Plans of the BASE collaboration after LS2 and far future

Stefan Ulmer

Christian Smorra

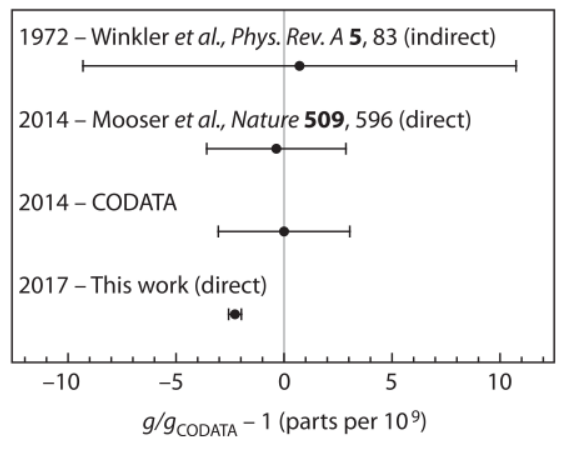
RIKEN,

Ulmer Fundamental Symmetries Laboratory

2019 / 12 / 08

BASE since 2014

Most precise proton g-factor measurment



g/2 = 2.792 847 350 (9)

A. Mooser *et al.*, Nature **509**, 596 (2014).

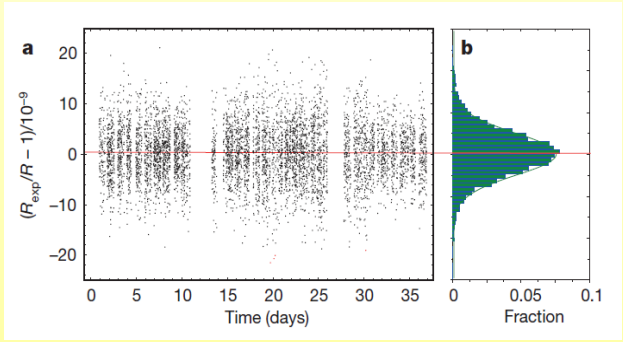
First direct high precision measurement of the proton magnetic moment.

g/2 = 2.792 847 344 62 (82)

G. Schneider et al., Science **358**, 1081 (2017).

Precise CPT test with baryons

S. Ulmer, et al., **Nature 524, 196 (2015)**

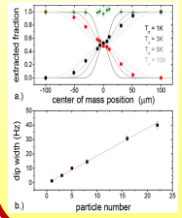


$$1 + \frac{(q/m)_{\bar{p}}}{(q/m)_{p}} = 1(69) \times 10^{-12}$$

$R_{exp,c}$ = 1.001 089 218 755 (64) (26)

To be improved by another factor of 10 to 100

Reservoir trap for antiprotons



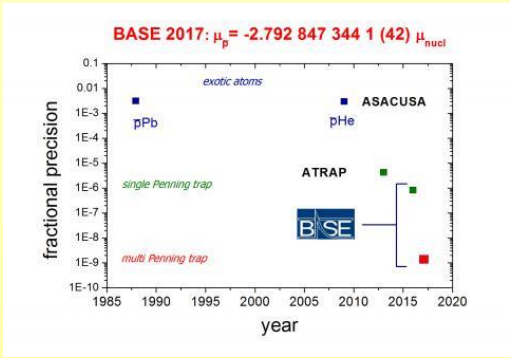
C. Smorra, et al., **Int. Journ. Mass Spec. 389, 10 (2015).**

Idea: Enable operation with antiprotons independent of accelerator run times.

