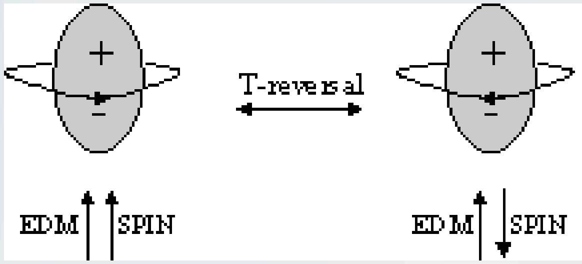
Neutron Electric Dipole Moment (NEDM)

Matt Eichenfield

04/20/2007

P and T Violations

$$H = -\mu \vec{B} \cdot \frac{\vec{s}}{|\vec{s}|} - d\vec{E} \cdot \frac{\vec{s}}{|\vec{s}|}$$



- EDM's of structureless particles cause parity violations in the strong interaction Hamiltonian
  - B and s are pseudovectors
    - Odd under P
    - Odd under T
  - E is a vector
    - Even under P
    - Even under T

CP Violations

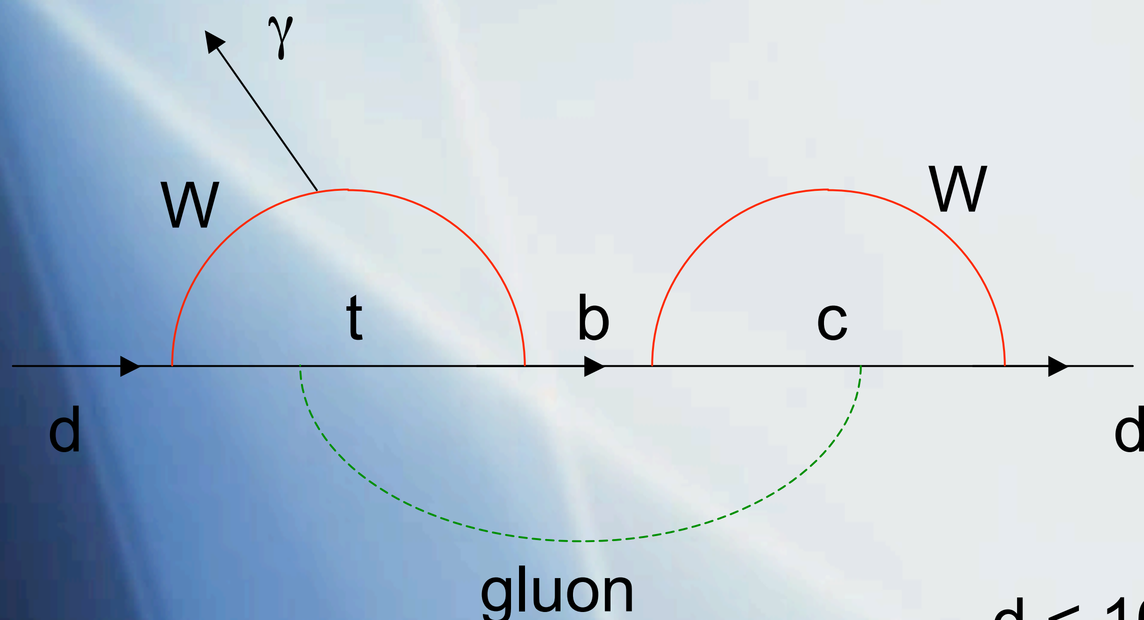
- Through CPT, T implies CP
  - CP violating interactions necessary to explain the Baryonic asymmetry of the universe

The Neutron's Constituents

- Three quarks
  - Two down (q = -1/3)
  - One up (q = +2/3)
- Time-averaged charge displacement with respect to spin axis gives EDM
  - CONSTITUENTS MUST HAVE EDM's

