Relativistic Shifts of μ^- *g*-factors: Finite Nuclear Size Effects

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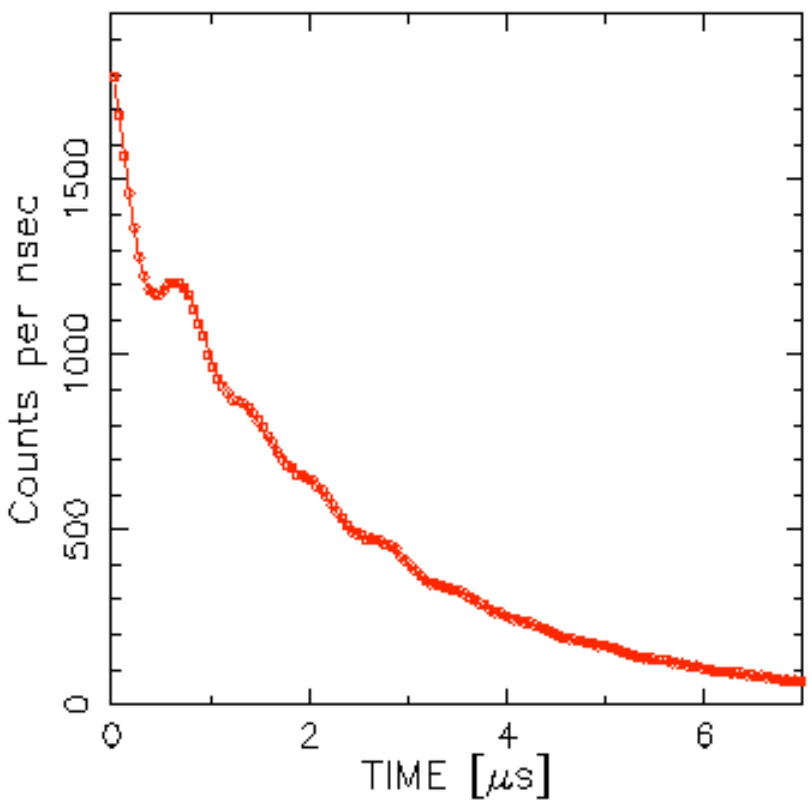
High precision measurements of μ^- spin precession frequencies at 2.4 T in high-Z muonic atoms reveal large relativistic shifts of the bound muon's magnetogyric ratio. New results on muonic tungsten and lead suggest that the relativistic shift is nearly independent of Z in heavy elements where the muon's ground state wave function is mostly inside the nucleus.

Cast of Characters

- 1928 Breit
- 1961 Ford, Hutchinson *et al.*
- 1974 Yamazaki *et al.*
- 2003, 2007 Mamedov *et al.*
- 2005, 2008 **Jess H. Brewer**, *Donald Arseneau*, Khash Ghandi, Scott Stubbs, Peter Russo, Aaron Froese & Bruce Fryer

