Fermilab U.S. DEPARTMENT OF ENERGY Office of Science

RF cavity for the IOTA ring

Giacomo Sala, Polytechnic University of Milan
ID #33406N, Fermilab AD IOTA/FAST Dept.
Supervisor: Alexander Valishev, Mentor: Kermit Carlson

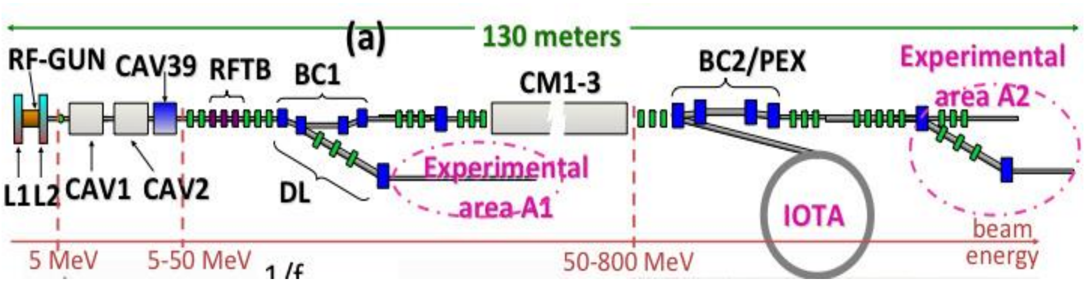
Italian graduate students program, Final report

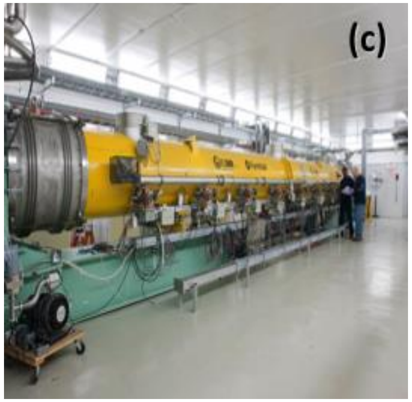
September 23rd, 2016

Outline

- FAST facility
- What is IOTA for?
- Why a RF cavity?
- The cavity
- The equivalent electrical scheme
- Impedance matching
- Resonance
- The RF driving system
- Hard work!
- A mechanical problem
- Tuning at ≈ 2.4 MHz
- Some noise: heating
- What we had planned to do
- What we have done
- What's next?

FAST Facility





Fermilab Accelerator Science and Technology Facililty

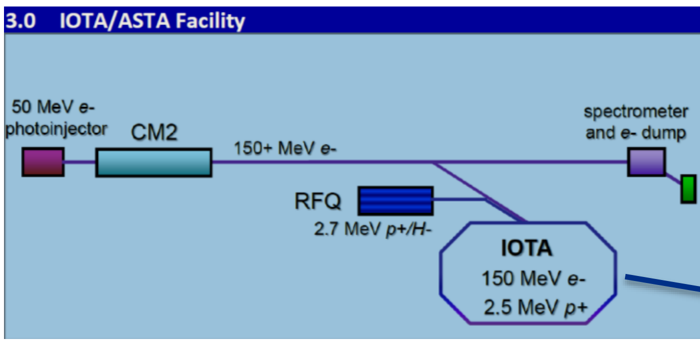
Some features of FAST:

1) Electron RF photoinjector coupled with superconducting accelerating cryomodules
2) RFQ proton injector
3) a storage ring capable of supporting ring-based advanced beam dynamics experiments (IOTA ring)

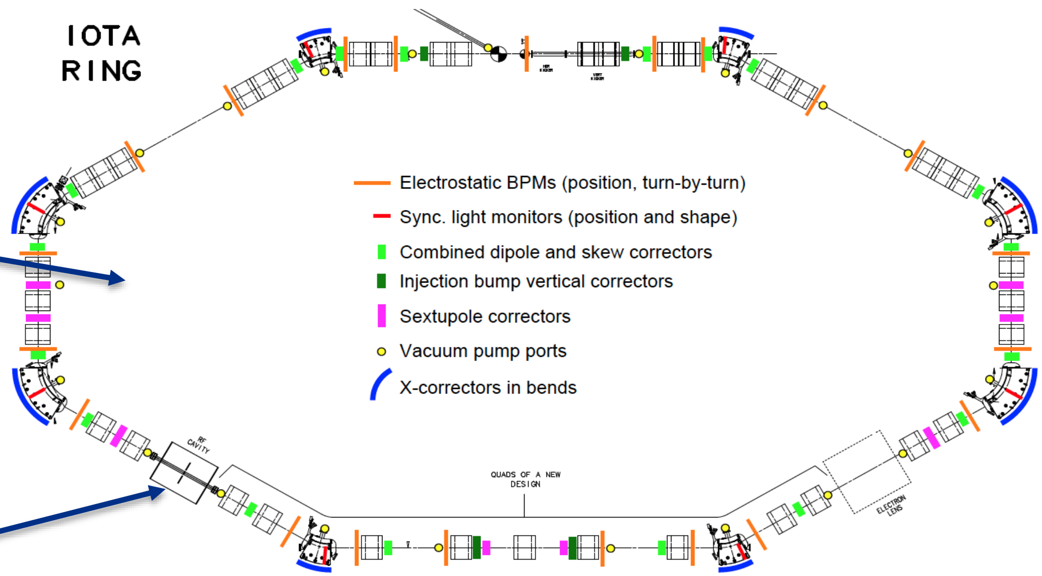
What is IOTA for?

