ESR Stochastic Cooling Energy Variation

Machine Experiment, Jul 10th, 2025

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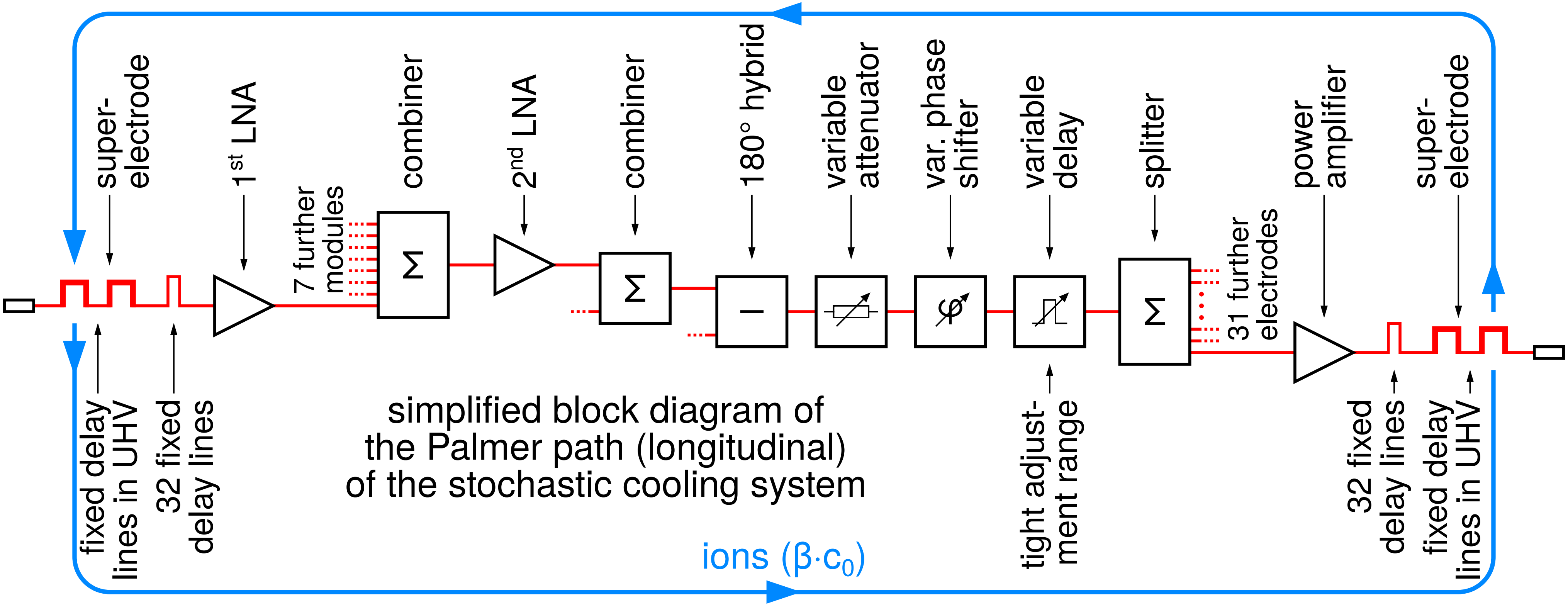
Dec 01, 2025

Present State of ESR Stochastic Cooling



- stochastic cooling of the ESR has been built for fixed energy of 400 MeV/u
  - this is good for stripping, but too high for some experiments
    → stochastic cooling at 400 MeV/u - deceleration with weaker electron cooling - experiment
  - fixed delay lines in the signal processing
    → upgrade with variable delays: needs a lot of engineering, but it is possible
  - fixed delay lines in the super-electrodes inside UHV
    → upgrade is not realistic

→ experiment: measure shunt impedance / BTF at different energies with existing electrodes

