The SM Prediction and Discrepancy

*Aoyama, Kinoshita, Nio, Atoms **2019**, 7(1), 28 and references therein*

C_{10} calculation → (12)

hadron loop → (11)

α measurement → (93)

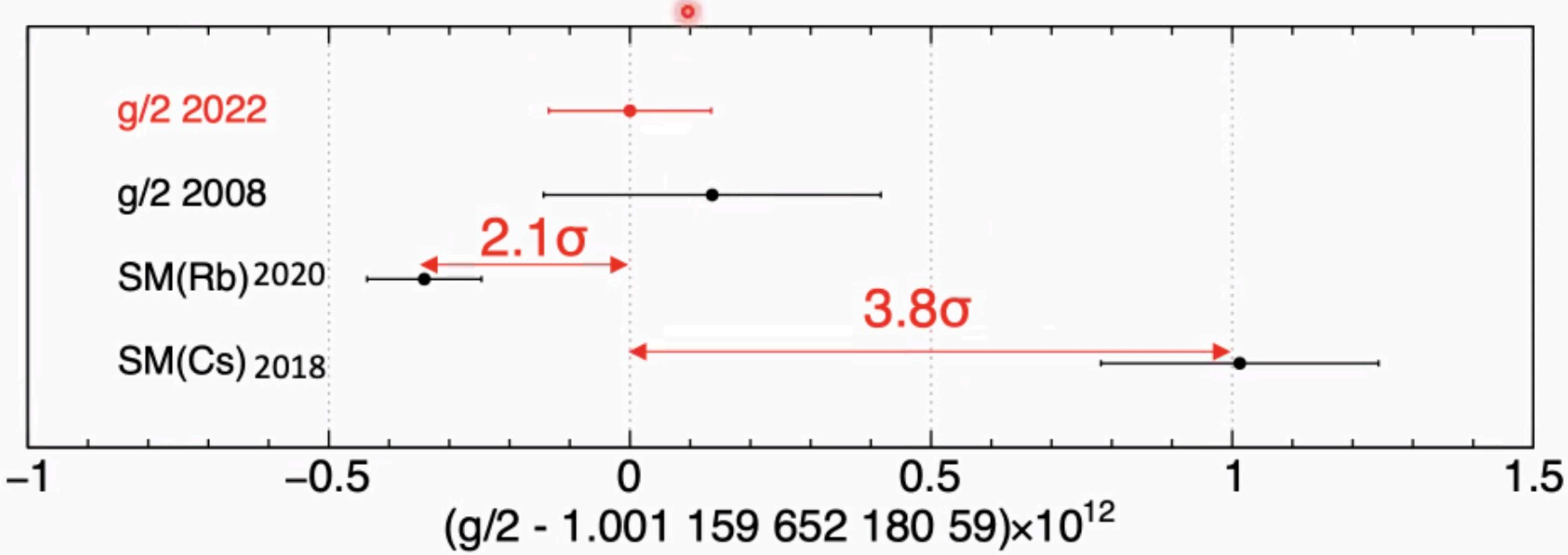
$$\frac{g}{2}(\mathrm{Rb}) = 1.001\ 159\ 652\ 180\ 254\ (12)\ (11)\ (93)$$

Nature **588**, 61 (2020)

$$\frac{g}{2}(\mathrm{Cs}) = 1.001\ 159\ 652\ 181\ 598\ (12)\ (11)\ (234)$$

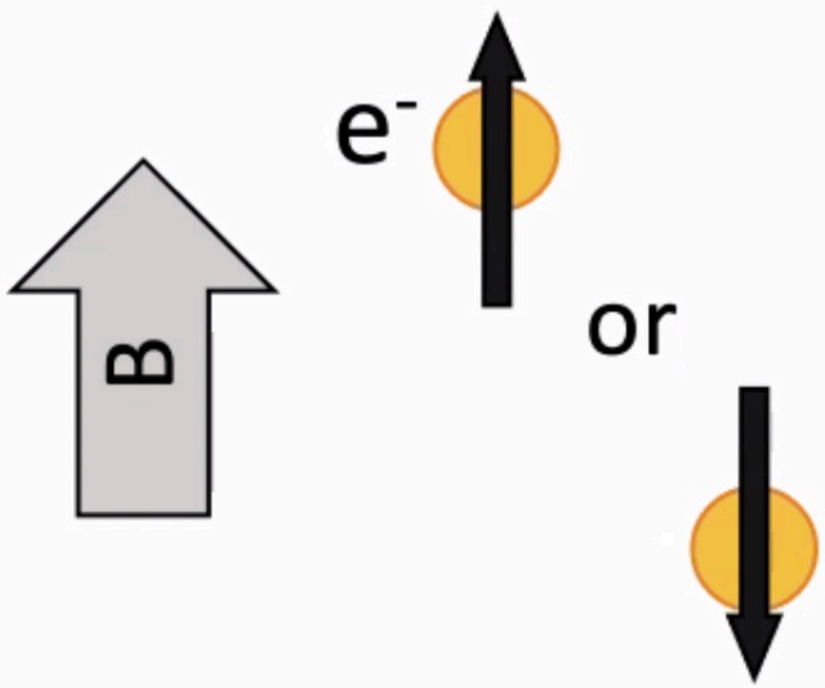
Science **360** 191 (2018)

