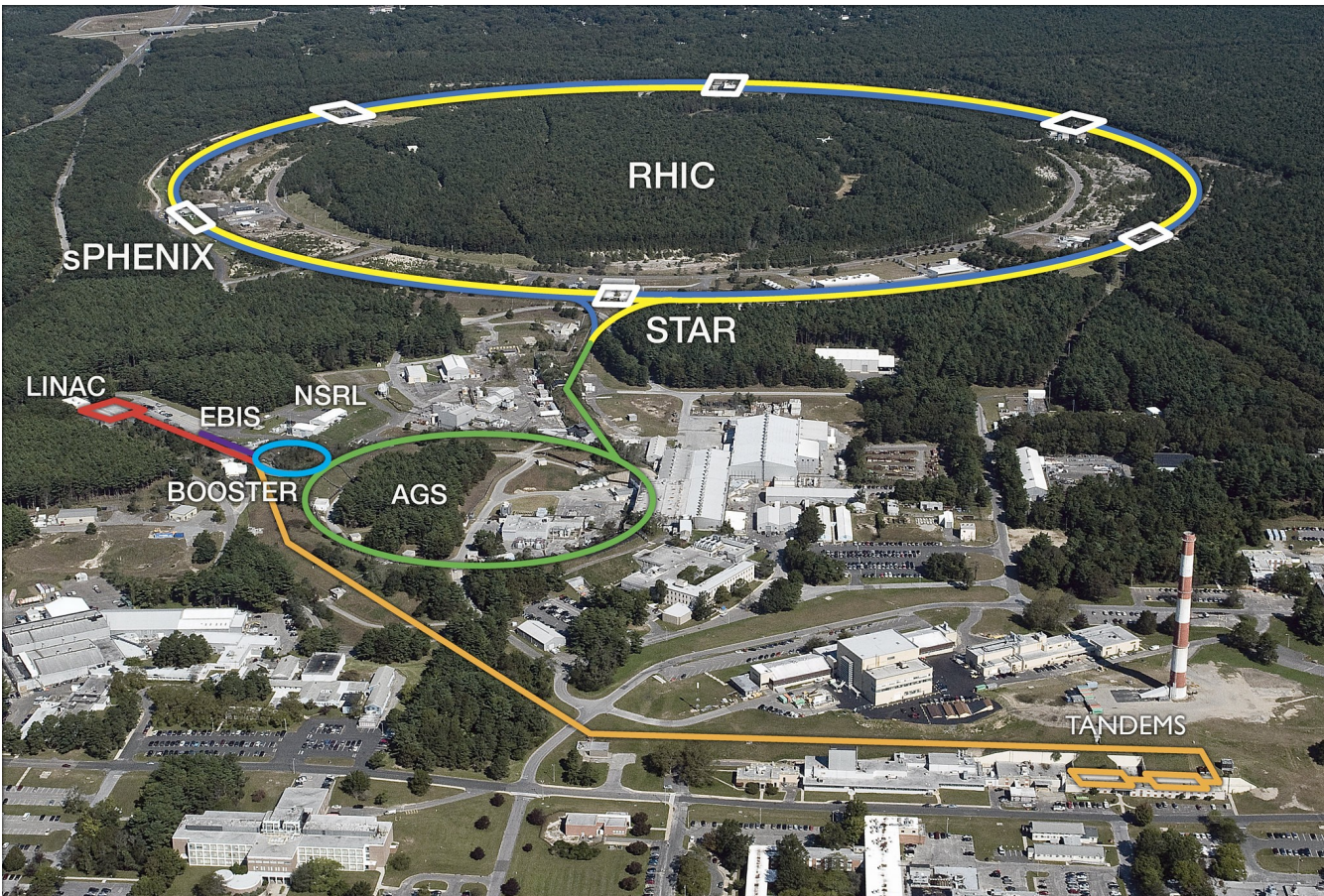


RF for Colliders

(or how I learned to stop worrying and love high frequency electric fields)

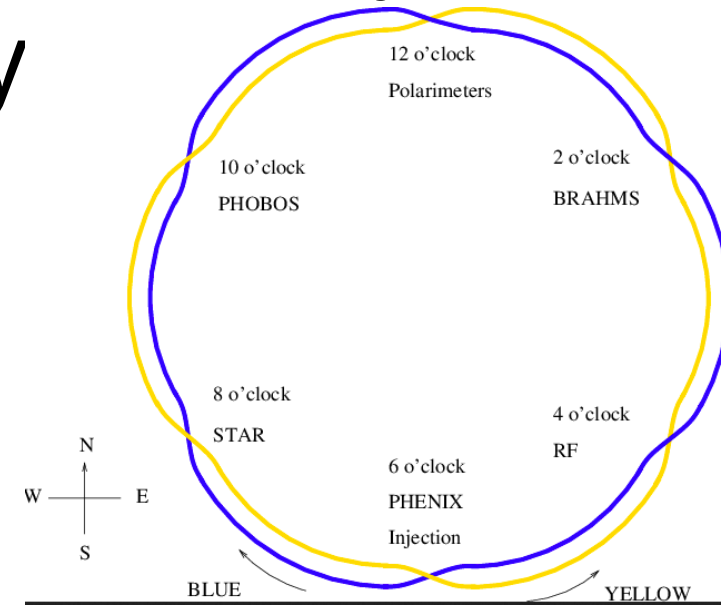


The RHIC tunnel

With clockwise and counter clockwise beam pipes (magnets at 4 K)

