ETH zürich

Status of Data Analysis for the PSI Neutron Electric Dipole Moment Experiment

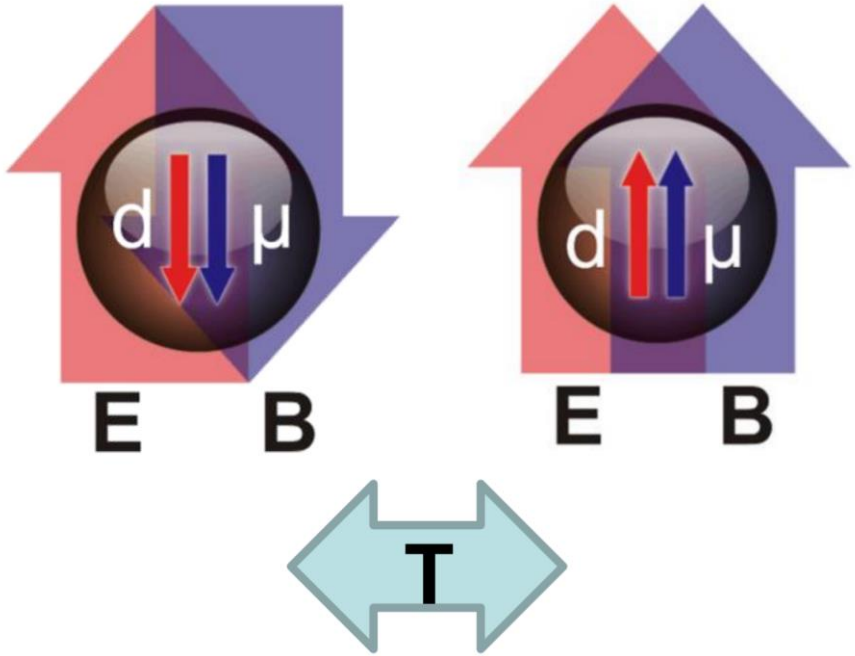
Nicholas J. Ayres on behalf of the PSI Neutron Electric Dipole Moment collaboration

Overview

- Motivation
- Principle of Measurement and Ultracold Neutrons
- Experiment
- Data Analysis
- Systematics
- Conclusion

Motivation

- An electric dipole moment (EDM) can be classically thought of as an asymmetric charge distribution
- From Sakharov (1967), CP violation is required for Baryogenesis, but the SM doesn't produce enough
- A wide variety of BSM theories give additional CP violation to explain Baryogenesis, but these commonly also result in large EDMs
- The CKM phase produces negligible SM background to EDM searches
- Nonzero θ_{QCD} would produce an extremely large nEDM, but this is not observed, leading to the "Strong CP" problem
- Current limit $|d_n| < 3*10^{-26}$ e cm, set by Sussex-RAL-ILL experiment [PRL 97,131801 (2006); PRD 92, 092003 (2015)]

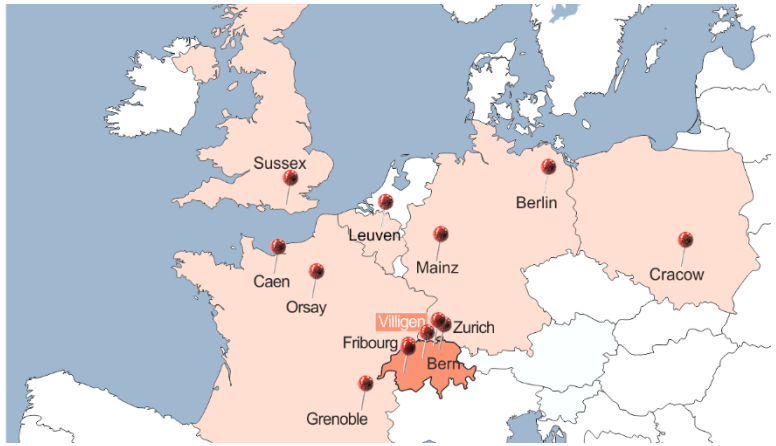


A nonzero neutron electric dipole moment would violate P and T

The Experimental Collaboration

- ~50 Experimenters across 16 institutions in 8 countries
- The goal: the world's most sensitive measurement of the neutron EDM
- The strategy:
  - Phase 1: achieve a new world limit using a totally renovated version of the previous Sussex-RAL-ILL apparatus [this talk]
  - Phase 2: build a totally new double chamber apparatus to allow for a new measurement on the d_n~10^{-27} e cm scale
- Talks later this session by S. Emmenegger, G. Bison & D. Pais, P-J. Chiu; talk by M. Rawlik 14:00 Thursday; Poster I. Rienäcker