this work



Principle of *g*/2 measurement

Ideally, measure g/2 in free space

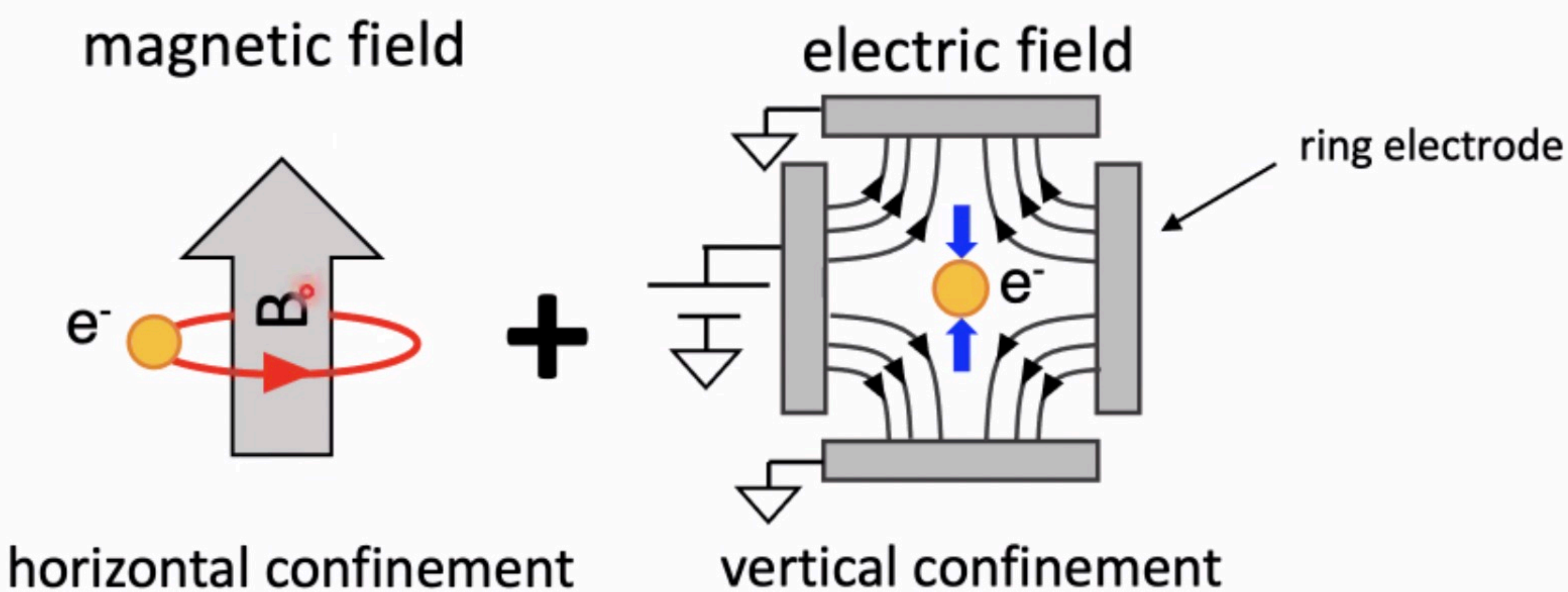


$$\Delta E_s = 2\mu \cdot B = \frac{g}{2} \times \frac{\hbar e B}{m}$$

spin precession energy $h\nu_s$

cyclotron motion energy $h\nu_c$

In actual, electron is trapped in a Penning trap



Why Measure ν_a, not ν_s?

$$\frac{g}{2} = \frac{\nu_s}{\nu_c} = 1 + \frac{\nu_a}{\nu_c}$$

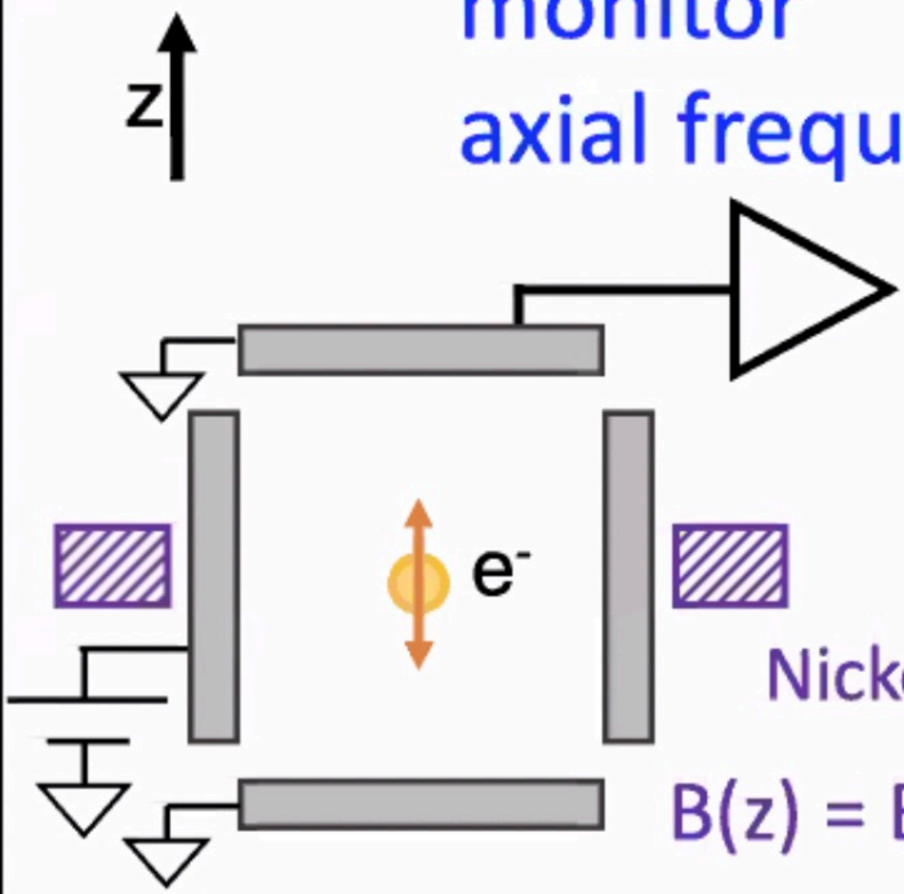
~1.001

😣 measure this with 10^{-13} precision

🤗 measure this with 10^{-10} precision (but this is not the end of the story)

How to Detect Transition?