What's a Collider (RHIC=Relativistic Heavy Ion Collider) and Why

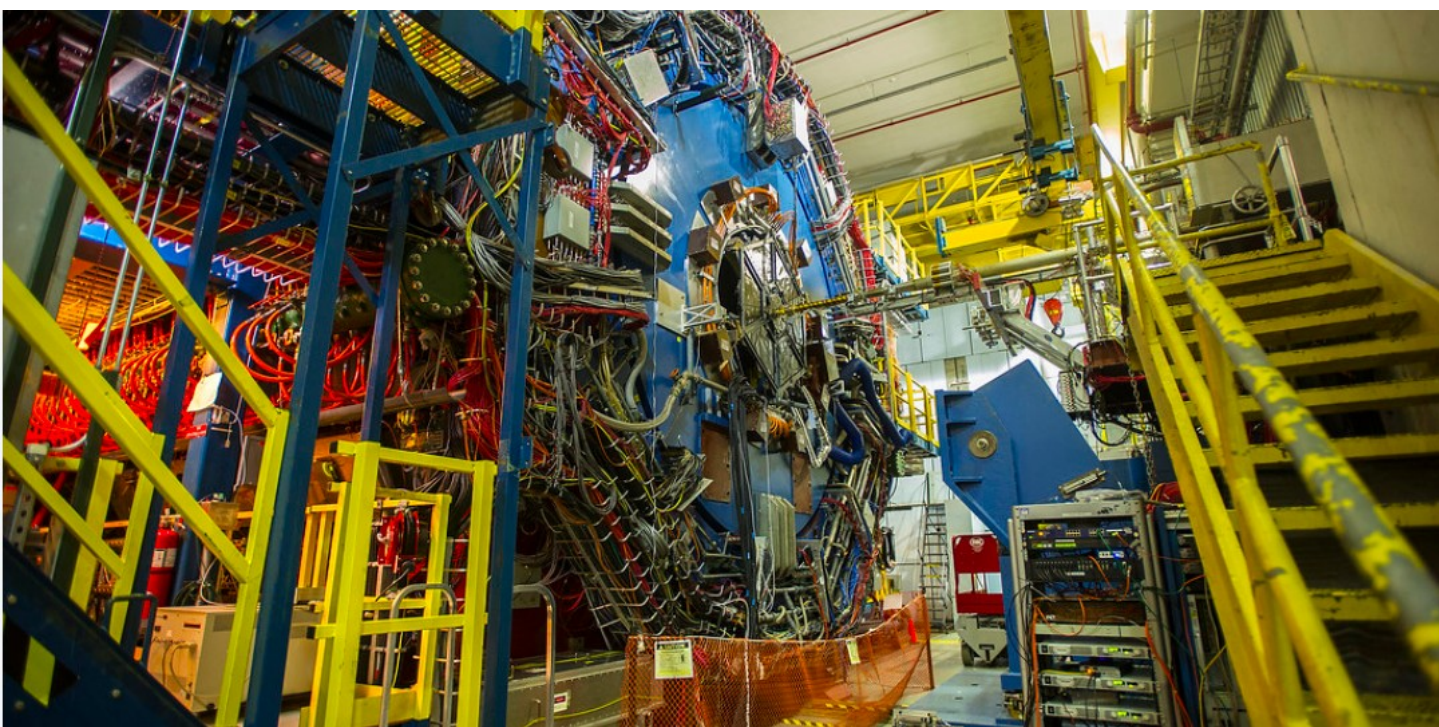
- Make collisions and see what happens. ("ask a Physicist how a watch works and they will smash it with a hammer to see what comes out")
 - Hopefully, quarks and QGP (Quark Gluon Plasma)
 - Same state of matter as air in the ionosphere, but...
 - QGP has not been seen in the universe since the Big Bang



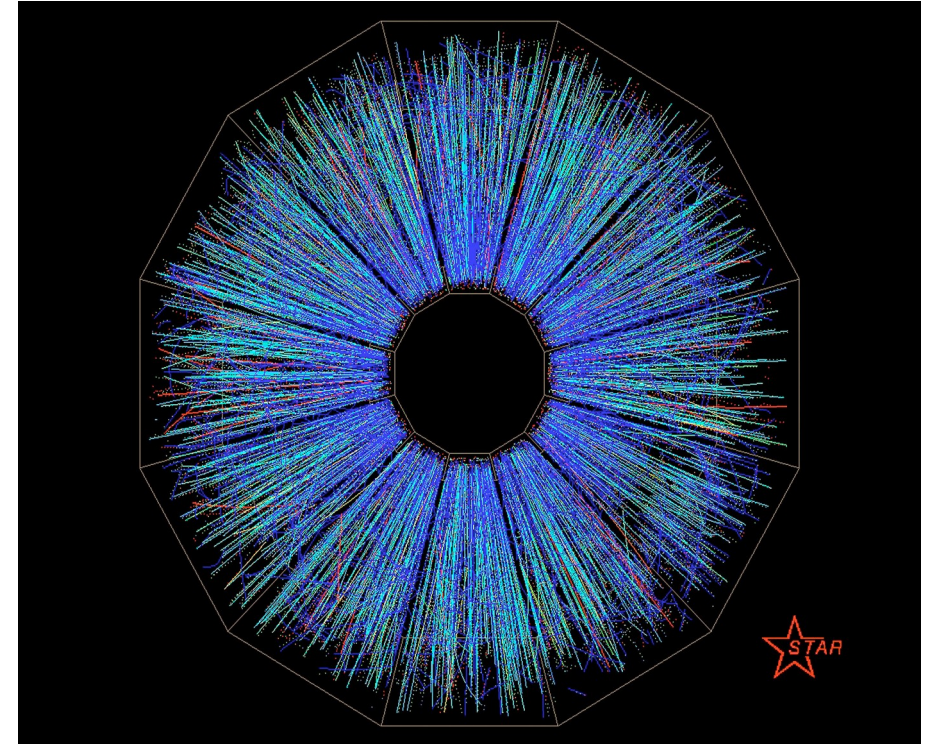
- A collider is a demolition derby of atomic nucleons. Hit head on at 100 billion electron volts.
- two rings ($2\pi R=3$ miles) of particle beams counter rotating until brought into collision at the experiments location
- What comes out? More than would fit in the kitchen sink

A little Physics.