NEDM in the Standard Model

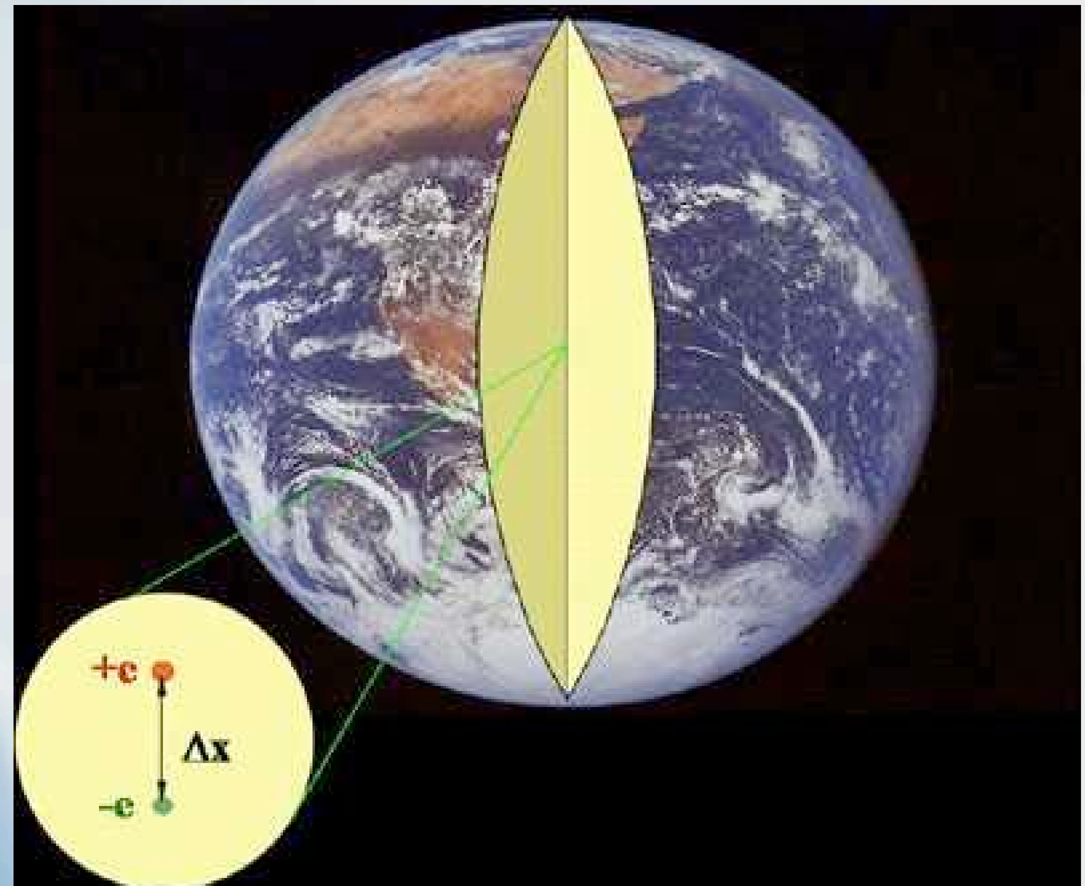
- CKM phase generates tiny EDMs



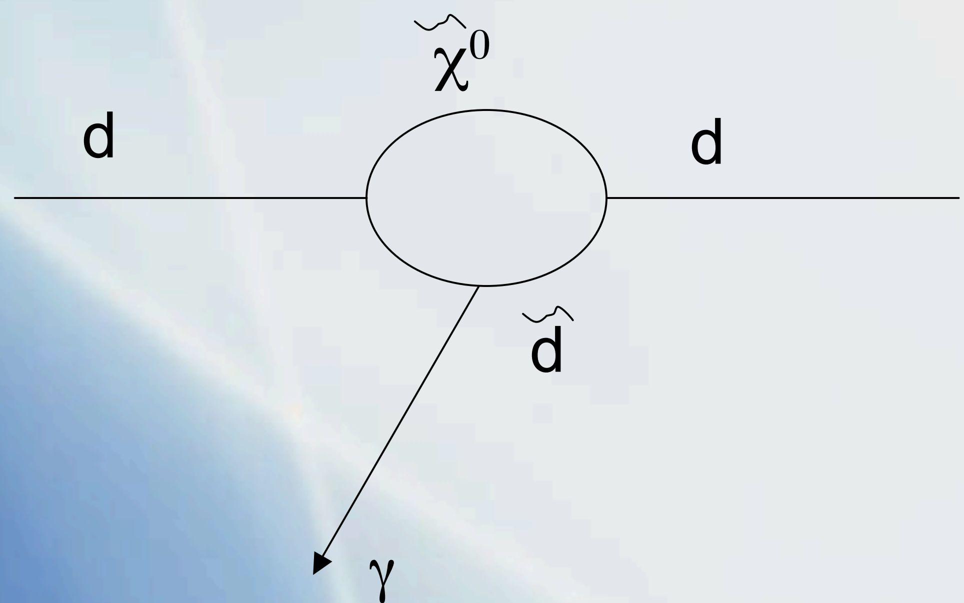
$d < 10^{-33}$ ecm

Very Small EDM