monitor
axial frequency ν_z



potential along z

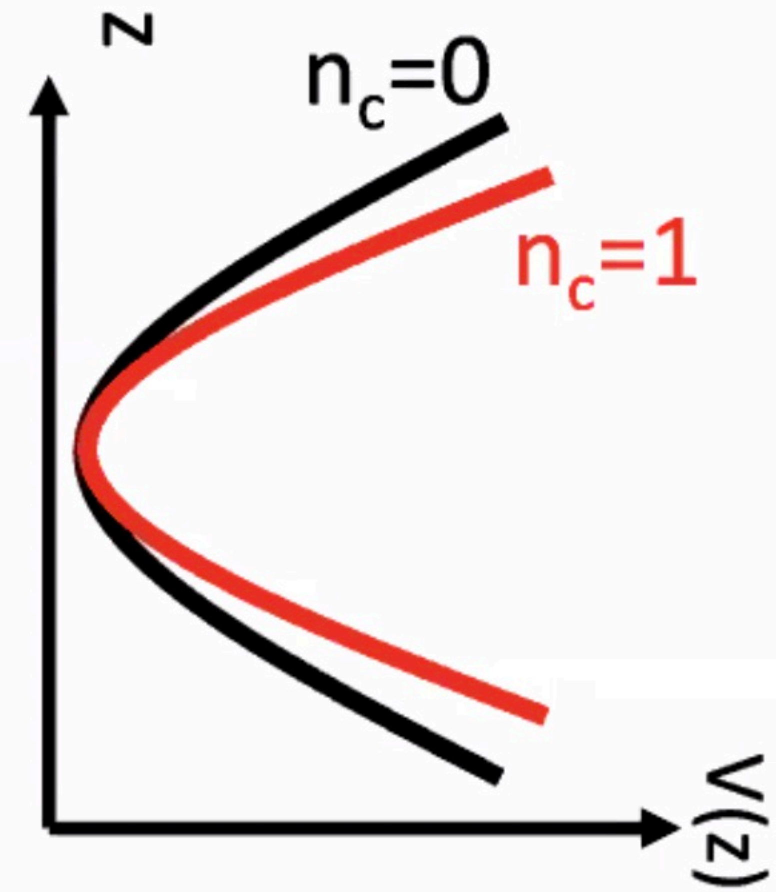
$$V(z) = eV_2z^2 + \mu_{tot}B_2z^2$$

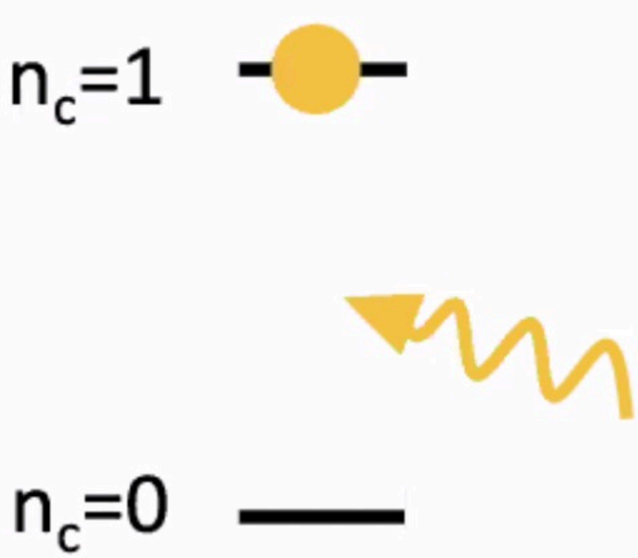
electric potential

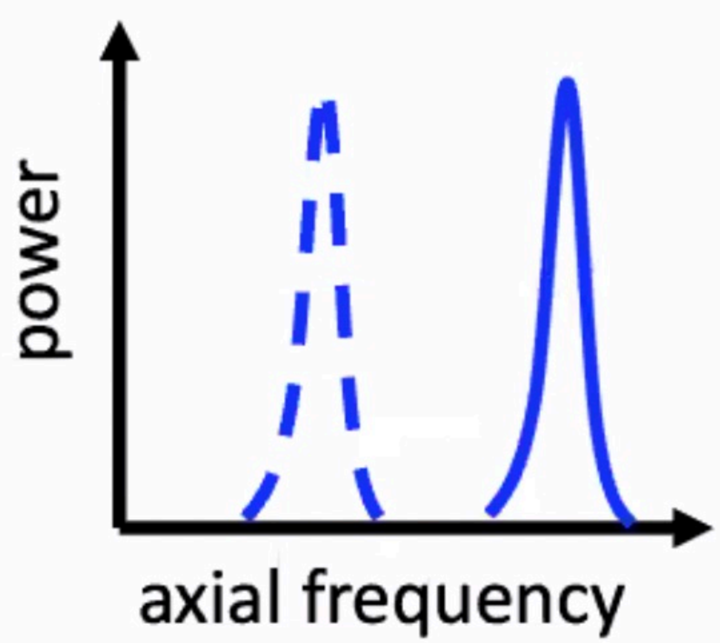
magnetic potential

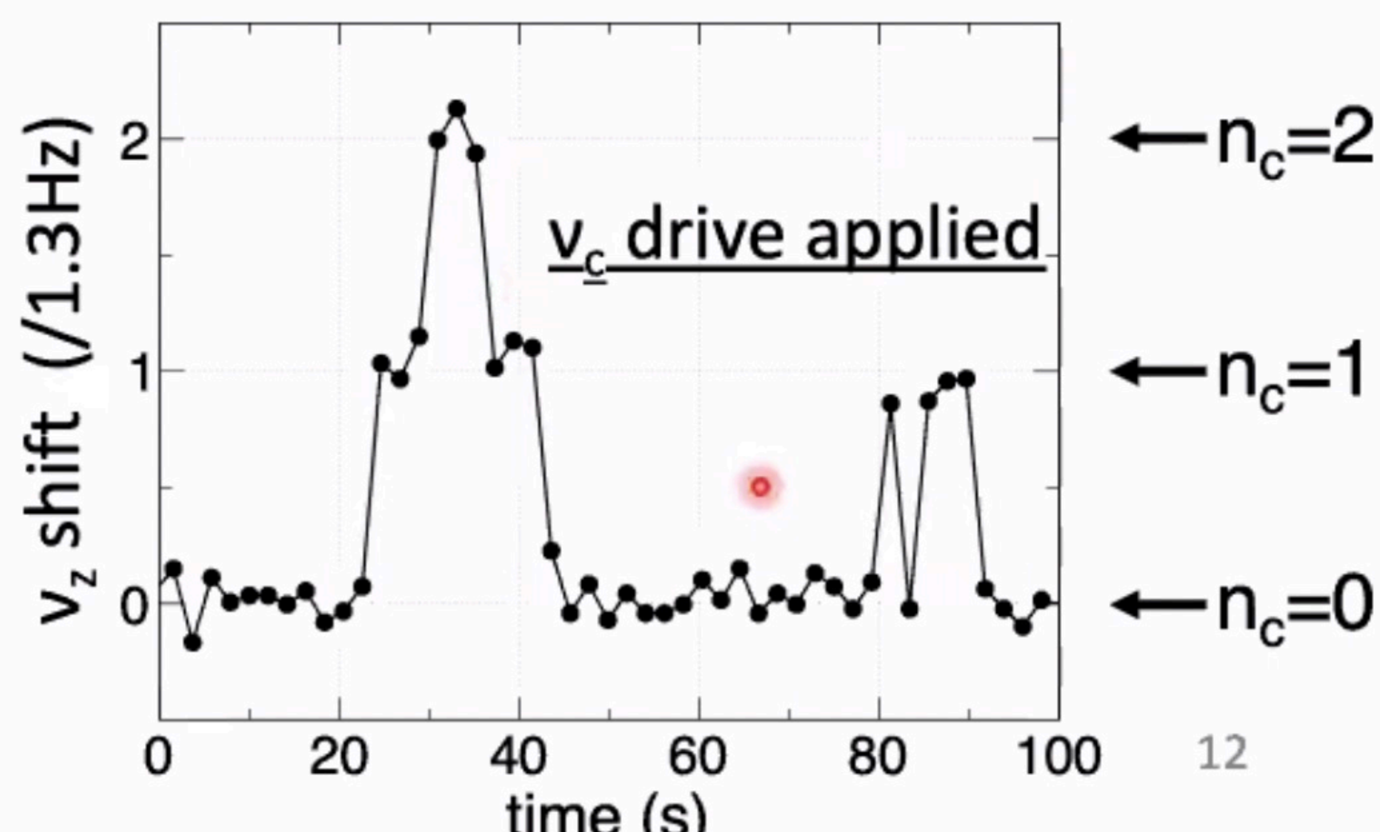
$B(z) = B_0 + B_2z^2$

$\mu_{tot} \propto (n_c+m_s)$





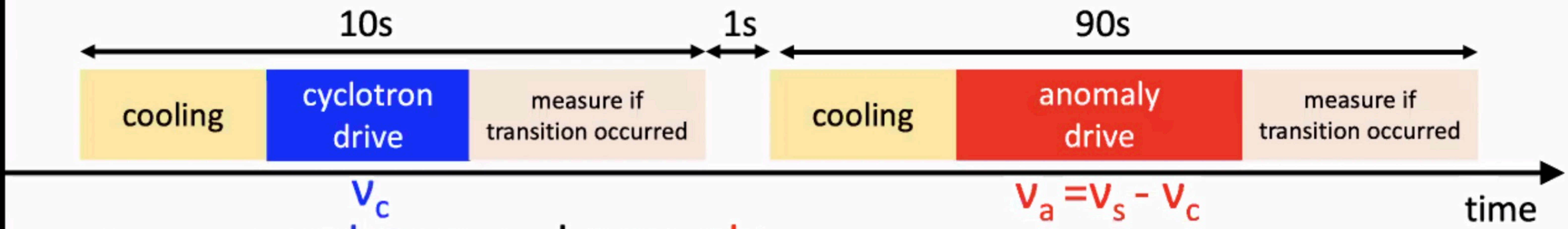




List of Improvements

1. Improved reliability and stability by a new system
   - ➢Constructed many modular and robust hardware for long-term reliable operation
2. Better stabilization of magnet
   - ➢^{3}He NMR probe to optimize the homogeneity
3. Reduction of microwave cavity sys. error

