B.A.S.E.

Direct High-Precision Measurement of the g-Factor of a Single Antiproton Stored in a Cryogenic Penning Trap

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JOHANNES GUTENBERG UNIVERSITÄT MAINZ

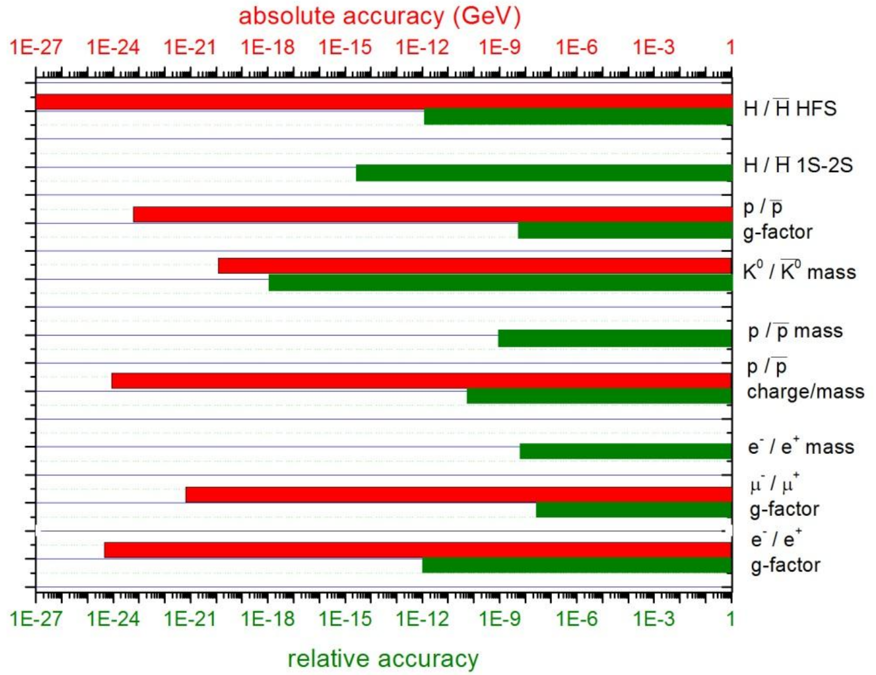
ADUC/ELENA Meeting
11/20/2012 CERN

GSI

Outline

- Physics Goal of B.A.S.E.
  - **B**aryon **A**ntibaryon **S**ymmetry **E**xperiment
- B.A.S.E. Collaboration
- Status of the experiment – progress report

Context – CPT Tests

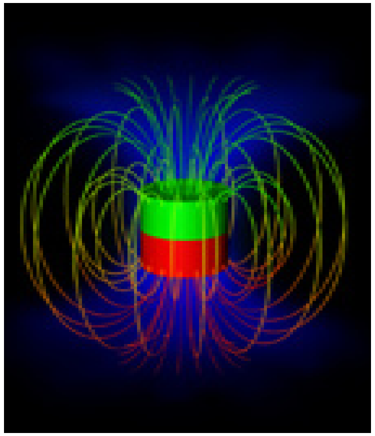


Currently: Magnetic moment of the antiproton known at relative precision of only 10^{-3}.

B.A.S.E. aims at millionfold improvement of antiproton magnetic moment

The Magnetic Moment

Every spin carrying charged particle behaves like a tiny bar magnet.



The magnetic moment:

$$\overrightarrow{\mu_p} = g_p \frac{e}{2\mathrm{m}_p} \vec{S}$$

characterizes its strength

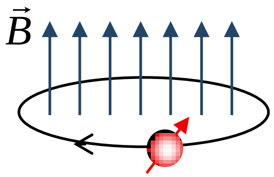
Do the magnets in the proton and the antiproton have the same strenghts ?