Machine Experiment

- Planned Measurement Program:
  - measurements of single pick-up module (4 electrodes)
    in sum mode (insensitive to beam position)
    at different beam energies from 200 to 400 MeV/u
  - measurement of Schottky signal using a spectrum analyzer
    → provides absolute shunt impedance data and noise temperature as by-product result
  - measurement of beam transfer function (BFT) using a vectorial network analyzer
    → provides phase data and relative shunt impedance

- Beam Time:
  - 238U 92+ coasting primary beam, injected at 400 MeV/u
  - deceleration down to 350, 300, 250, and 200 MeV/u
  - electron cooling at end energy
  - 3.1…17.7$\cdot 10^6$ Ions after deceleration

- Results:
  - all measurements could be successfully completed
    → 844 spectra data sets and 5 BTF transmission data sets
    all data is analyzable and interpretable

Shunt Impedance Measurement Principle

spectrum analyzer in ESR Cave:
152…191 spectrum measurements around harmonics of the revolution frequency for each ion beam energy

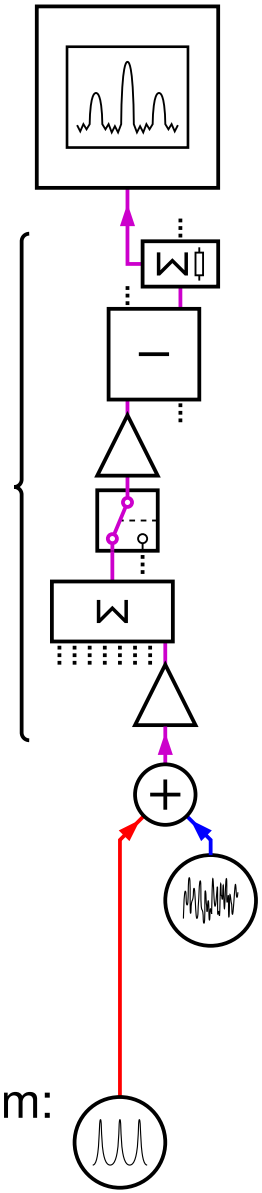
signal processing from super-electrode to spectrum analyzer:
measurement of transmission versus frequency (1501 points)

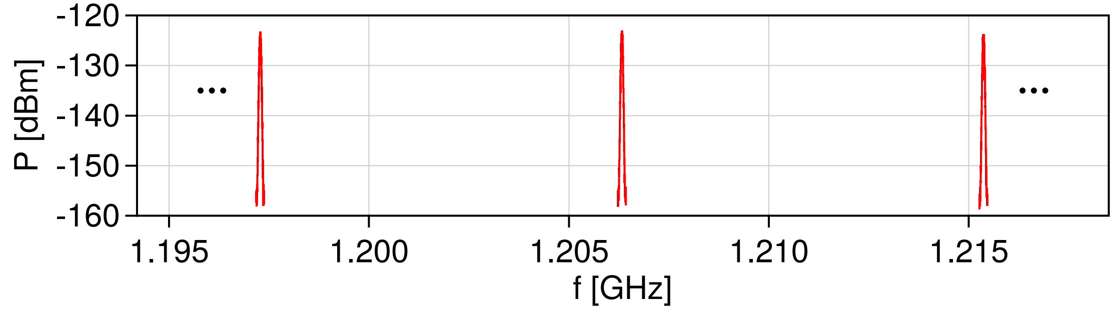
spectral noise power density of terminator and super-electrode:

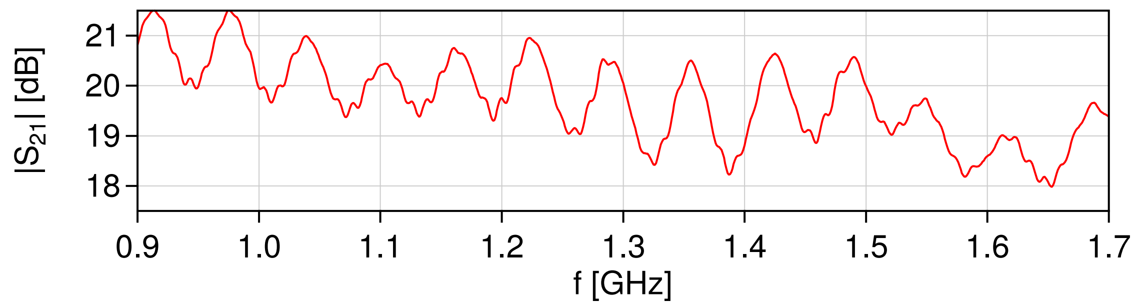
$$\frac{dP_{noise}}{df} = k_b \cdot T_{noise}$$

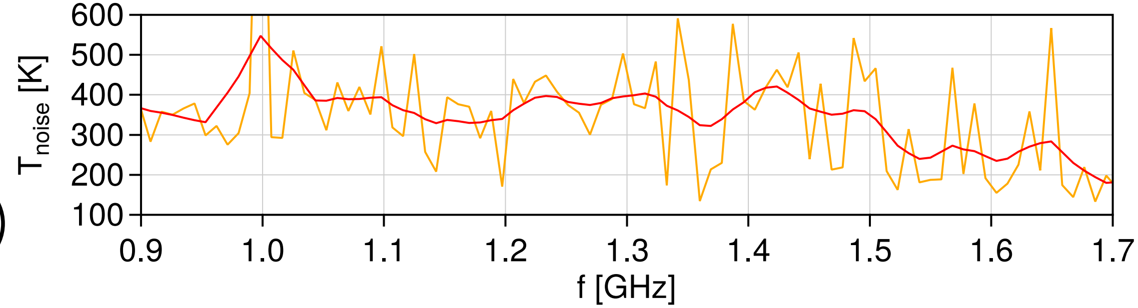
power of line in Schottky spectrum:

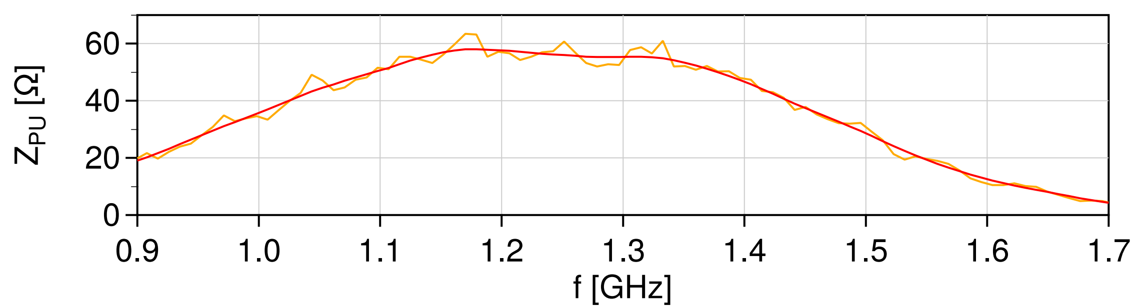
$$P_{Schottky} = 2 \cdot N \cdot (q_i \cdot f_{rev})^2 \cdot Z_{PU}$$