Collaboration Meeting, Caen, June 2019



Ultracold Neutrons

- Extremely low energy neutrons, energy <300 neV, speed a few m/s
- Strong interaction with some materials allows total reflection for any angle of incidence
- Can be stored for hundreds of seconds in bottles made of relatively everyday materials
- Available at a few locations around the world
- PSI provides the strongest source worldwide

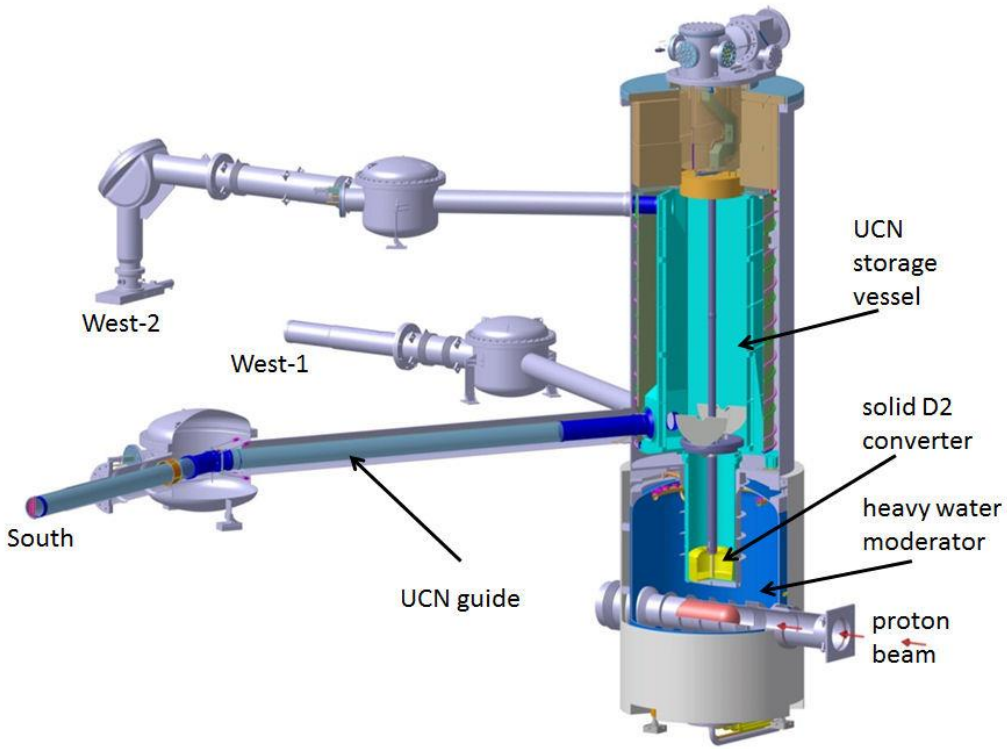


Diagram of the PSI UCN Source

The Measurement Principle

- Store Ultracold Neutrons in (anti-)parallel E and B fields

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

- Measure neutron frequency with Ramsey Technique
- Measure neutron frequency shift correlated with E