Measurement Scheme

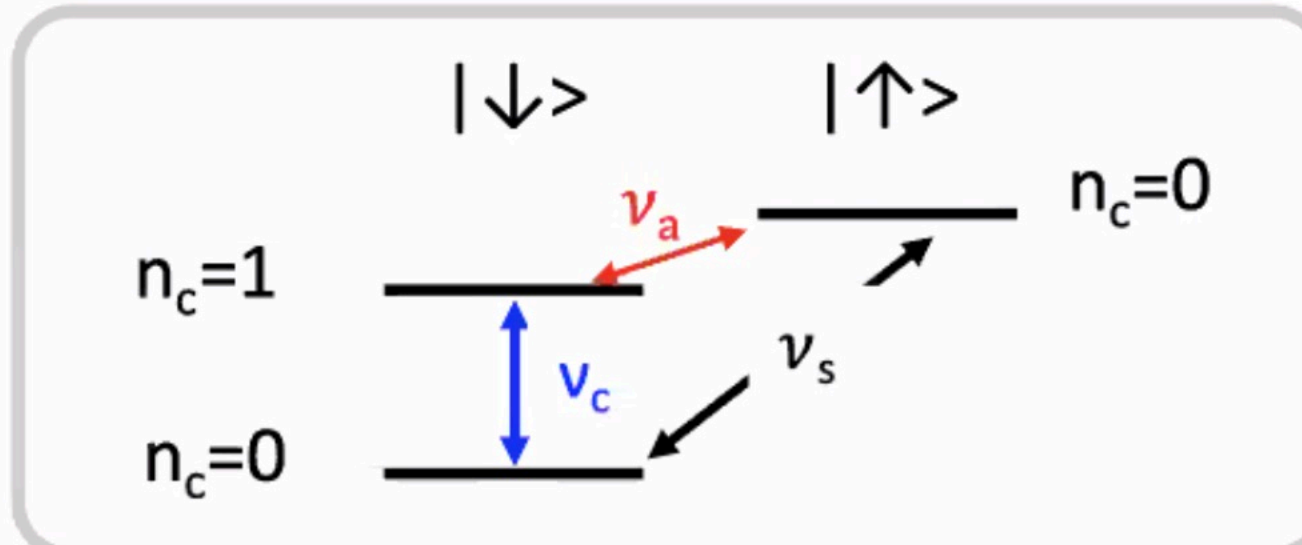


- measure cyclotron and anomaly alternately

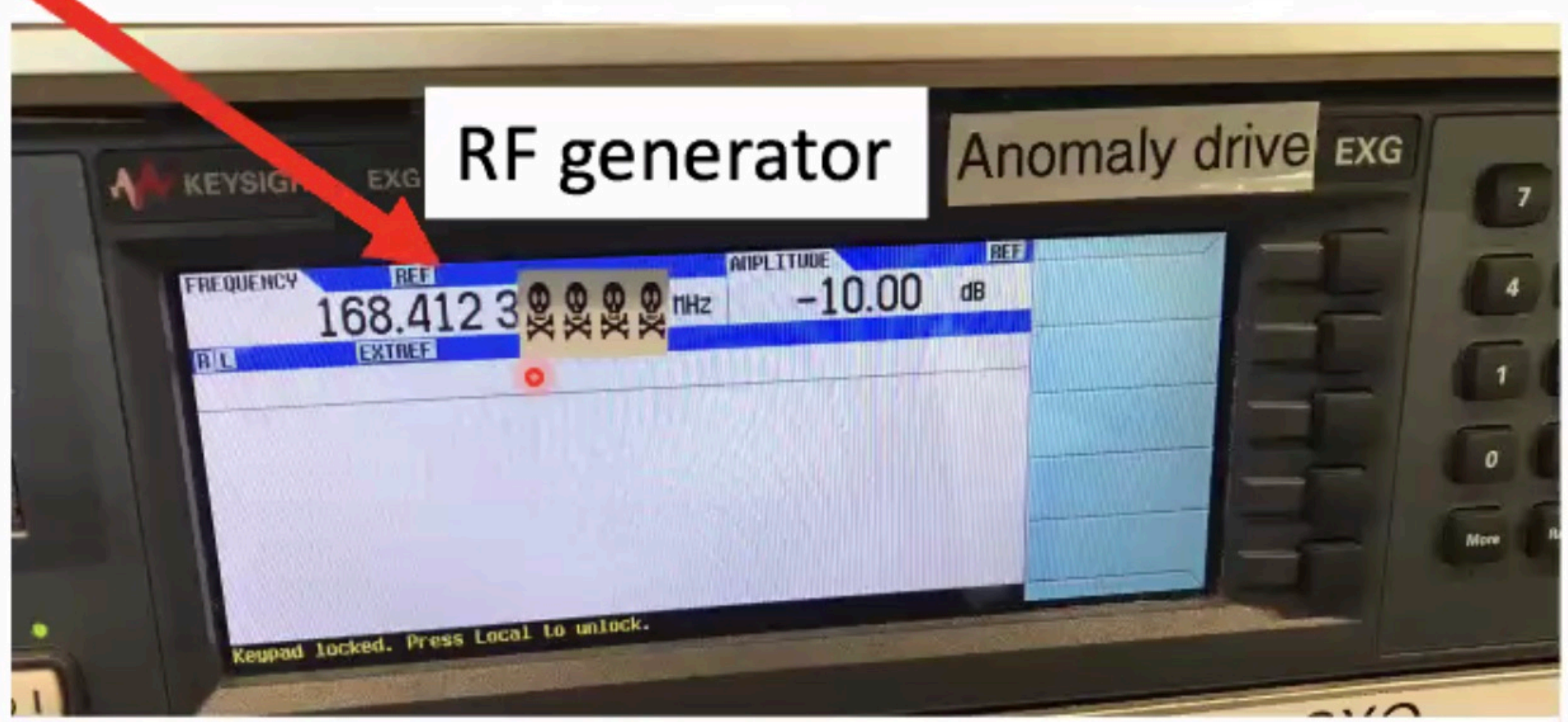
→cancels slow B drift

→record transition prob. vs drive freq.