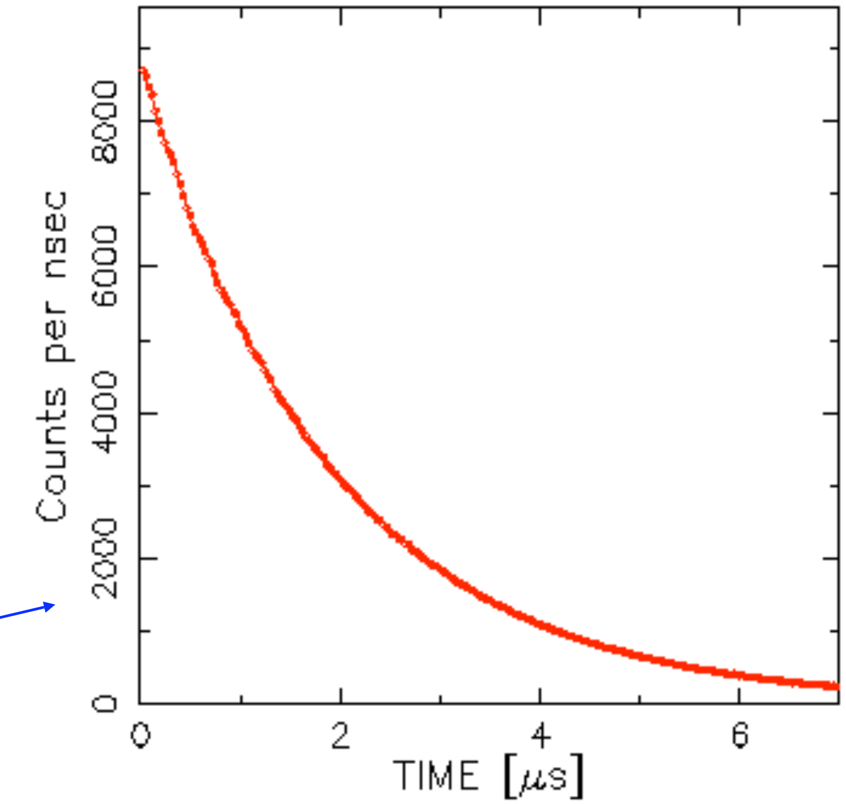
μ^+SR *vs.* μ^-SR

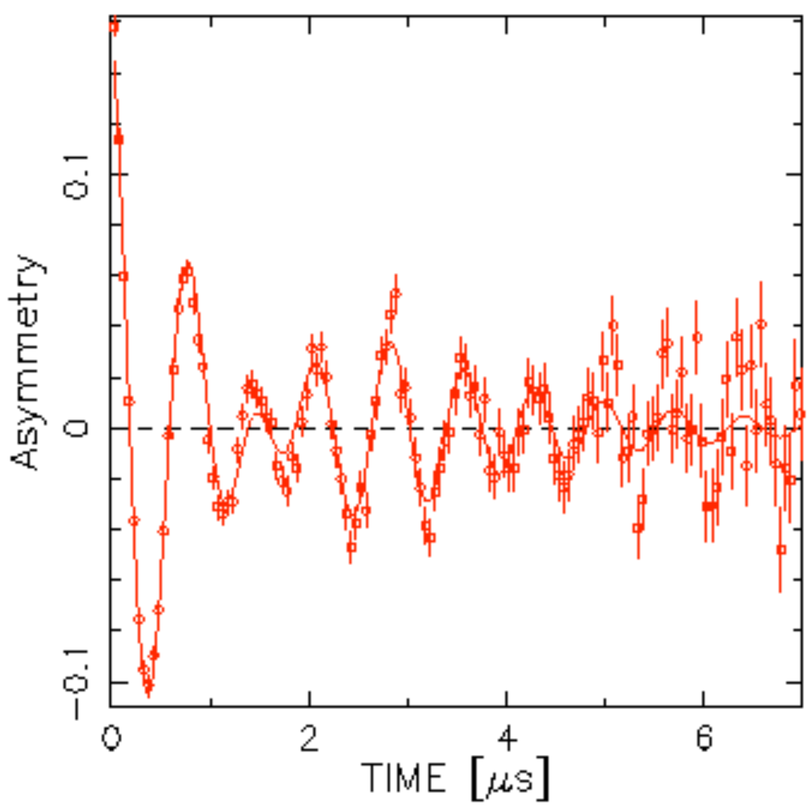


Typical time spectrum
(histogram)

Single lifetime
τ_μ = 2.197 μs

Multiple lifetimes
(some very short!)

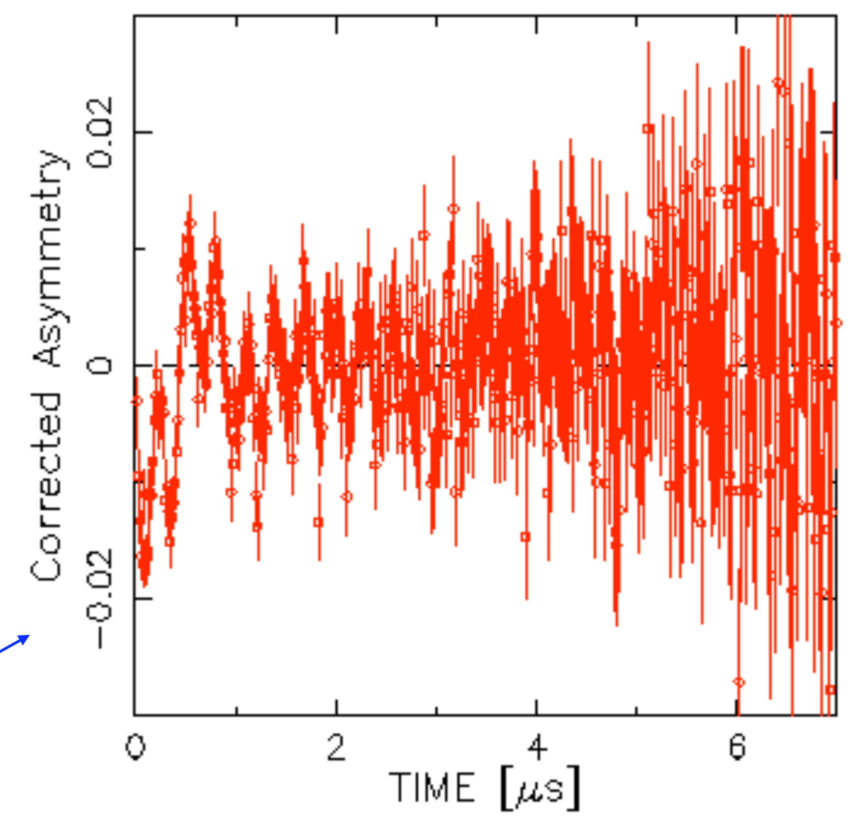




Asymmetry spectrum

Large amplitudes

Small amplitudes



An Old Story:

Relativistic Shifts of Bound μ^- g-factor

A negatively charged lepton in the ground state of an atom experiences a relativistic shift of its spin precession frequency in a given magnetic field. This effect was first calculated by Breit in 1928 assuming pointlike nuclei; the result is the same for electrons or muons:

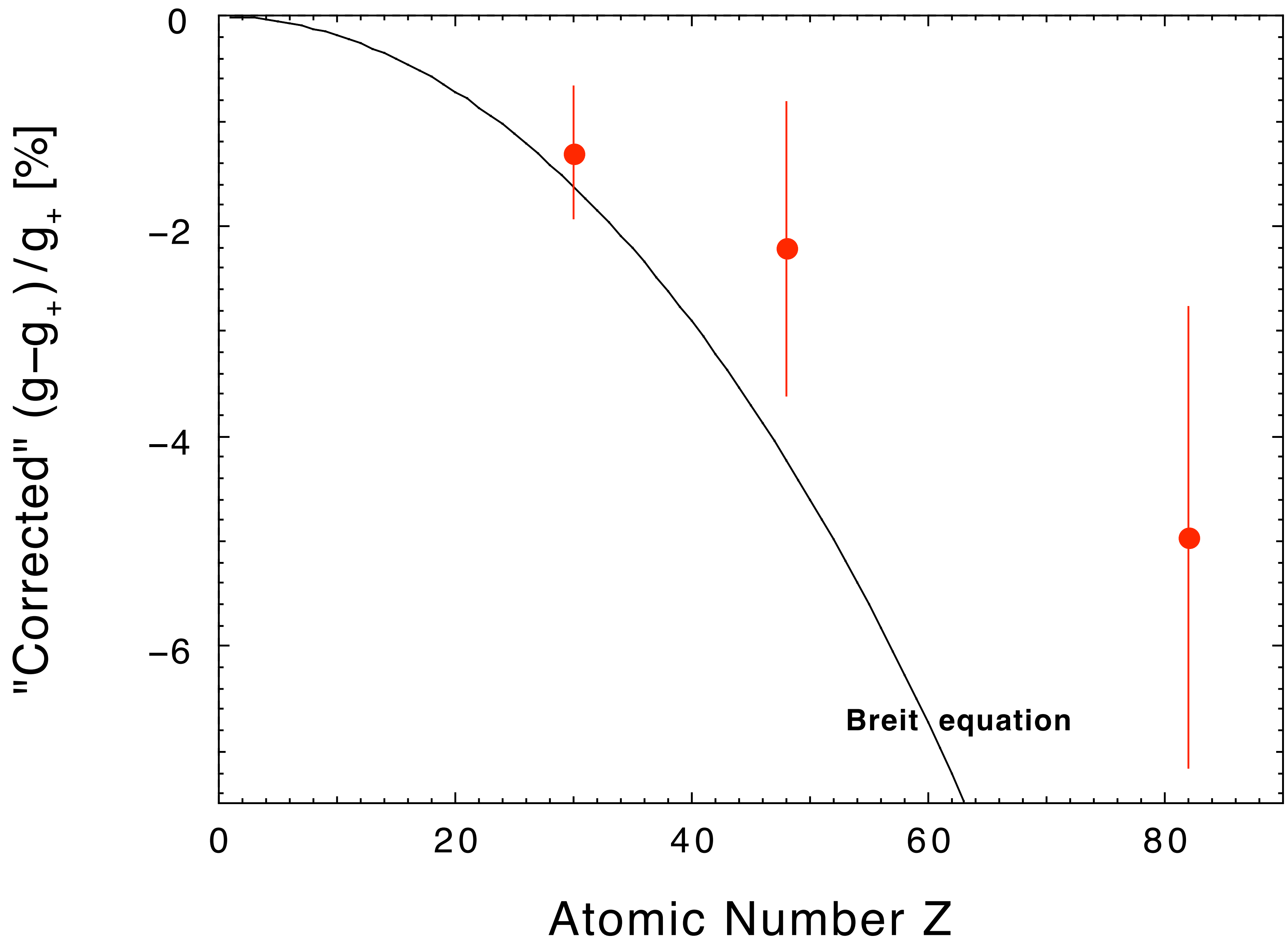
$$\frac{g_{\rm free} - g}{g_{\rm free}} = \frac{2}{3}\left(1 - \sqrt{1-\alpha^2 Z^2}\right) \approx \frac{1}{3}\left(\frac{\bar{v}}{c}\right)^2$$

More refined calculations for muonic atoms, including the effects of a finite nuclear size, were made by Ford, Hughes and Wills in 1961 and agreed well with the first measurements by Hutchinson *et al.* in the same year for Z up to 16. In 1974 Yamazaki *et al.* extended these measurements to $Z = 82$ with modest precision. This result went unchallenged until 2003, when Mamedov *et al.* remeasured muonic Zn and Pb and reported much smaller shifts.

In 2005 I had an opportunity to measure these shifts to much higher precision, so I did, obtaining results consistent with Yamazaki's. Mamedov responded with another measurement in 2007, confirming his previous disagreement. What could I do but repeat my measurement at the highest field ever used, with such overwhelming statistics that the signals can be easily observed by eye even at the very high frequencies? Here are the results, which vindicate Yamazaki . . . .