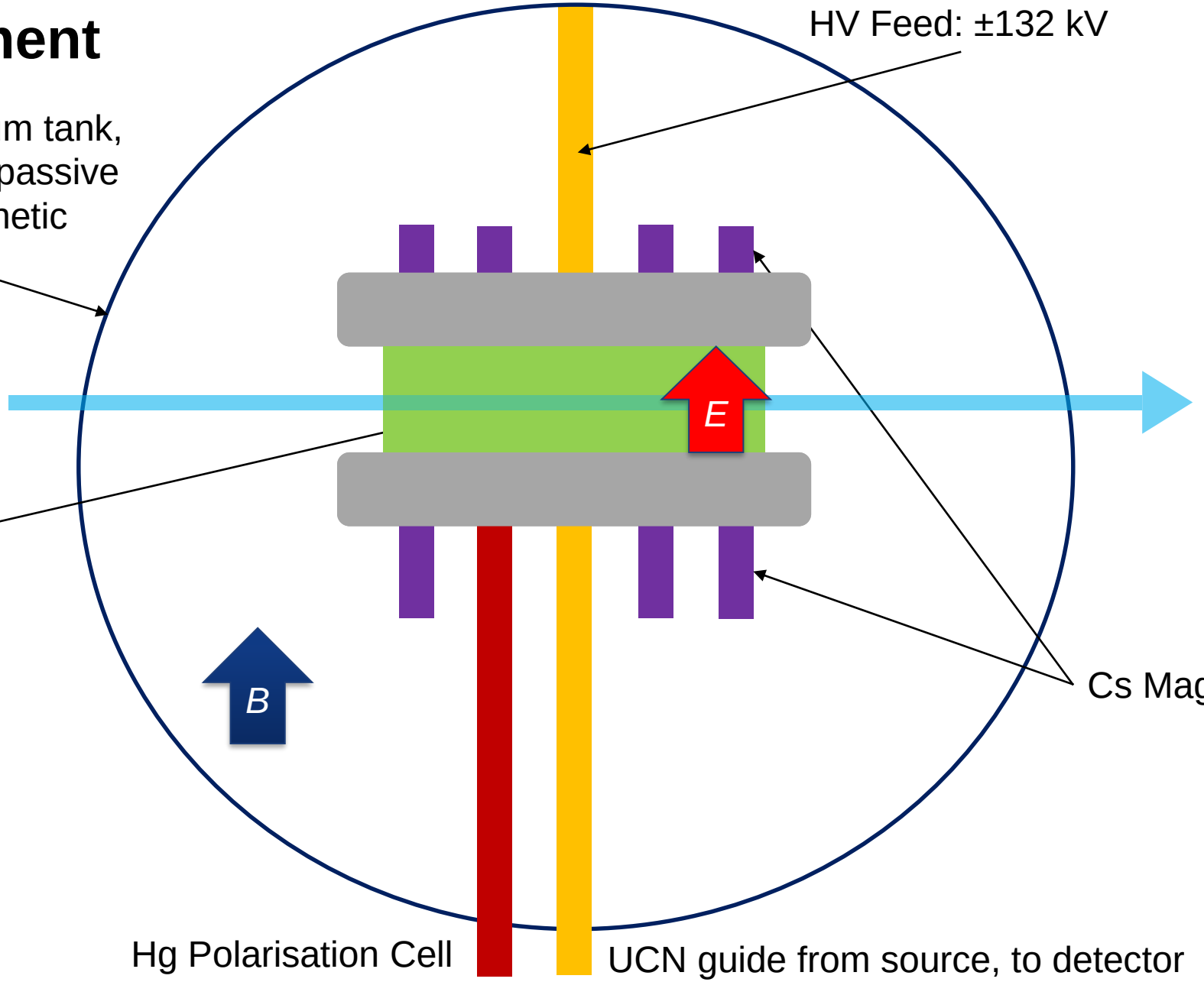
$$d_n = \frac{1}{4E}\left(h\left(f_{\mathrm{n}}^{\uparrow\uparrow} - f_{\mathrm{n}}^{\uparrow\downarrow}\right) - \mu_{\mathrm{n}}\left(B^{\uparrow\uparrow} - B^{\uparrow\downarrow}\right)\right)$$

- Correct B drift with Hg comagnetometer

$$\mathcal{R} = \frac{f_{\mathrm{n}}}{f_{\mathrm{Hg}}} \quad \Rightarrow \quad d_n = \frac{h\,|f_{\mathrm{Hg}}|}{4E}\left(\mathcal{R}^{\uparrow\uparrow} - \mathcal{R}^{\uparrow\downarrow}\right)$$

The Experiment

B coil wound on vacuum tank, within 4-layer μ-metal passive shield and active magnetic shield