IOTA Program Goals

- Complete the construction of the IOTA storage ring and of its proton and electron injectors
- Perform studies of high beam intensity effects, such as integrable optics and space-charge compensation
- Establish a centre of excellence in beam theory and experiments



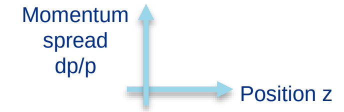
≈ 40 m circumference

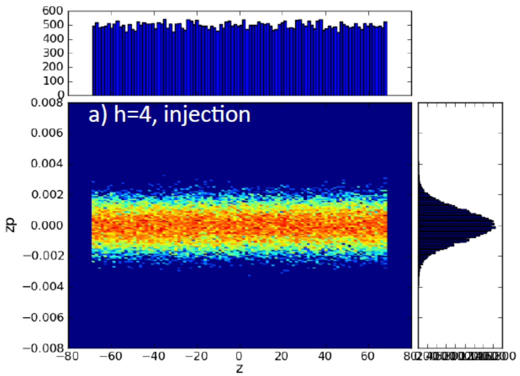


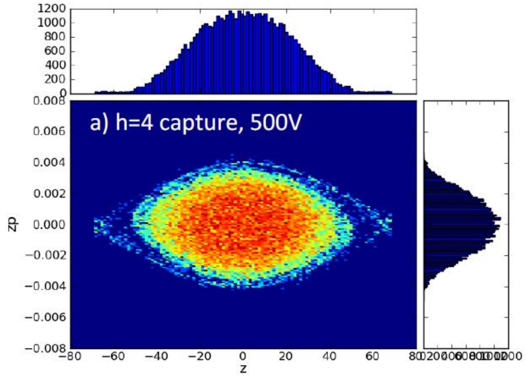
RF cavity

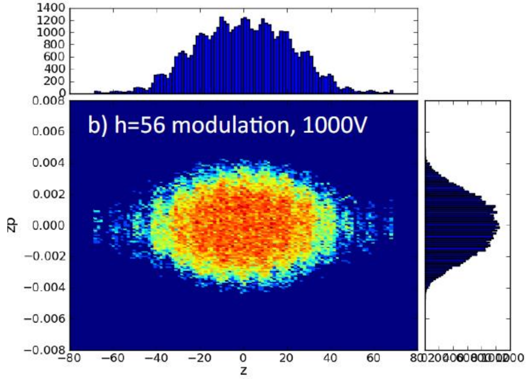
IOTA: Integrable Optics Test Accelerator

Why a RF cavity?



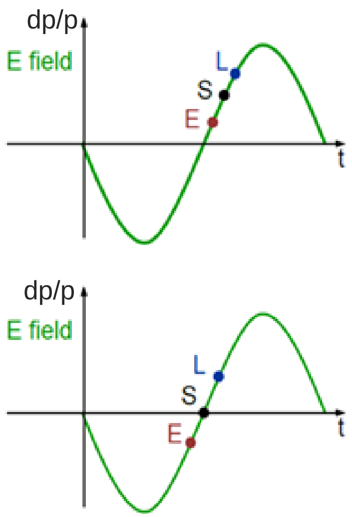




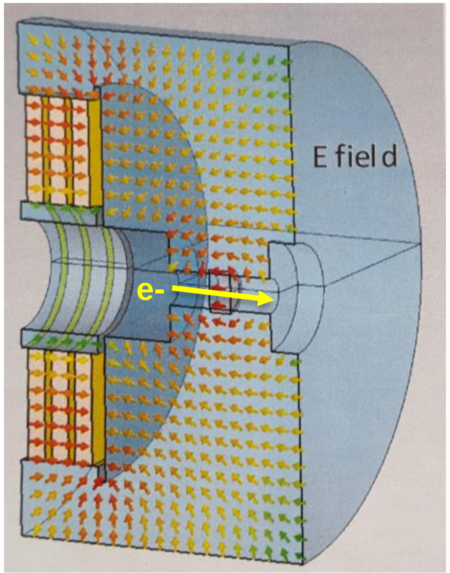


$$\Delta p = eE\Delta t$$ *: momentum variation*

The packet is accelerated



The packet is not accelerated
L: late, E: earlier, S: synchronous.