Most precise antiproton g-factor measurment

H. Nagahama, et al., Nature Comms. **8, 14084 (2017)**

C. Smorra *et al.*, Nature **550**, 371 (2017)



g/2 = 2.792 846 5 (23)

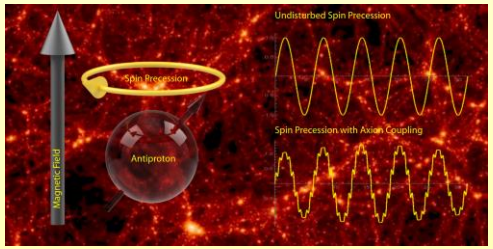
Sixfold improvement compared to previous measurement

g/2 = 2.792 847 344 1 (42)

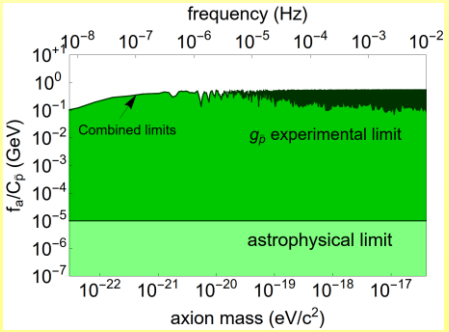
350-fold improvement compared to previous measurement

Limits on antiproton / dark matter coupling

C. Smorra *et al.*, Nature **575**, 310 (2019)



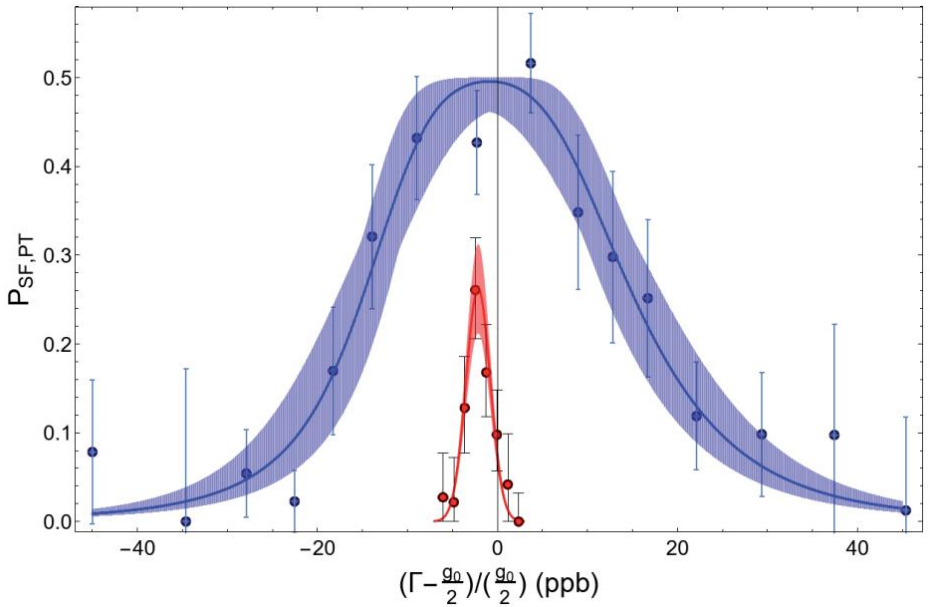
Time-base analysis of antiproton g-factor resonance allows to constrain antiproton/axion coupling



5-o.o.m. improved constraints compared to astrophysics limits

Partly comparable work by J. DiSciacca, G. Gabrielse et al.. (ATRAP/TRAP collaboration)

After LS2: Improved g-factor measurement



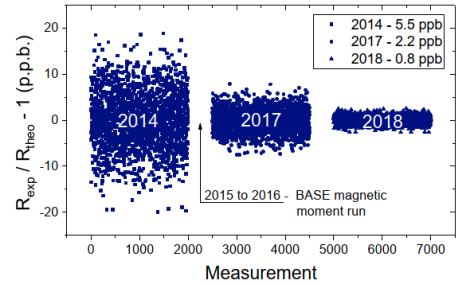
$$\frac{g_{\bar{p}}}{2} = 2.792\,847\,344\,1\,(42)\,(1.5\,p.p.b)$$