Hg Magnetometer Readout Light

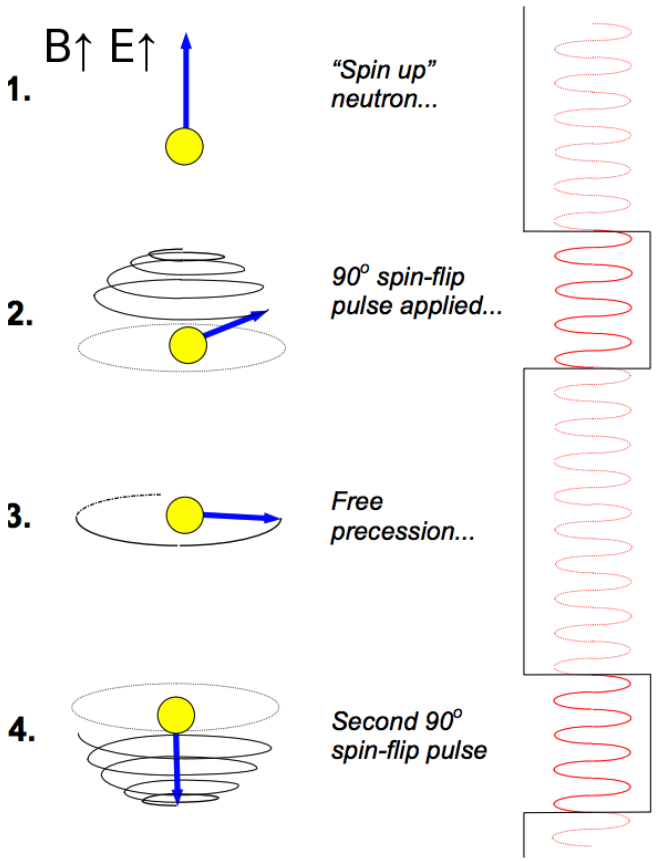
UCN + Hg Precession Chamber

Cs Magnetometers

Hg Polarisation Cell

UCN guide from source, to detector

The Ramsey Technique



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

- Neutron is spin ½
- Can do "Larmor Precession" in a magnetic field
- The Ramsey technique is an NMR Technique to precisely determine the resonant frequency, and thus the energy level gap

$$d_n = \frac{1}{4E}\left(h\left(f_{\mathrm{n}}^{\uparrow\uparrow} - f_{\mathrm{n}}^{\uparrow\downarrow}\right) - \mu_{\mathrm{n}}\left(B^{\uparrow\uparrow} - B^{\uparrow\downarrow}\right)\right)$$