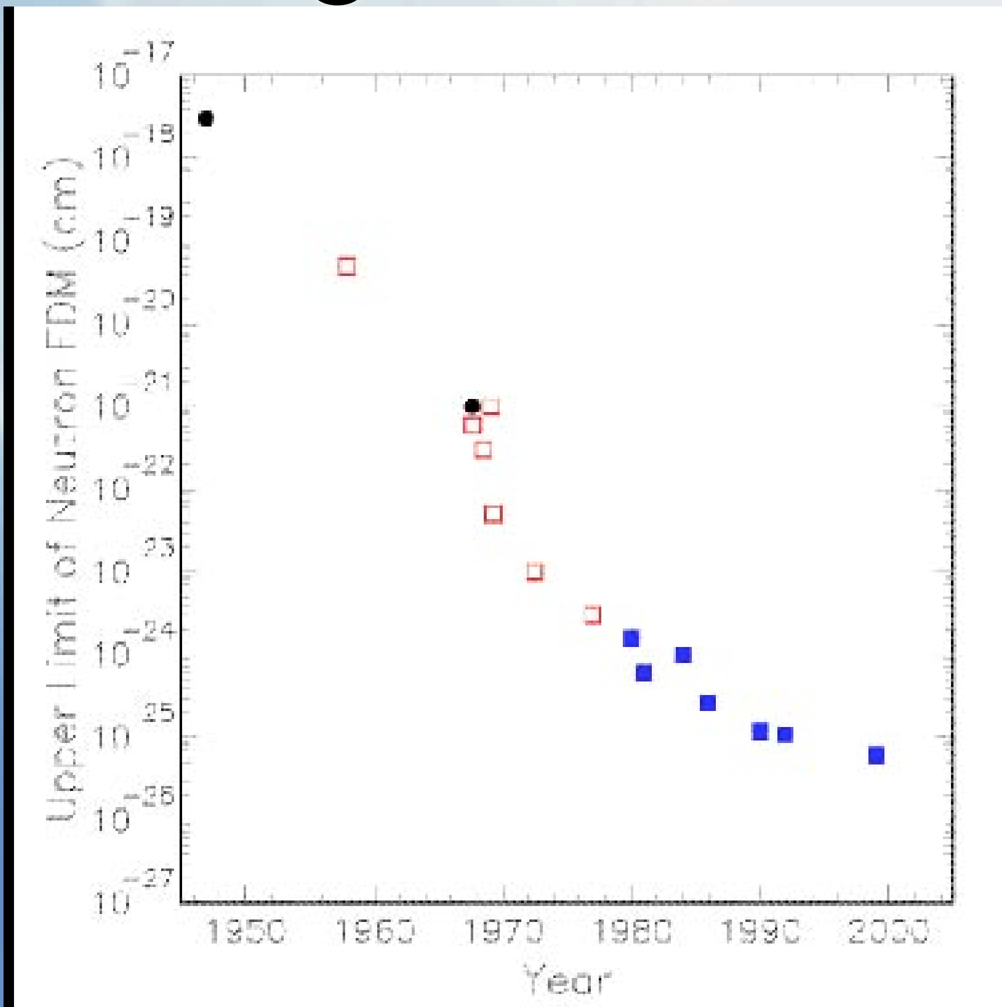
Assuming 1 Fermi neutron radius, the separation causing the SM NEDM would be about 1 micron when scaled to the size of the earth