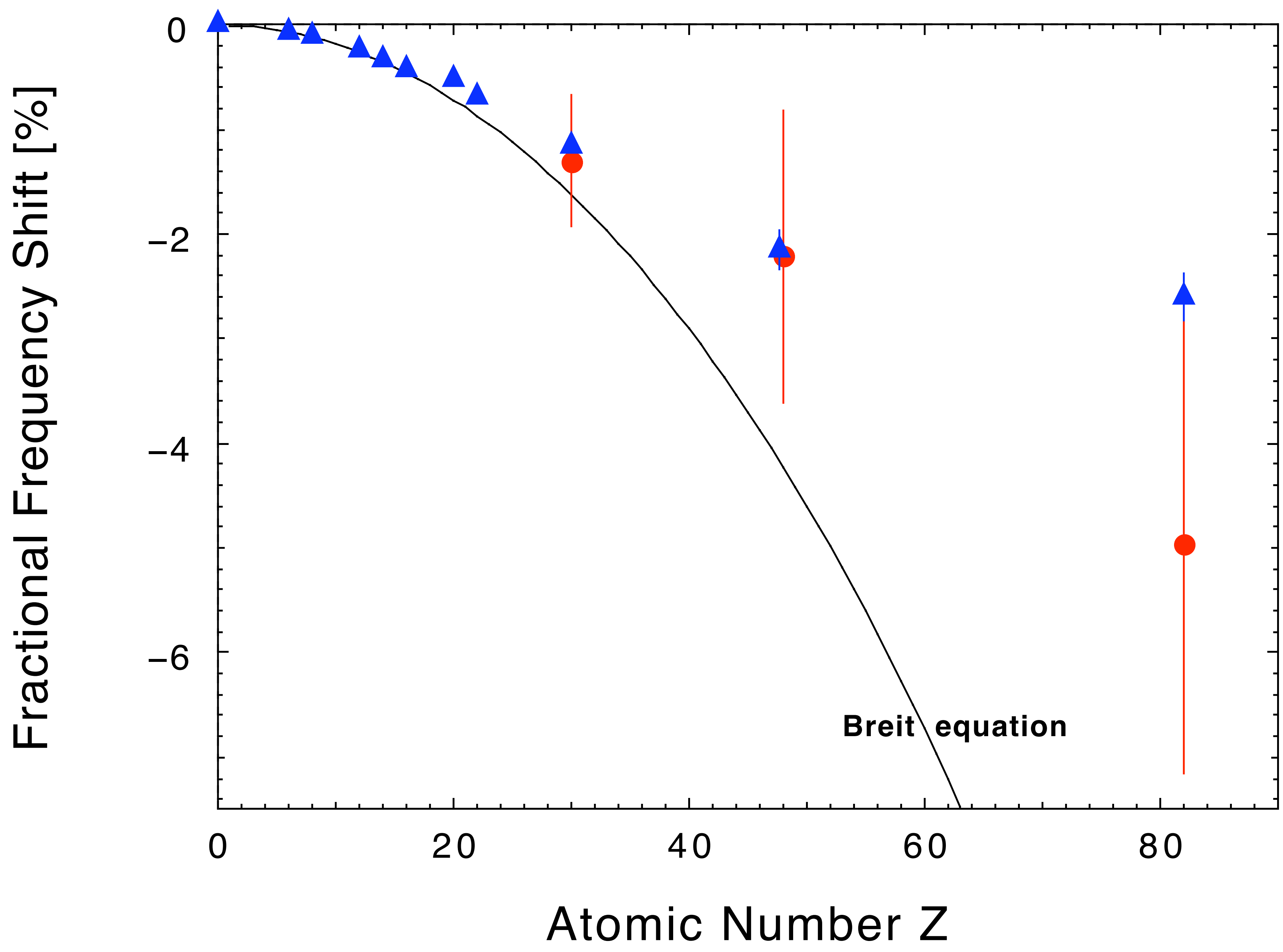
Relativistic Shifts of Bound μ^- g-factor