- $E=mc^2$ [$m=E/c^2$] E in RHIC = 100 GeV/n
 - 100 billion electron volts



The detector, inside which the collisions happen

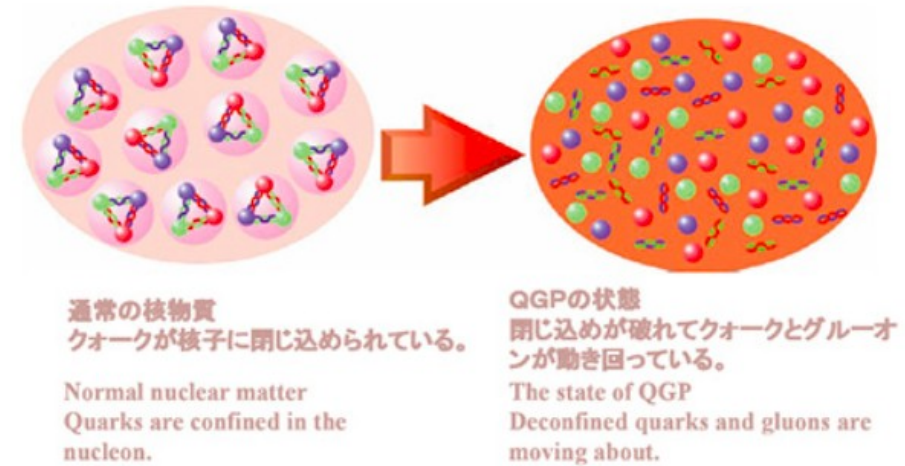


Actually: A lot of Physics, 1000 particles

1. Protons, neutrons
2. Pions
3. Muons
4. Kaons
5. J/ψ
6. ... [Sorry, no Higgs Bosons]

The why?

- To make QGP (Quark-Gluon Plasma)
- Same idea as plasma in the ionosphere
 1. Except that it's quarks that are released not electrons and nuclei
 2. The stuff probably hasn't been around anywhere in the universe since the big bang
 3. And yes they do study propagation in the QGP



Where Does RF come in?

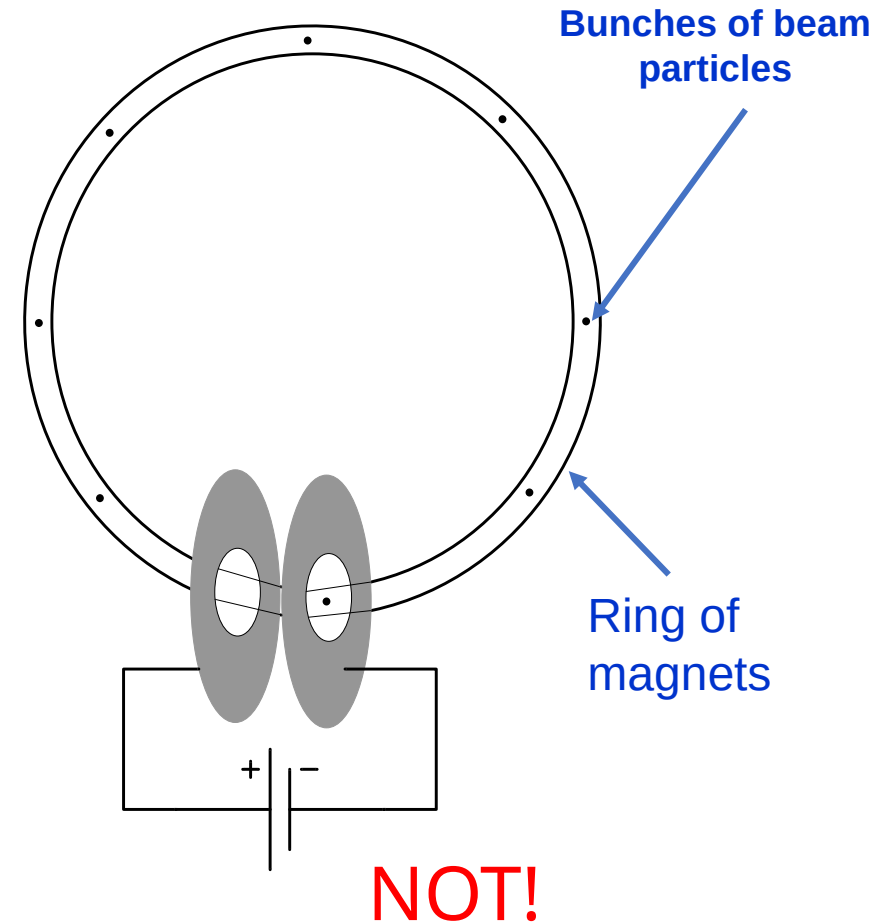
It puts the accel in accelerator

- The magnets hold the beam in a ring
- Must have an electric field to accelerate the beam
- Must be AC electric field,

RF!

