

Towards Driving Quantum Systems in Cryogenic Environments with the Near-Field of Modulated Electron Beams

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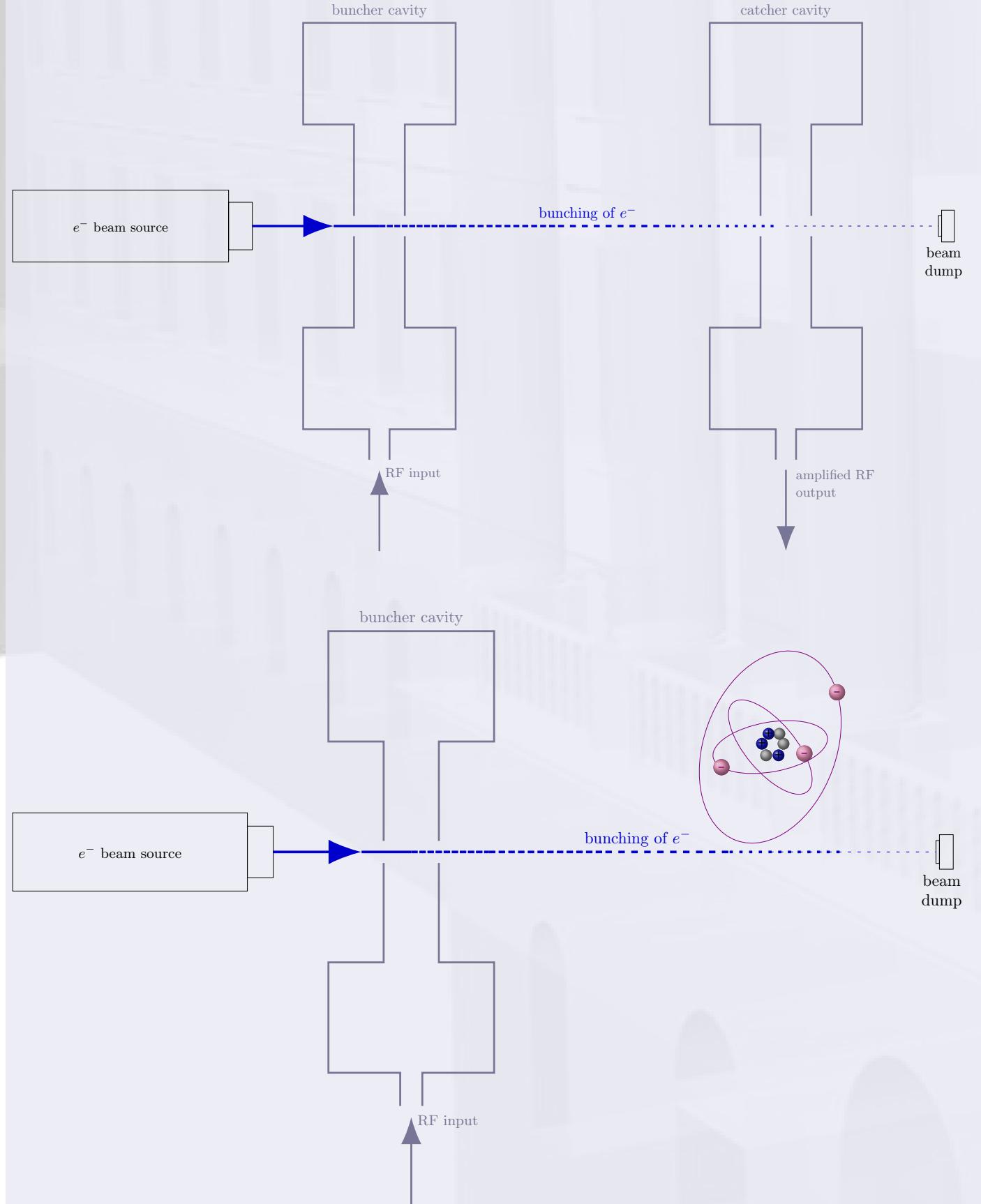
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Abstract

Coherent electro-magnetic control of quantum systems is usually done by electro-magnetic radiation - which limits addressing single selected quantum systems, especially in the microwave range. In our proof of concept experiment we want to couple for the first time the non-radiative electro-magnetic near-field of a spatially modulated electron beam to a quantum system in a coherent[1]. As the quantum system we use the unpaired electron spins of a free radical organic sample (Koelsch radical - α, γ -Bisdiphenylene- β -phenylallyl) that is excited via the near-field of the modulated electron beam. The readout of the spin excitation resembles a standard continuous wave electron spin resonance experiment and is done inductively via a microcoil using a lock-in amplifier.