Principle: g-factor Measurement

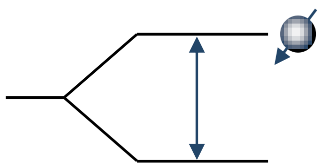
Cyclotron Motion

Larmor Precession

$$\vec{\mu} = g \frac{e}{2m_p} \vec{S}$$



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



$\hbar \omega_L$

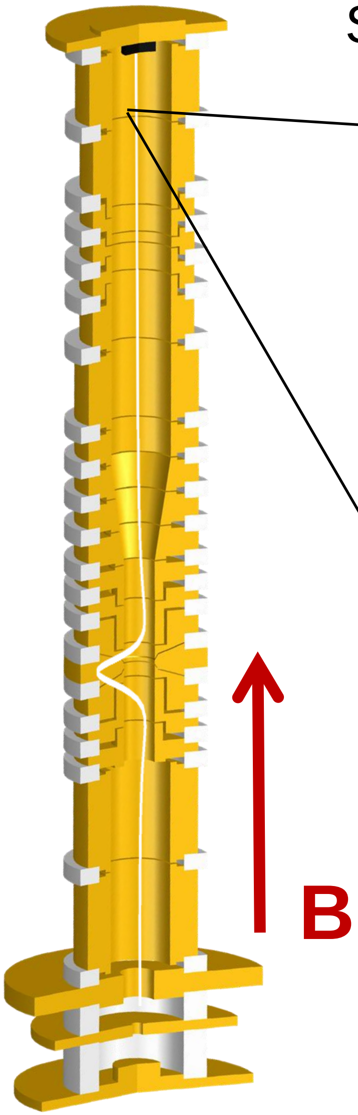
$$\omega_c = \frac{e}{m_p} B$$

$$\omega_L = g \frac{e}{2m_p} B$$

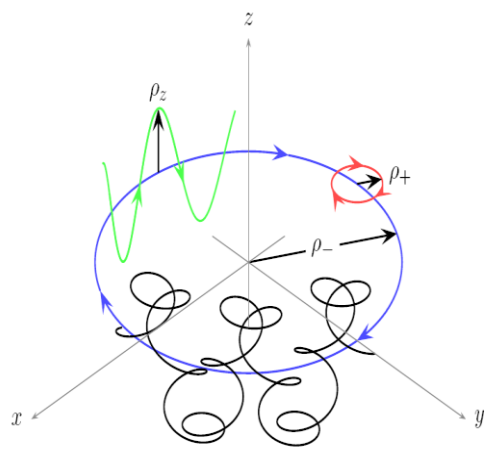
Determination of the g-factor reduces to the determination of a frequency ratio -> in principle a very simple experiment

strong proposal for a precision measurement

The Penning Trap



Superposition of a homogeneous magnetic field and an electrostatic quadrupolar potential



