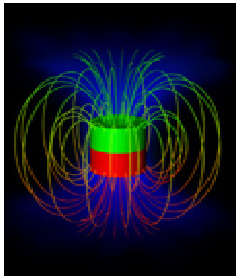
Progress Report 2013

Stefan Ulmer

RIKEN / BASE

SPSC Meeting 2014/01/14

BASE



Mainz

CERN

$$\vec{\mu}_{p/\bar{p}} = g_{p/\bar{p}} \frac{q_{p/\bar{p}}}{2 m_{p/\bar{p}}} \vec{S}$$

Direct high precision measurements of the

PROTON **ANTIPROTON**

magnetic moments

μ_p = 2.792 847 357(23) Winkler et al. (1972)

μ_{pbar} = 2.792 845(12) diSciacca et al. (2013)

μ_{pbar} can be improved by at least three orders of magnitude

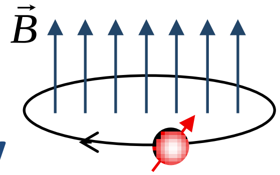
Principle

- Magnetic moment is measured using a single particle in a Penning trap.

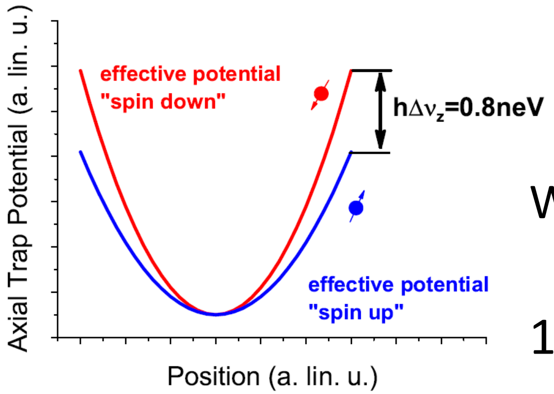
$$g = 2\frac{\omega_L}{\omega_c} = 2\frac{\nu_L}{\nu_c}$$

Larmor Frequency

Cyclotron Frequency



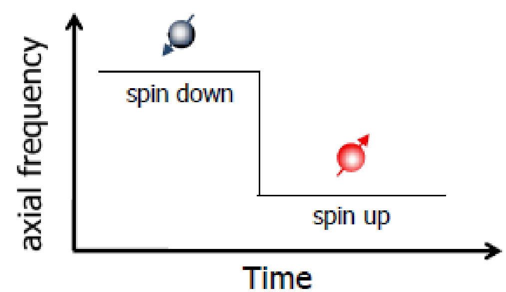
- Strong magnetic inhomogeneity is used to detect the (anti)proton's spin state



$$\Delta\nu_z \sim \frac{\mu_p B_2}{m_p \nu_z} := \alpha_p \frac{B_2}{\nu_z}$$

We use: $B_2 = 300000\ T/m^2$

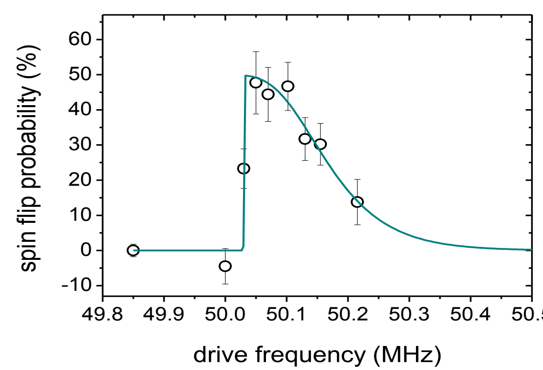
171 mHz out of 740 kHz



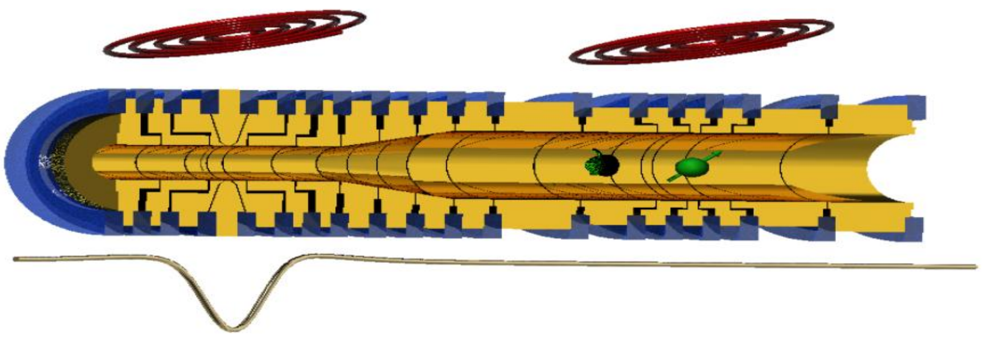
- Magnetic bottle broadens spin-line and limits precision