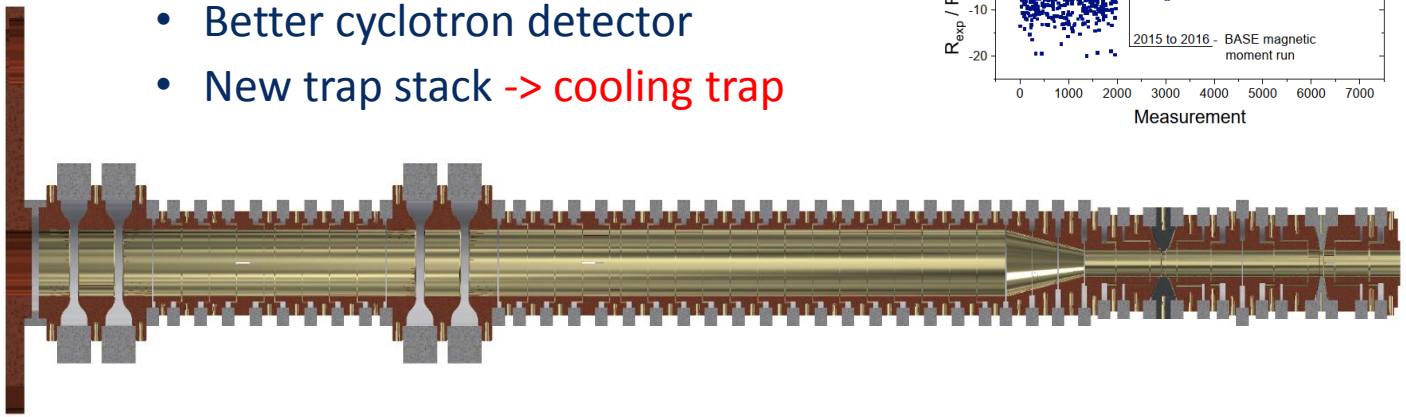
- Deliberately saturation broadened / systematics at 1 p.p.b., imposed by magnetic inhomogeneity

$$\frac{g_p}{2} = 2.792\,847\,344\,62\,(82)\ \textbf{(0.3 p.p.b.)}$$

- Mainz measurement: Limited by sideband method, magnet stability, magnet homogeneity and statistics

- Measure **faster** in at **reduced systematic effects**
  - Recent developments at CERN
    - Improved axial frequency measurements
    - Advanced magnetic shielding system
    - Improved magnet stability
    - Implementation of local magnets
    - Better cyclotron detector
    - New trap stack -> cooling trap

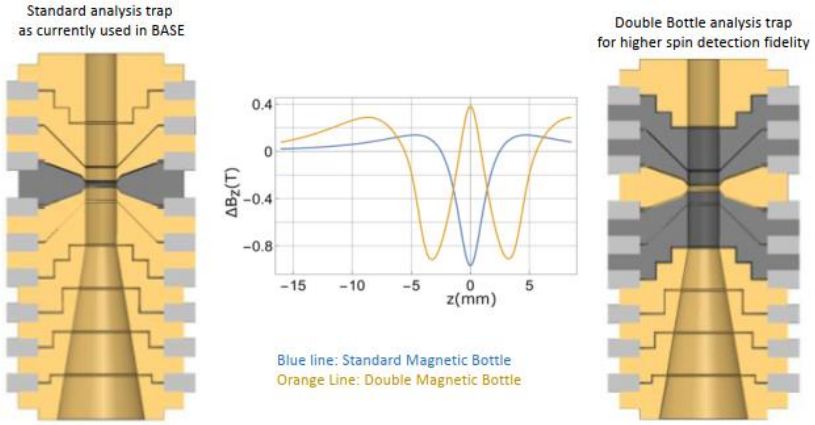




- Quite confident that measurement at a level of 100 p.p.t to 200 p.p.t. are in reach (at higher axion band-witdh) -> Plan for runs after LS2 (2 years at least).