Yamazaki et al. (1974)



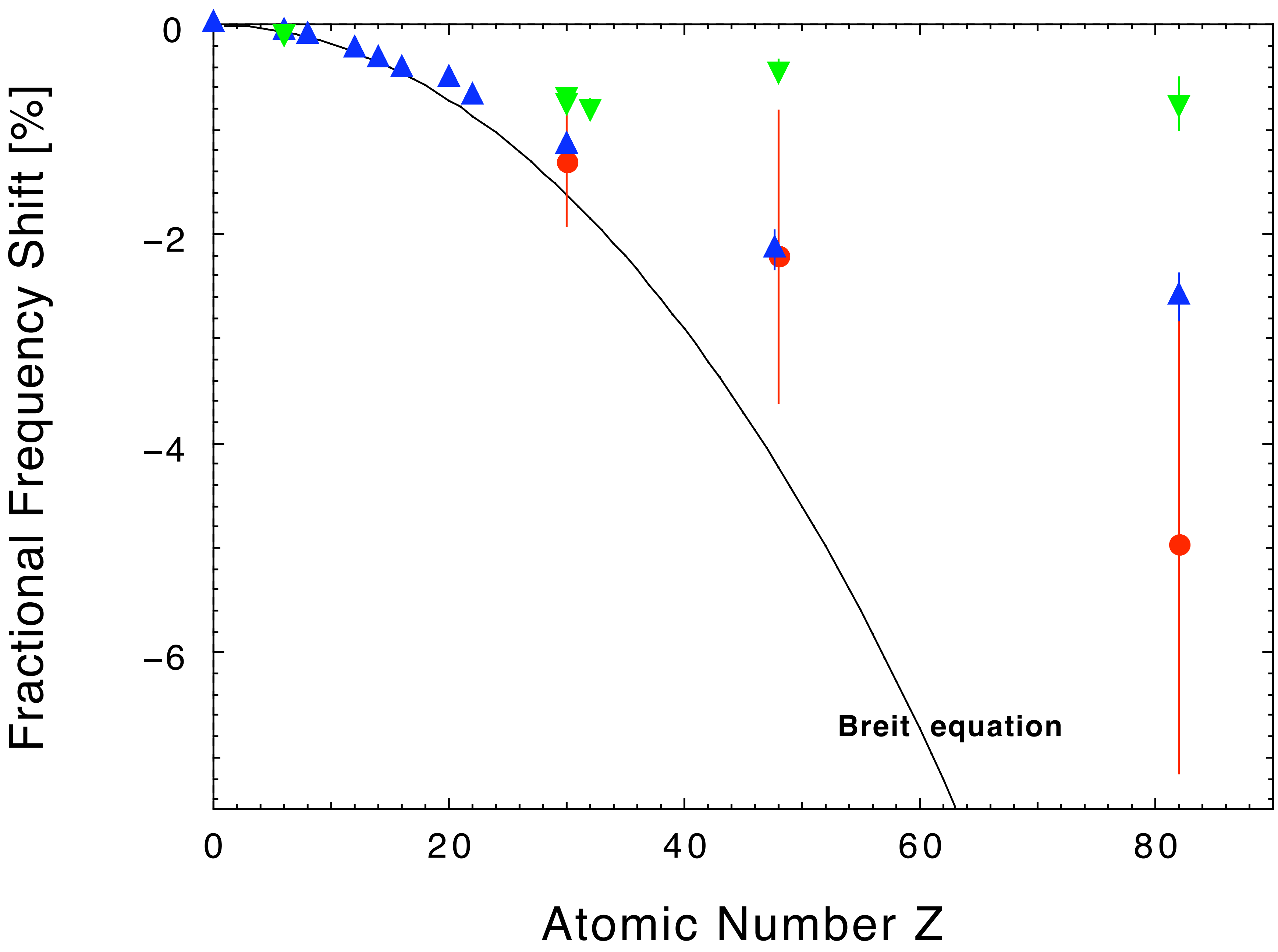
Relativistic Shifts of Bound μ^- g-factor