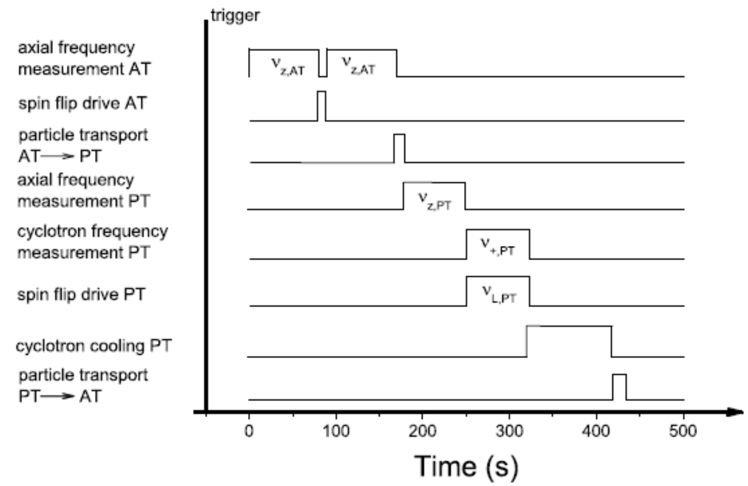
Mainz: 1.8 ppm

Harvard: 1.7 ppm



Double Trap Technique





narrows the width of the spin-line by factor of > 1000

requires spin state detection with high fidelity

very difficult

The Challenge

Typical axial frequency: 700 kHz

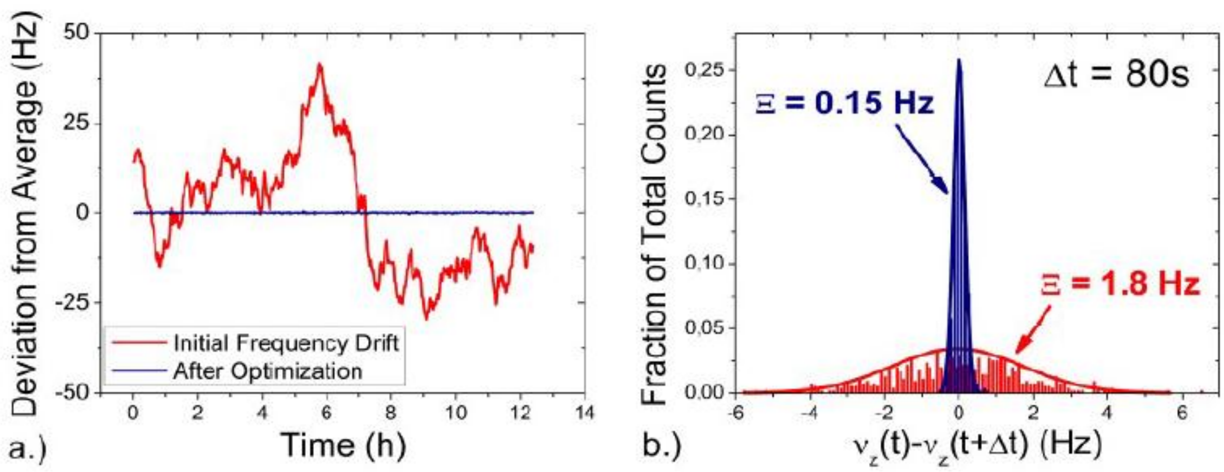
$$\Delta\nu_z \sim \frac{\mu_p B_2}{m_p \nu_z} := 0.4 \cdot \mu Hz \cdot B_2$$

We use: $B_2 = 300000\ T/m^2$

171 mHz out of 740 kHz

Magnetic bottle coupling: $\Delta\nu_z = \frac{1}{4\pi^2 m \nu_z}\frac{B_2}{B_0}(dE_+ + dE_-)$ -> 0.9 Hz/µeV

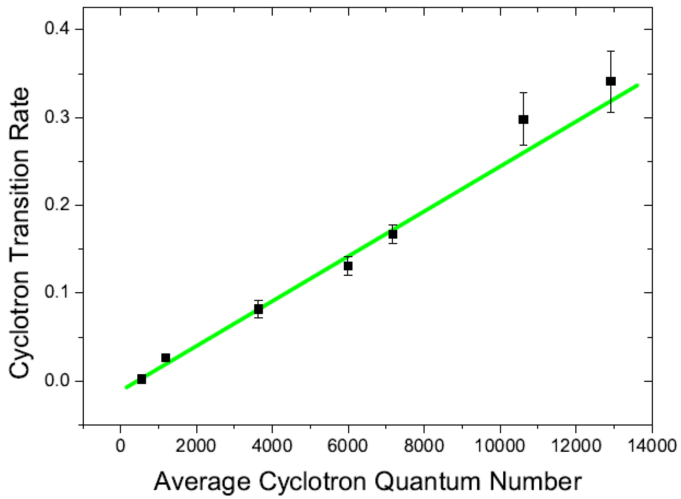
One cyclotron quantum jump (56 neV) shifts axial frequency by 63mHz

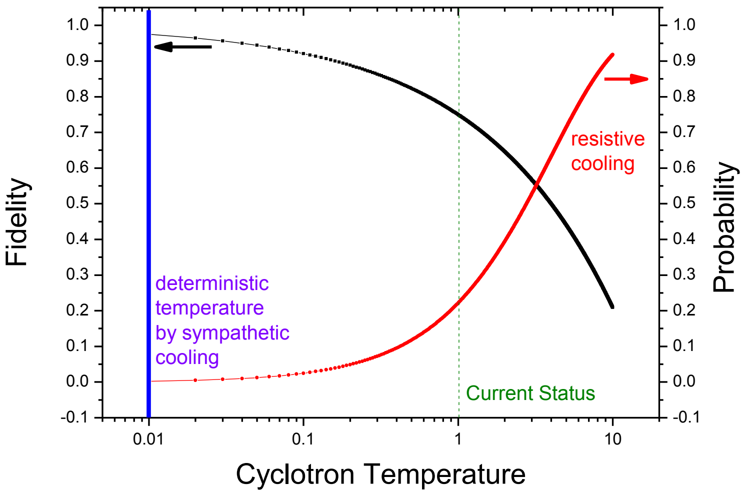


corresponds to 200pV/Hz$^{1/2}$ of white noise on electrodes (50 Ohm @ 300K -> 1nV/Hz$^{1/2}$)

Heating Rates

Heating rates, and thus, stability scale with cyclotron quantum number.

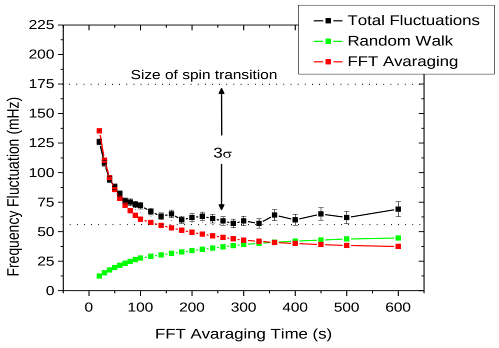




$$p_{n\to n\pm 2} = \frac{q^2}{4m_{\mathrm{P}}^2\,\omega^2}(n+1\pm 1)(n\pm 1)\,\underbrace{\int_{\mathbb{R}} \mathrm{d}t'\,\mathrm{e}^{\pm 2\mathrm{i}\omega t'}\left\langle E^{(1)}(t)E^{(1)}(t+t')\right\rangle}_{S(\pm 2\omega)}$$

