Dual H&D Cavity for the PAX Target Polarimeter

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- PAX polarimeter - requirements
- Tuned twin lines - principle of operation
- Technical realization and test
- Conclusions

Overview of the PAX target

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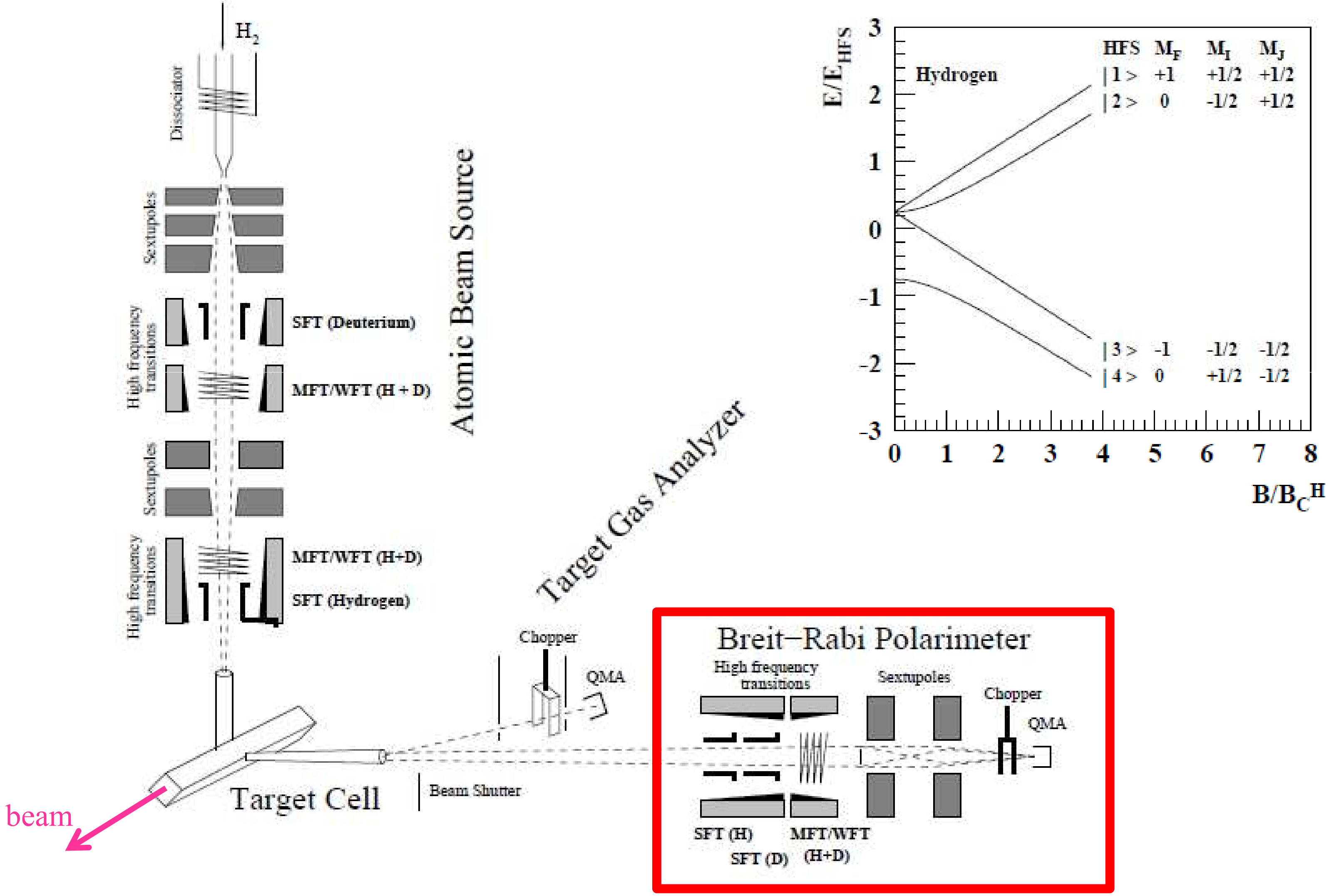
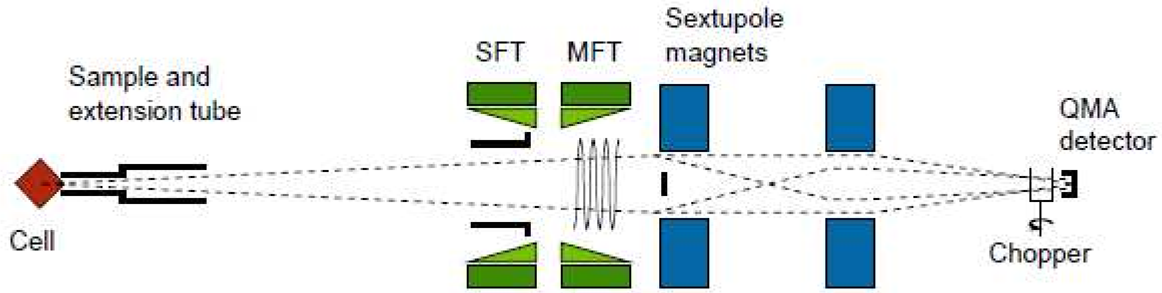
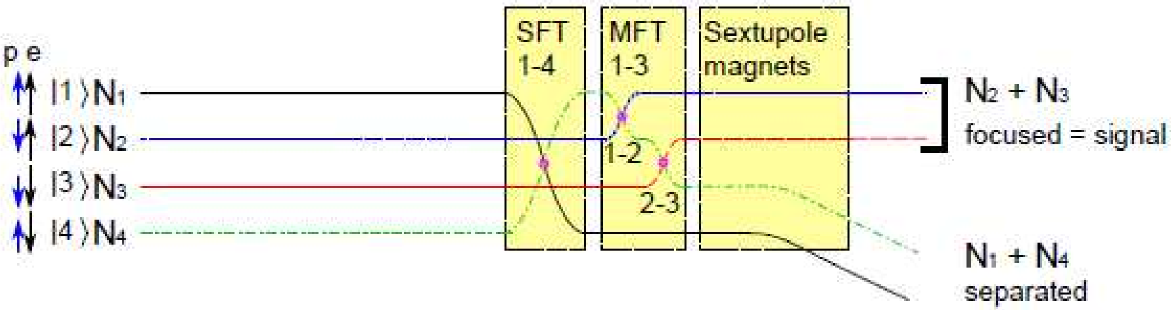
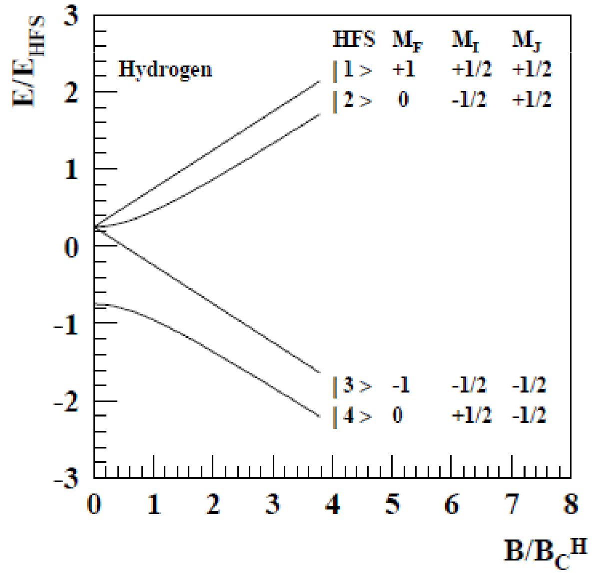