In the long term this experiment should demonstrate the feasibility of coherent driving and probing of quantum systems far below the diffraction limit of electro-magnetic radiation by exploiting the high spatial resolution of an electron beam.

The Quantum Klystron



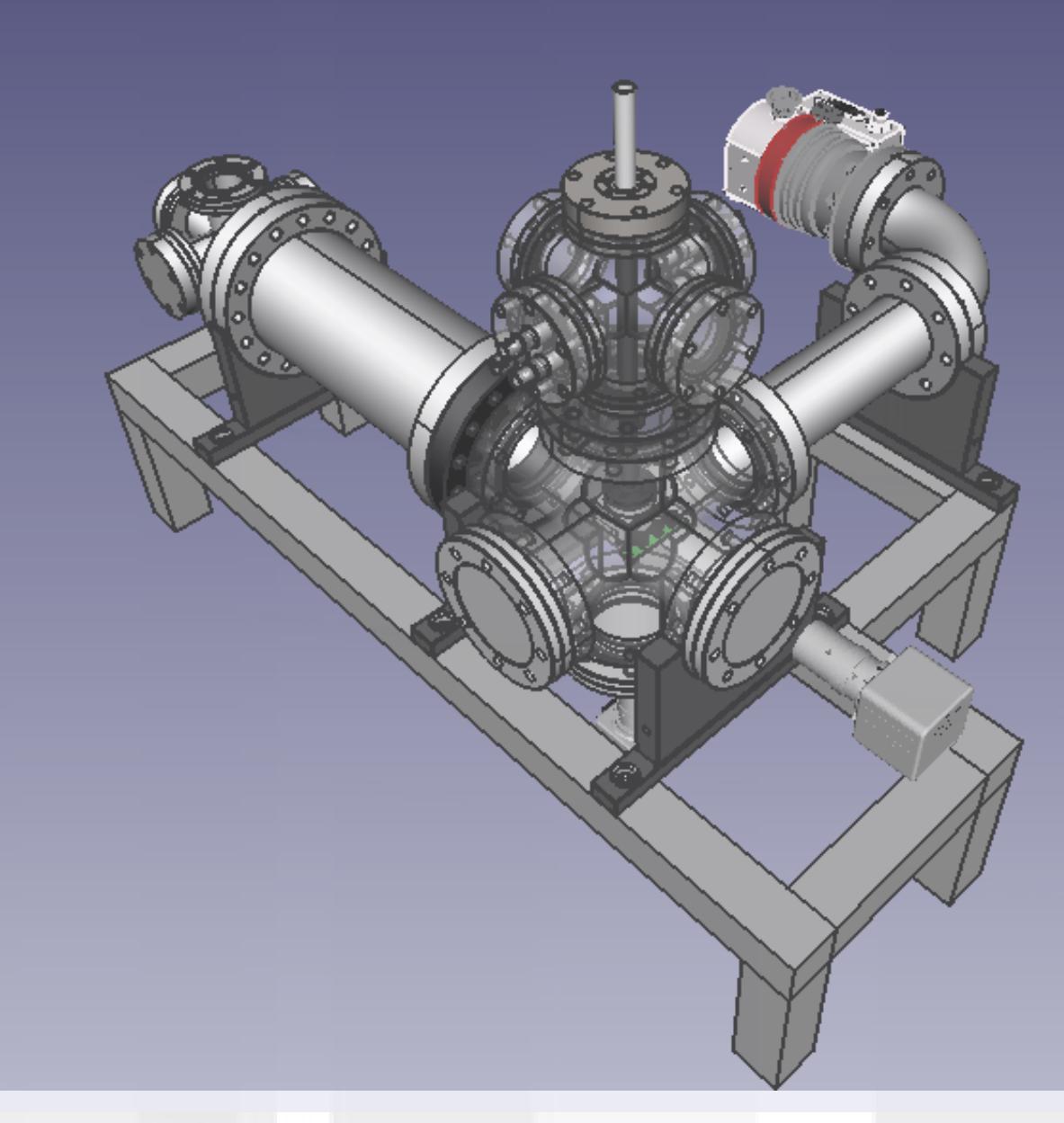
Klystron

- Linear beam vacuum tube invented in 1935, used as RF and microwave amplifier
- Electron beam velocity modulated by microwaves in a (buncher) cavity
- Velocity modulation causes current modulation
- Outcoupling via a catcher cavity