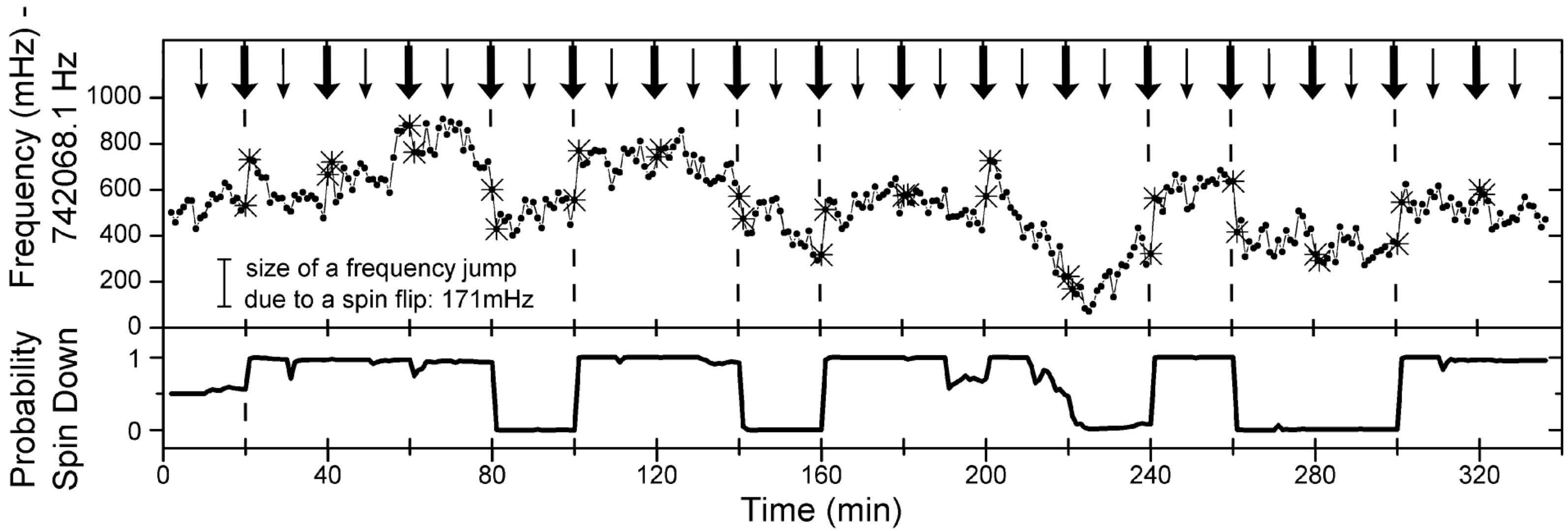
Resolution of Single Spin Flips

- Significant improvement of noise on apparatus
- Application of a Bayesian filter (conditional probability)



Update of state probability given complete frequency, noise and previous state information

Fidelity: fraction of correctly assigned spin states in a series of measurements



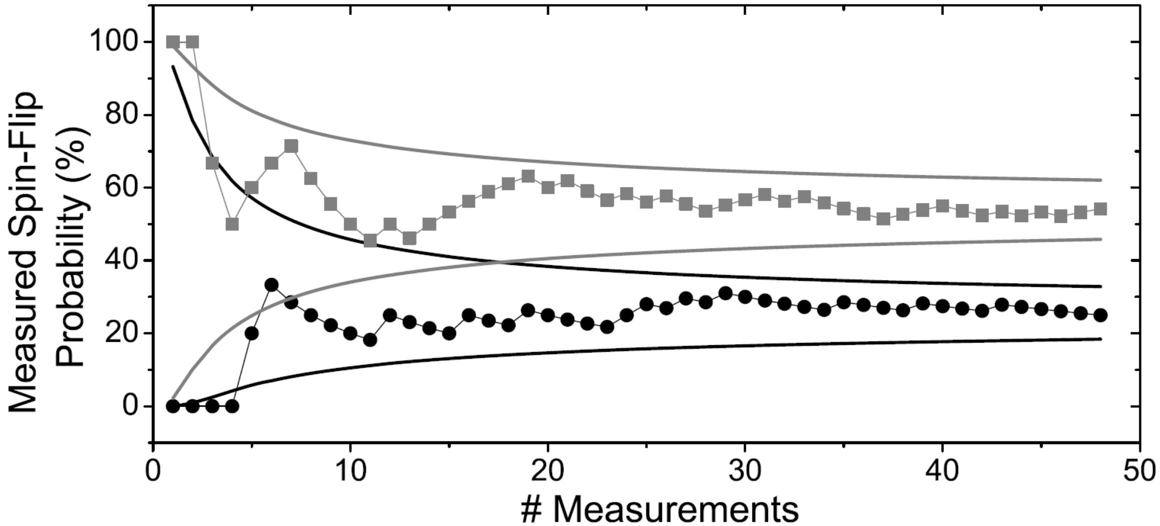
A. Mooser, K. Franke *et al.* Phys. Rev. Lett. **110**, 140405 (2013)

DiSciacca *et al.* Phys. Rev. Lett. **110**, 140406 (2013)

Double-Trap: First Demonstration

Spinflips driven in the precision trap and detected in the analysis trap

Saturated resonance for first on/off proof of principle



50% - saturation

25% - due to limited fidelity

A. Mooser, S. Ulmer *et al.* PLB **723**, 78 (2013)

Next step: scan frequency, measure g-factor resonance

Preparation time of 2h to 3h for each data point.

Limited fidelity due to axial frequency noise.