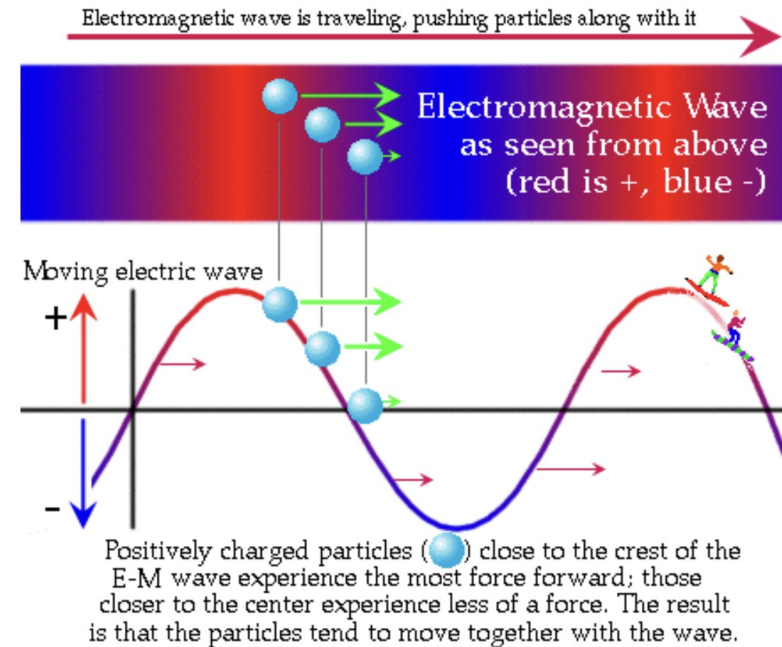
$$\vec{F} = q(\vec{E} + \vec{v} \times \vec{B}) \quad (\text{Lorentz force})$$

$$P = \vec{F} \cdot \vec{v} \quad (\text{Power transferred})$$



The Voltage has to come from RF

- The frequency must be an EXACT harmonic of the revolution frequency (phase-locked)
 - Frequencies can range from soup-to-nuts
 - The rings sizes vary greatly
 - The beam speeds up (from $0.05c$ to $99.999c$)
 - Sometimes f_{rev} goes down

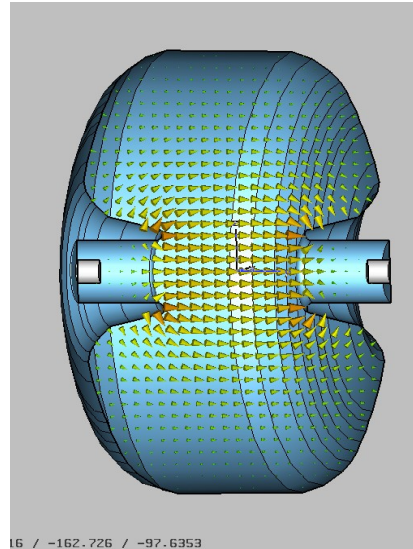


RF; 0.4 to 70,000 MHz

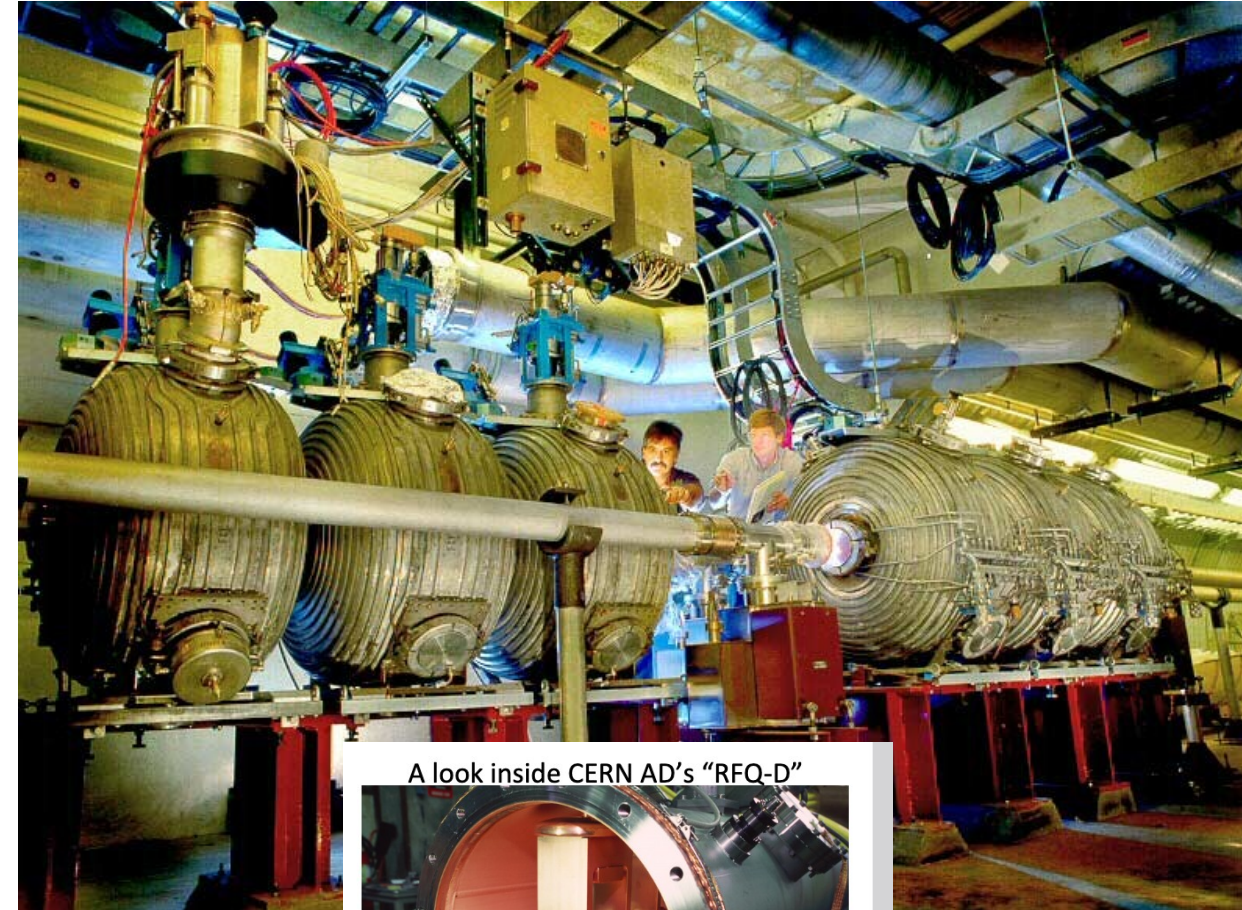
- RF = Radio Frequency
- Lower bound = Beam revolution period
 - Booster Gold ions at injection
- Upper bound = Beam spot diameter
 - Stochastic cooling kickers
- Typical cavity = RHIC storage 200 MHz
- 70 GHz = Microwave link for stochastic cooling



