maker.



Mode Zero Damper.

Wakes are caused by fundamental mode in the cavities