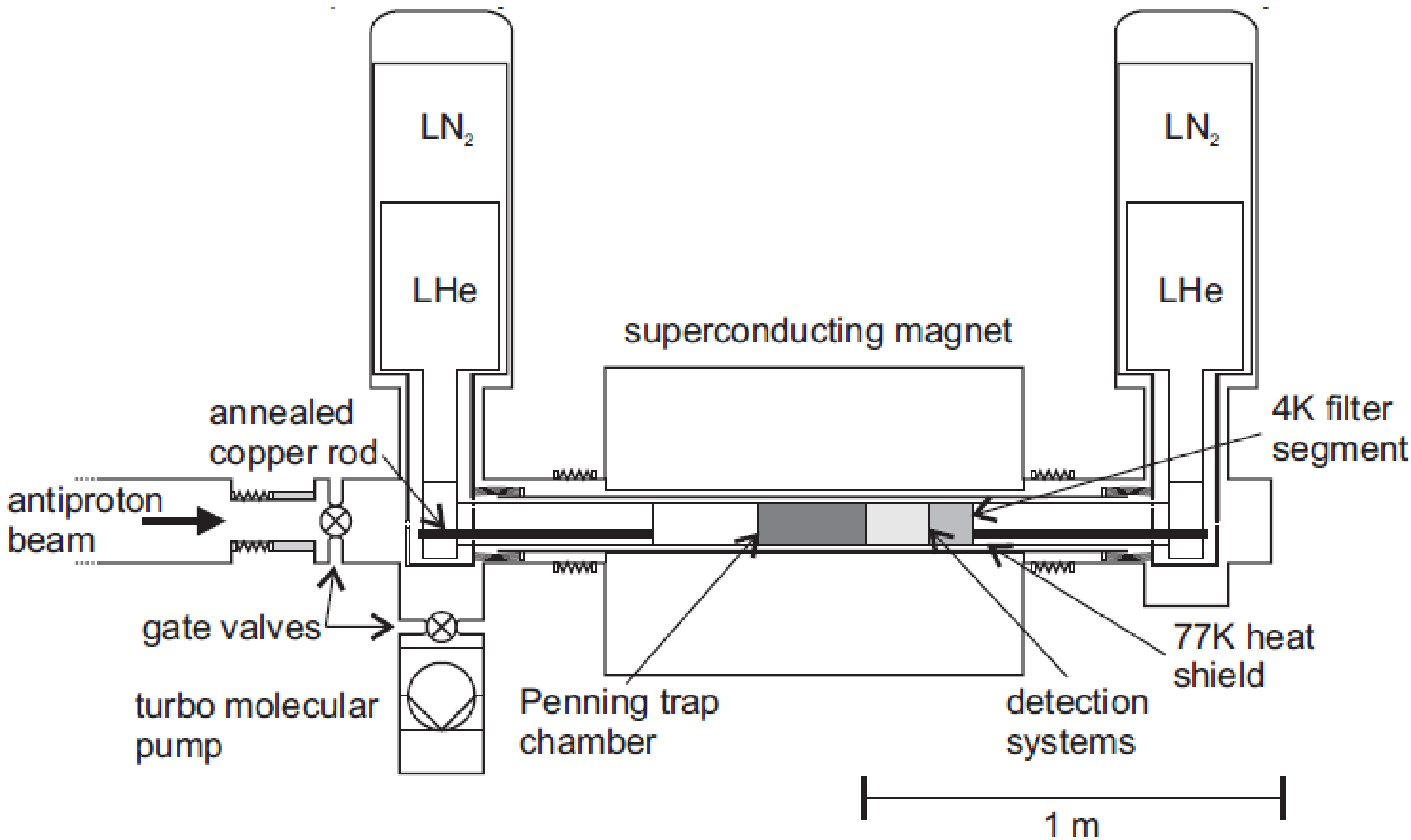
3 months per resonance

Strategy BASE-CERN: faster cooling / faster frequency measurements

CERN

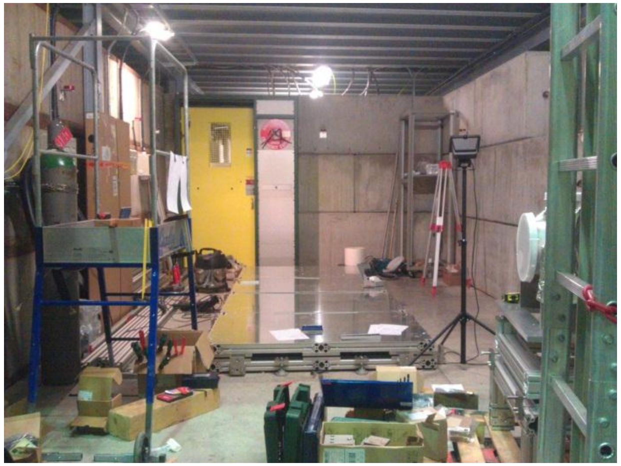
Experiment was approved in June 2013

BASE Experiment at CERN



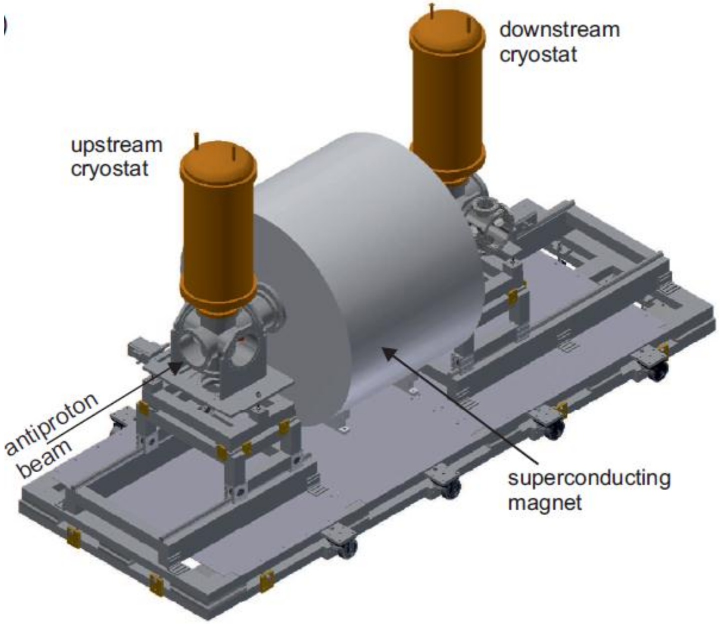
Status Core Experiment

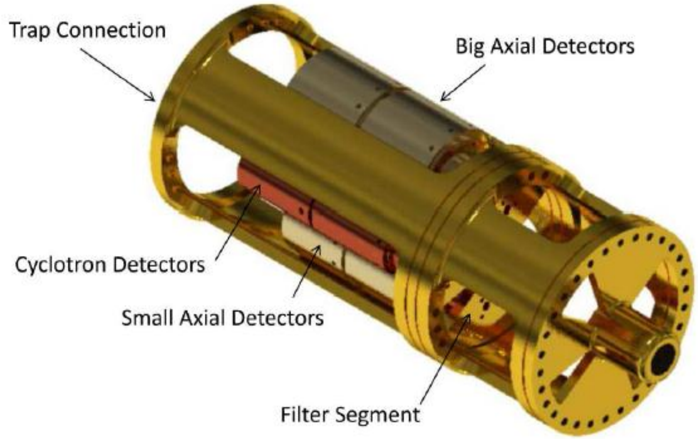
- **Experiment zone:** Provided by CERN (2013/10)
- **Experiment frame (Mainz):** Constructed, machined, assembled in the zone
- **Cryostats:** delivered, installed and tested
- **Cryogenic inlay (GSI):** delivered, installation in progress
- **Superconducting magnet:** delivered, installed, cooling will take place in one week.