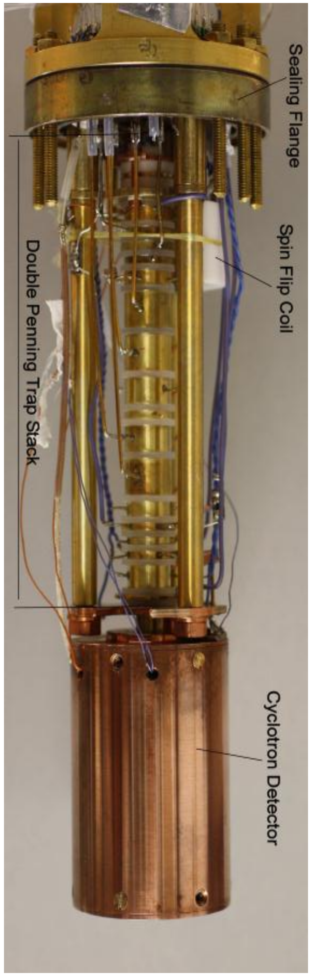
Axial: 700 kHz

Modified Cyclotron: 29 MHz

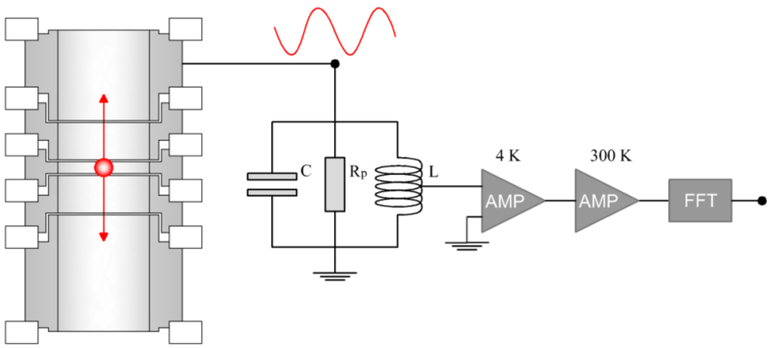
Magnetron: 8 kHz

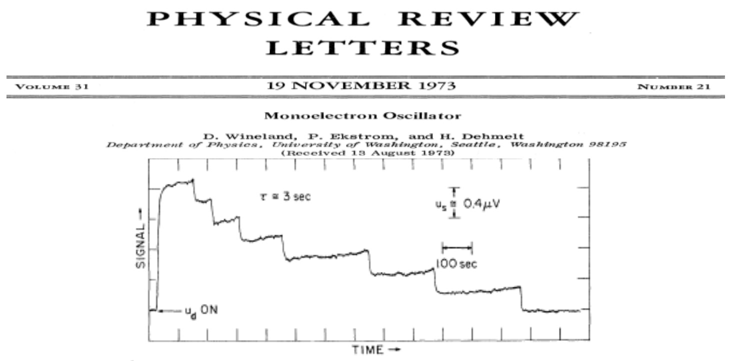
$$\nu_c{}^2 = \nu_+^2 + \nu_-^2 + \nu_z{}^2$$

“invariance theorem” makes Penning traps to strong tools for precision experiments



Frequency Measurements




PHYSICAL REVIEW LETTERS

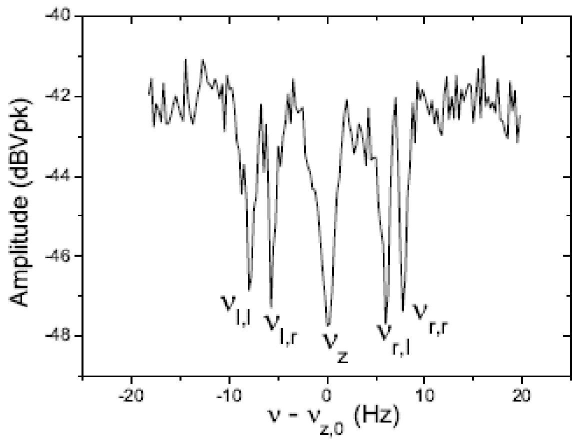
VOLUME 31 | 19 NOVEMBER 1973 | NUMBER 21

Monoelectron Oscillator

D. Wineland, P. Ekstrom, and H. Dehmelt
Department of Physics, University of Washington, Seattle, Washington 98195
(Received 13 August 1973)

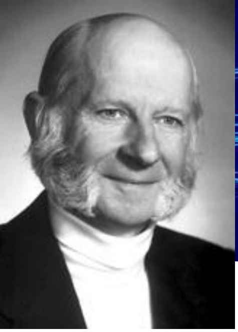
Five simultaneous signals by one single trapped particle