Principle of the Breit-Rabi Polarimeter



- SFT, MFT = RF-transitions
- Sextupoles for state selection
- QMA with chopper and single-ion counting





By measuring many combinations of hf states one can extract all four hydrogen occupation numbers $N_1 - N_4$
→ nuclear polarization

"Adiabatic" Rf transitions

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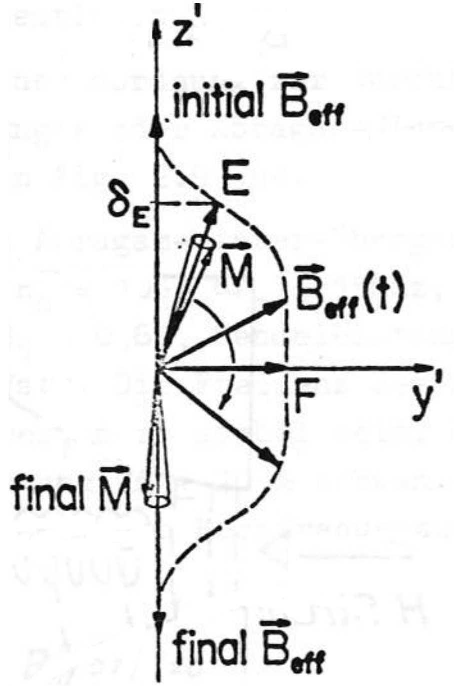
Required:

- RF field with appropriate orientation of oscillating B field
- Static B field (usually transverse to atomic beam, AB) with adjustable gradient

→ adiabatic passage through resonance enables 100% efficiency [for the exchange of hf states (Abragam & Winter 1958)]

Semi-classical picture of the adiabatic rf-transition: the magnetization M is reversed during passage of the resonance (taken from Haeberli 1967), resulting in $m_F \leftrightarrow -m_F$



z' = z, y': rotating system

Generation of RF fields

Low frequency [≤ 50 MHz]:

solenoid coil with axis || to AB axis (field longitudinal)

Implies $B_{RF} \perp B_{stat}$, i.e. $\Delta m_F = \pm 1$, and $\Delta F = 0$ (± 1 not possible at low frequency).

→ Used for WFT = weak field transition $m_F \leftrightarrow -m_F$, MFT = medium field transition = incomplete WFT.

High frequency [e.g. ≈ 330 MHz for deuterium (D), 1430 MHz for hydrogen (H)]:

tuned twin lines!

Example of a "strong field" transition SFT

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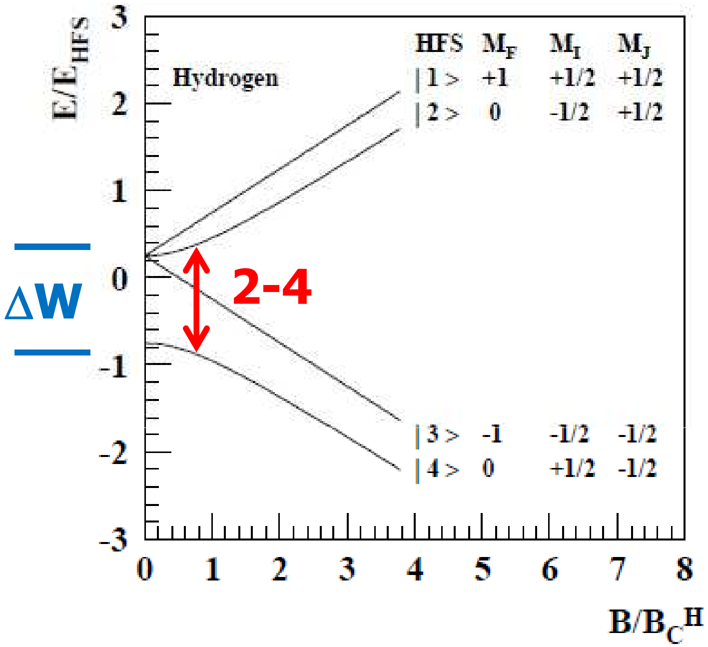
Note: "Strong field" purely historical!

Better: "Two-level transition"



Species	ΔW / h [MHz]	$B_{critical}$ [mT]
Hydrogen	1421.4	50.7
Deuterium	327.4	11.7

Two-level transitions ($\Delta F = 1$): level spacing is of the order ΔW

- RF fields in the range 100 MHz to few GHz are produced by means of resonating structures. Most flexible: a resonator, e.g. a $\lambda/4$ rod, in a conducting Cu box. Results in Q ≈ few 100.
- The length of a $\lambda/4$ rod is 5.3 cm for hydrogen (H) and 23 cm for deuterium (D). While for H such a rod fits to the length of a rf transition, it has to be reduced for D.

Tuned Twin Lines

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- In the early days: standard method for atomic beam resonance machines
- Improved version: tuned twin lines in a conducting box, e.g. silver plated for higher Q (used at ORNL, ANAC/Glavish, PSI/Basel group)

Example: 300 MHz resonator of the polarized Lithium source at MPI Heidelberg [Steffens et al., 1977]

Two $\lambda/2$ strip lines, excited by coupling loop; rf field monitored by pick-up loop at the center.

Two "open ends": $\lambda/2$ resonator with maximum voltage amplitude at the ends, and current maximum in the center (virtual ground).

One end grounded: $\lambda/4$ resonator; works as well.