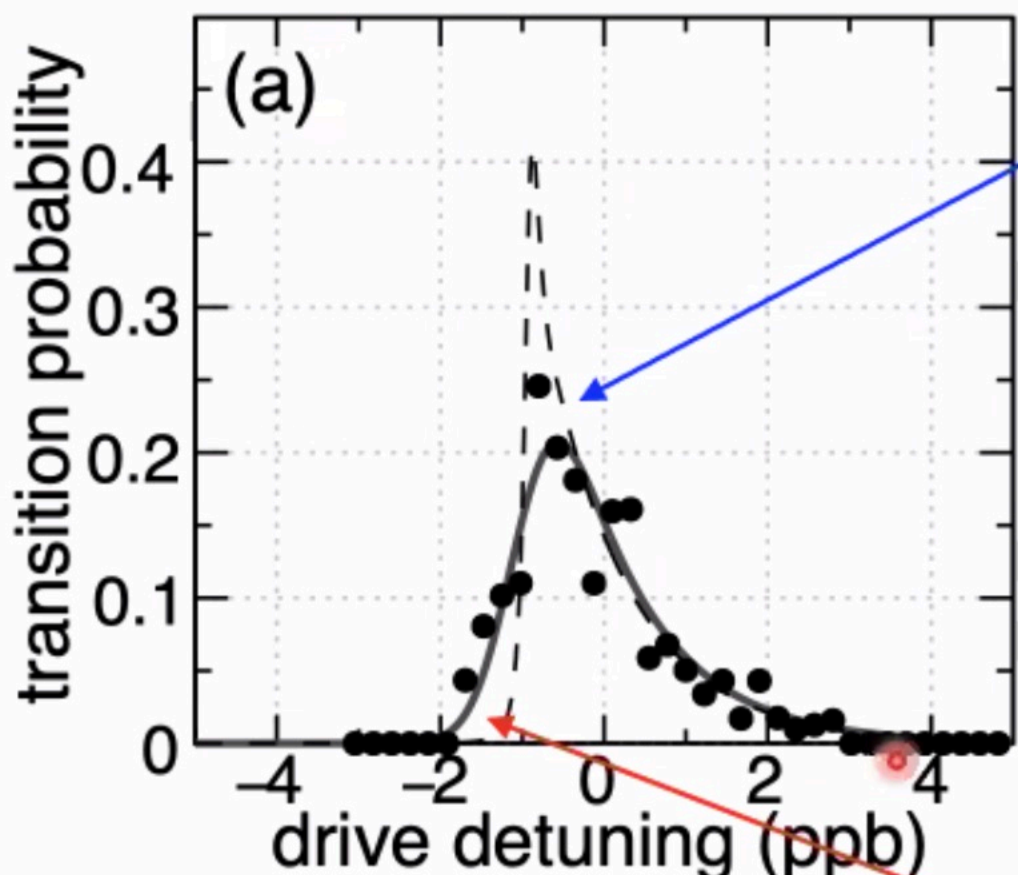
- the exact anomaly freq was blinded



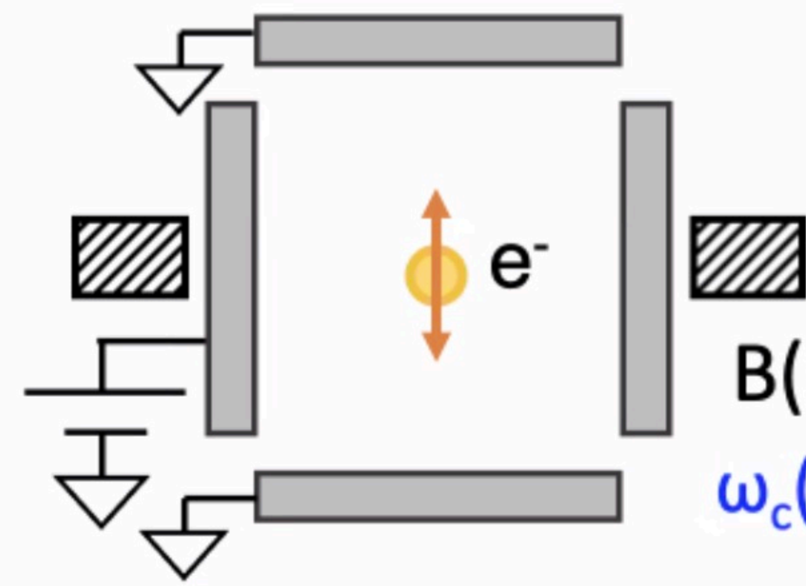
$$\nu_a^{true} = \nu_a^{set\ in\ computer} + X$$



Why is Cyclotron Broader?



theoretical lineshape



$B(z) = B_0 + B_2 z^2$

$\omega_c(z)=\omega_c(0)+qB_2z^2/m$

z^2 follows Boltzmann distribution

$$P(z^2) \propto \exp(-\frac{m\omega_z^2 z^2}{k_B T})$$

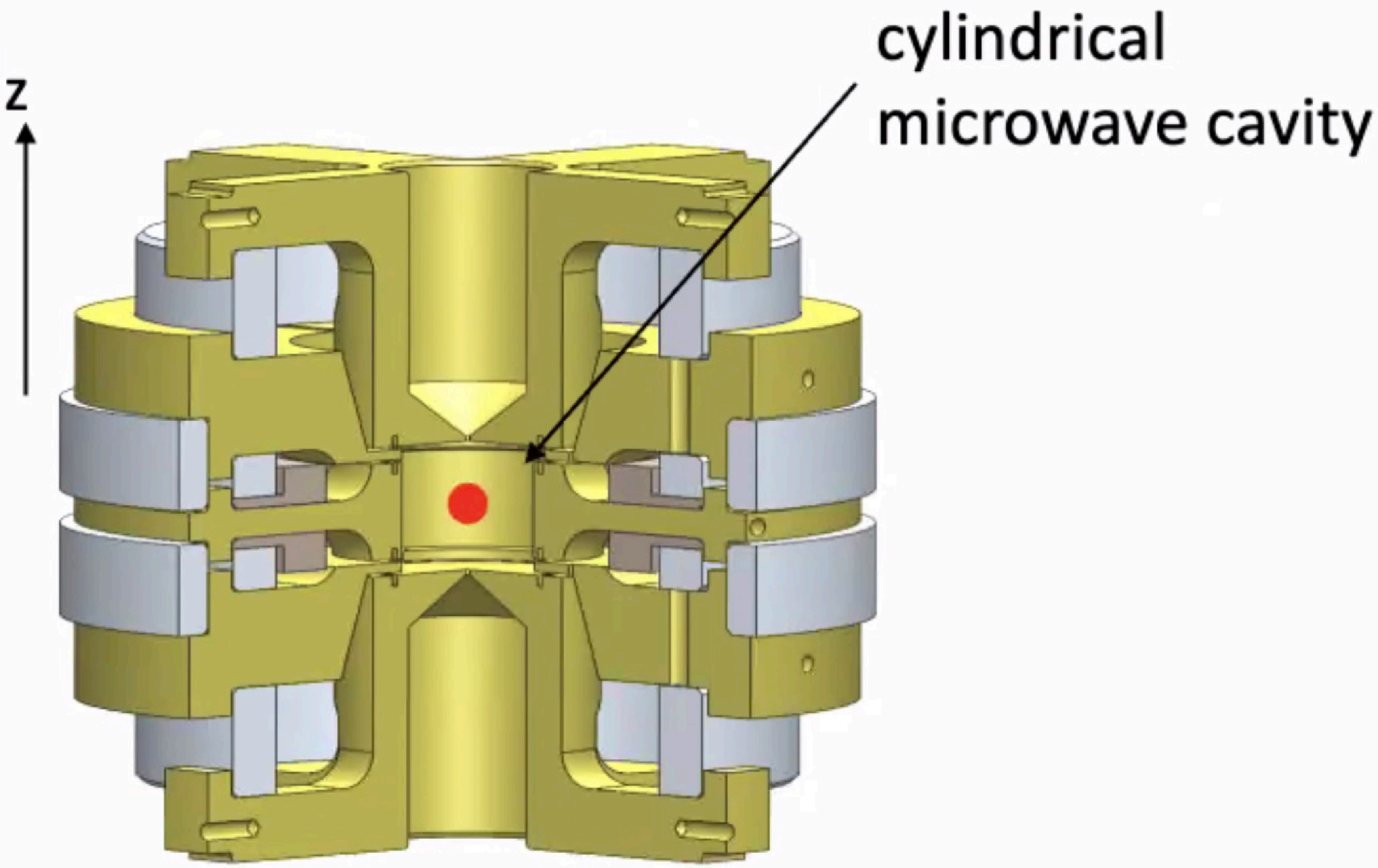
- We see additional broadening!
- Fit with many noise shape models