Brewer et al. (2005)

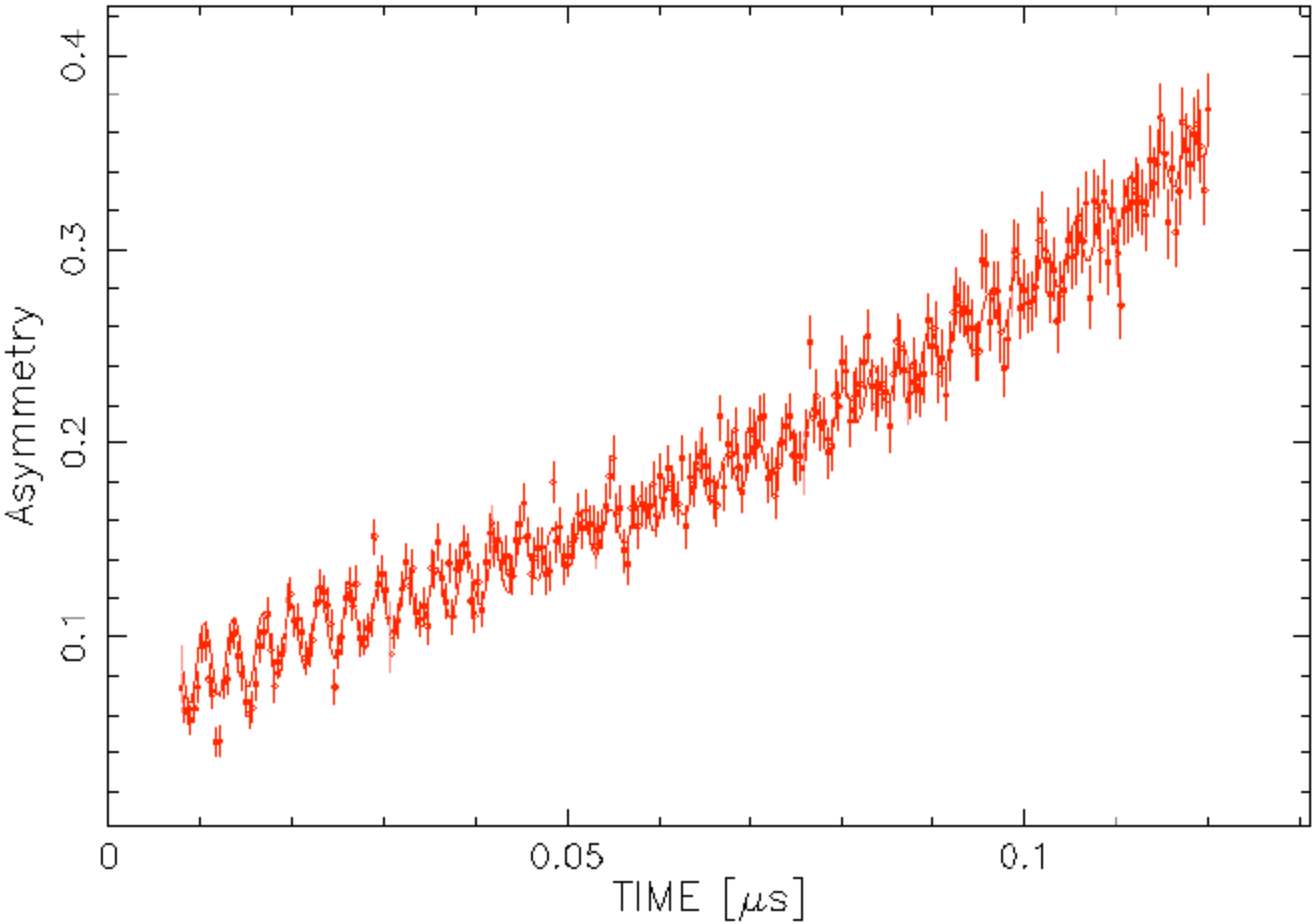


Relativistic Shifts of Bound μ^- g-factor

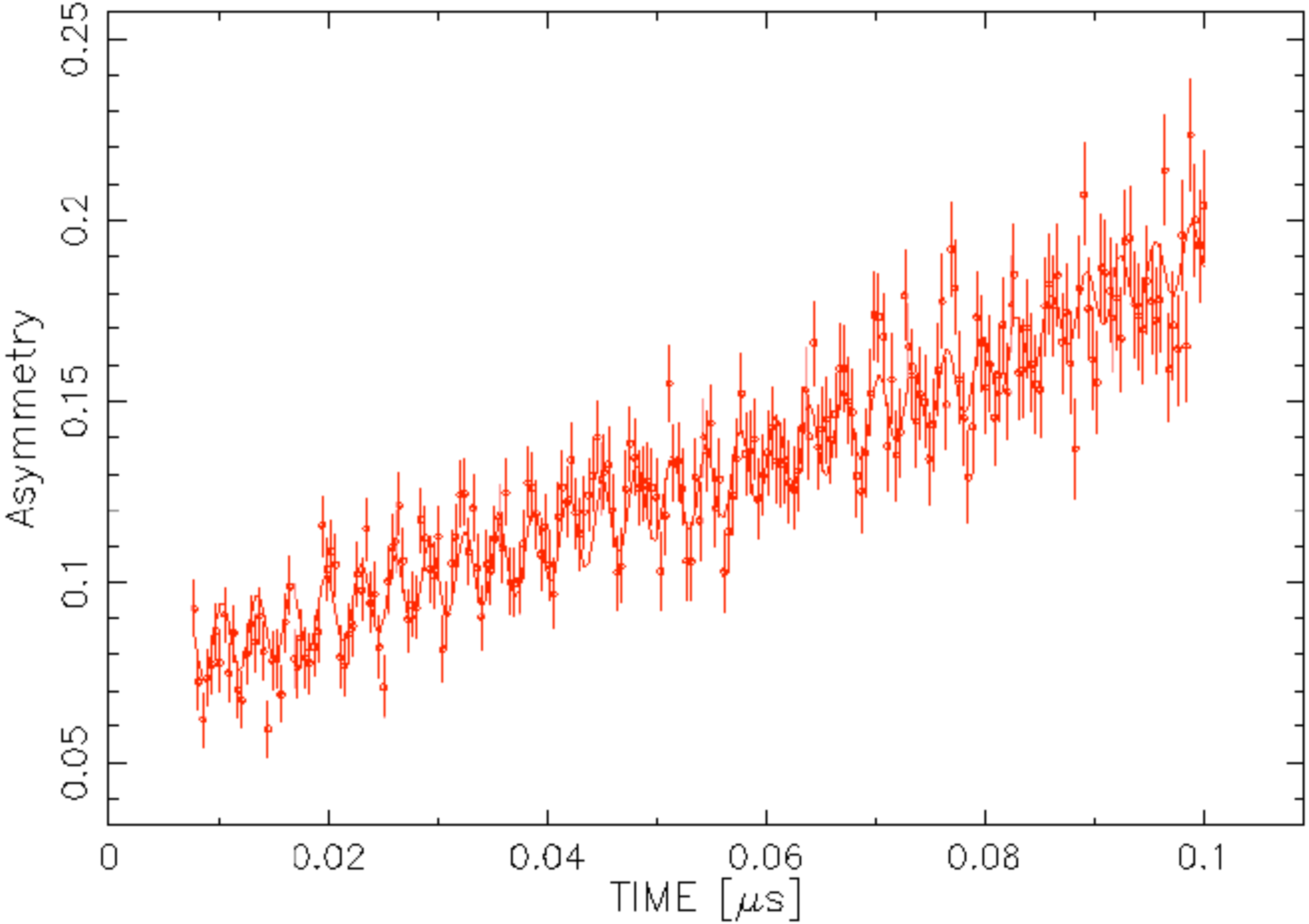
Mamedov et al. (2007)