MAIN PARAMETERS	Electrons	Protons
Kinetic energy [MeV]	150	2.5
pc [MeV]	150.5	68.5
Beta	≈ 1	≈ 0.073
Revolution time	133 ns	1.9 μs
Ring circumference [m]	40	40
Harmonic number h	4	4
Bunching frequency [MHz]	30.62	2.19
Modulation frequency [MHz]	-	30.62
Required gap voltage [V]	1000	500

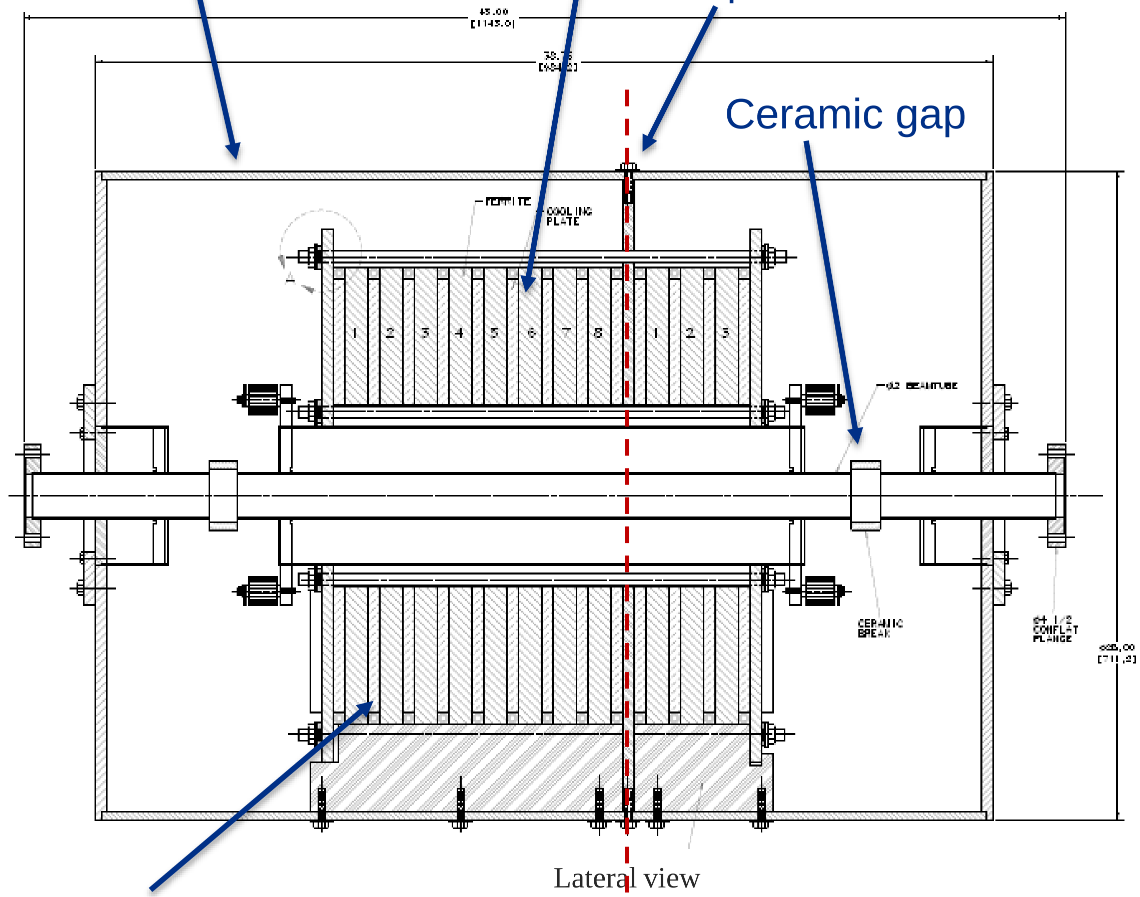
The cavity

Aluminum pillbox cavity

Ferrite disks (from a previous simulation: 8 for protons μ_r=15, 3 for electrons μ_r=5)