Spectrum contains all required frequency information

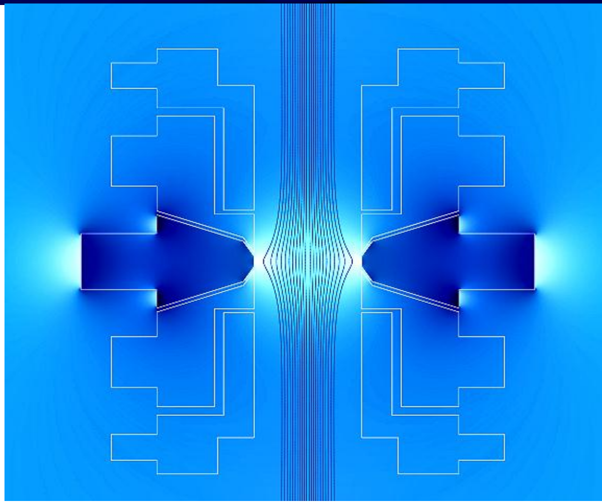


FIRST DIRECT MEASUREMENT OF FREE CYCLOTRON FREQUENCY
$(Dn_c/n_c = 5*10^{-9})$

S. Ulmer *et al.* **Phys. Rev. Lett** 107, 130005 (2011)



The Continuous Stern Gerlach Effect



Energy of magnetic dipole in magnetic field

$$\Phi_M = -(\overrightarrow{\mu_p} \cdot \vec{B})$$

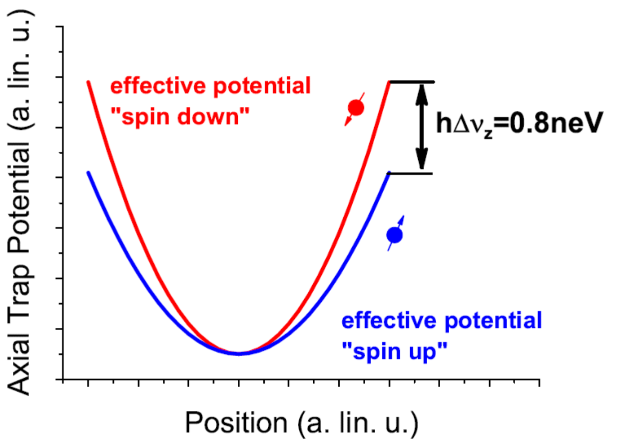
Leading order magnetic field correction

$$B_z = B_0 + B_2\,(z^2 - \frac{\rho^2}{2})$$

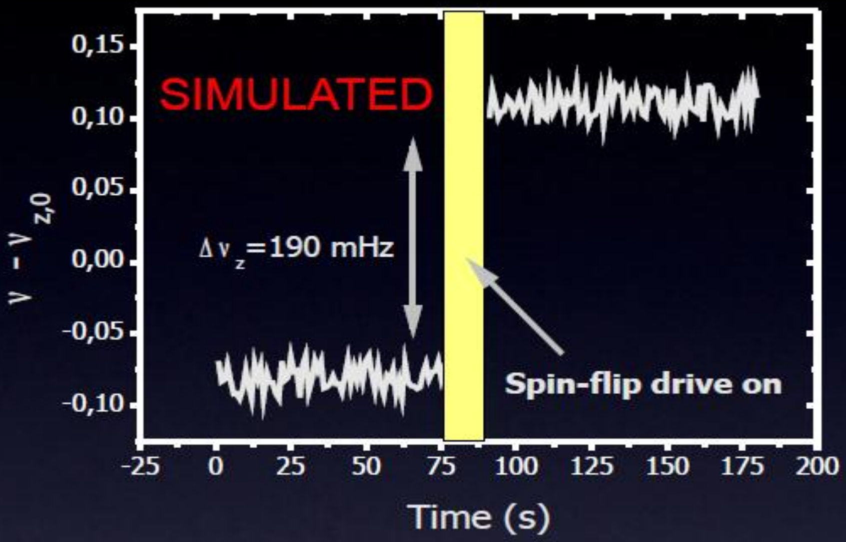
This term adds a spin dependent quadratic axial potential
-> Axial frequency becomes function of spin state

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

- Very difficult for the proton/antiproton system.
- Most extreme magnetic conditions ever applied to single particle.