Quantum Klystron

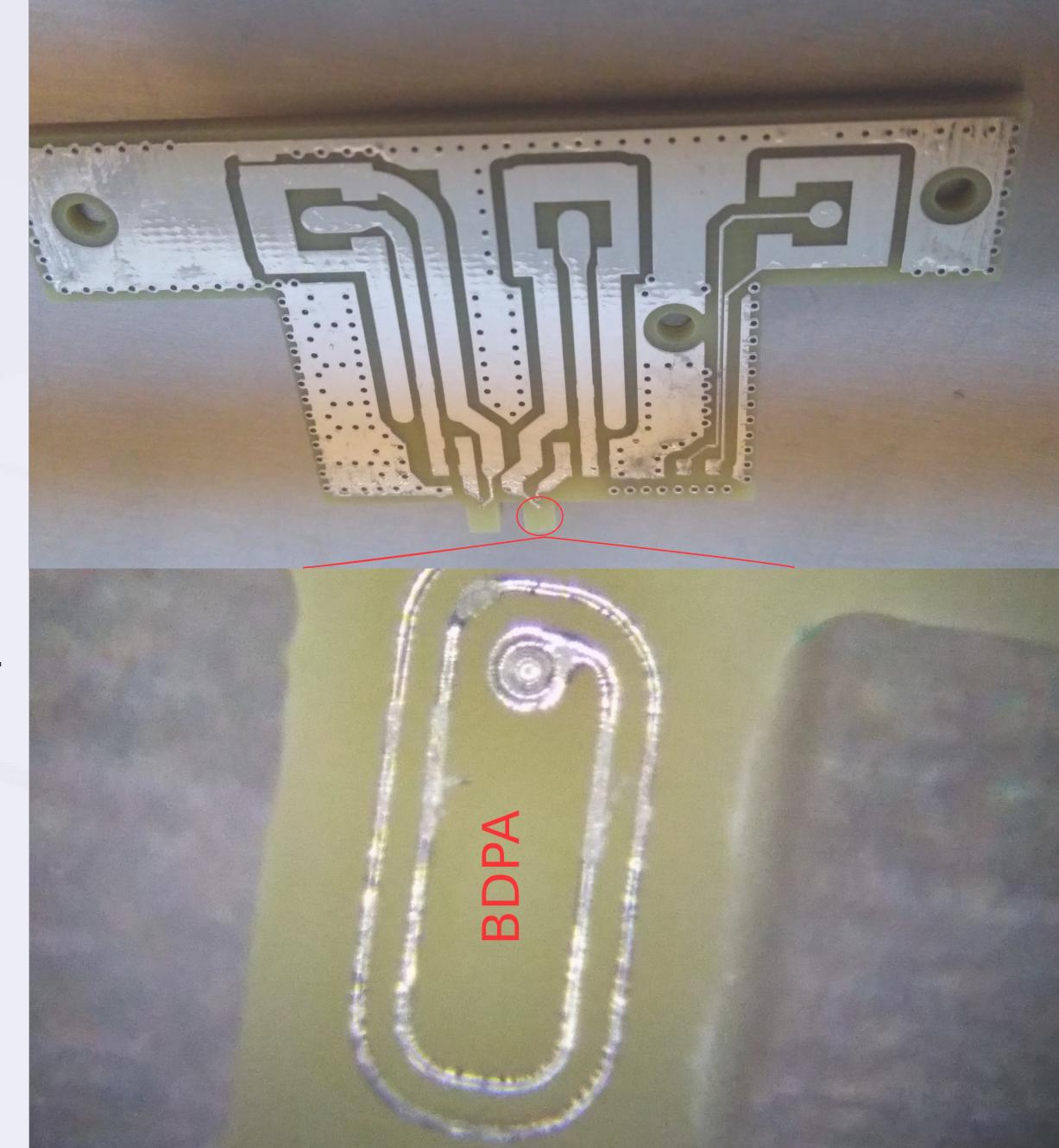
- Replace catcher cavity by a 2 level quantum system (QS)
- Drive the QS using the *non-radiative electro-magnetic near-field* of the electron beam.
 - Either modulate in
 - time domain - bunching / density modulation
 - spatial domain - deflection
- Paint arbitrary potentials (dipole, quadrupole or multipole transitions)
- High spatial resolution