Separator

Ceramic gap



Copper cooling plate

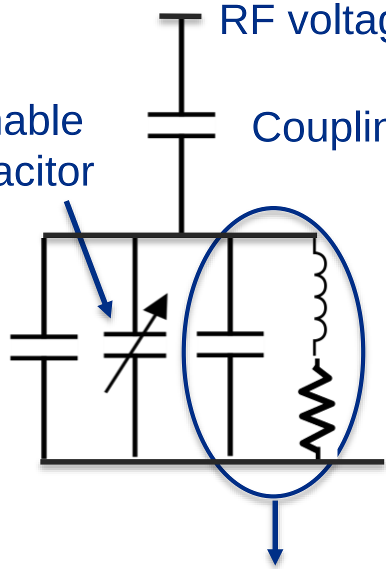
PROTON SIDE

ELECTRON SIDE

Intended particle operations:
-2.5 MeV protons at f ≈ 2.2 MHz
-150 MeV electrons at f ≈ 30.6 MHz

Fermilab

The equivalent electrical scheme



RF voltage

Tunable capacitor

Coupling C

Parallel capacitor

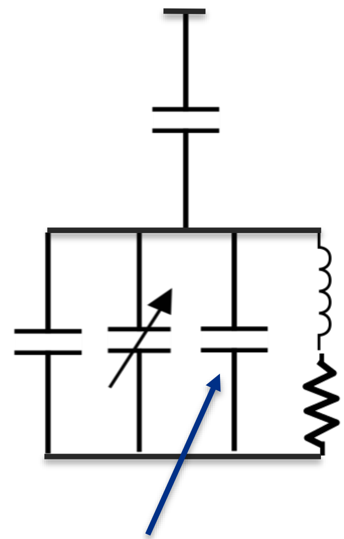
Ground potential

Model of the cavity

Resonance frequency

$$\omega = \frac{1}{\sqrt{LC_{tot}}}$$

1st ferrite function: reduce ω



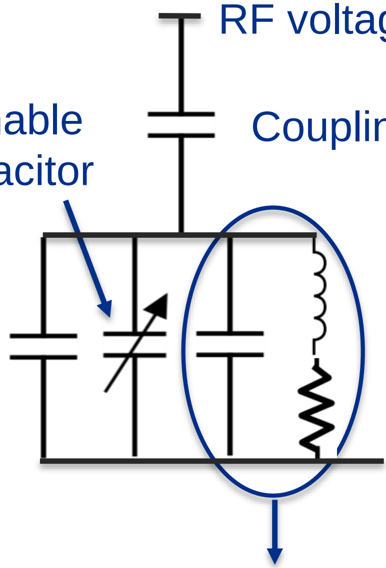
L represents the ferrite rings

R: due to the resistive path travelled by the current

C represents the ceramic gap

We use the parallel and tunable capacitor to ensure resonance; the coupling capacitor is required for impedance matching

Impedance matching



Reflection coefficient

$$\Gamma = \frac{z_0 - z}{z_0 + z}$$

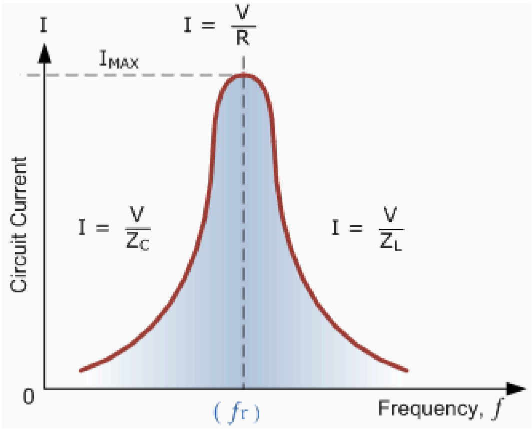
Standing wave ratio

$$SWR = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

Requirement on impedance matching:
SWR better than 1.2:1 (equivalently less than 0.8% of power loss)

What we obtained:
By using a coupling C of 17 pF, SWR was less than 1.1:1

Resonance



Parallel capacitance:
400-600 pF
Tunable capacitance:
30-50 pF
Further improvement:
use another ferrite disk

Q is dominated by the ferrite (2nd function);
example for the proton side:
f ≈ 2.46 MHz
Δf ≈ 0.063 MHz

$$Q = \frac{f}{\Delta f} = \frac{1}{R}\sqrt{\frac{L}{C_{tot}}} \approx 40$$

Q is a quality parameter: it measures the stored energy inside the cavity as compared to the energy loss in one cycle

Requirements on phase stability:

- Steady state rms accuracy of phase ± 0.5˚
- Ability to recover the set point after a perturbation no greater than 40˚