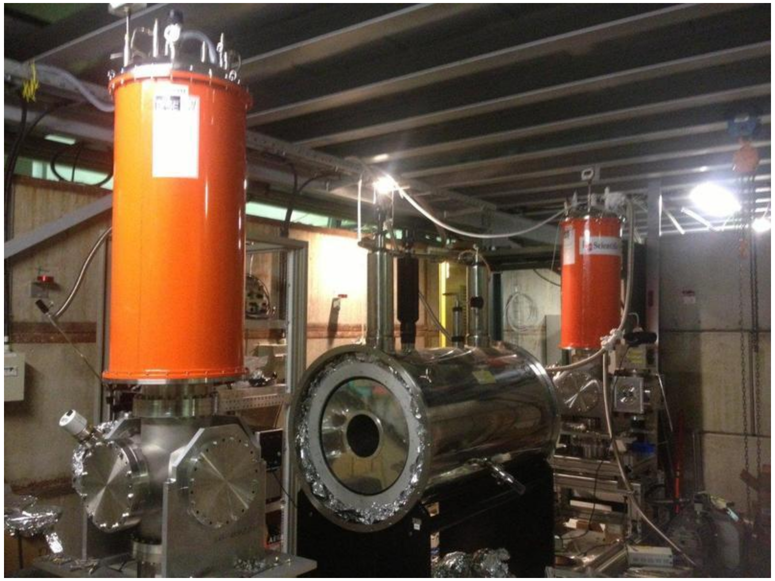
Status

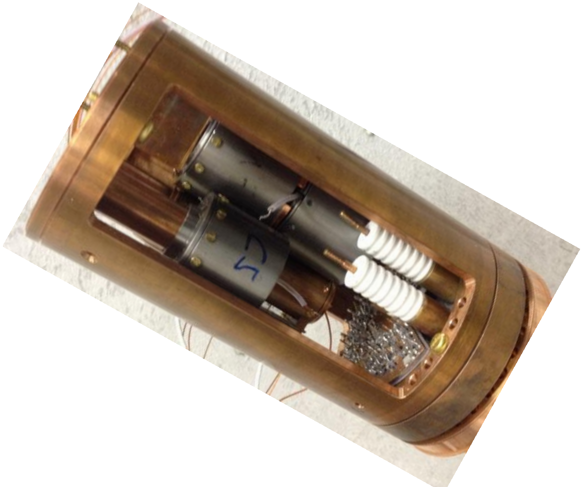
- Constructed





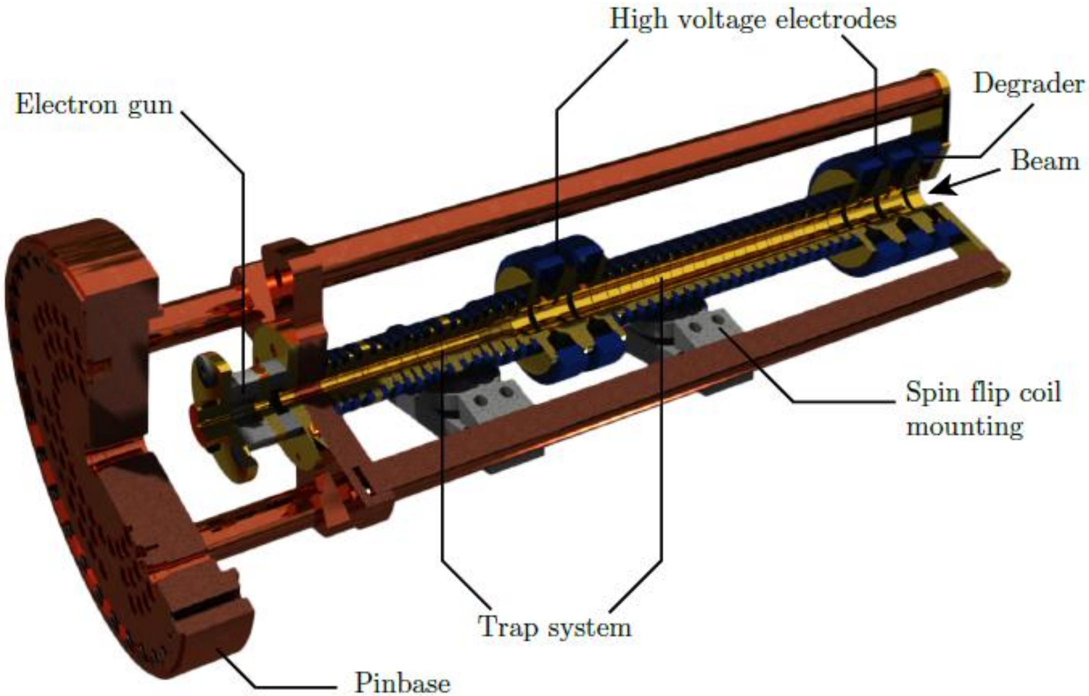
- Real World

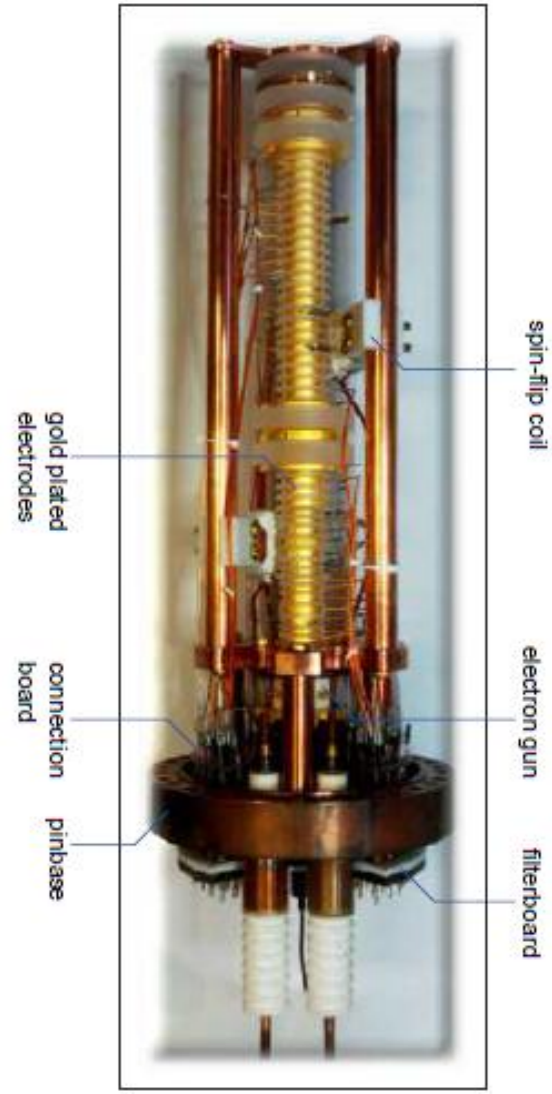




BASE Trap

- 4 trap system: RT / PT / AT / CT





- Trap electrodes: designed / machined / gold-plated / assembled
- Cooling Trap: Provides factor of 10 faster cooling

G. Schneider *et al.*

BASE Detection Electronics

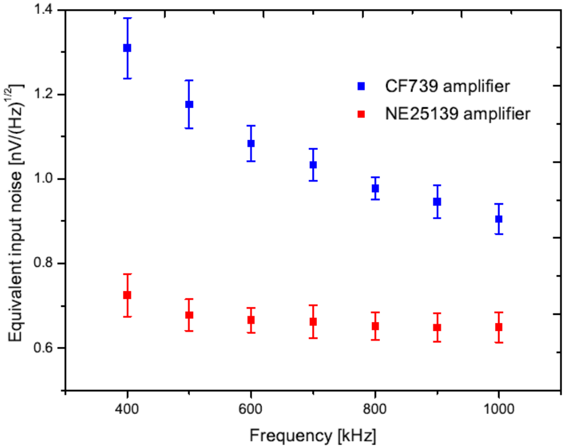
- Superconducting cyclotron detection system

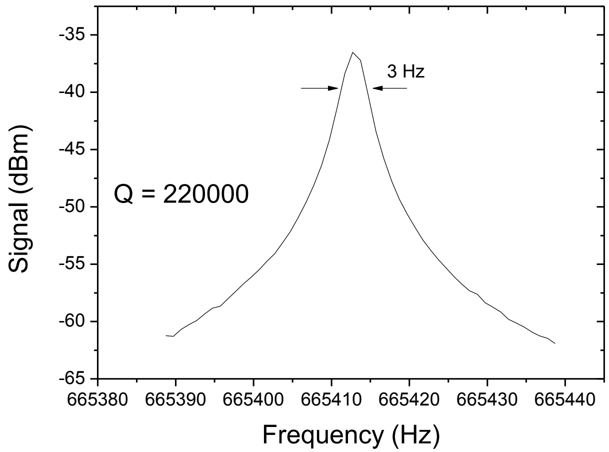
	Mainz	CERN
Q	800	2500
D (mm)	15	4.6
t_cool	100 s	3 s