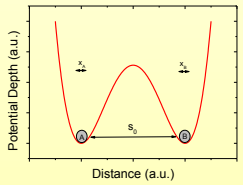
Additional Developments

- Implementation of hyperpolarized ^{3}He probes for magnet stabilization.
- Advanced trap geometries
- Implementation of laser cooling techniques for higher sampling rate cycles at reduced systematic effects.



New Method

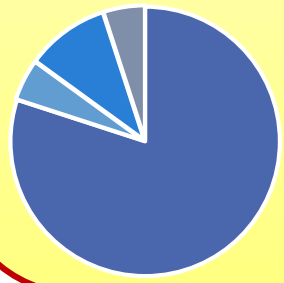
Couple protons/antiprotons sympathetically to laser cooled $^9Be^+$ ions and imprint Doppler temperatures to the antiproton



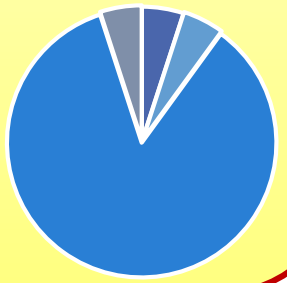
Publication: K. R. Brown, C. Ospelkaus, Y. Colombe, A. C. Wilson, D. Leibfried, D. J. Wineland, Nature **471**, 196 (2011).

Was demonstrated for $^9Be^+$ ions in Paul traps – implement same in Penning traps

Current Time Budget

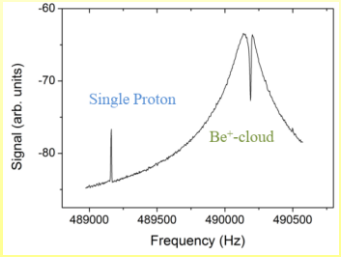


Laser Time Budget



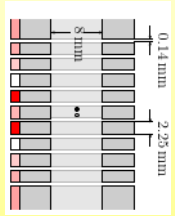
Effort at University of Mainz

5 trap design implemented and simultaneous detection of $^9Be^+$ ion and proton in common endcap trap was demonstrated.

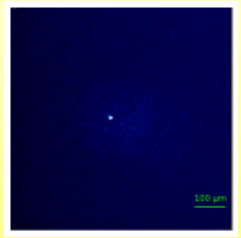


C. Smorra, A. Mooser, M. Bohman, M. Wiesinger et al.

Effort at University of Hannover and PTB

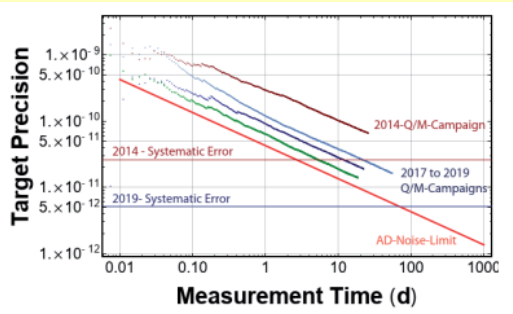


Recent dramatic progress:
Detection of a single laser cooled $^9Be^+$ ion, in a Penning trap system which is fully compatible with the BASE trap system at CERN