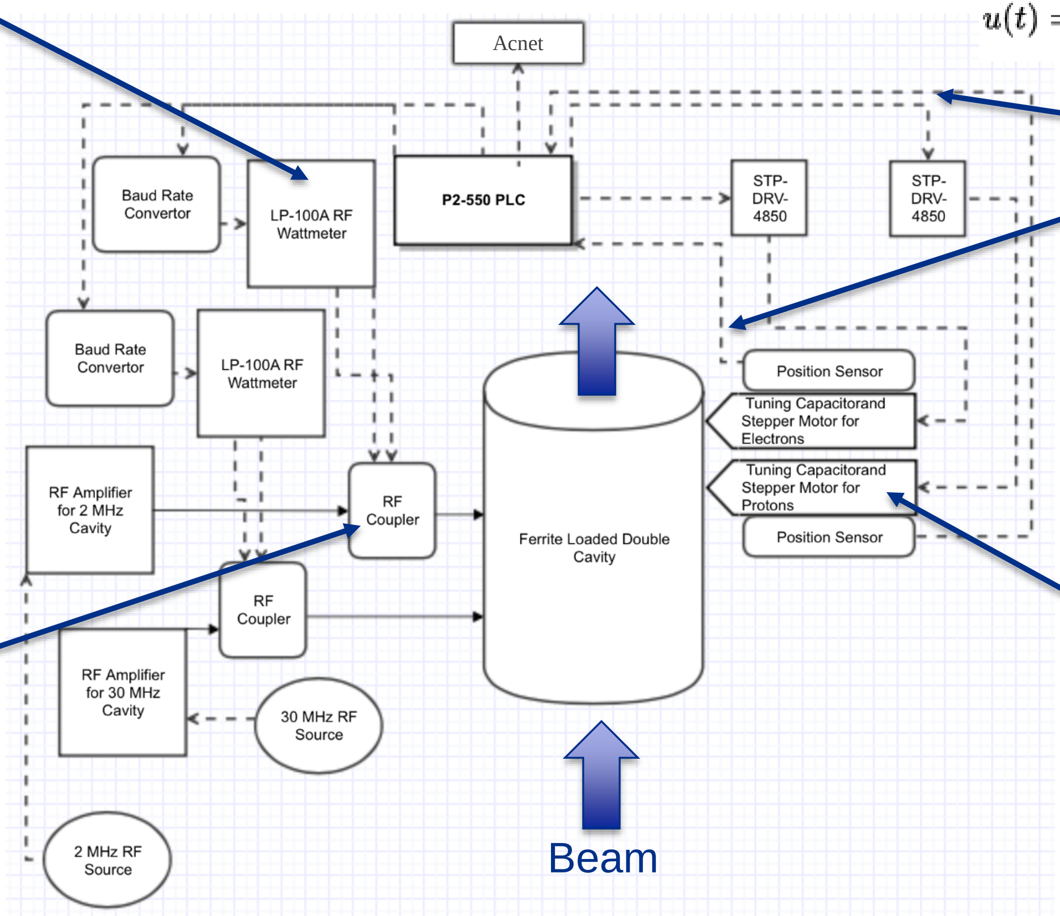
The RF driving system

Measurement of transferred power and phase

Scan rate: 500 ms

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{de(t)}{dt}$$

PID loop



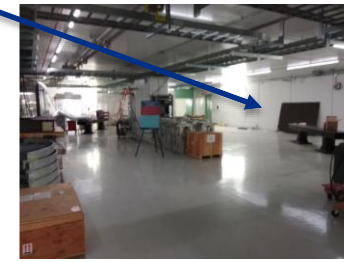
Voltage and current feeding

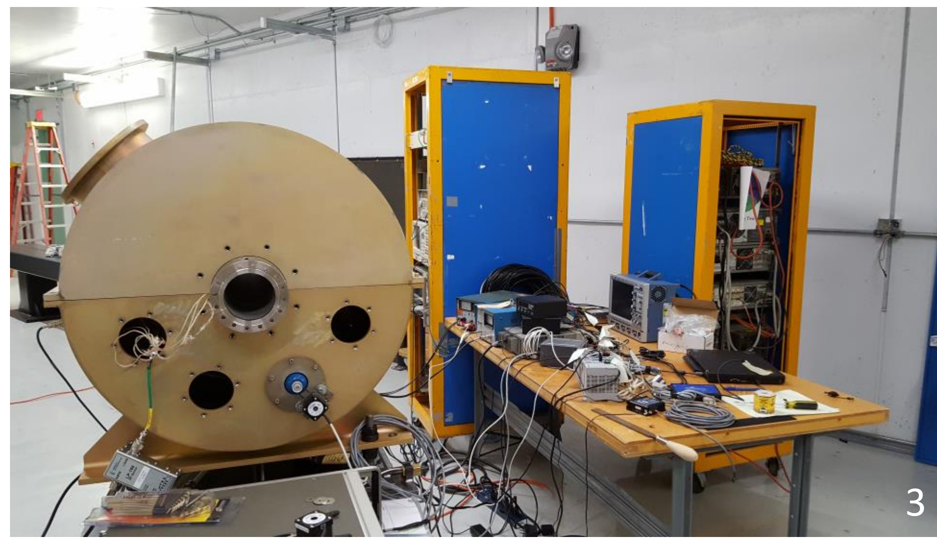
Beam

Tuning of the capacitance

Hard work!

We moved the cavity, the electrical appliances and devices and all the required stuff from the CMTF building to the room where the IOTA ring is being built