Provides factor of 30 faster cooling as resistive cooling system at Mainz

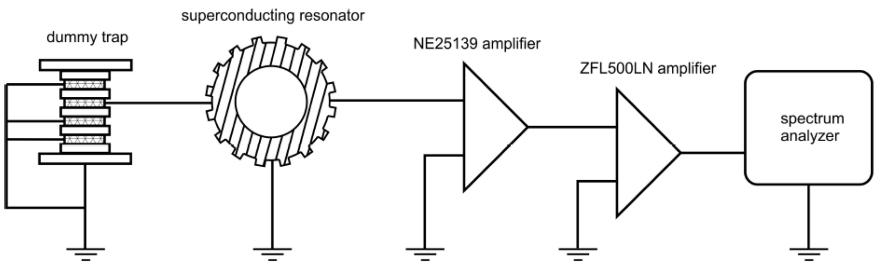
C. Smorra, K. Franke.

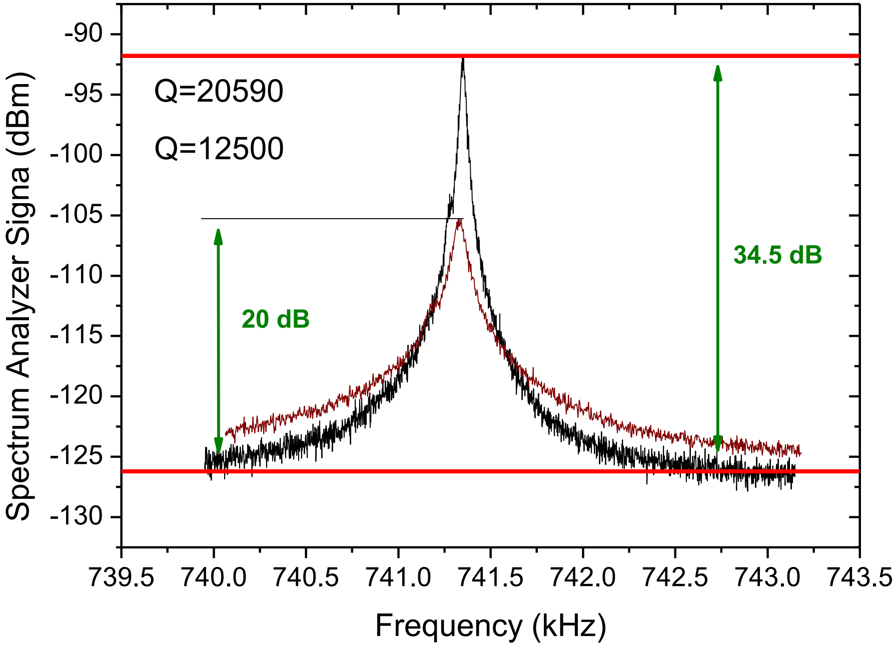
- Superconducting axial detection systems
  - New amplifiers developed: 2 times lower noise
  - New resonators developed: higher Q-values





Detector Connected Wired to Trap



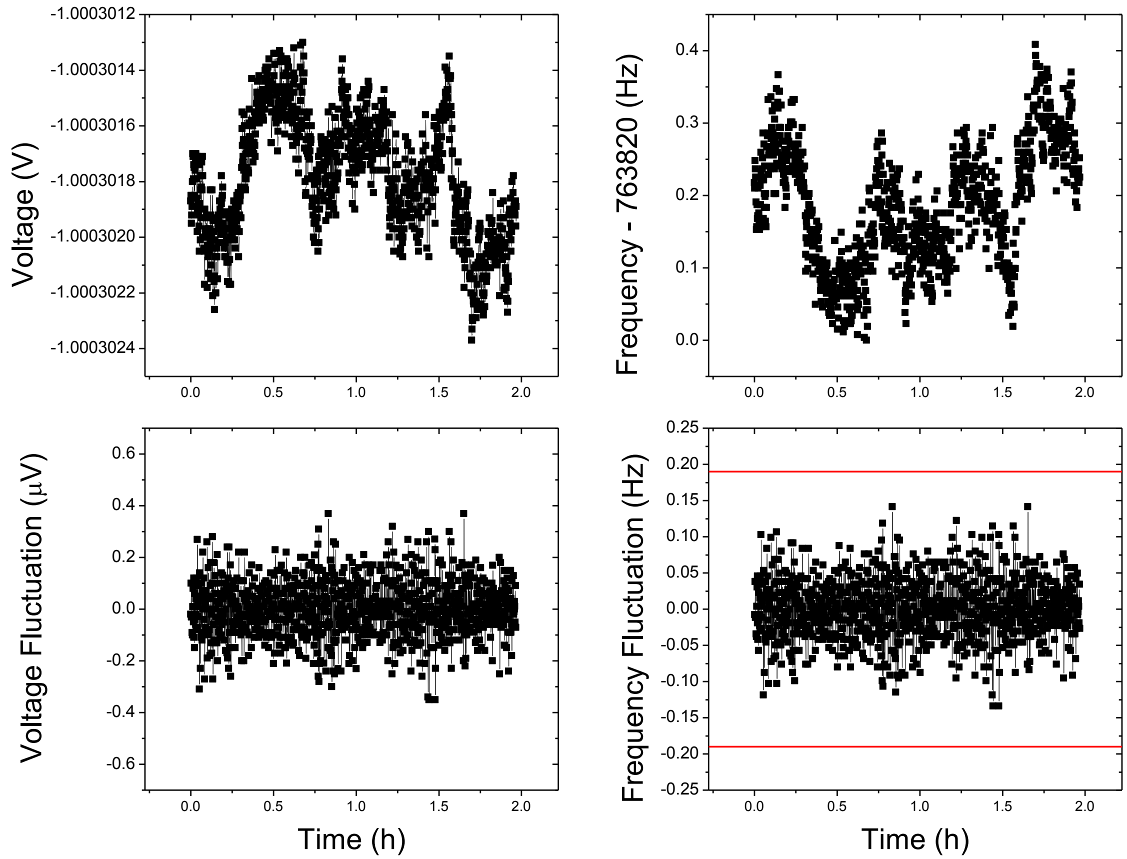


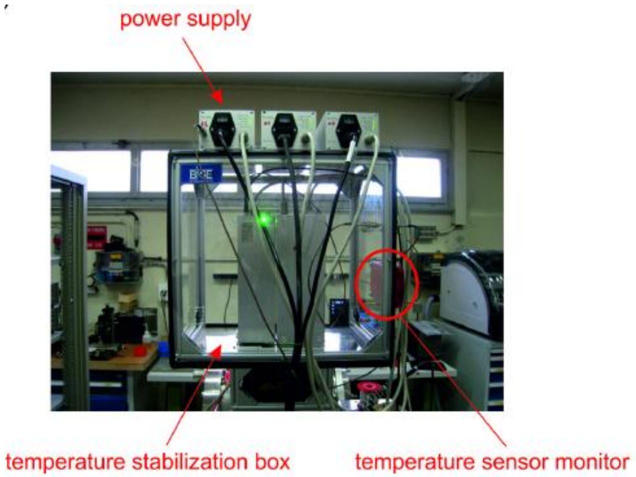
$$\sigma(f_0) = \alpha\,[\text{window, overlap}] \times \sqrt{\frac{1}{4\pi}\frac{\Delta f'}{T_s}\frac{\sqrt{\text{SNR}}+1}{\sqrt{\text{SNR}}-1}}$$