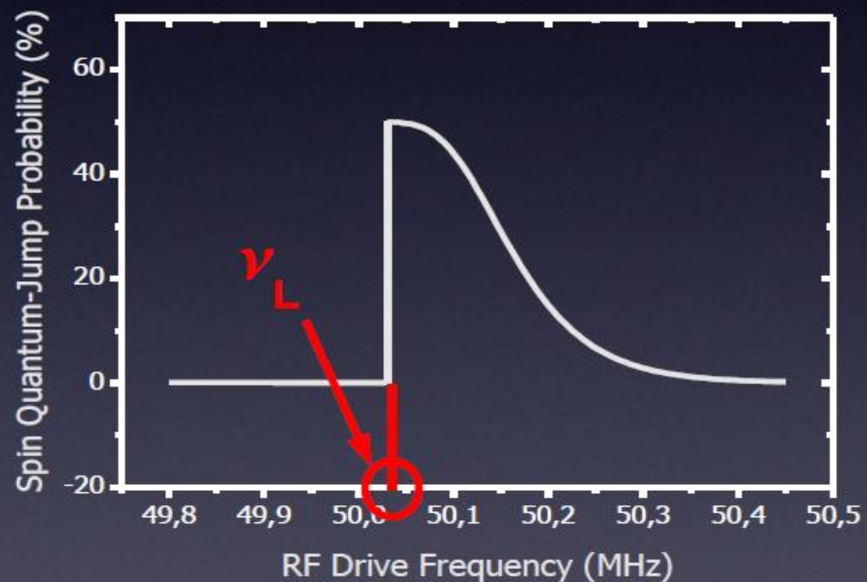


Larmor Frequency Measurement



Measure this several hundred times for different drive frequencies

$\rightarrow P_{SF}(\nu_{rf})$

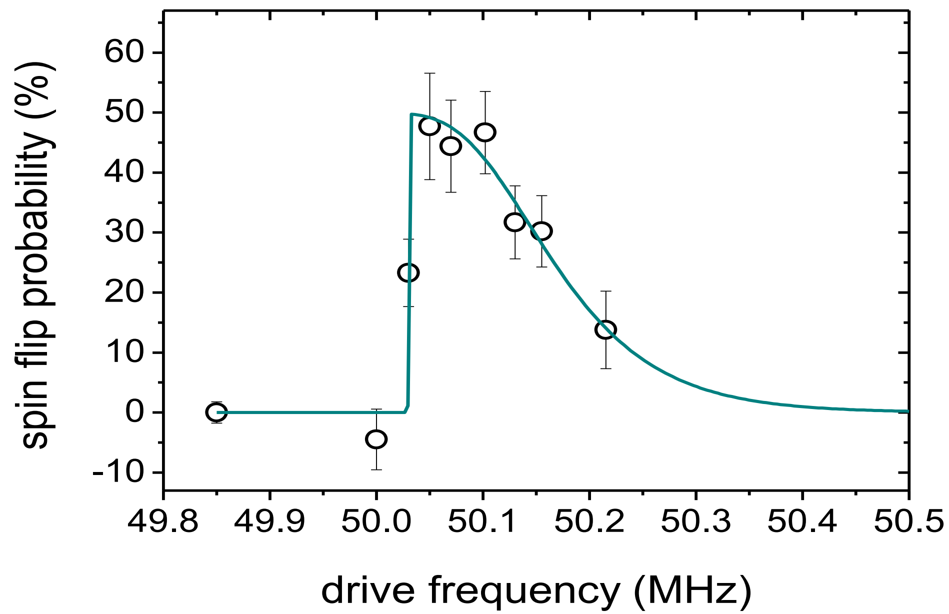


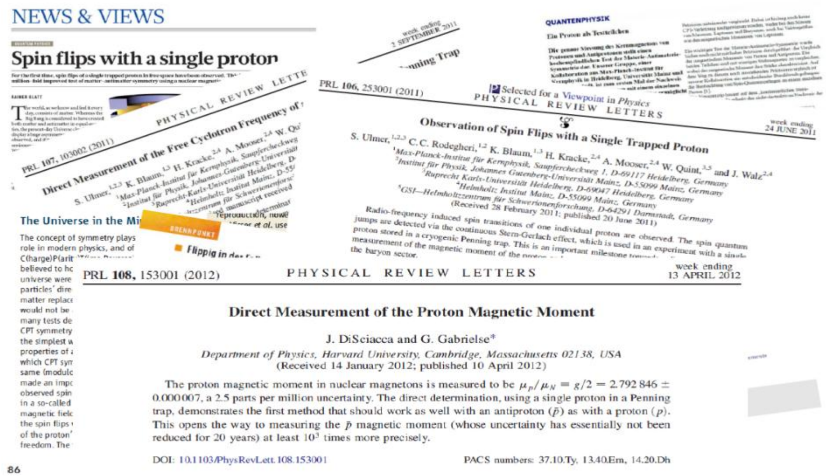
$$\nu_L = \frac{1}{2\pi} g_p \frac{e}{2 m_p} \left(B_0 + B_2 z^2 \right)$$

Sharp "cutoff" reflects zero temperature Larmor Frequency

Absolute frequency stability below 190 mHz needed

Results





NEWS & VIEWS

Spin flips with a single proton

PRL 106, 253001 (2011) PHYSICAL REVIEW LETTERS week ending 24 JUNE 2011

Observation of Spin Flips with a Single Trapped Proton

S. Ulmer, C.C. Rodegheri, K. Blaum, H. Kracke, A. Mooser, W. Quint, and J. Walz

PRL 107, 103002 (2011)

Direct Measurement of the Free Cyclotron Frequency of ...

The Universe in the Mi...

PRL 108, 153001 (2012) PHYSICAL REVIEW LETTERS week ending 13 APRIL 2012

Direct Measurement of the Proton Magnetic Moment

J. DiSciacca and G. Gabrielse*

Department of Physics, Harvard University, Cambridge, Massachusetts 02138, USA
(Received 14 January 2012; published 10 April 2012)