NEDMs in SUSY



Memories…NEDM Limits Throught The Years



Killing Flies With Sledgehammers

- “Particle physics is occasionally likened to trying to understand how a Swiss watch works by smashing it to pieces, using an increasingly energetic series of hammers, and studying the bits that fly out.”
- Deep inelastic scattering experiments probe constituents’ (quarks’) electromagnetic properties

A Gentler Approach

Ultra-Cold Neutron (UCN) experiment, like the g-2 experiments for the electron, seek to obtain the same information about the NEDM without using collision/collection methods

How to Detect It Without Smashing Neutrons

- Ramsey Precession
  - Uniform B field causes precession rate
  - Application of rotating B field rotates moments
  - Coherent reapplication of rotating B field flips moments
  - Any difference in precession rate will mean smaller magnetization than initial magnetization

A Decent Experiment Needs…

- A good source of neutrons. The sensitivity depends directly on the square root of the total number of neutrons detected.
- Parallel E and B fields. B’ = (v/c)xE, changes sign with E.
- A way to polarize the neutrons, and to analyse their polarisation at the end. The sensitivity depends on alpha, the product of the polarisation and analyzing efficiency.
- A constant magnetic field, B. Any inhomogeneity in this field will cause neutrons in different parts of the volume to precess with different frequencies, destroying the coherence thereby reducing alpha and reducing the sensitivity.
- A way to control the magnetic environment to reduce and monitor stray environmental B fields. Either stray fields must be reduced to the point that they do not affect the measurement or they must be monitored and corrections applied during analysis.
- An electric field, E. The sensitivity depends linearly on the magnitude of this field, which should therefore be as great as possible. However any leakage currents arising from the application of this field will produce B fields which can produce systematic uncertainties or even a false EDM signal. Control of these currents is therefore essential.

Neutron Source

- Pick a momentum (8.9 Angstrom Neutrons at LANSCE…necessary for 4He downscattering)
- Source
  - Reactor
  - proton beam spallation target
- Convert fast neutrons to slow neutrons
  - Crystal (cooled Bi) Bragg scattering velocity selection
  - Sympathetic cooling (Liquid Hydrogen moderator)

Polarization

- Neutrons
  - Supermirror
  - Stern-Gerlach
- Magnetometer
  - Optical pumping
  - Polarization transfer from atomic polarization

Magnetic Fields

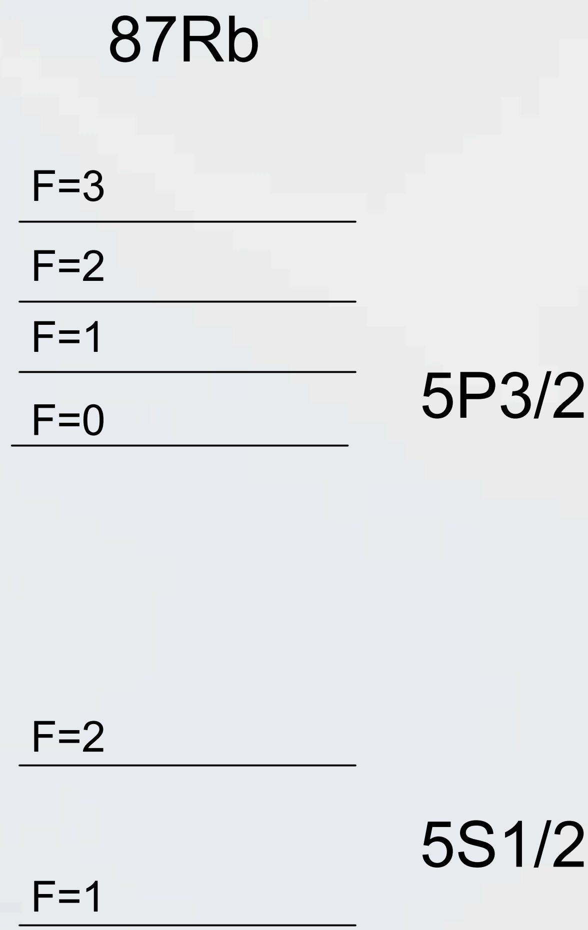
- Slow precession rate (but not too slow)
  - 30 Hz in older experiments
  - 3 Hz in newer experiments
- Uniformity
- Stability
- Parallel to E field