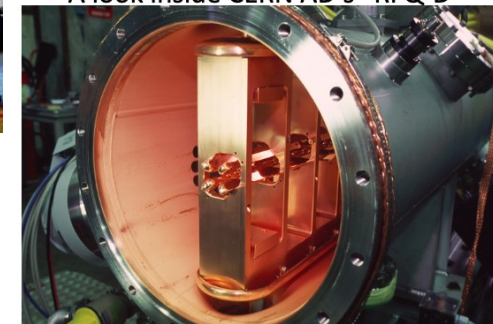
10 GHz cavities



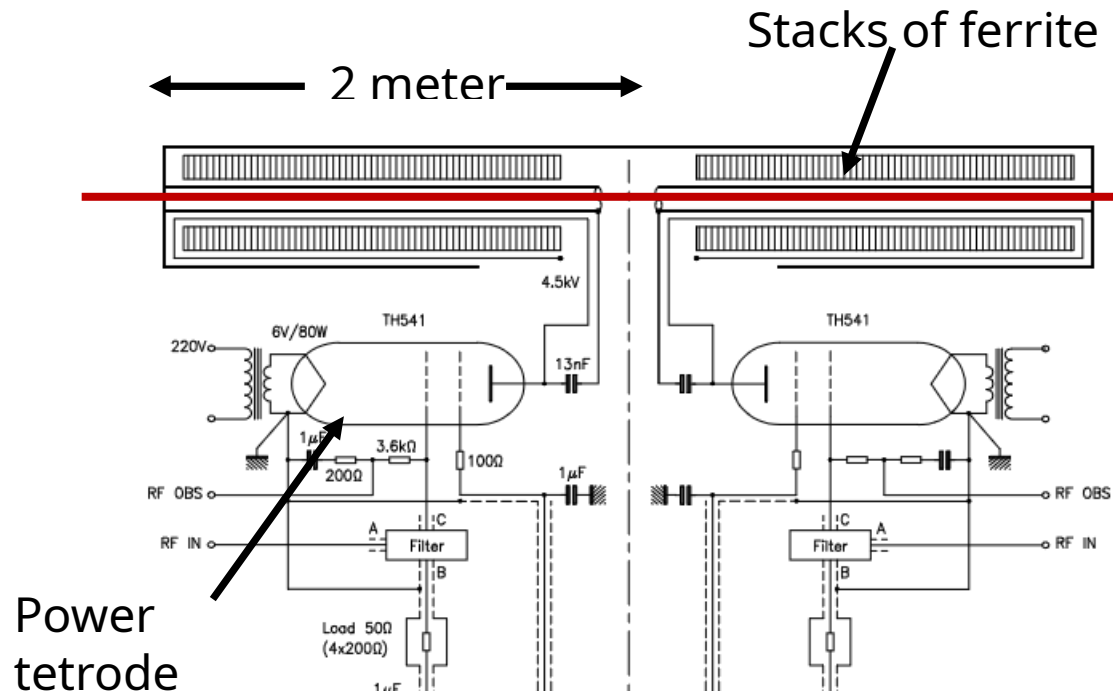
200 MHz cavity



A look inside CERN AD's "RFQ-D"