M. Niemann, J. M. Cornejo, **C. Ospelkaus** et al.

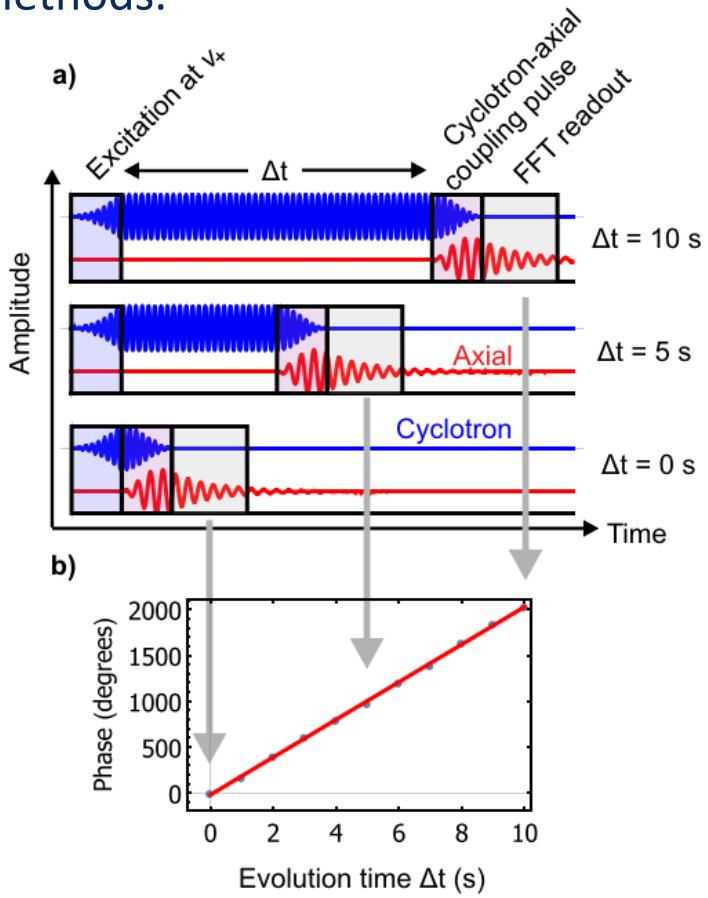
Whatever we do, we will eventually be limited by background magnetic field fluctuations



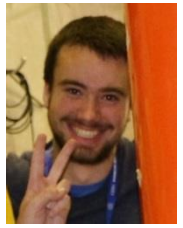
Green: reached precision
Red: AD limit

Improved Charge-to-Mass ratio measurement

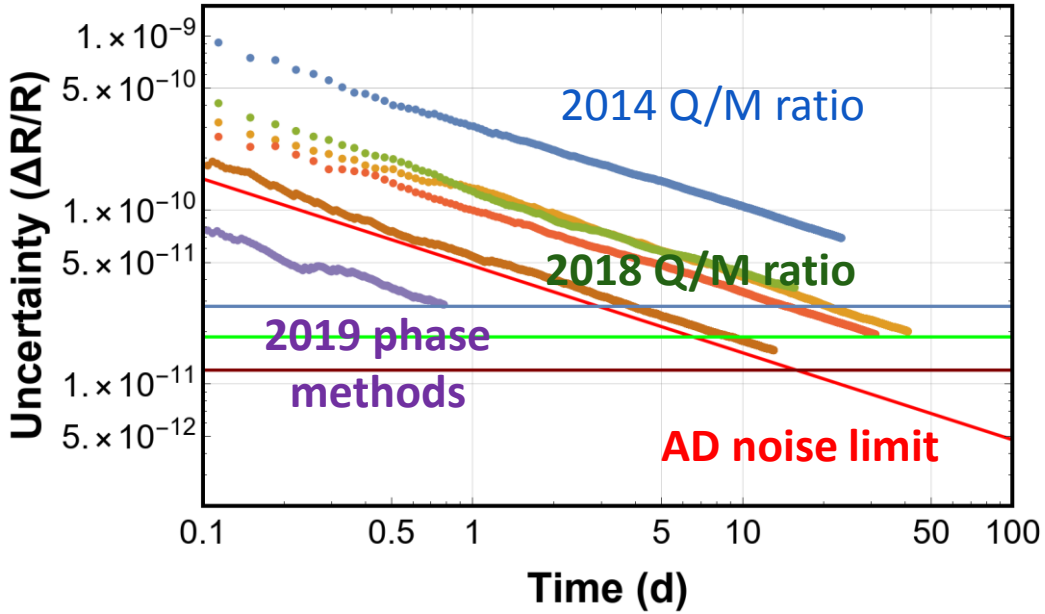
- Given the current data situation -> need to reach 1 p.p.t. precision level
- Recent developments: Implementation of phase sensitive methods.