Containing The Neutrons

- High Reflectivity Cell
  - Neutrons can’t penetrate walls/escape
- Black Magic Coating
  - Can’t absorb/capture the neutrons
  - Must maintain the spins of the neutrons during collisions with the walls
    - ✓Hydrogen-rich substances tend to be spin-maintaining during collisions
    - ✓Work done on optical pumping lead the way
    - ✓Deuterated hydrogen (polystyrene) coatings both preserve spin and don’t capture neutrons

In Situ Magnetometry: A Good Trick

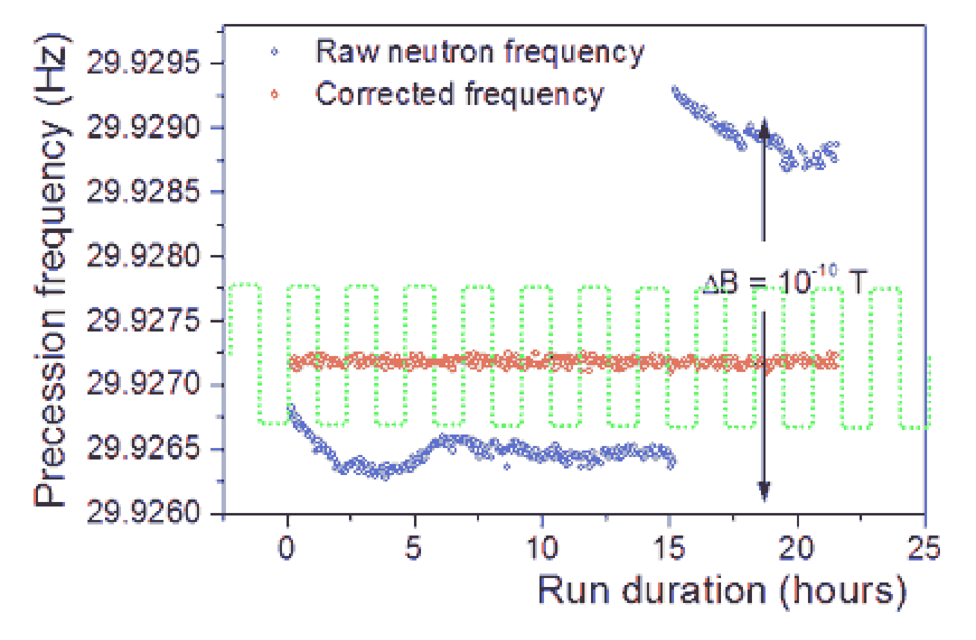
- Addition of polarized 199Hg
- Atoms precess like neutrons
- Magnetization-Precession read optically
- RMS Inhomogeneity, time-dependent fluctuations deduced