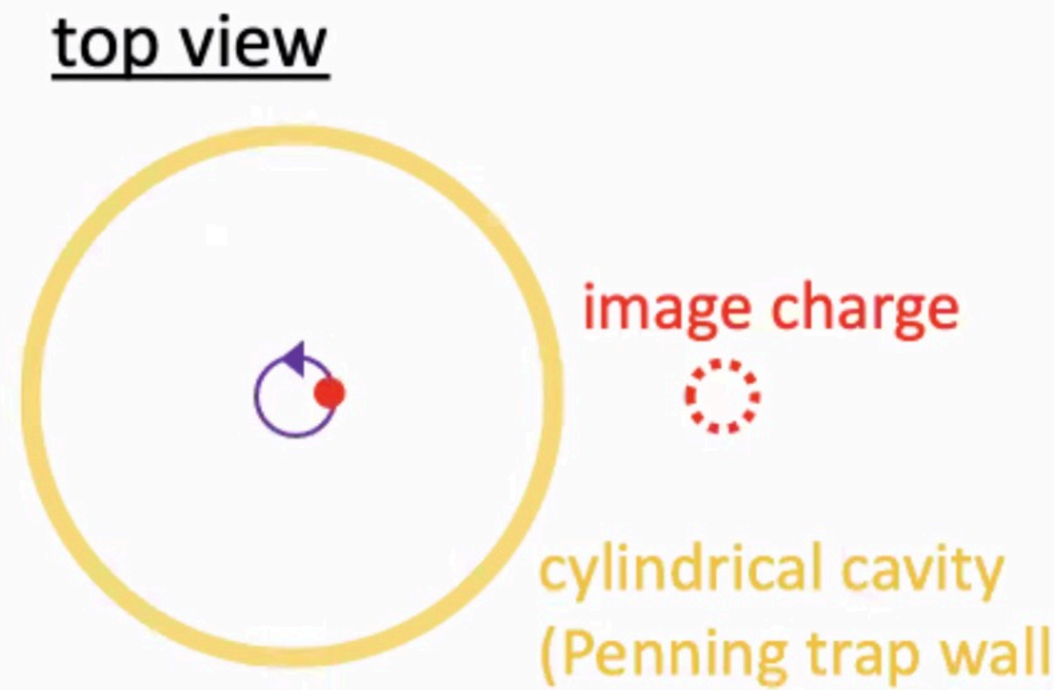
Gaussian, Lorentzian,
30 Hz noise, 60 Hz noise, rectangular shape

most likely from p-value test

Took the discrepancy as sys. error

Major Systematic Error: Microwave Cavity Correction

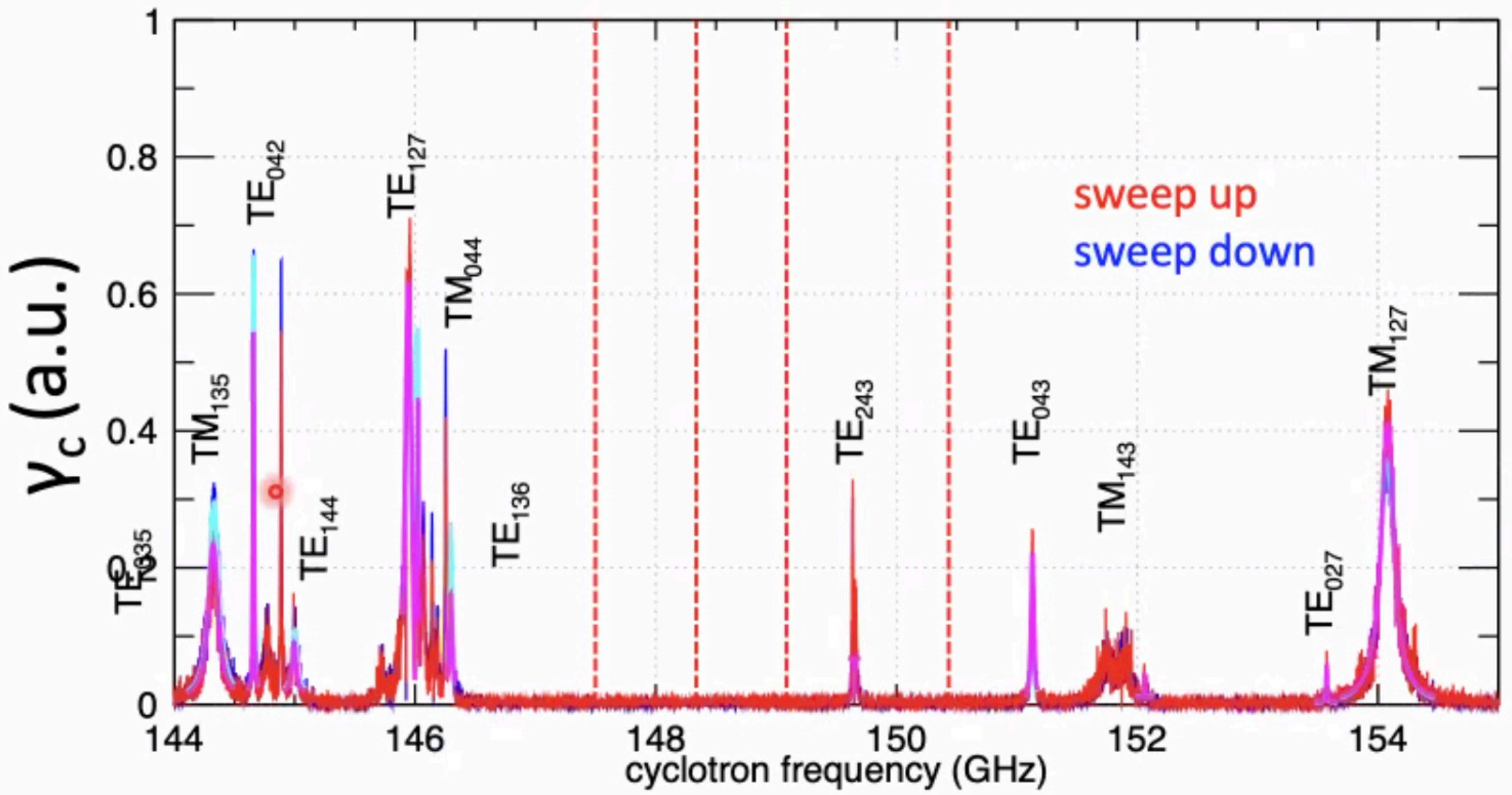




$$\frac{g}{2} = \frac{\nu_s}{\nu_c + \Delta\nu_c^{cav}}$$

- ν_c is affected by the electrodes, <u>but ν_s is not!!!</u>
- Large when ν_c is resonant with cavity resonance
  - →measure cavity resonances accurately
  - →measure g/2 at many different ν_c (=different B-fields)