Experimental Setup

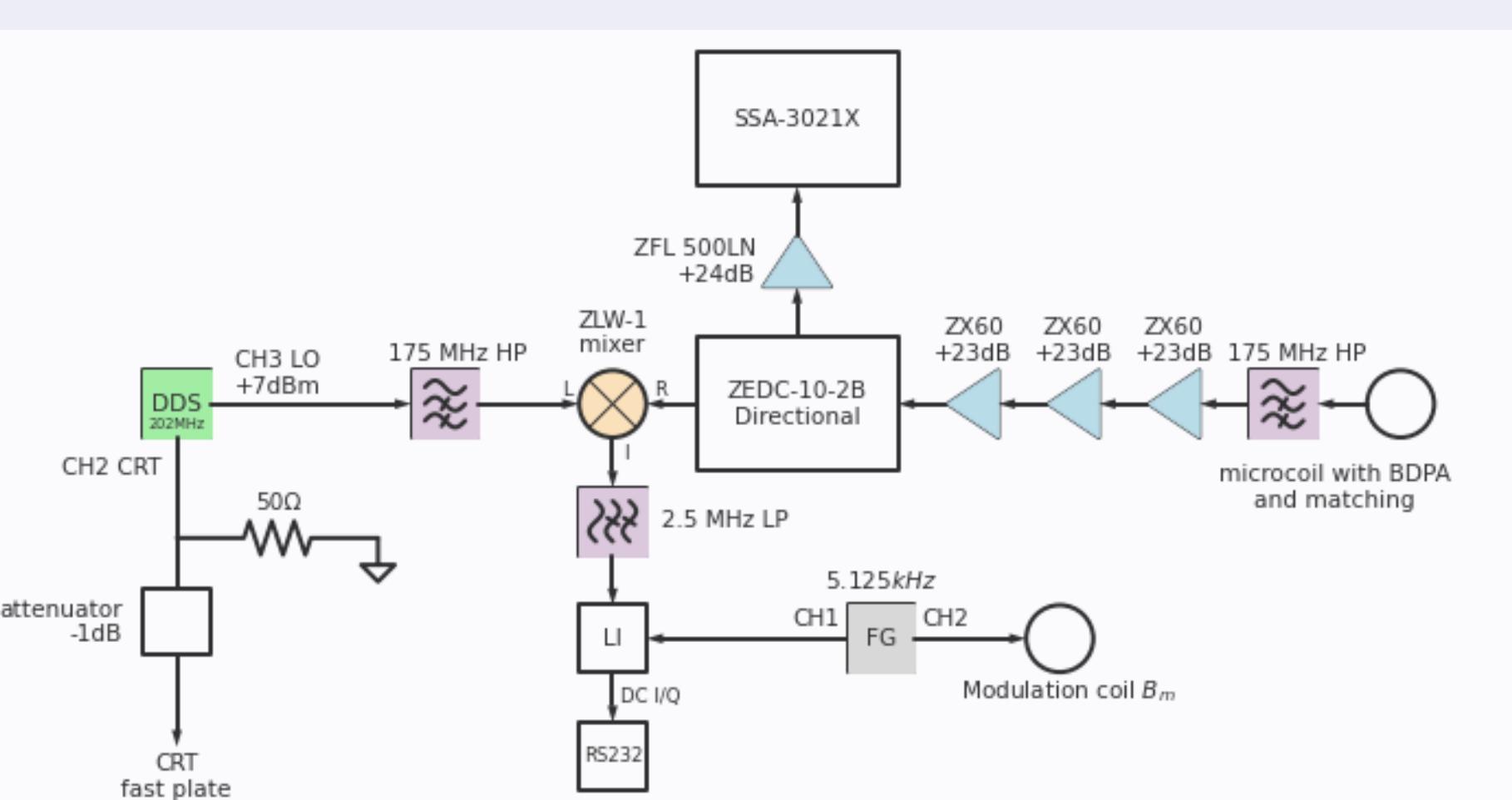


- Barium-Strontium cathode, electrostatic beam deflection. Current $\geq 10\mu A$ at up to 2.2kV.
- Modulation frequency $\approx 250MHz$
- Two cameras imaging phosphor screens
- Cooling with liquid nitrogen
- Vacuum $\leq 10^{-8}$ mbar