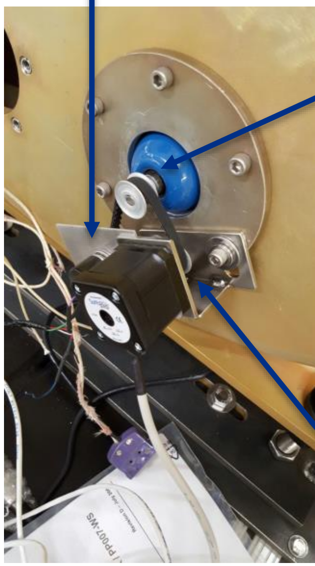
Fermilab

A mechanical problem

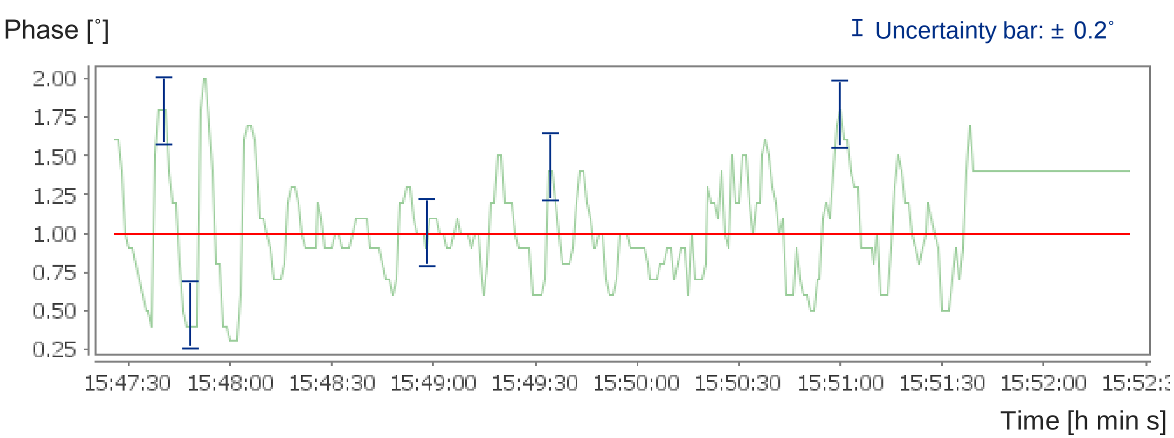
Potentiometer

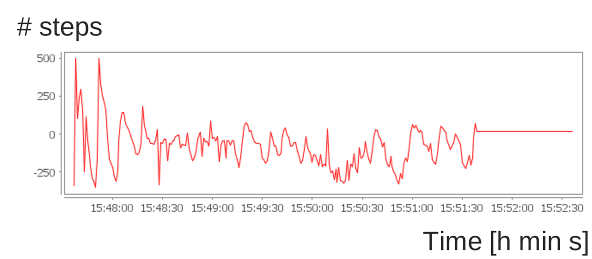
Capacitor's shaft

Stepper motor



A temporary solution

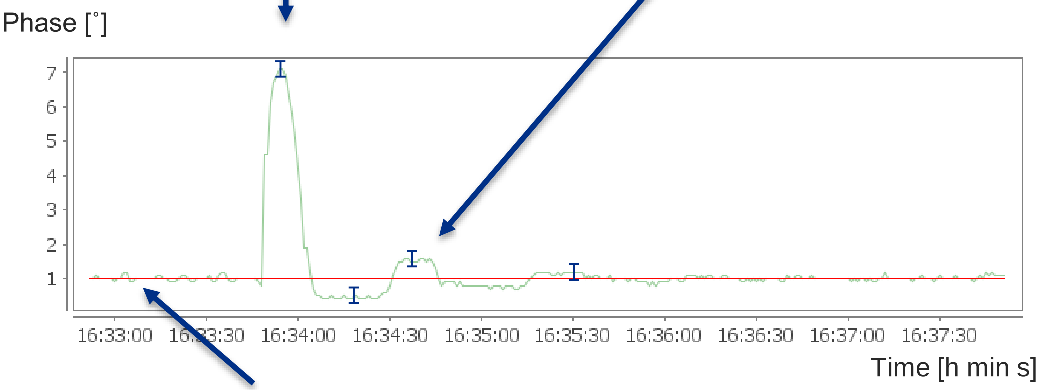


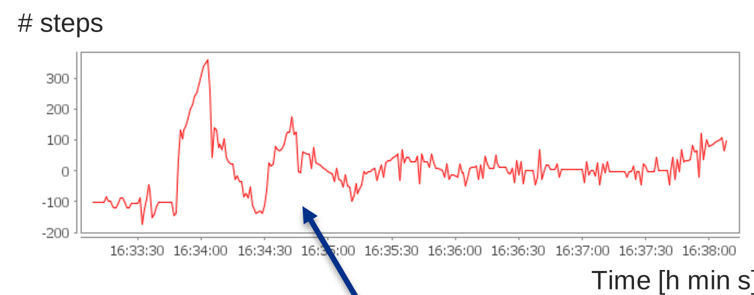


Tuning at ≈ 2.4 MHz

Induced perturbation (power from 15 W to 4 W)