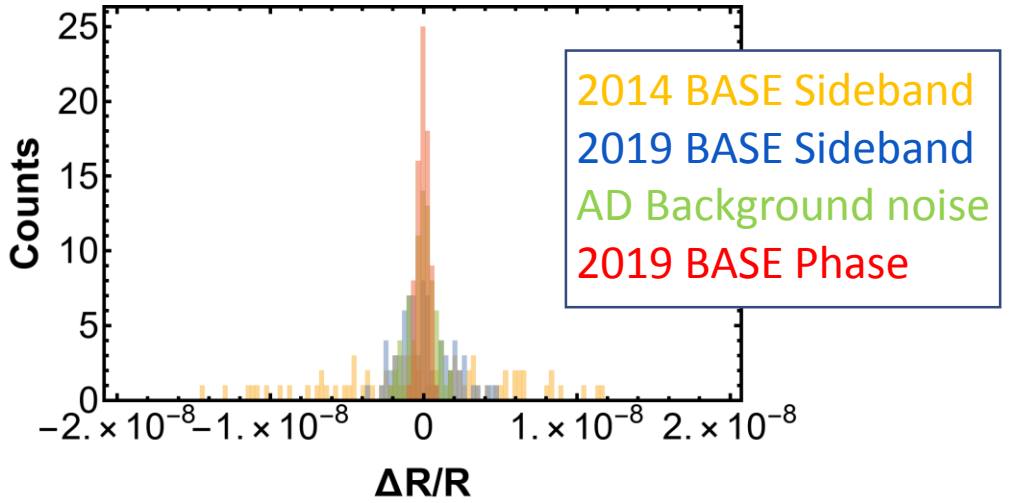


J. Devlin
CERN/RIKEN



M. Borchert
Hannover/RIKEN

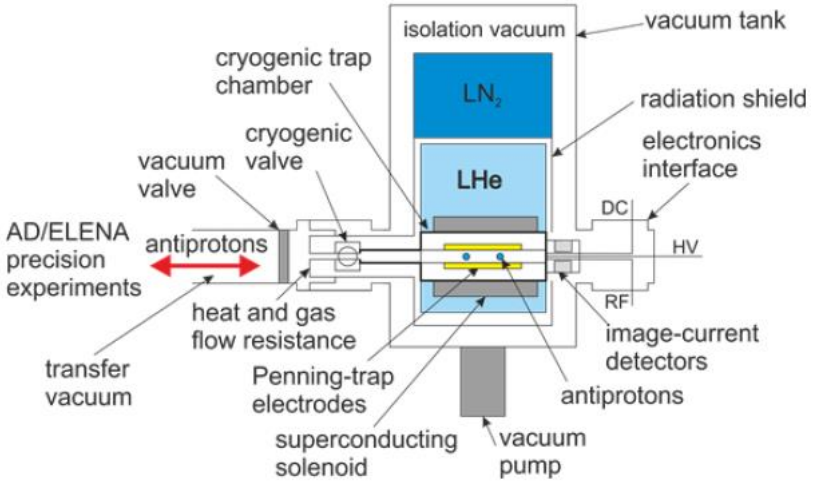




-> Long term: Need to move out of the AD hall (after LS3)