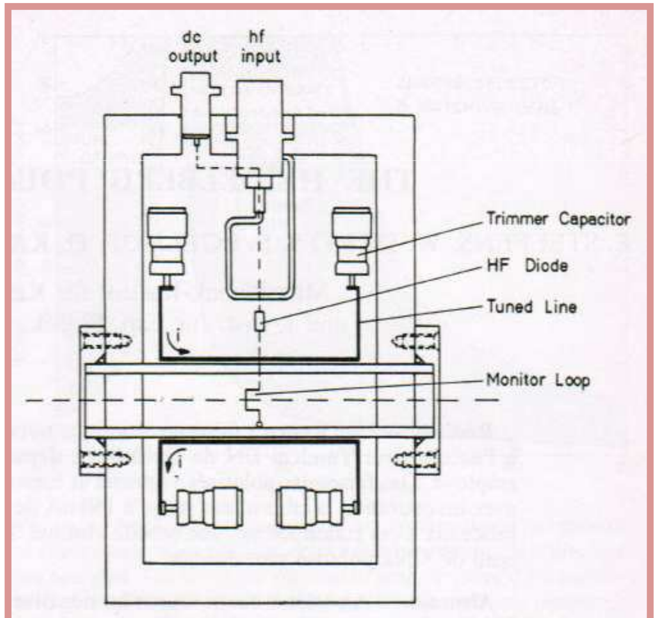

FIG. 3. — 300 MHz-resonator for the production of the dynamic field. The length of the tuned line is 4 cm.

Principle of the Twin-Line resonator

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(taken from Doctoral Thesis D. Kassen, Heidelberg 1977)

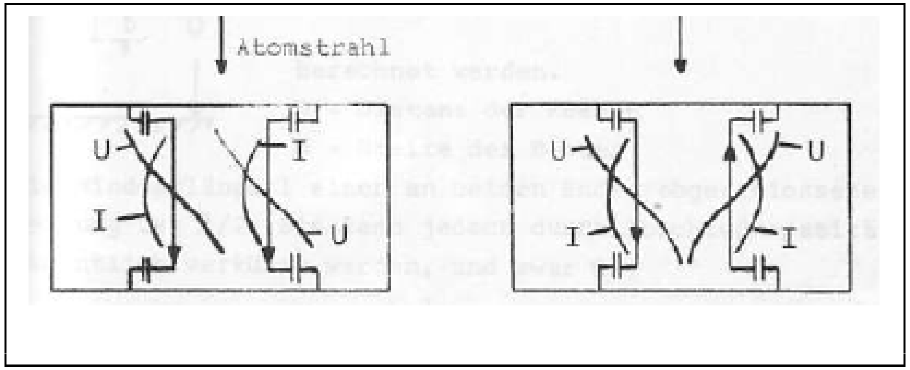
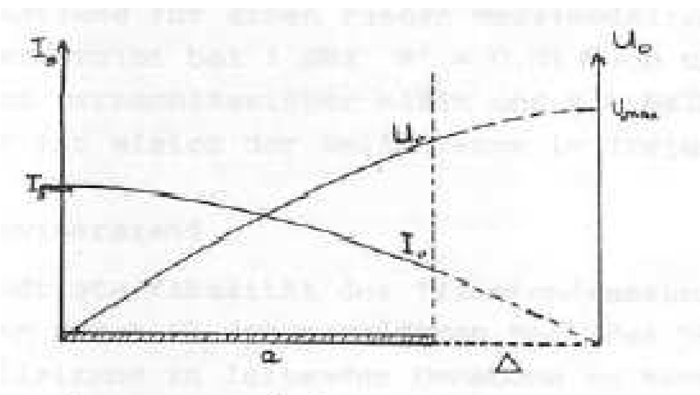
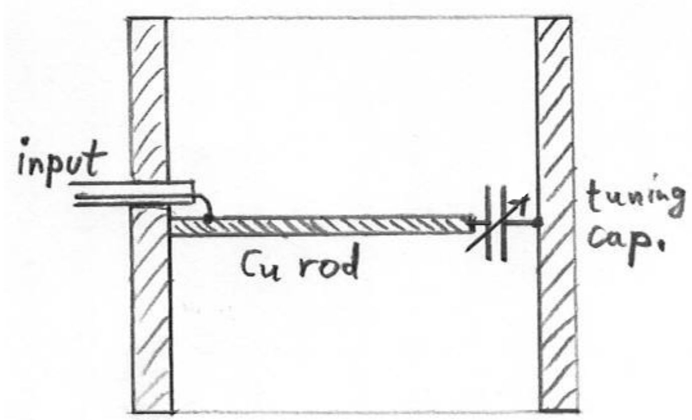


Figure 1: Principle of Twin-Line resonator, here of the $\lambda/2$ type. The a n passes vertically on the centerline between the two lines. The voltage and current distributions are indicated (left: common mode = push-push mode, right: counter mode = push-pull mode). The Counter Mode results in a non-zero field at the centerline (wanted!) [1].