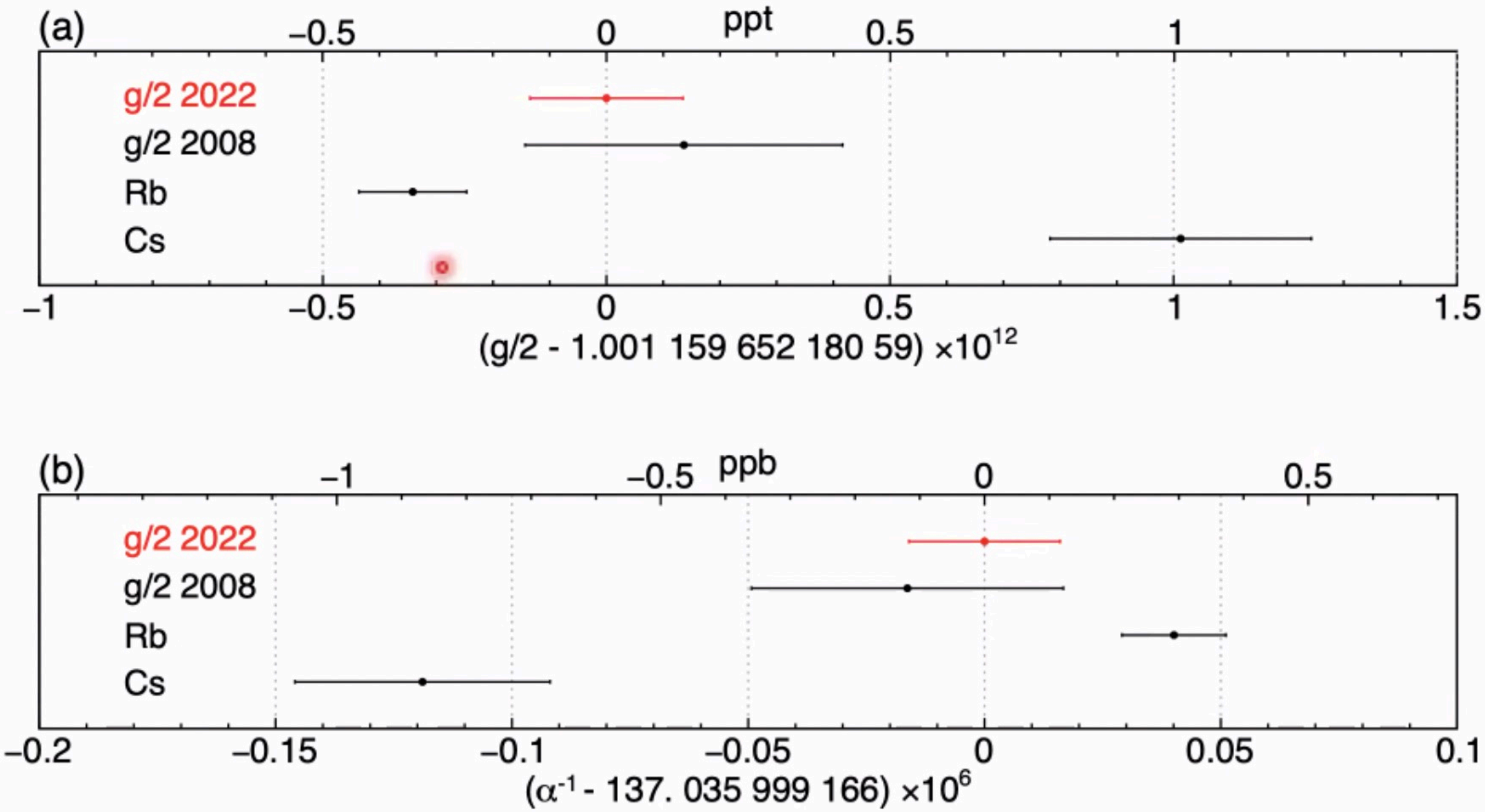
Microwave Resonances Measured by a Cloud of Electrons



--- g-factor measurement frequency

One narrow range from the whole range (60-160 GHz)