Readout and Radio Frequency Setup



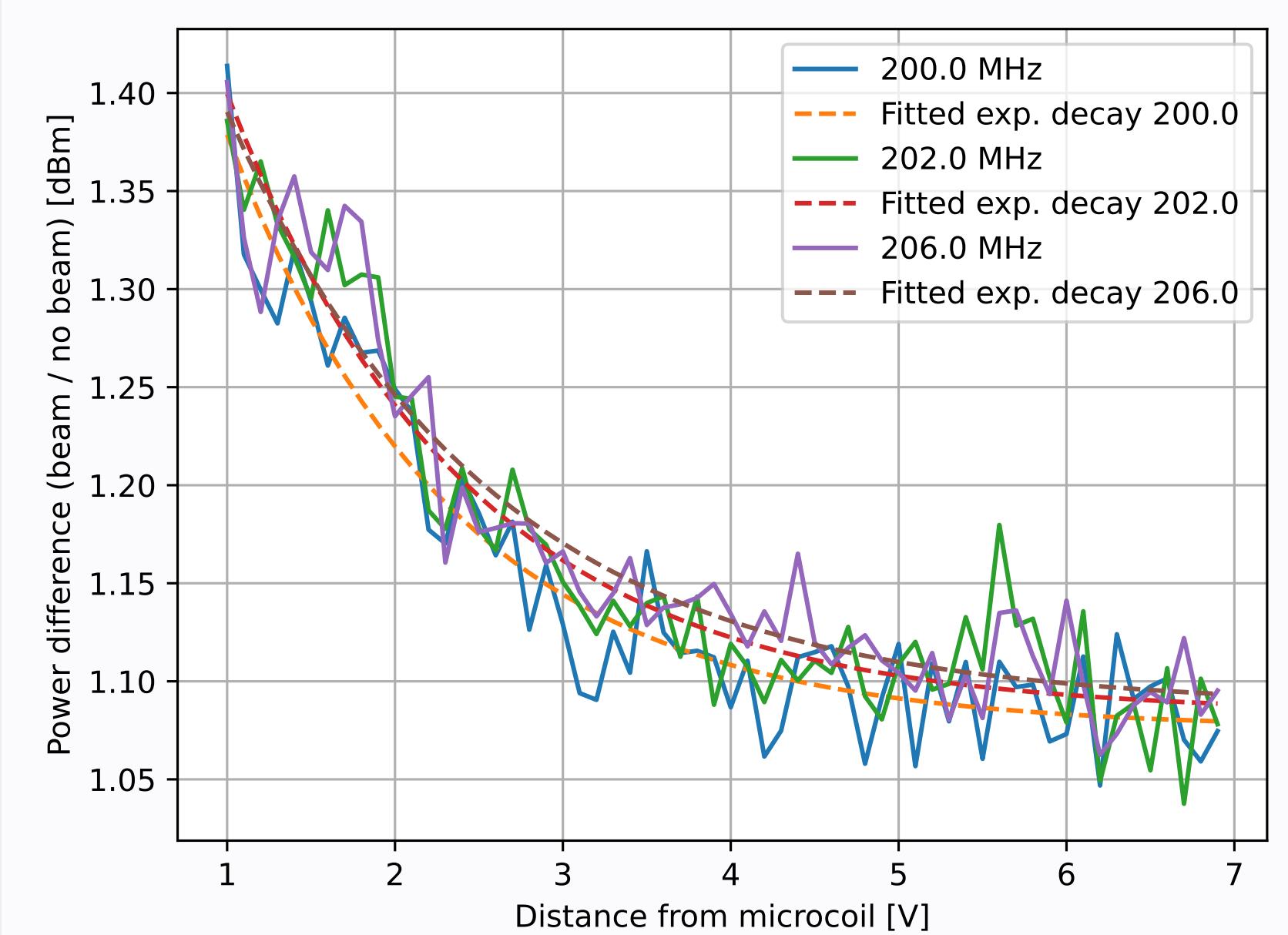
- Inductive readout by a microcoil on a printed circuit board (also including impedance match)
- Second microcoil for reference measurements
- BDPA inside microcoil (2 windings, 2.58 x 1.14mm outer diameter, 1.5 x 0.5mm sample area) in milled pocket



- Two independent channels of an AD9959 based DDS
- Applying 5.123kHz modulation field B_m parallel to B_0 for lock-in detection

First Runs at Room Temperature

- Electron beam at 2.2kV
- deflected at 202MHz
- Scanning distance to microcoil (*slow position*)
- Beam wiggled by B_m field
- Coupling of *near-field* into microcoil
- Shows $\frac{1}{r}$ behaviour (Biot-Savart law)



References & Acknowledgements

[1] D. Rätzel, D. Hartley, O. Schwartz, P. Haslinger, A Quantum Klystron - Controlling Quantum Systems with Modulated Electron Beams. *Phys. Rev. Research* 3, 023247 (2021)

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