The $\lambda/2$ twin line is excited by means of a coupling loop, as shown before. A simpler twin line resonator consists of two coupled $\lambda/4$ resonator with a grounded end and an open end with load capacity to ground, in order to tune the frequency at a fixed length. The coupling is done here simply by galvanic coupling to one of the rods close to ground.

Tunable λ/4 resonator





Conducting rod of length a grounded at the left corner. The voltage and current distribution of a ficticious rod of length $\lambda/4 = a + \Delta$ is shown. The difference Δ is accounted for by a load capacity between the end of the rod and the ground to the right.

The quantity Δ is given by: $\boldsymbol{\Delta = (\lambda_R / 2\pi) \arctan(\omega C Z_L)}$

with
- λ_R = wavelength on the line resonator (in good approximation equal to $l_{free\text{-}space}$)
- ω = resonance angular velocity
- C = capacity between end of rod and ground
- Z_L = impedance of rod resonator

This expression can be used for estimating the load capacity C.

Effect of a tilted twin line plane

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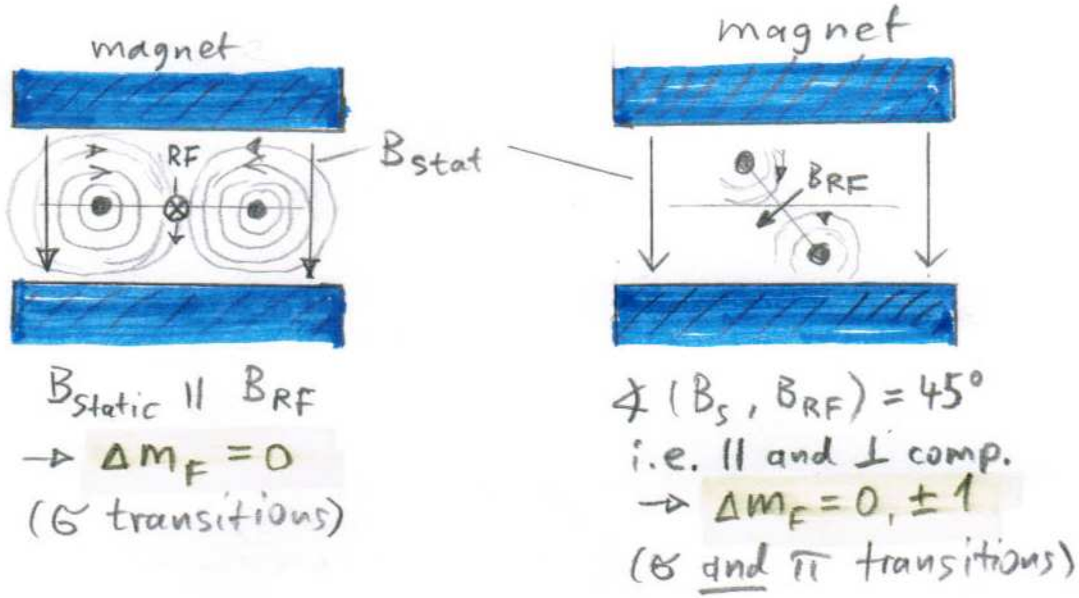
By tilting the normal of the twin line plane from parallel to B_{stat} to 45°, one has both parallel and perpendicular components of the RF field with respect to B_{stat} , i.e. $\Delta m_F = 0$ and ± 1 are enabled. This is important for Deuterium (F = ½ and 3/2) in particular.

no tilt



tilted

A tilted plane also provides space for an additional pair of lines!

Dual H&D cavity – tilted planes

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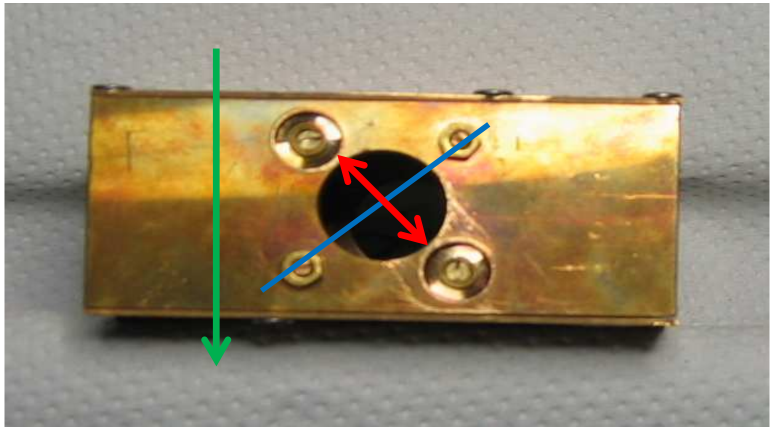
Cavity seen along AB direction