The proton magnetic moment in nuclear magnetons is measured to be $\mu_p/\mu_N \equiv g/2 = 2.792\,846 \pm 0.000\,007$, a 2.5 parts per million uncertainty. The direct determination, using a single proton in a Penning trap, demonstrates the first method that should work as well with an antiproton ($\bar{p}$) as with a proton (p). This opens the way to measuring the $\bar{p}$ magnetic moment (whose uncertainty has essentially not been reduced for 20 years) at least 10^3 times more precisely.

DOI: 10.1103/PhysRevLett.108.153001 PACS numbers: 37.10.Ty, 13.40.Em, 14.20.Dh

g/2 = 2.792 848 (24)	**C.C Rodegheri et *al.*, accepted by NJP**
g/2 = 2.792 846 (7)	**J. di Sciacca, G. Gabrielse PRL 108 153001 (2012)**

Both experiments measured Larmor frequency at 10^{-6} level…

B.A.S.E. - Progress

Letter of Intent to the CERN SPSC

CERN-SPSC-2012-019 / SPSC-I-241
14/06/2012

Direct High-Precision Measurement of the g-Factor of a Single Antiproton Stored in a Cryogenic Penning Trap

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Helmholtz Institut Mainz, D-55099 Mainz, Germany

Contact Person: Stefan Ulmer (stefan.ulmer@cern.ch)

(Dated: May 24, 2012)