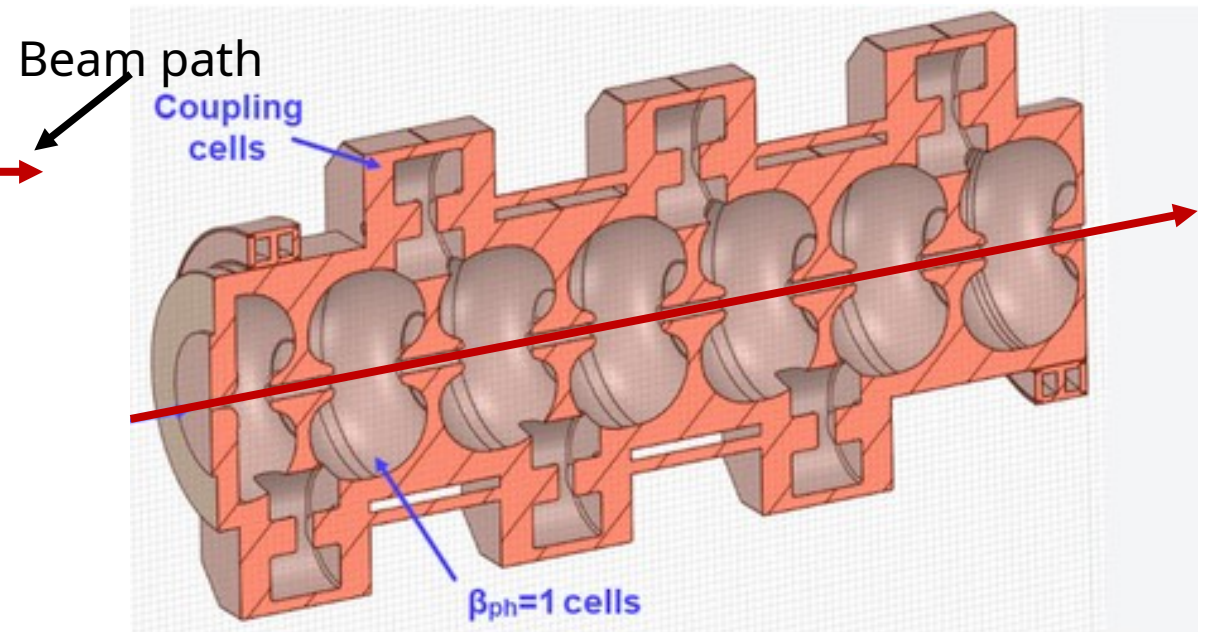


The necessary very high voltages are created in high **Q** RF cavities



Low frequency cavity, 0.1 to 10 MHz

$$Q \cong 50$$



Multi-cell cavity, spacing must match beam speed and frequency

$$Q \cong 50,000$$

Superconducting RF Cavities, $Q > 10^8$

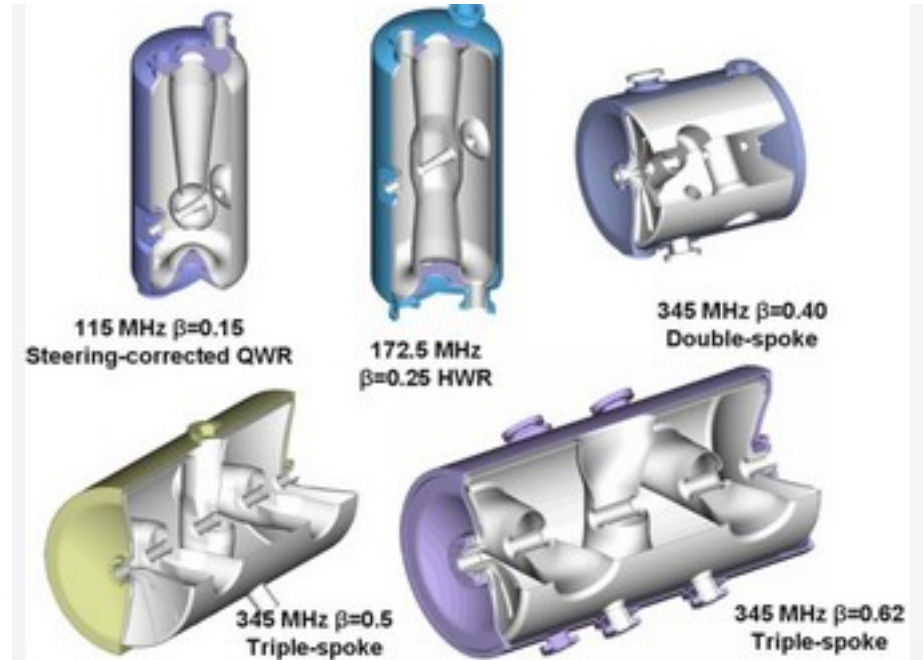
Voltage can be as high as 10MV/m

Made from ultra pure Nb

But alas, operating temperature = 4 K (-270 C)

Class 1000 cleanroom for assembly

Bandwidth = $100 \text{ MHz}/10^8 = 1 \text{ Hz}$ (whatever you do don't slam the door)



Power Sources

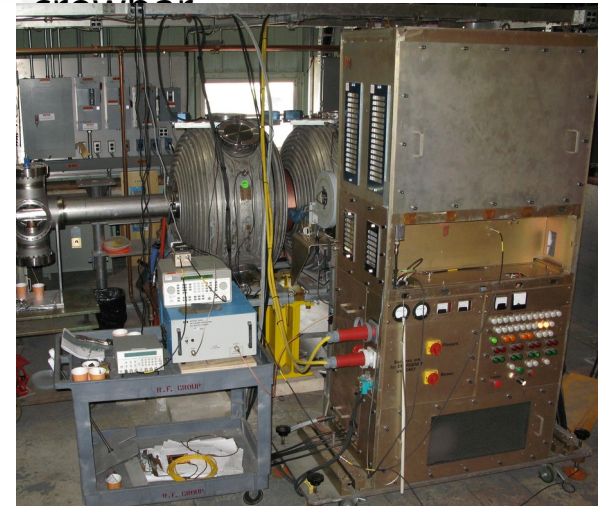
- Vacuum tubes
 - Triodes, 2 MW pulsed radar
 - Tetrodes, linear pure current source
- Klystron, >500 MHz, 100 kW
- TWT traveling wave tube
- Solid state, frontier, ~50 kW CW
 - GaN and SiC
 - Not rad hard
 - Complicated protection



4CX500000 500kW CW,
30 gpm water
Damn the swr, full power
ahead. Stand clear of the
anode cap