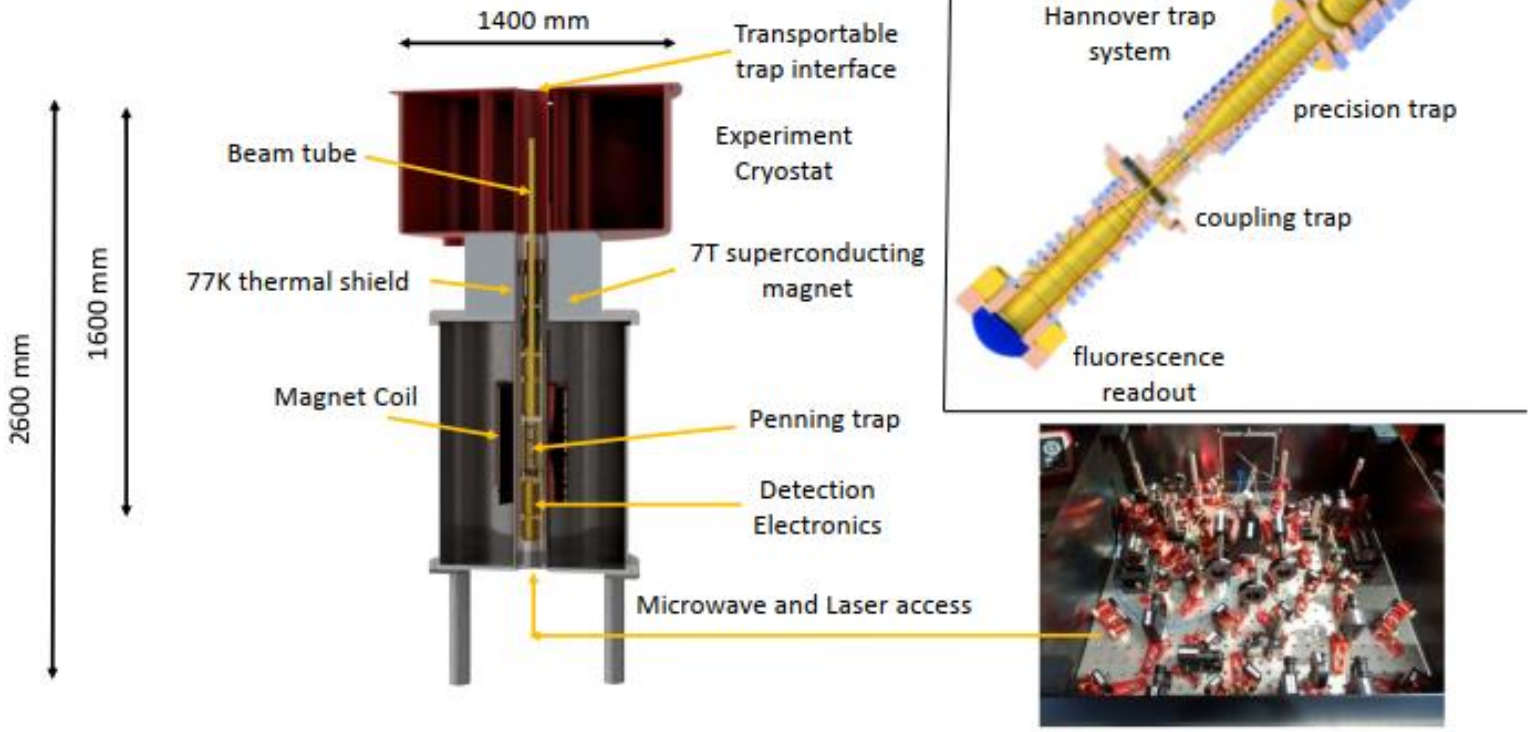
Recent Proposal -> applied for offline lab space

-> Transportable trap (BASE/STEP)



C. Smorra
RIKEN

-> BASE II / offline lab



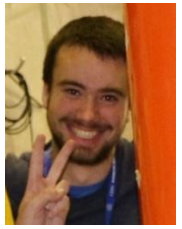
Thanks for your attention!

S. Ulmer
RIKEN

J. Devlin
RIKEN

E. Wursten
CERN / RIKEN

J. Harrington
MPIK/RIKEN



M. Borchert
Hannover/RIKEN

S. Erlewein
MPIK/RIKEN

M. Fleck
RIKEN/U. Tokyo

M. Sato
RIKEN/U. Tokyo

J. Warncke
Hannover/RIKEN

C. Smorra
RIKEN

M. Bohman
RIKEN/MPIK

M. Wiesinger
RIKEN/MPIK

K. Blaum, Y. Matsuda,
C. Ospelkaus, W. Quint,
J. Walz, Y. Yamazaki