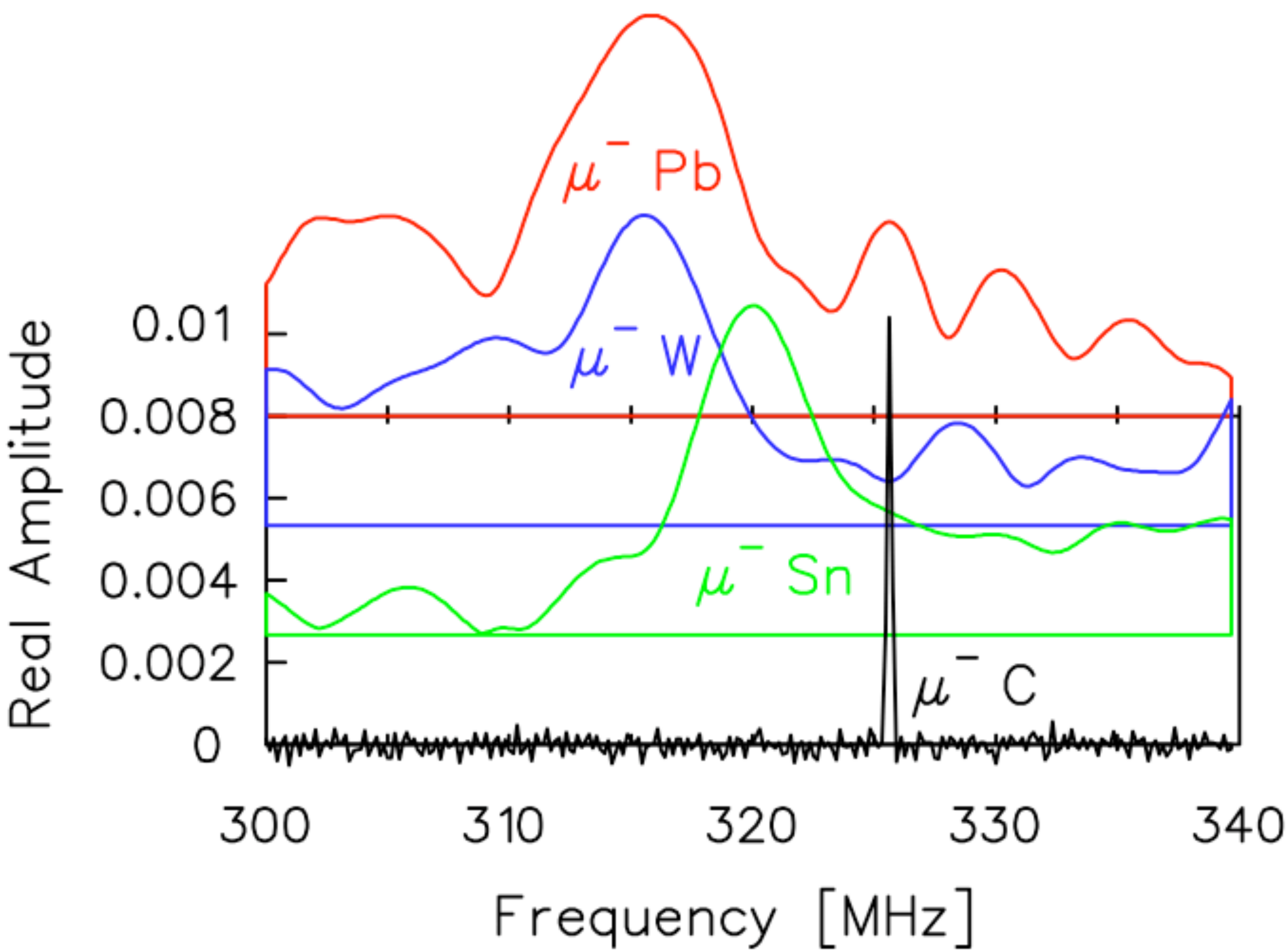
NEW: $\mu^{-}Pb$ at 2.4 T



NEW: $\mu^{-}W$ at 2.4 T

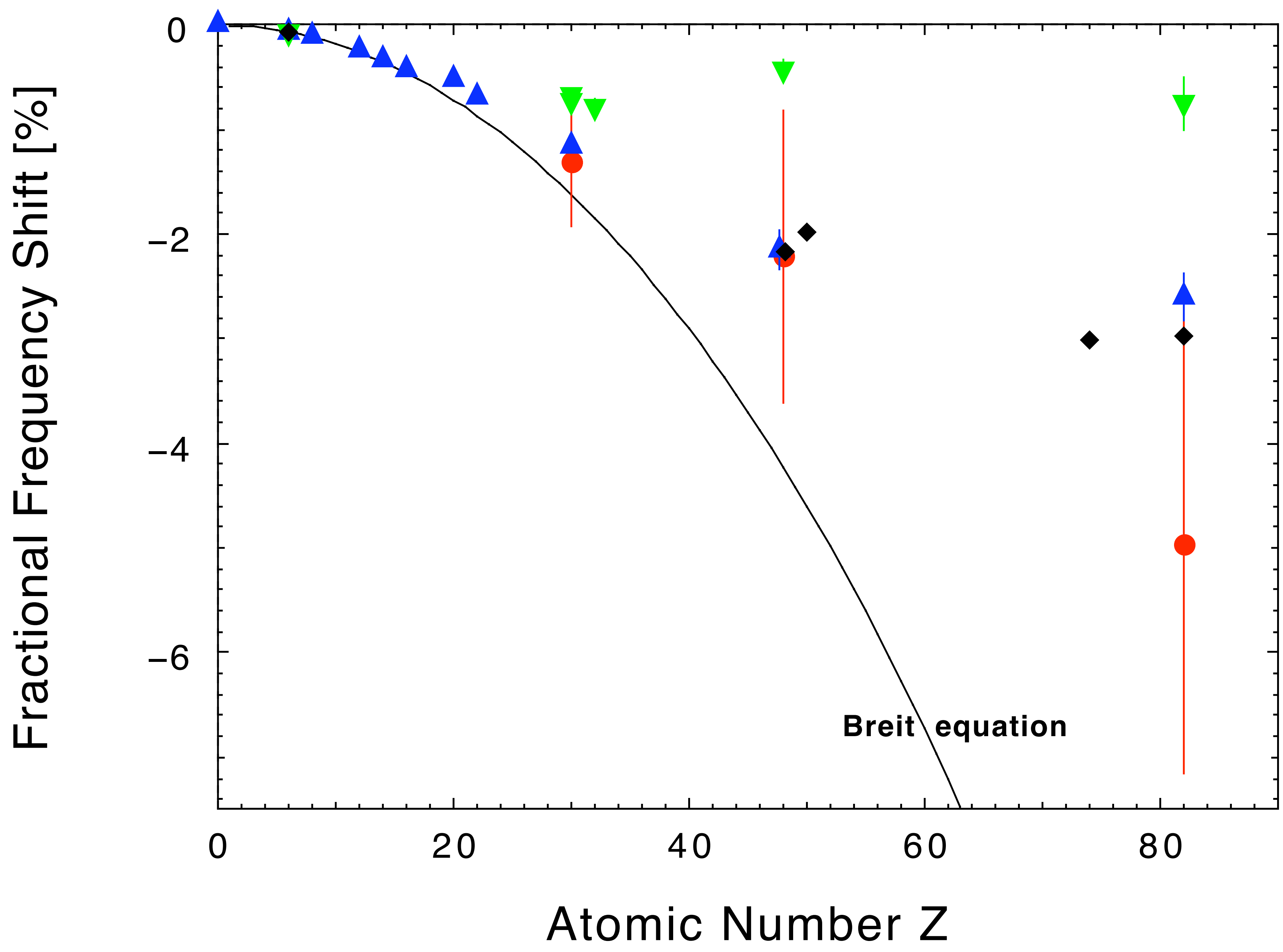


Fourier Transforms at 2.4 T