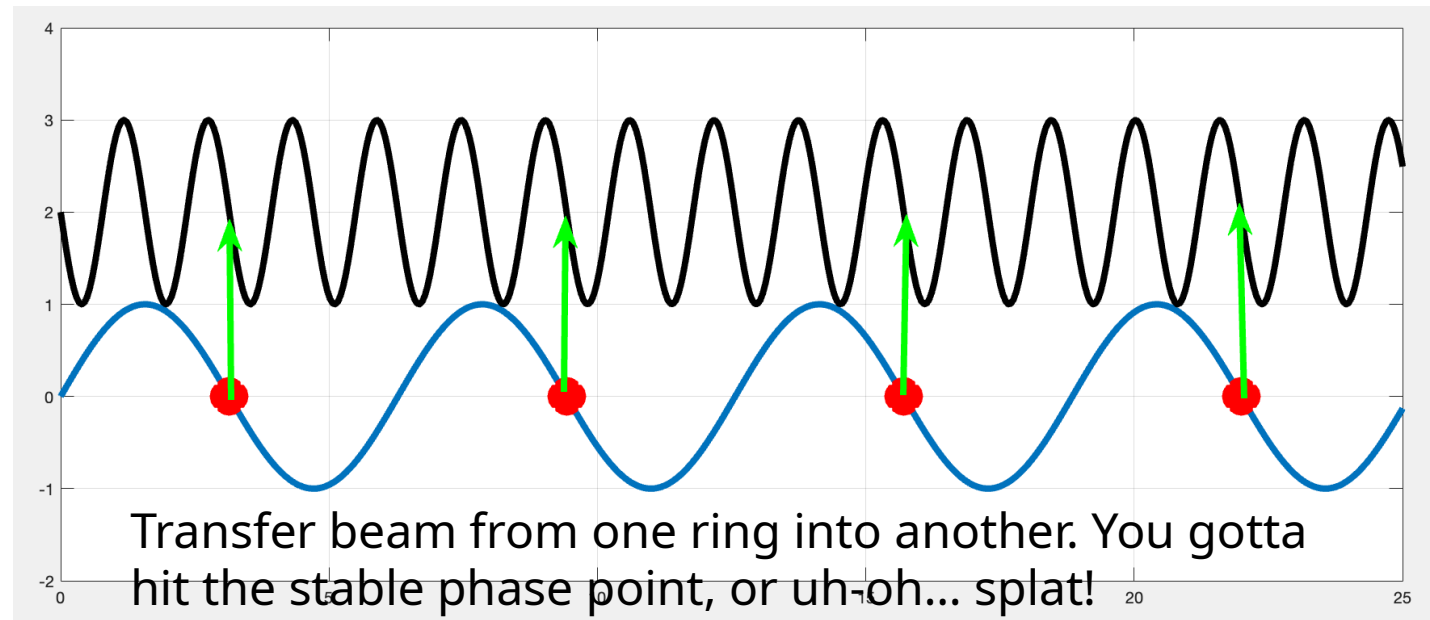
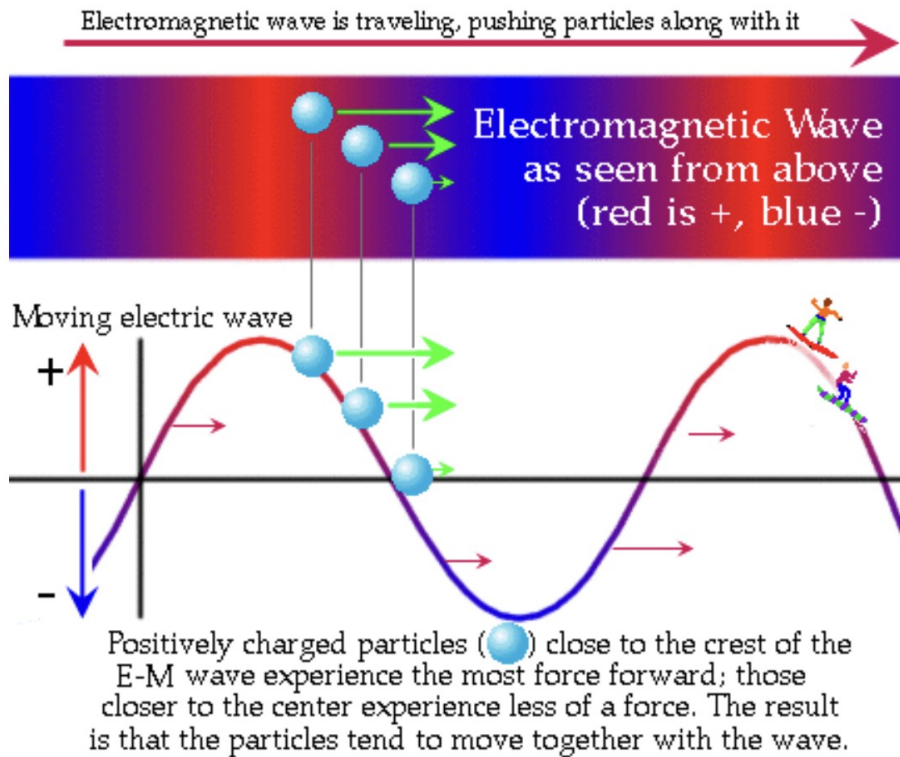
Solid state 50 kW CW



Amp with 4CX500000

Control Electronics

- Really helped by digital processing
 - Everything is done in I/Q format(vector)
 - Scaler: amplitude and phase-360+1=0
 - Vector: I and Q - 360+1=361
 - Precision of DDS(VFO) is essential. Both frequency and phase have to be spot-on
- Feedback loop upon feedback loop locks everything together