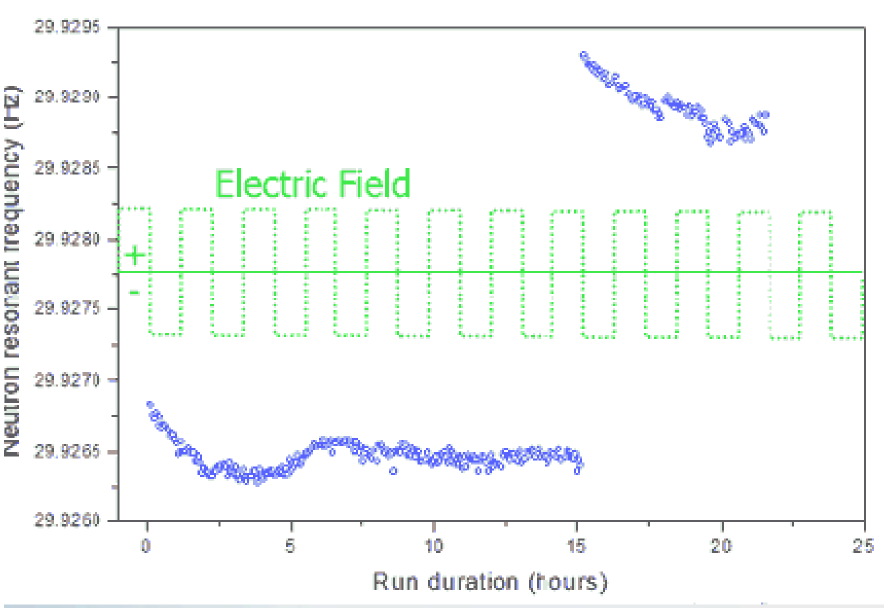


Old Experiment

- OPEN PDF

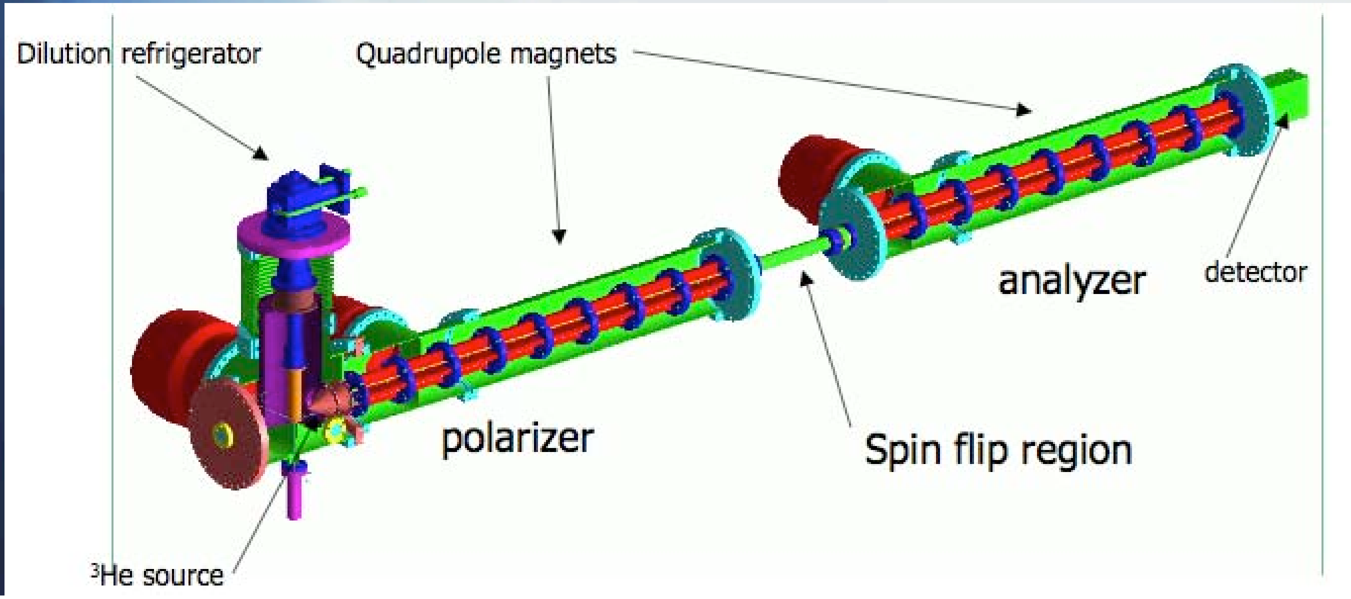
No Correlation With E Field



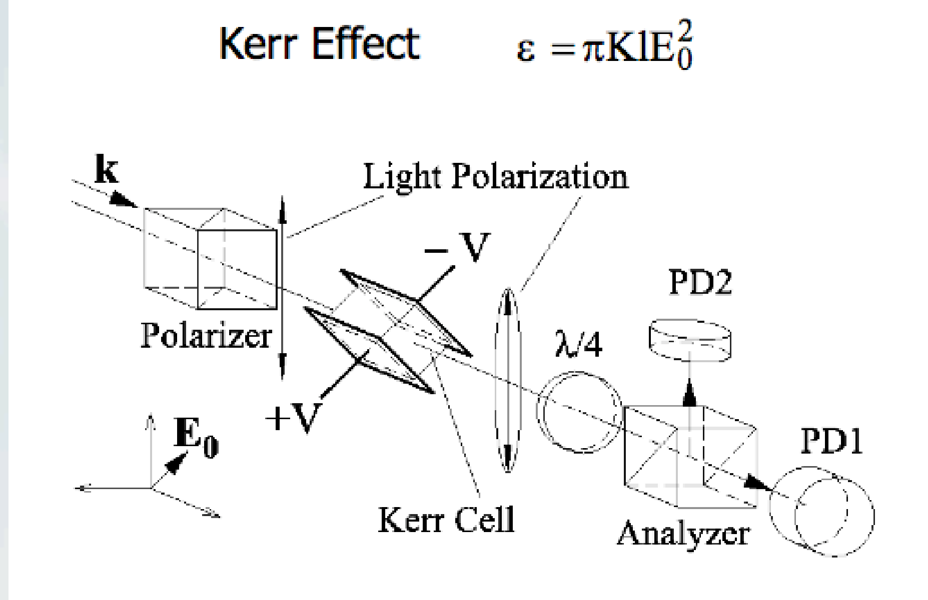


Improvements

- Downscatter UCNs in Liquid 4He with diffused 3He magnetometers
  - High density of UCNs
  - Use Squids to detect B field from 3He
    - 3He has essentially zero EDM (Schiff shielding)
    - 3He diffuses VERY slowly in liquid 4He
    - Allows ACTIVE magnetic shielding in addition to passive shielding (10^-12 T/cm inhomogeneity)
  - 3He absorbs neutrons
    - Requires 3He/4He ~10^-10
      - Neutron density 5*10^2/cc
      - 3He density 0.8*10^12/cc
      - 4He density 2.2*10^22/cc