- Enables factor of 2 faster frequency measurements
- Higher state detection fidelity close to 100 %

Precision Voltage Sources

- Three bipolar, ultra stable power supplies (48 Ch) delivered and integrated into experiment

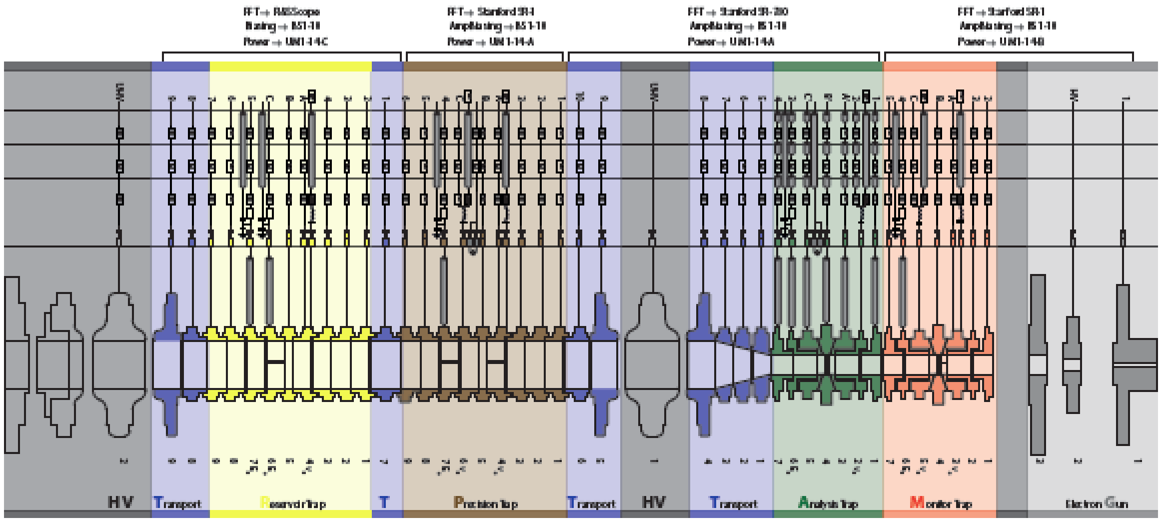


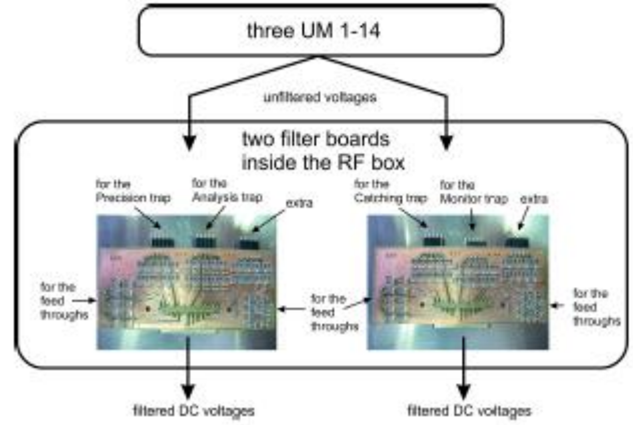


- **Absolute** stability 0.1 ppm
- Short term jitter 40mHz
- Stabilized Allan Deviation 10s: 10mHz
- Spin transition: 190 mHz