Relativistic Shifts of Bound μ^- g-factor

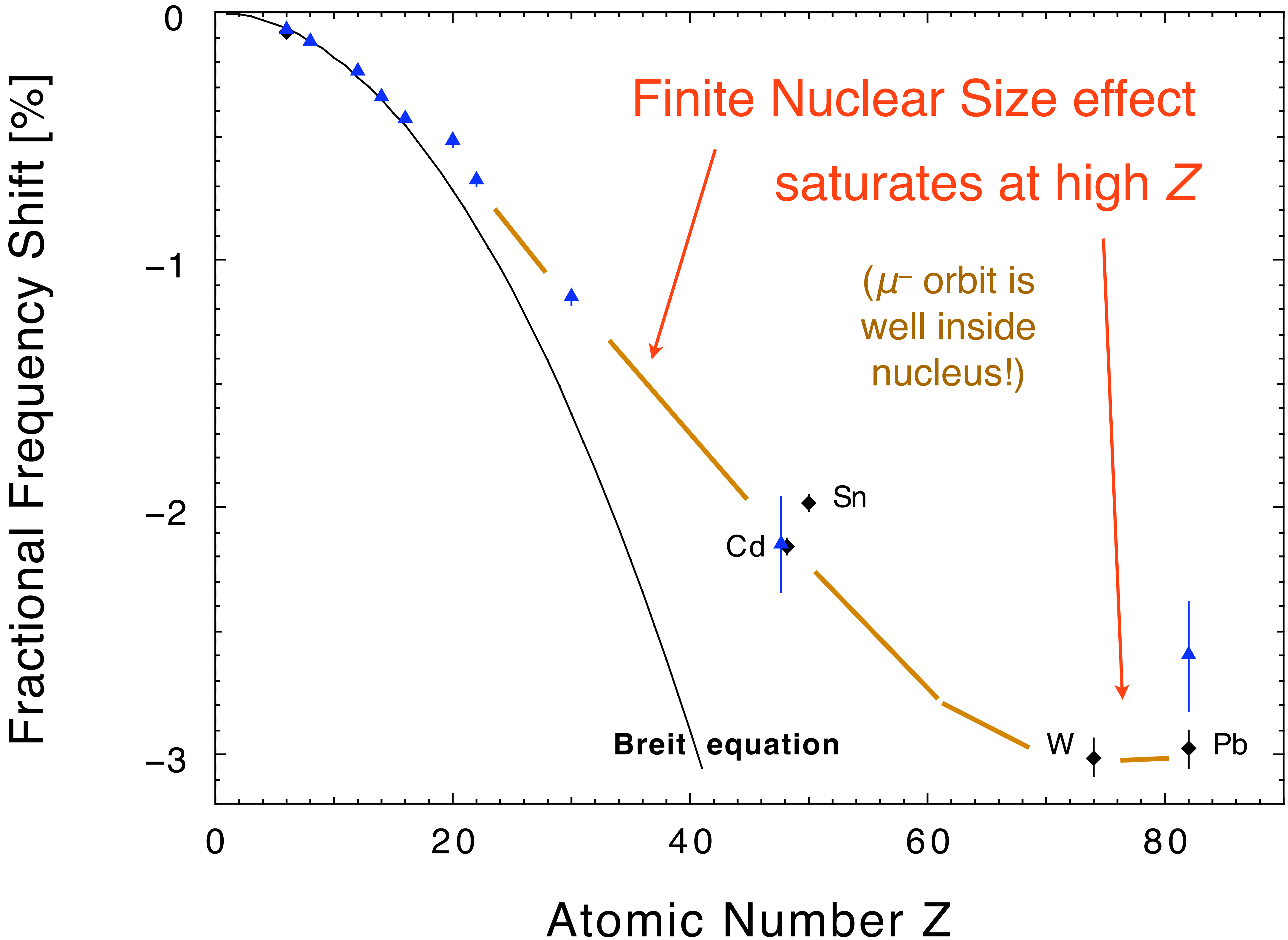
Brewer et al. (2008)



So What?

Who Cares?

New way to measure nuclear charge distribution?



Finis