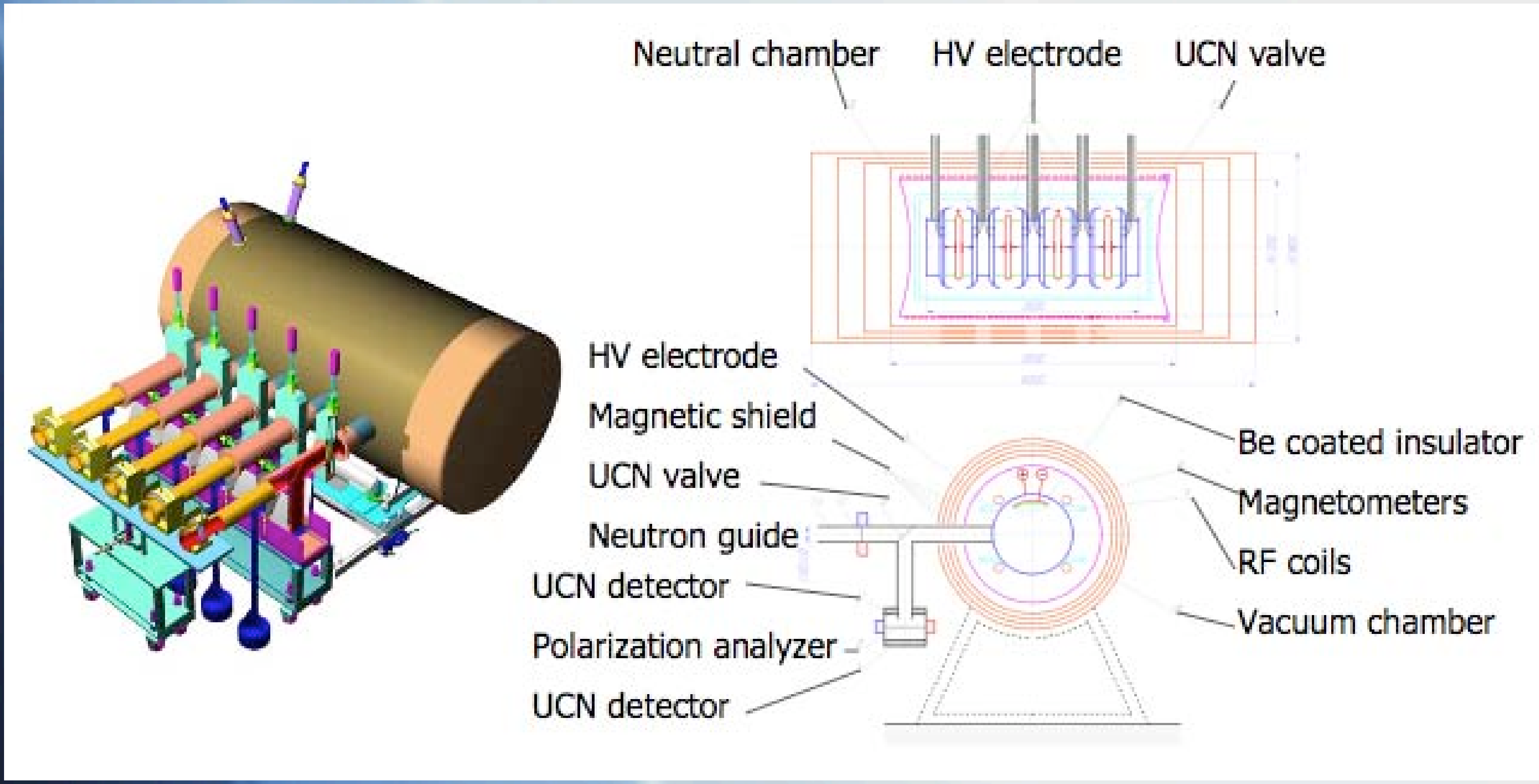


Improvements (cont.)

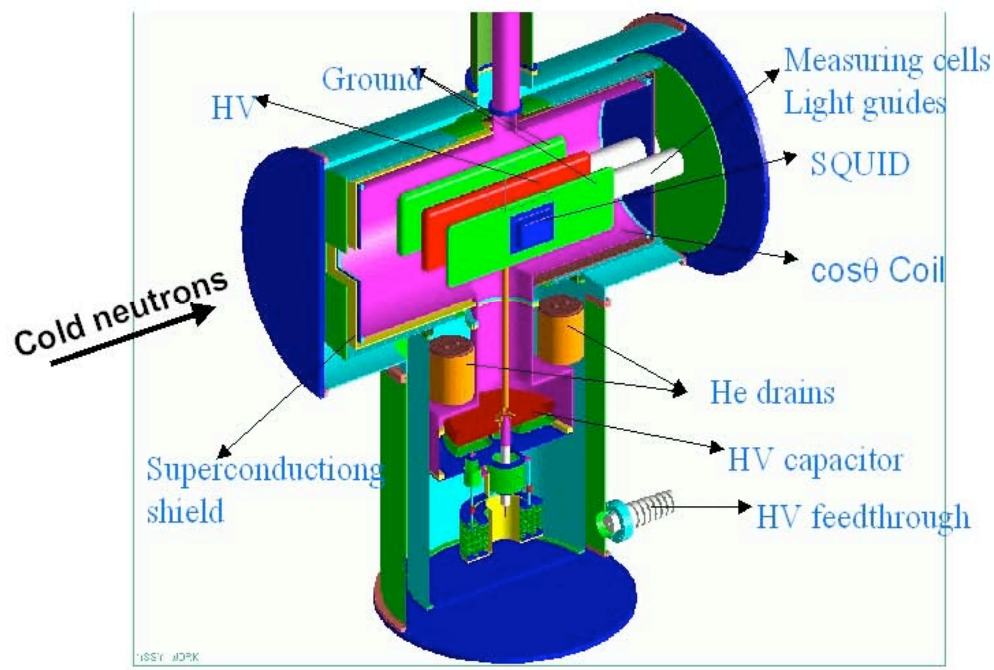


- Measure E field
  - Kerr Cells inside chamber
  - High density of UCNs
- Use Squids to detect B field from 3He
  - 3He has essentially zero EDM (Schiff shielding)
  - 3He diffuses VERY slowly in liquid 4He
- 3He Capture/4He Scintillation detection
  - 3He + n -> t + p
  - t+p share 764 kEv of kinetic energy…scintillate while stopping in 4He

New Experiment



Newer Experiment



Conclusion: If the sensitivity is pushed to ~ 10 -28 e cm, then either:

- We will observe an nEDM
- SUSY is not a property of nature
- CP violation is an approximate symmetry of nature
- There are large cancellations, or some as-yet unknown other mechanism strongly suppresses EDMs despite CPv elsewhere