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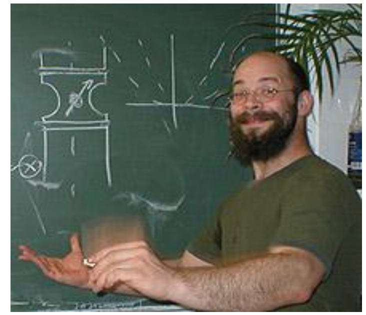
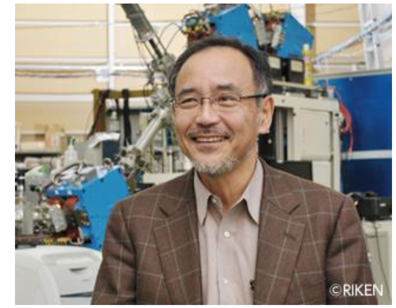
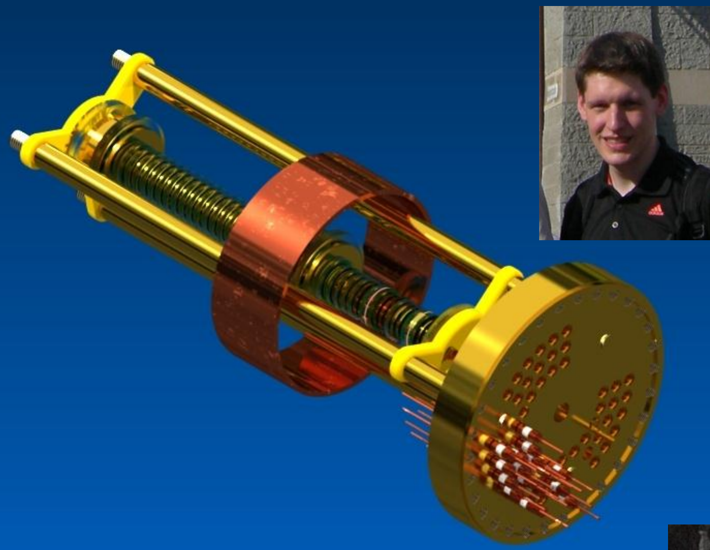
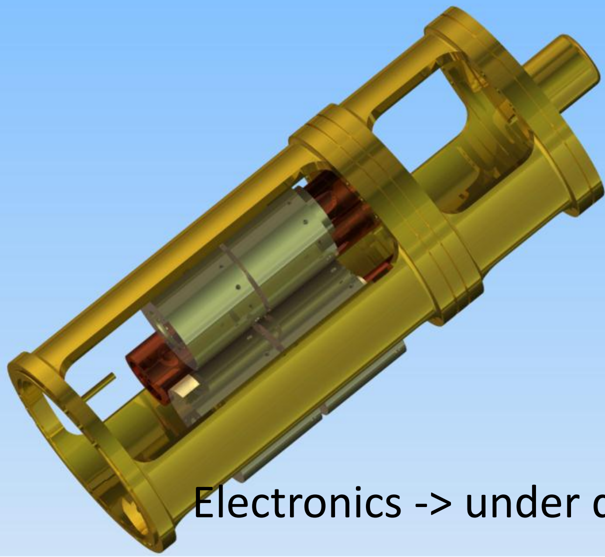