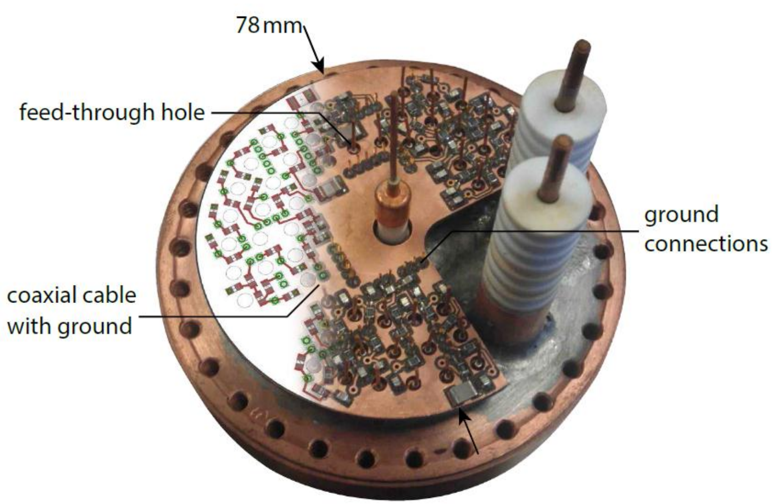
H. Nagahama *et al.*

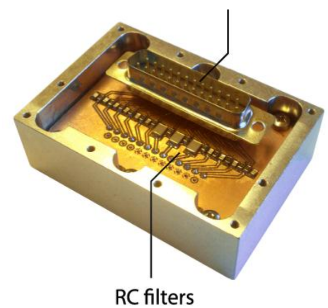
Additional Electronics





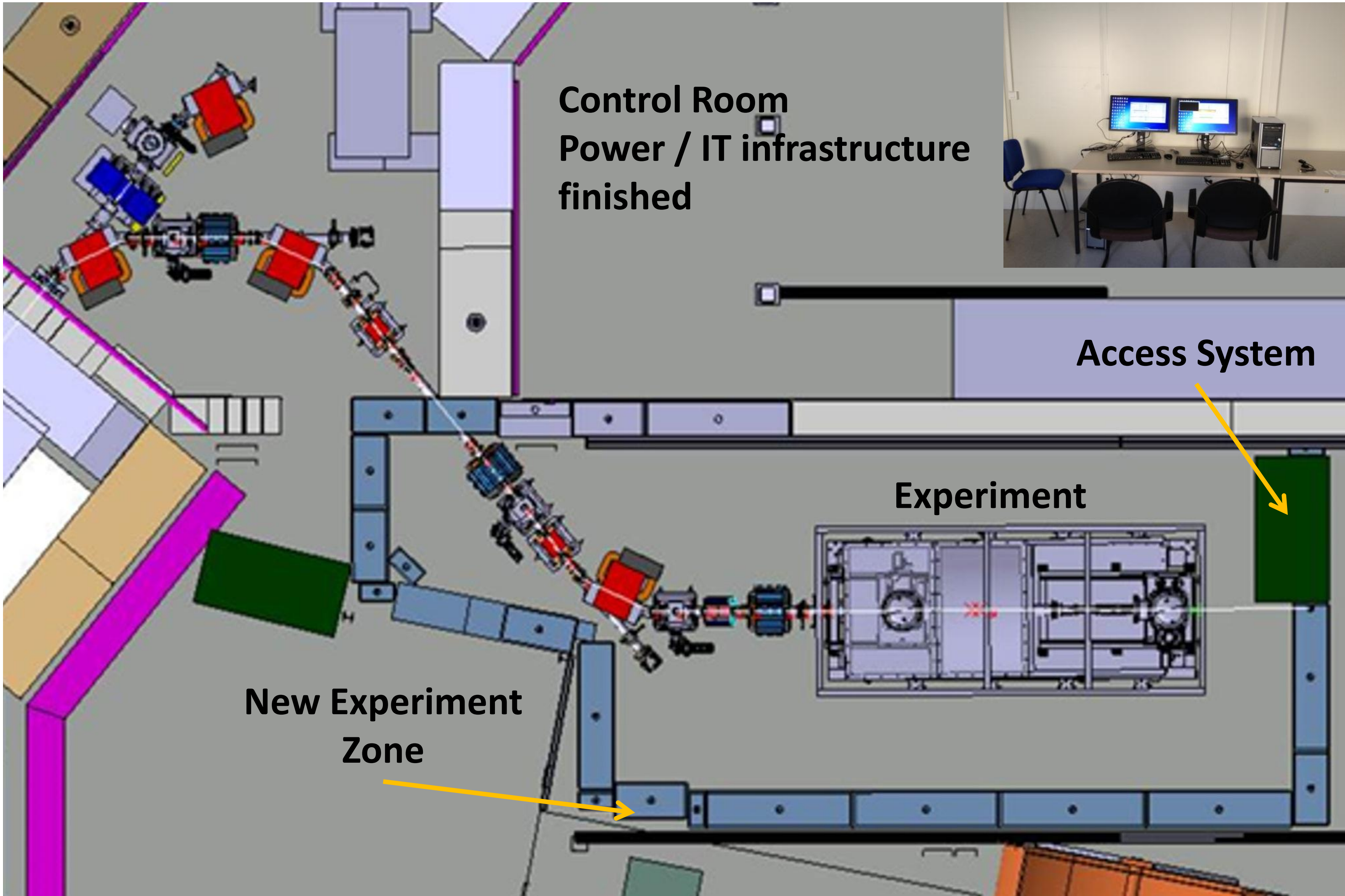
G. Schneider *et al.*



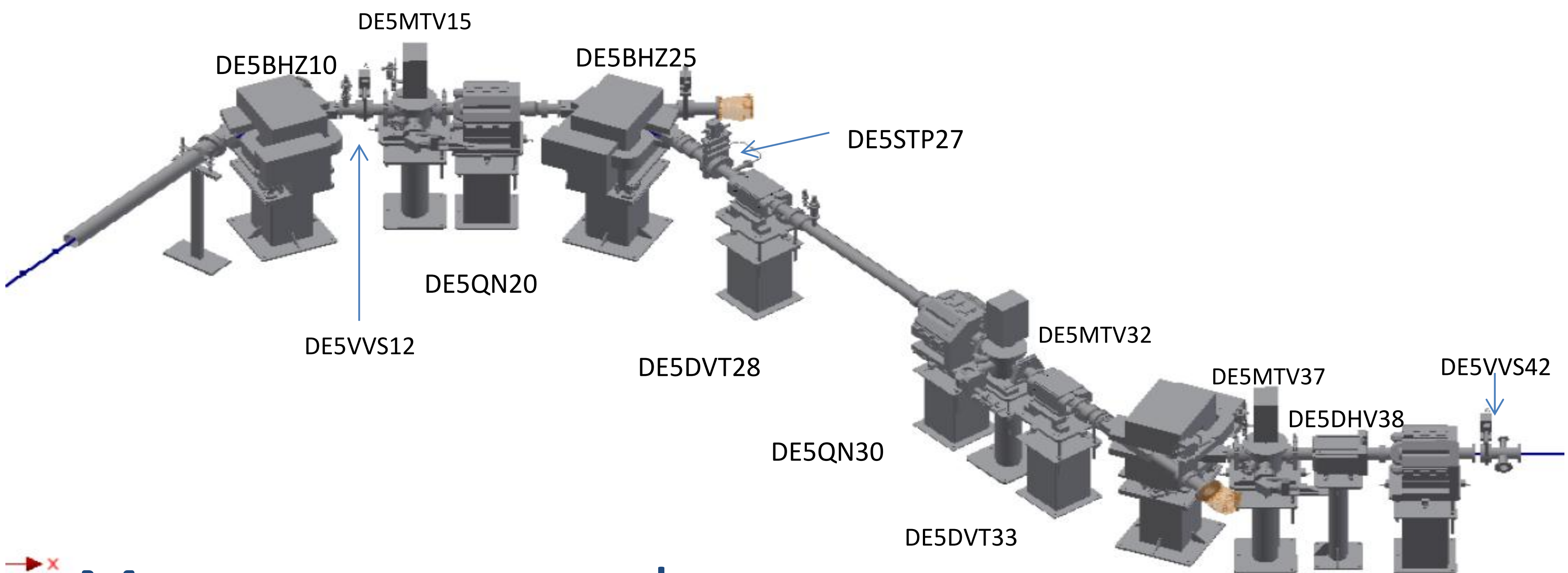


- 300K / 77K / 4K1 / 4K2 filter stages, amplifiers, mixing stages, switching stages etc... developed

Integration



Beamline



- Magnets: prepared
- Power supplies: good progress
- Profile Monitors: good progress
- Beam Stopper: prepared
- Vacuum chambers.....

Vacuum chambers

- Beamline consists of 19 chambers
- 80% will be produced by BASE
  - delivery by middle of April 2014
- y-chambers: produced by CERN
  - delivery by beginning of June 2014 (critical)

Summary

- BASE-Mainz: single spin flip detection, first demonstration of double trap technique, next step: application of double trap method.
- BASE-CERN: construction of experiment in progress. Major components delivered, significant improvement of resistive cooling and detection systems.
- Critical: delivery of y-chambers for beamline
- Planned:
  - 2014/02: Start experiments with protons
  - 2014/09: take AD–beam

Thanks for your attention !

C. Smorra, K. Franke, G. Schneider, H. Nagahama, S. Van Gorp, S. Ulmer