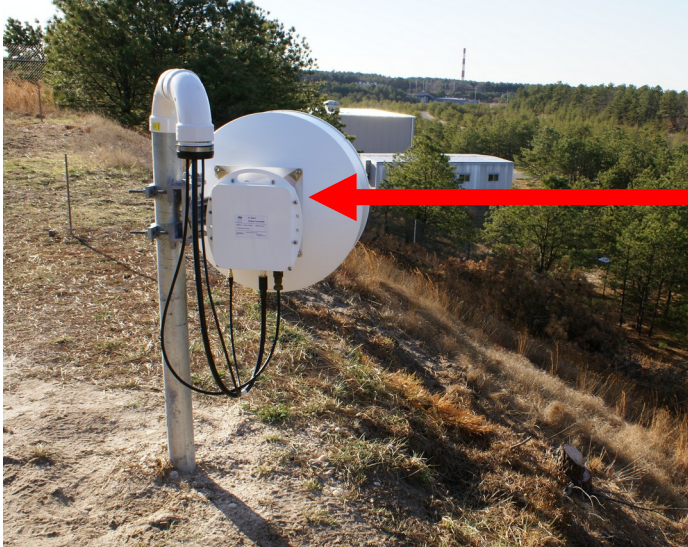


Feedback on Everything, Including the beam

E Band link at 70 GHz beats the race to the beam by cheating

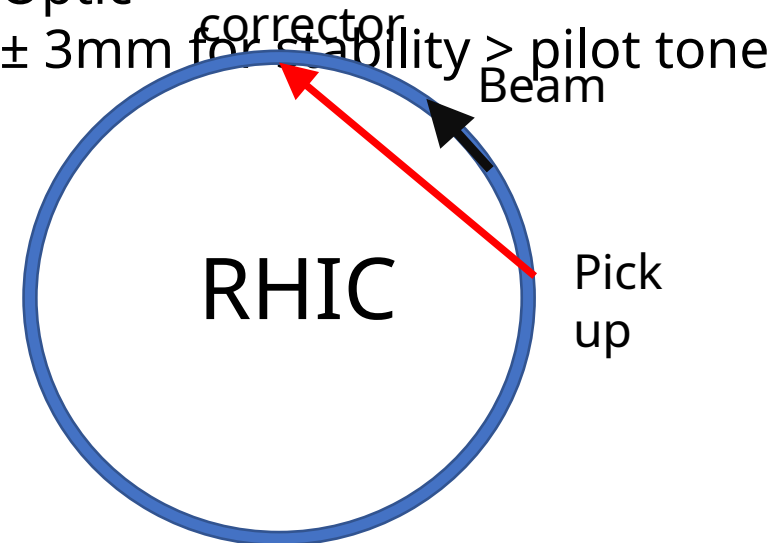


Umbrella in a tree



What? Hack the electronics?

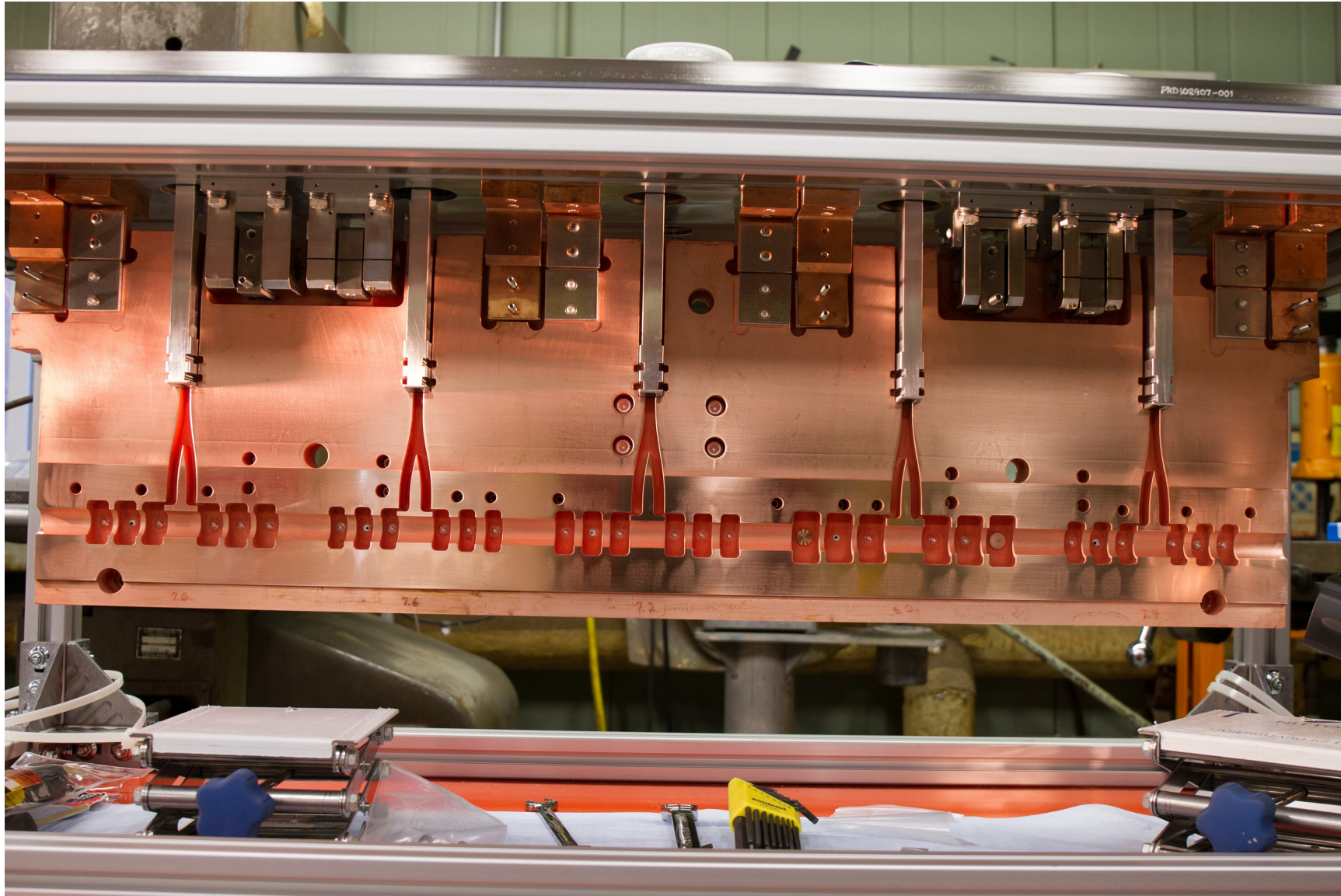
- Measure>process>transmit>apply correction to beam with < 100 ns latency
- Realtime bandwidth = 3GHz AM
- TX on 70-73 GHz section of the E-Band
- 17 GHz Local Oscillator sent on Fiber Optic
- $\pm 3\text{mm}$ for stability



OH No. Is that Slim Pickens?



Full 9 GHz cavity



antenna