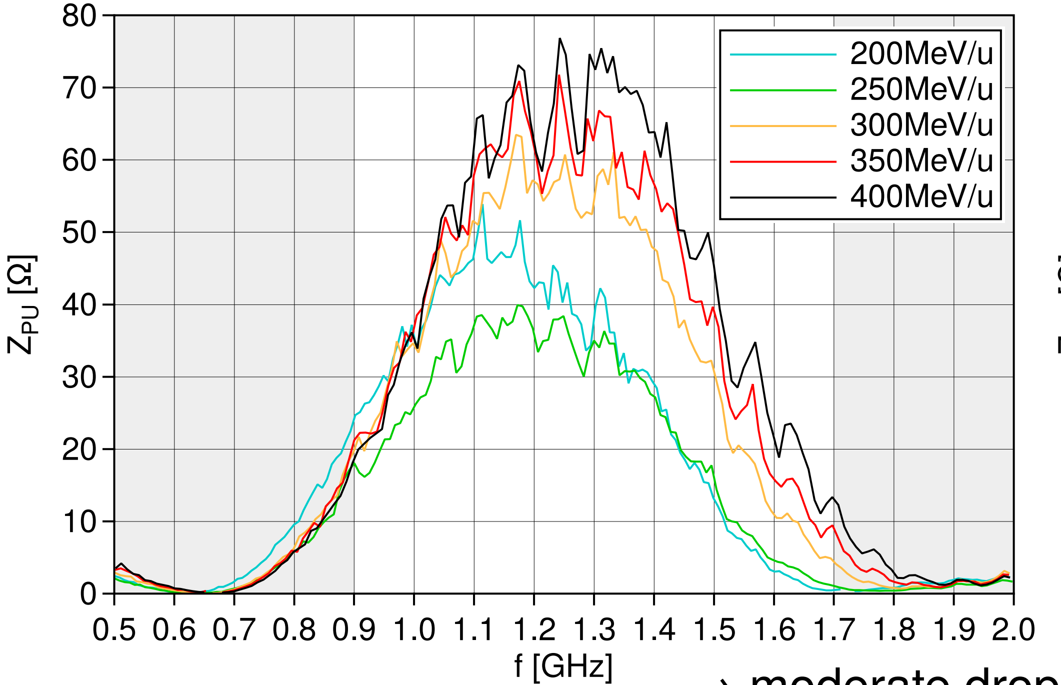




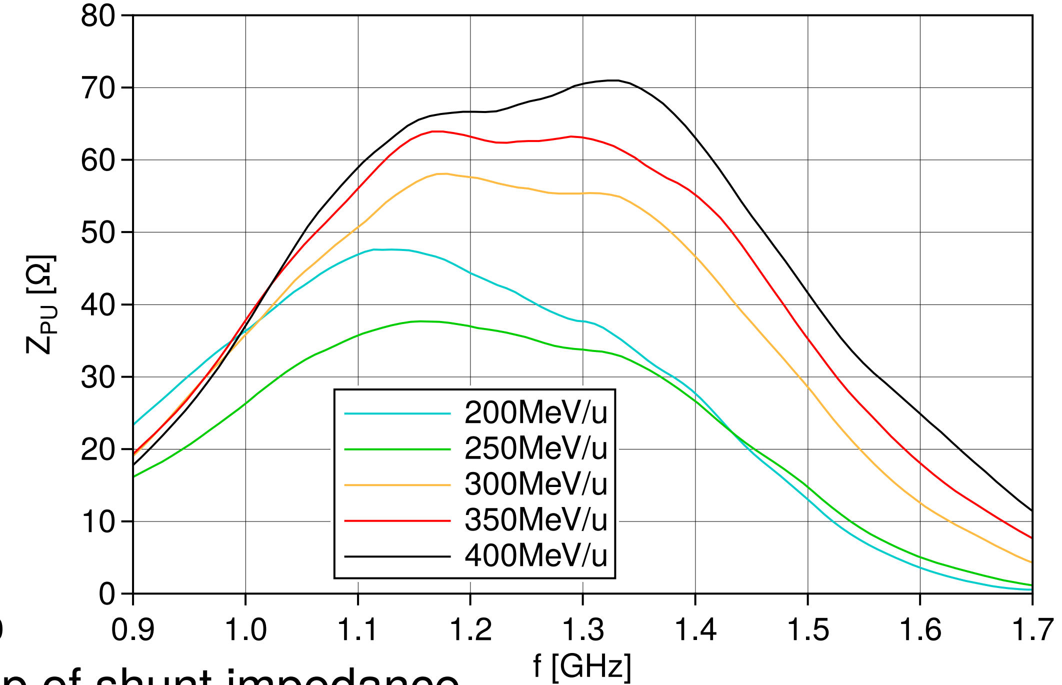


Measured Shunt Impedance

one module (4 electrodes) in sum mode:

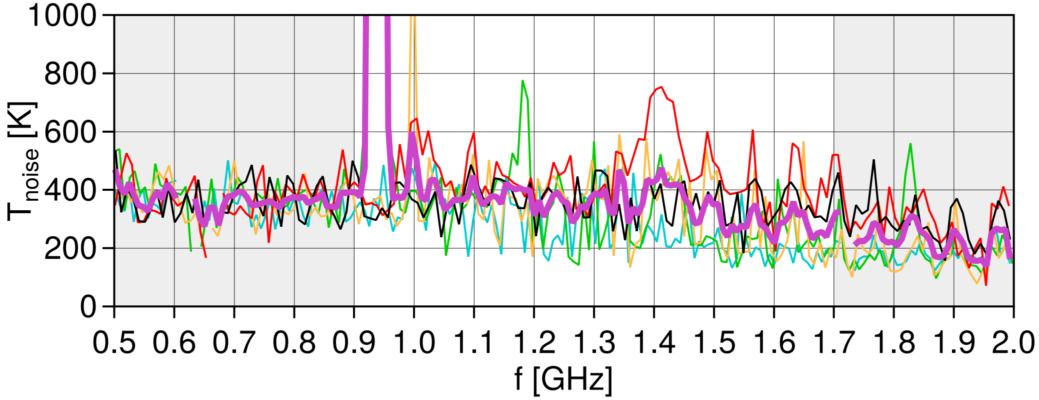


nominal frequency range, smoothed:

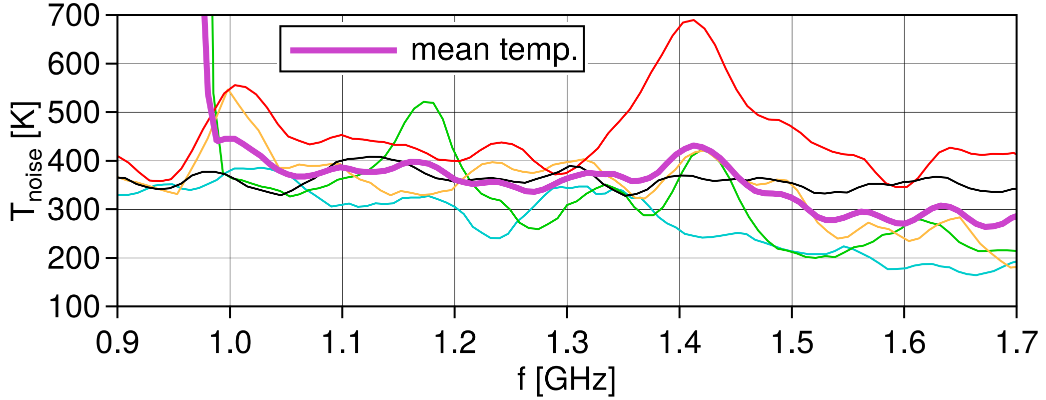


→ moderate drop of shunt impedance

noise temperature (by-product result):