Current phase

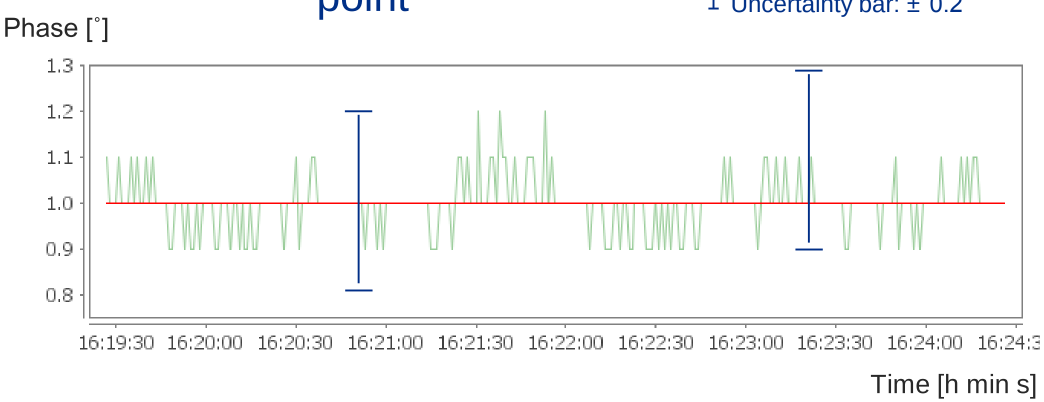


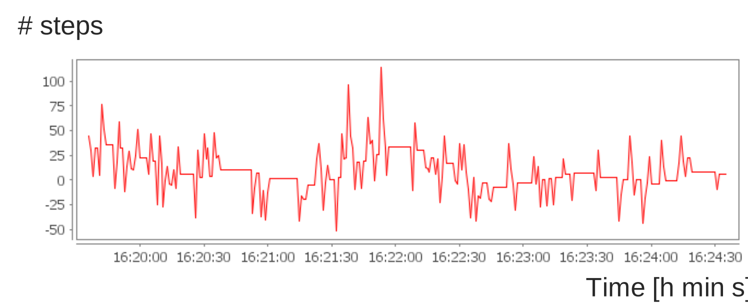


Reference point

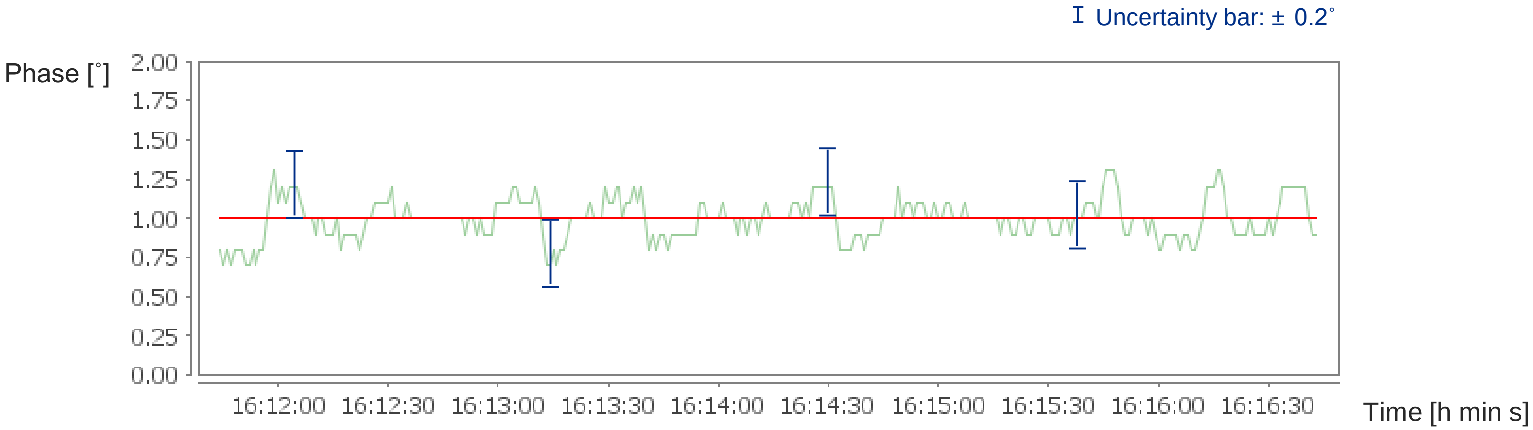
Output of the PLC sent to the stepper motor

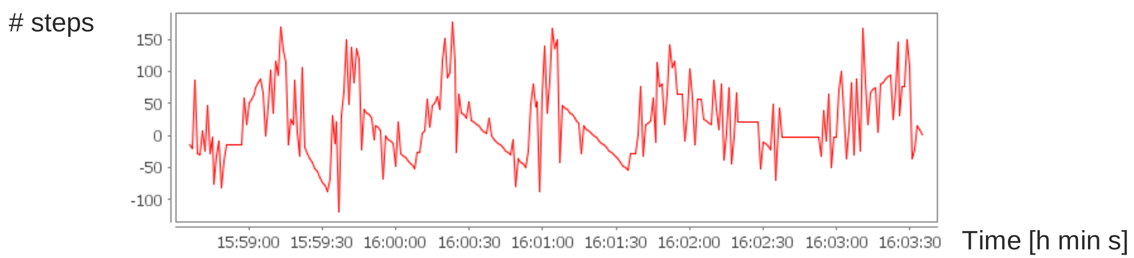
I Uncertainty bar: ± 0.2˚





Some noise: heating





A solution for now: adjust the PID parameters for the control action to be less sensitive to noise

Ultimate solution: use copper plates for cooling

What we had planned to do

- Accommodate the cavity in its proper position in the IOTA ring
- Prepare the experimental set up and assess the feasibility of reaching the matching and resonance conditions
- For the proton side repeat the same operation as for the electron side, that is check it is possible to tune the phase also at $\approx 2.2\ \mathrm{MHz}$
- Complete the assembling with the final pieces
- Assemble and place in position the vacuum pumps

What we have done

- Accommodate the cavity in its proper position in the IOTA ring ✓
- Prepare the experimental set up and assess the feasibility of reaching the matching and resonance conditions ✓
- For the proton side repeat the same operation as for the electron side, that is check it is possible to tune the phase also at $\approx 2.2\ \mathrm{MHz}$ ✓
- Complete the assembling with the final pieces
- Assemble and place in position the vacuum pumps

In particular:

➢ Impedance matching has been obtained with a coupling capacitance of 17 pF; as a result SWR was equal to or better than 1.1:1

➢ The efficacy of the tuning process has been assessed; rough adjustment of the resonance frequency is performed with a parallel capacitance of 400-600 pF (and likely with the introduction of another ferrite disk), fine regulation is allowed by the tuning of the variable capacitor

What’s next?

- Complete the cavity with the final pieces
- Redesign the assembling for the pulley system (bearings should be used to support the capacitor’s shaft)
- Assemble and place in position the vacuum pumps

Acknowledgment

Thanks to my Supervisor Alexander Valishev and to all those who have allowed me to come at Fermilab and live an unforgettable summer

Thanks to my mentor Kermit Carlson for your support, suggestions, teaching and for the great experience while working with you (and for the lunches and dinners you offered me!); I have learnt a lot standing by your side

Thanks to Gerrit Bruhaug for being so patient, helpful and friendly to me during the first weeks

Finally, thanks to my all companions for the fun and joyful time we had together!