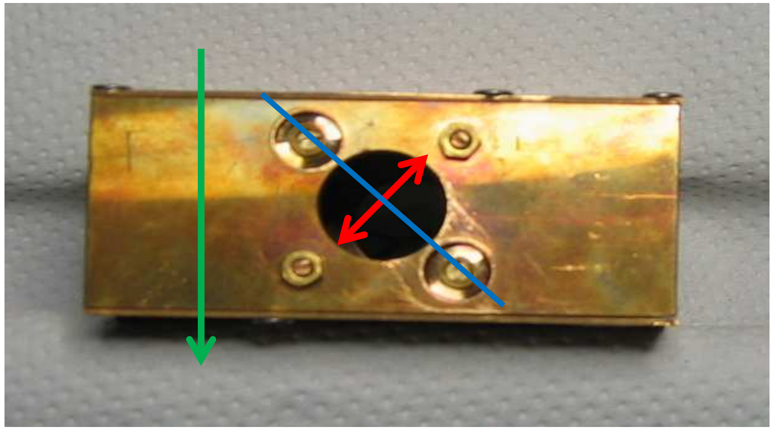
Plane of Deuterium twin line

Oscillating field B_{RF}, static field B_{Stat}

→ Both parallel and perp. components, i.e. σ and π transitions can be excited!



Same for Hydrogen twin line



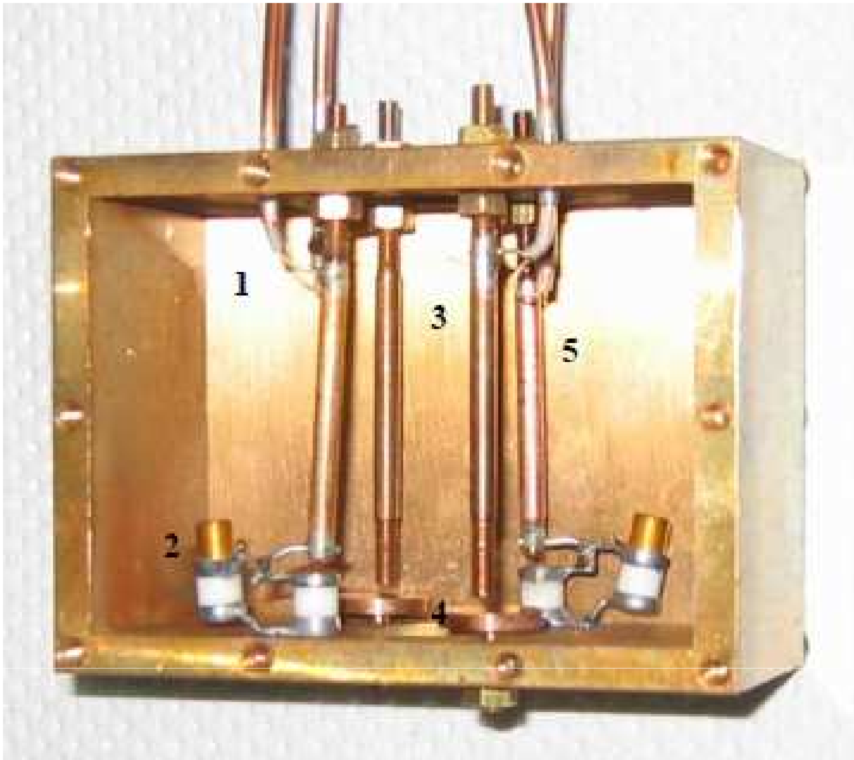


Photo of the Dual Cavity The upper wall is removed. The atomic beam axis is (approx.) vertical. The two pairs of rods (H & D) are arranged in two planes, tilted by ± 45° to the plane of paper. **1:** Upper left D rod with grounding point and galvanic coupling to the power cabel. **2:** Free end of D rod loaded by a set of two trim capacitors (the left one set to a fixed value, the right one screwed to the wall and tunable from outside) which are needed to reach the required capacity of about 10 pF. **3:** Upper right H rod with grounding point and coupling. The rod can be tuned by means of a screw inside the bottom wall which points to the free end of the rod. **4:** Ends of the H rods and tuning plates. **5**: Fixed pick-up loops are located at each uncoupled rod close to the grounding point, the D loop is visible below .