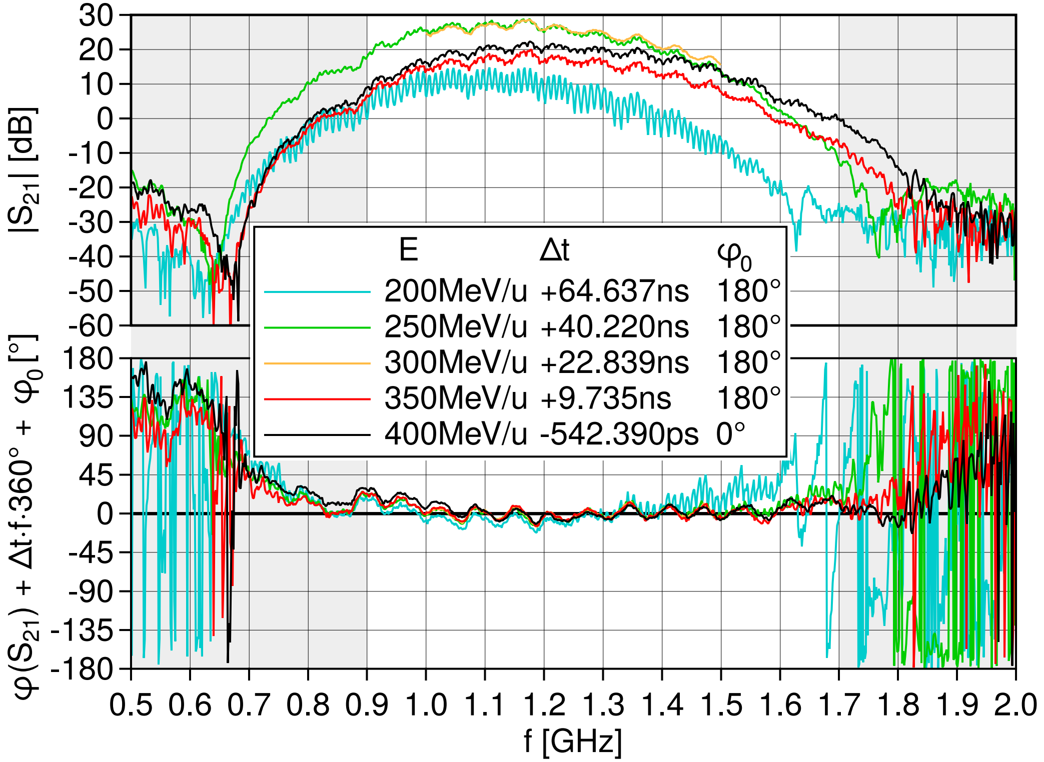


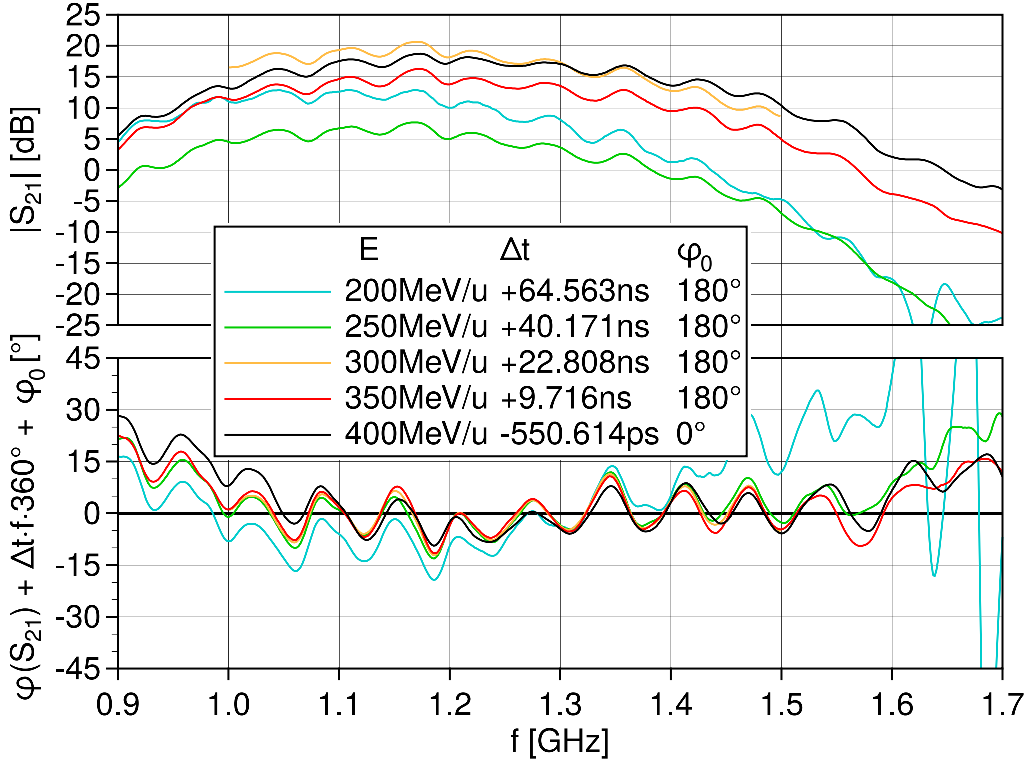
nominal frequency range, smoothed:



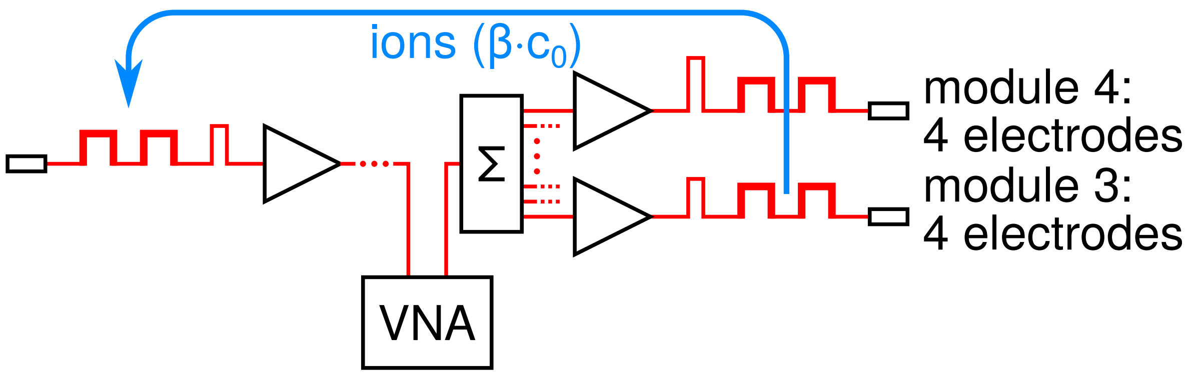
→ plausible measurement data, theoretical value is 349 K (room temperature + LNA noise)
the peak at 934 MHz is probably an irradiation from GSM-900 net

Measured Beam Transfer Function





- raw beam transfer function measurements
  - two kicker modules to one pick-up module
  - fixed delay line of module 3 has wrong length



- corrected and smoothed BTF in nominal frequency range
  - phase at 250…400 MeV/u is good
  - phase at 200 MeV/u is borderline, it could cause heating effects
  - transmission at 300MeV/u is strange, probably some wrong setting

Summary and Outlook

- Machine Experiment
  - The shunt impedance of a pick-up module has been measured for beam energies of 200, 250, 300, 350, and 400 MeV/u.
  - A BFT measurement has been done for each energy to get phase data.
- Energy Variation
  - From the point of shunt impedance, stochastic cooling with energies down to 200 MeV/u would be possible with the existing electrodes.
  - From the point of phase this would be possible down to 250 MeV/u. For 200 MeV/u, the phase is borderline and could cause heating instead of cooling.
- Outlook
  - To really use the stochastic cooling for lower energies, many components of the signal processing has to be replaced. It is possible, but a lot of engineering would be needed.
  - The fixed delays has to be replaced by a combiner with switchable delays on each input. A β-switch, similar to a device, designed for the CR could be designed. For acceptable noise temperatures, each LNA behind the old combiners has to be replaced by 8 LNAs in front of the new β-switches. Also the driver amps should swap to the other side.
  - The variable delay has to be replaced by a new one with a much wider adjustment range.
  - There is no proposal or decision to go in this direction.