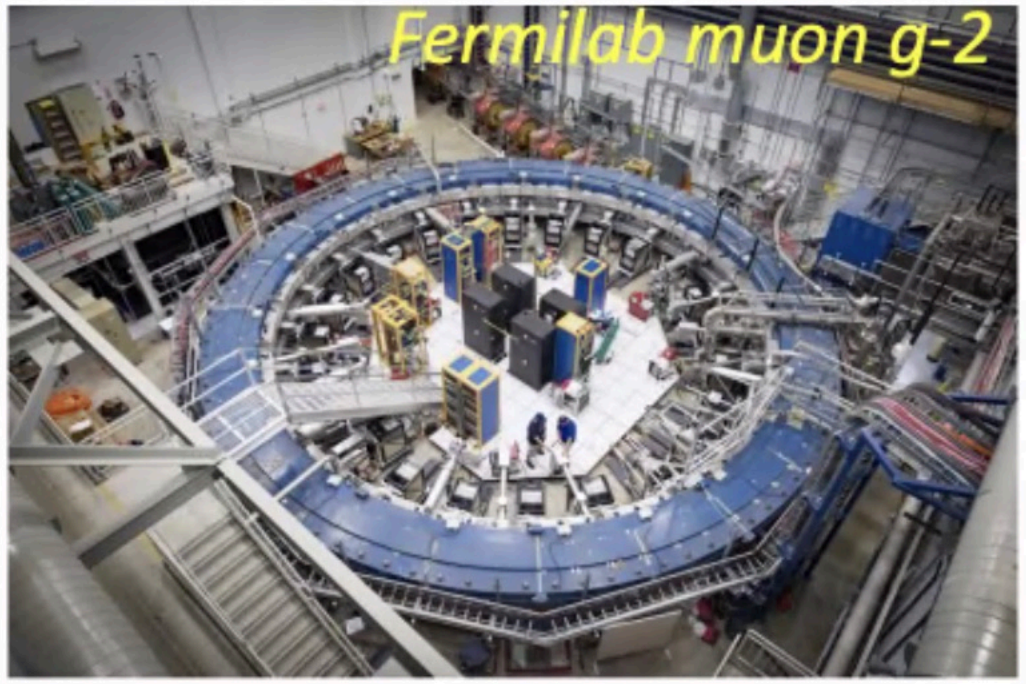
Result

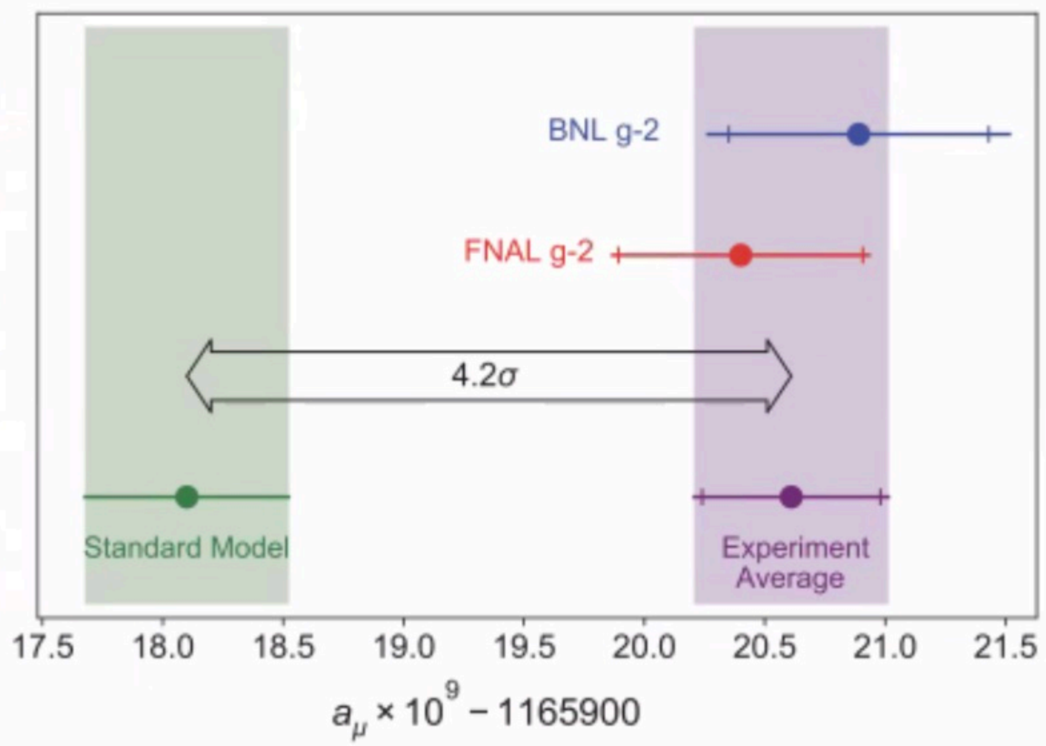


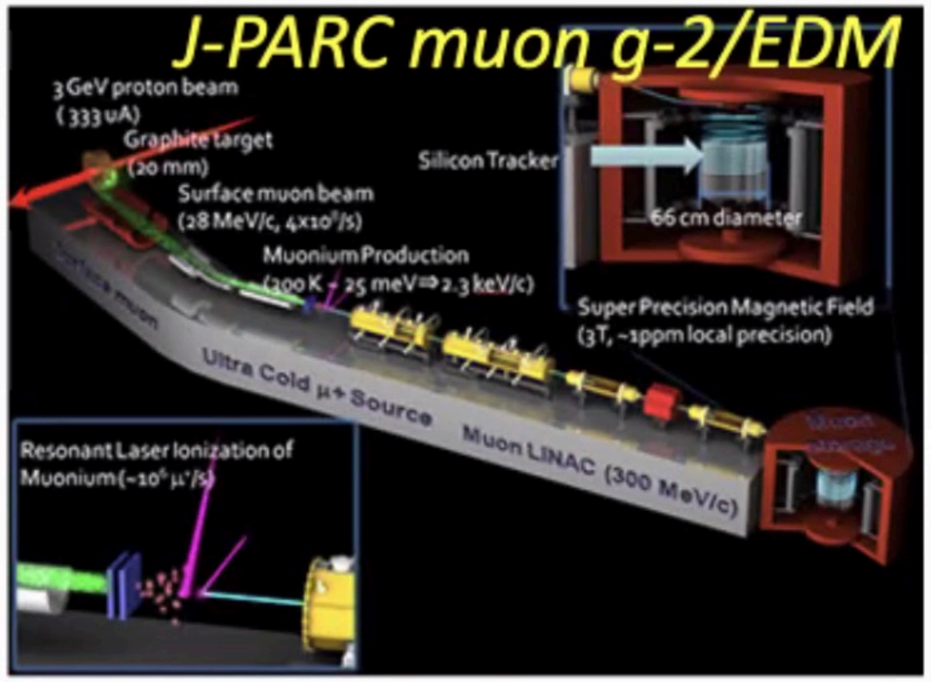
$$g/2 = 1.001\ 159\ 652\ 180\ 59\ (13)$$

stat.	0.029×10^{-12}
sys. (line shape)	0.094×10^{-12}
sys. (microwave cavity)	0.090×10^{-12}

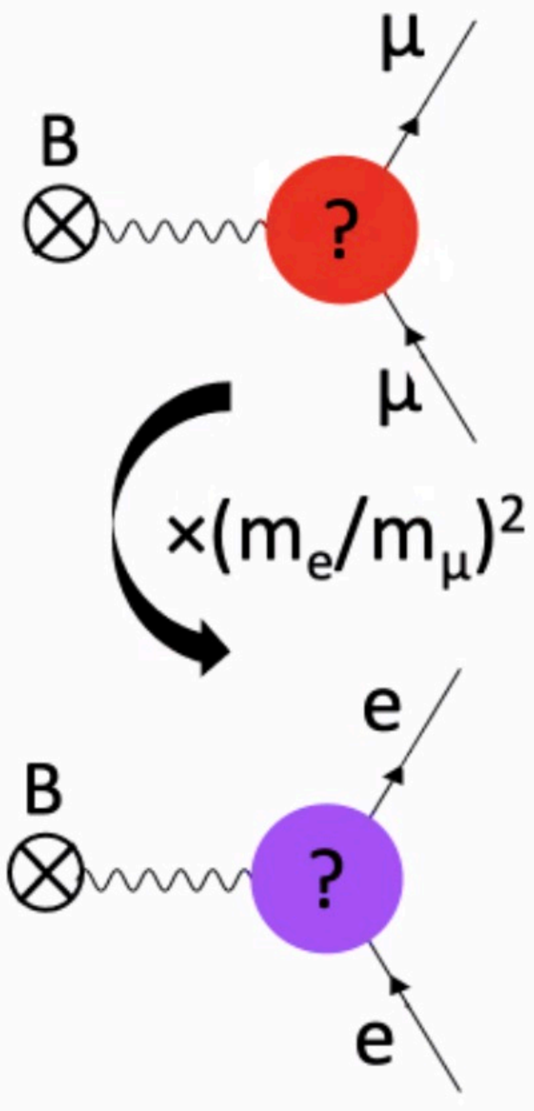
Able to check μ g-2?







PRL **126**, 1418019(2021), PRD **73** 072003(2006) PRD **102**, 033002(2020)), PTEP **2019**, 053C02 (2019)



$$\Delta g_\mu/2 = g_\mu/2^{\text{exp}} - g_\mu/2^{\text{theo.}} = 251(59)\times 10^{-11} \quad 4.2\sigma$$

$$\Delta g_e/2 = \Delta g_\mu/2 \times (m_e/m_\mu)^2 = 0.058(14)\times 10^{-12}$$

this time: $\sigma(g_e/2)=0.13\times 10^{-12}$

need another factor 2.2 improvement
(and a consistent α measurement)