Dual H&D cavity – different views

LEFT

top: grounded ends of the rods with galvanic coupling and pick-up loops;

bottom: tuning capacitors

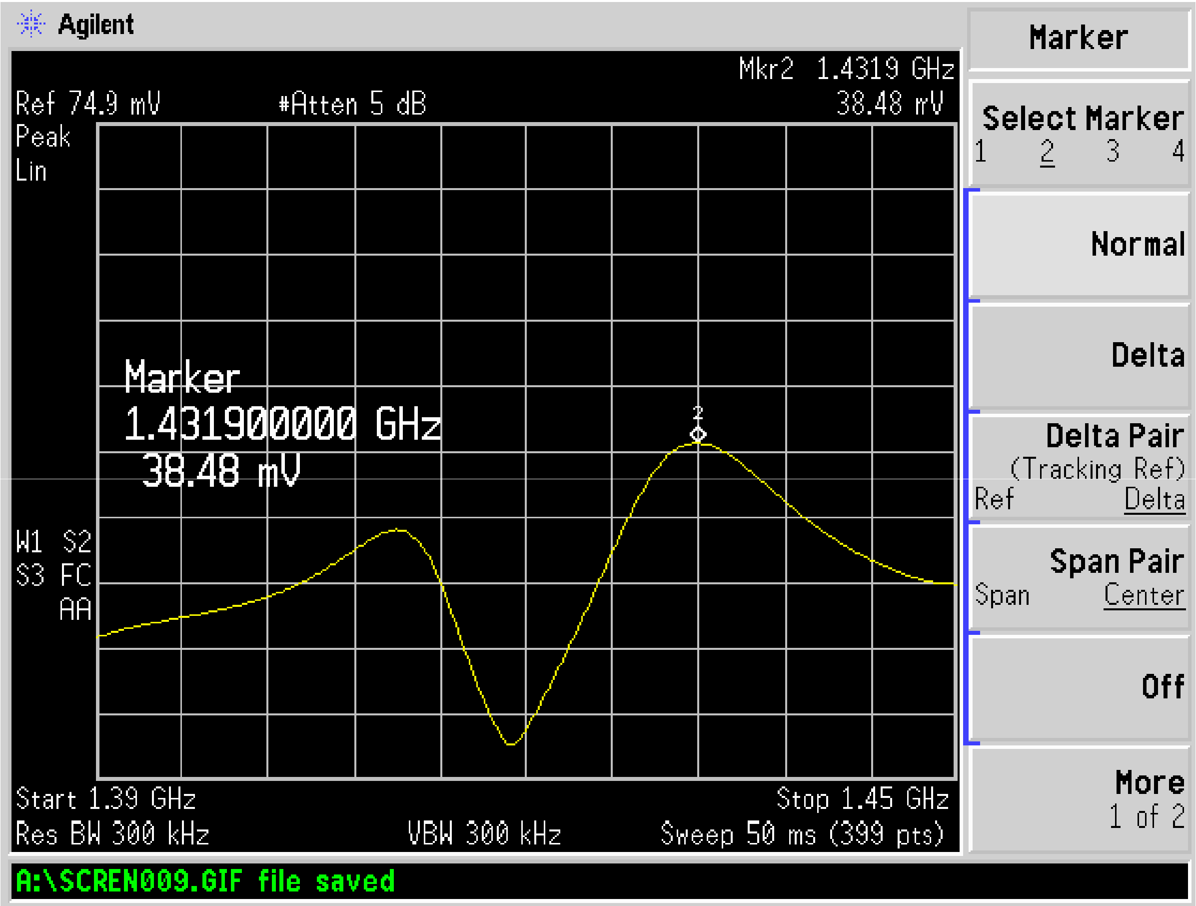
RIGHT

top: open ends of the rods with tuning capacitors

bottom: micro coax lines

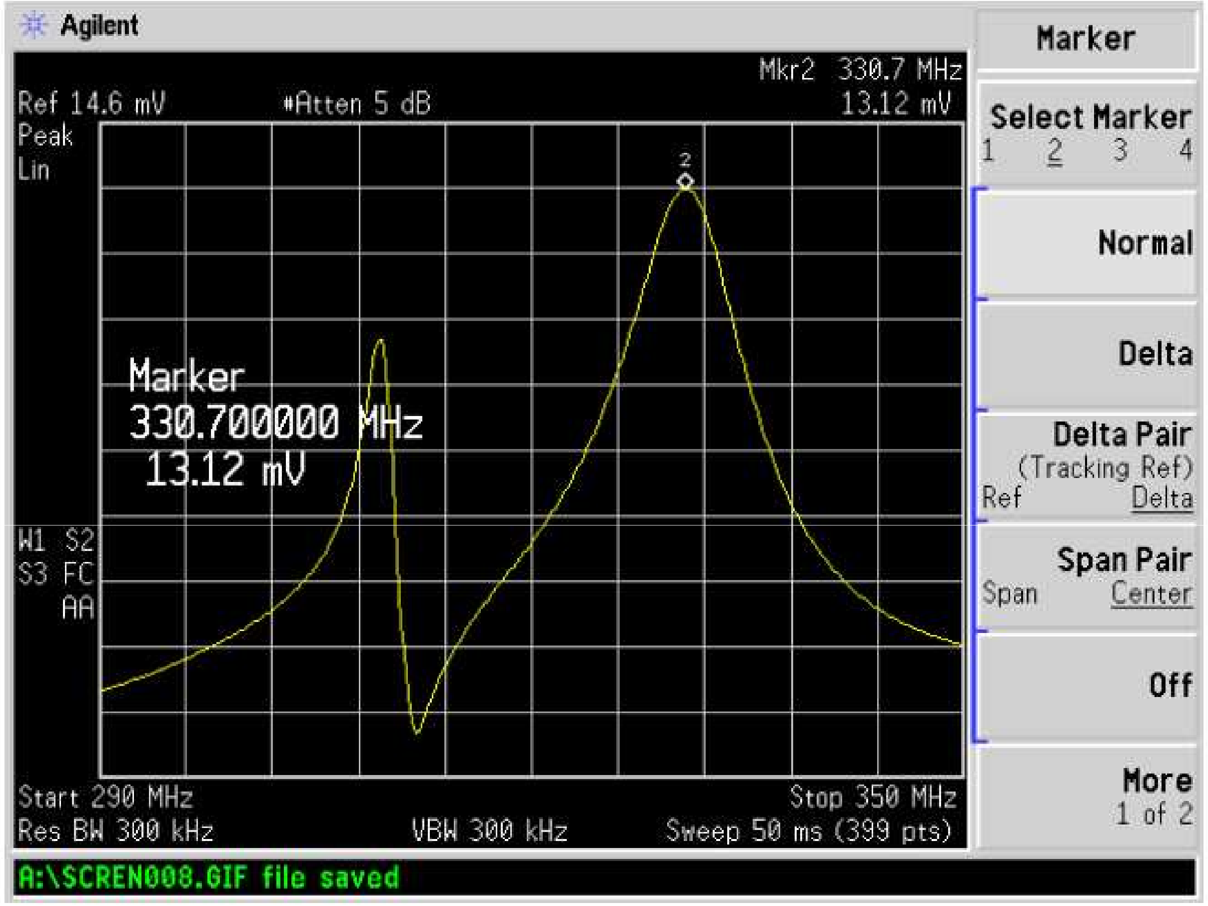
Tuning of the resonators and result

The frequency scans were performed by means of a Network Analyzer (Agilent E 4402B).



Hydrogen Scan of the hydrogen resonator between 1.39 and 1.45 GHz. The vertical linear scale shows the PU voltage of the fixed coil placed near the grounded end of the uncoupled H rod (see Fig. 3 and 8). The upper peak at 1.432 GHz corresponds to the required counter mode, the lower one to the common mode.

Tuning of the resonators and result



Deuterium Scan of the deuterium resonator between 290 and 350 MHz. The vertical linear scale shows the PU voltage of the fixed coil placed near the grounded end of the uncoupled D rod (see Fig. 3 and 8). The upper peak at 330.7 MHz corresponds to the required counter mode, the lower one to the common mode.

Test results for the Dual cavity

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Hydrogen twin line

With 3 – 5 W of RF power, a field amplitude of 0.06 – 0.1 mT has been obtained. This results in 30 – 60 precessions of F around the RF field component which ensures adiabatic passage conditions.

Deuterium twin line

Up to now, tuning only of the twin line has been performed. The full test requires a power amplifier for the 350 MHz-range, which were not available at the time of the test.

Conclusions

- A tuned twin line dual cavity has been developed which works both on Deuterium and Hydrogen frequencies in the “tilted“ mode, i.e. all possible two-level transitions can be excited.
- The cavity has been tested electronically using a Network Analyzer. For hydrogen a sufficient RF field strength has been demonstrated. The deuterium twin line is still to be tested, but no problems are to be expected.
- The cavity will be installed soon at the Jülich PAX target and tested with atomic H&D beams.

Thank you!