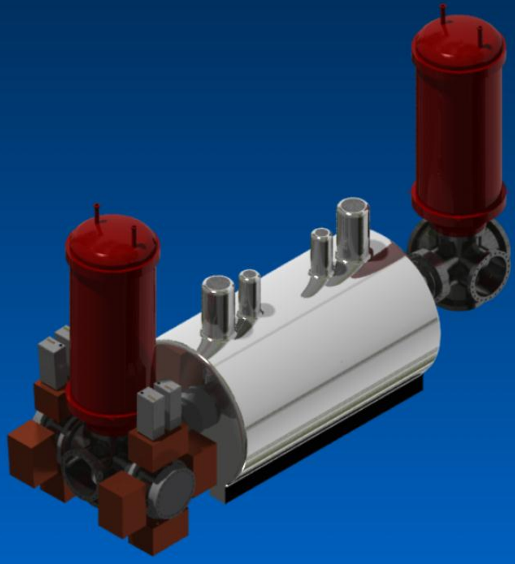
Apparatus



4 Penning Trap Design -> finished and currently at machine shop



Electronics -> under development

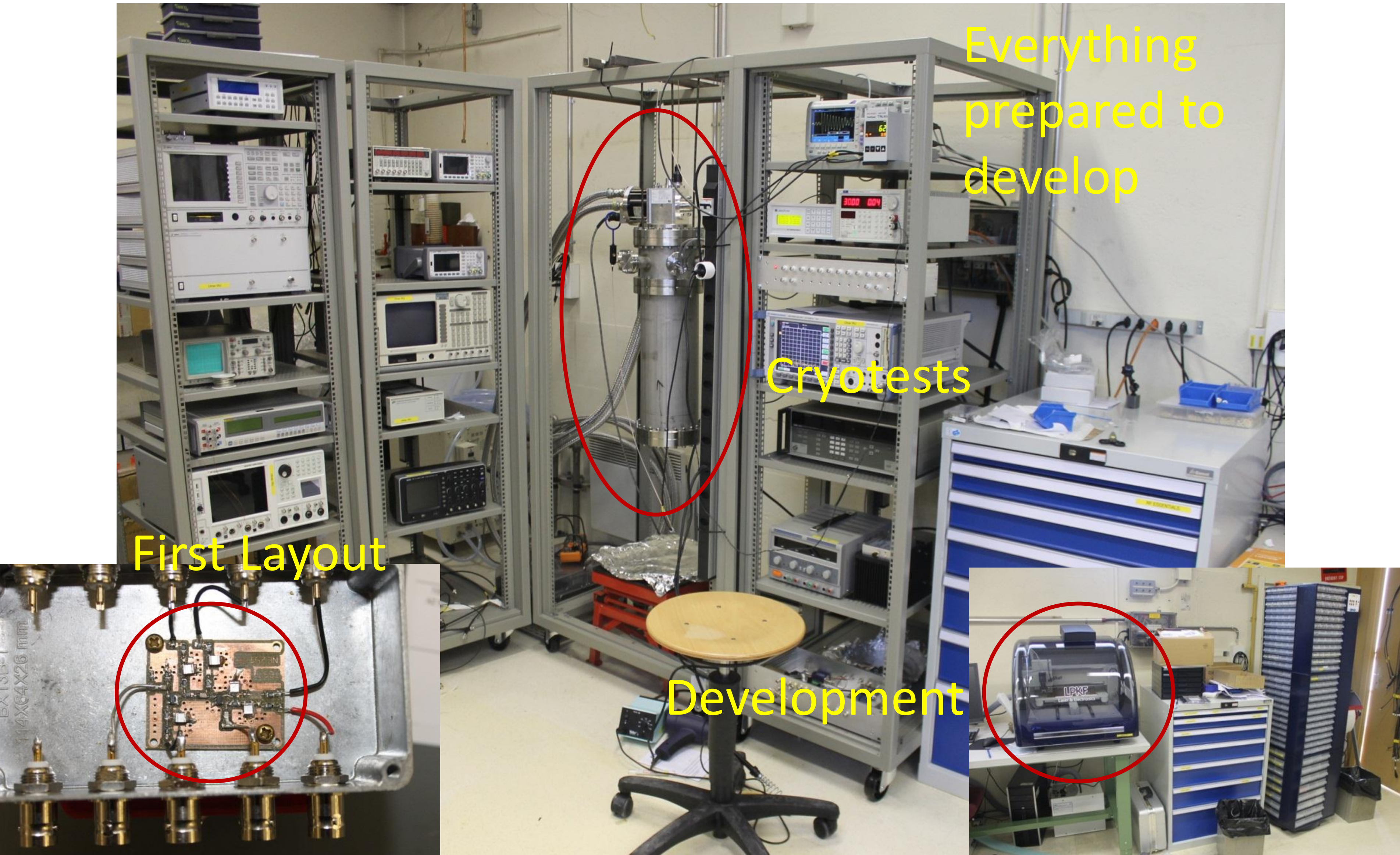


Cryogenics -> Under development

Vivid discussion with AD group (L. Bojtar and T. Eriksson) in progress

B.A.S.E.-lab at CERN

friendly supported by M. Doser



Funding

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!!! thanks for your attention !!!