Datataking Summary and Timeline

2015 and earlier: commissioning and test measurements

May 2016: Start of 2016 datataking

January-April 2017: Field mapping

October 2017: Start dismounting nEDM

2014

2015

2016

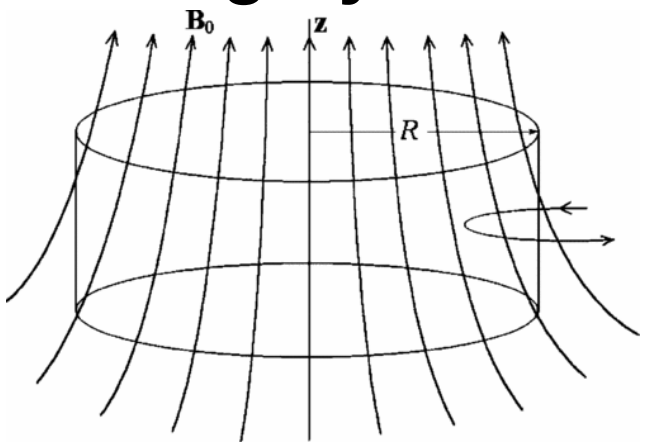
2017

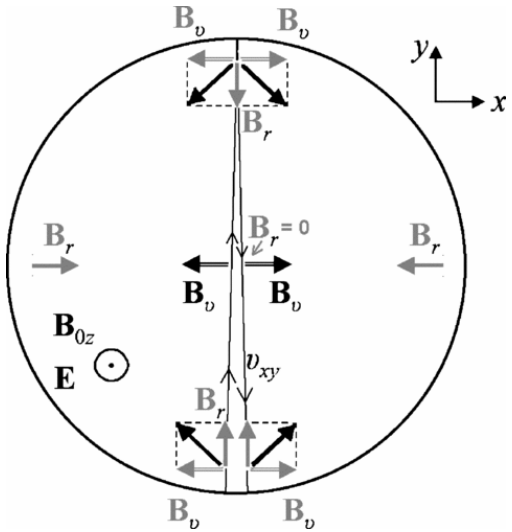
2018

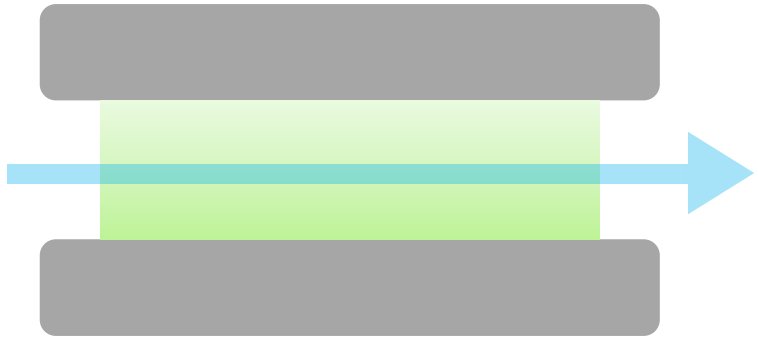
2019

Enough statistics accumulated to set a new best measurement!

Leading Systematic: False EDMs and Gravitational Shift







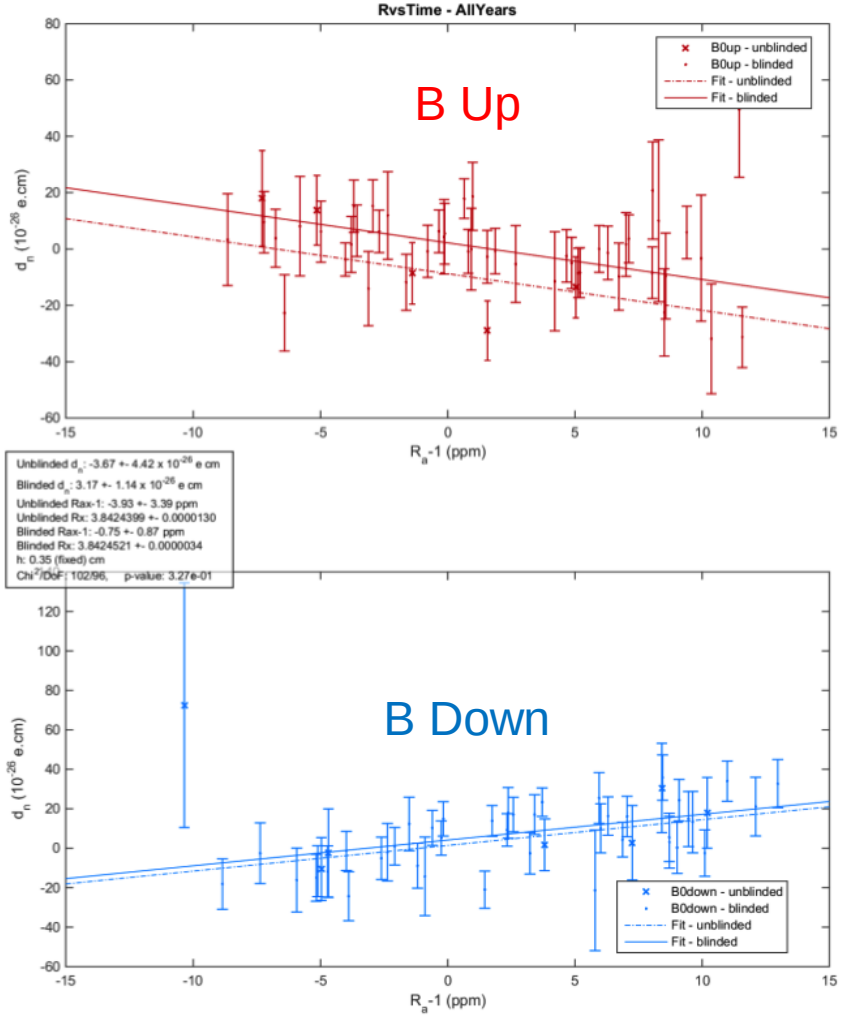
Conspiracy between vertical gradient and motional magnetic field from Lorentz transform of *E* into Hg atom rest frame causes *E*-correlated frequency shift

Slow UCN hang at the bottom of the chamber, while thermal Hg samples whole chamber
Gives R shift proportional to vertical gradient

$$\Delta h \approx 0.35 \text{ cm}$$

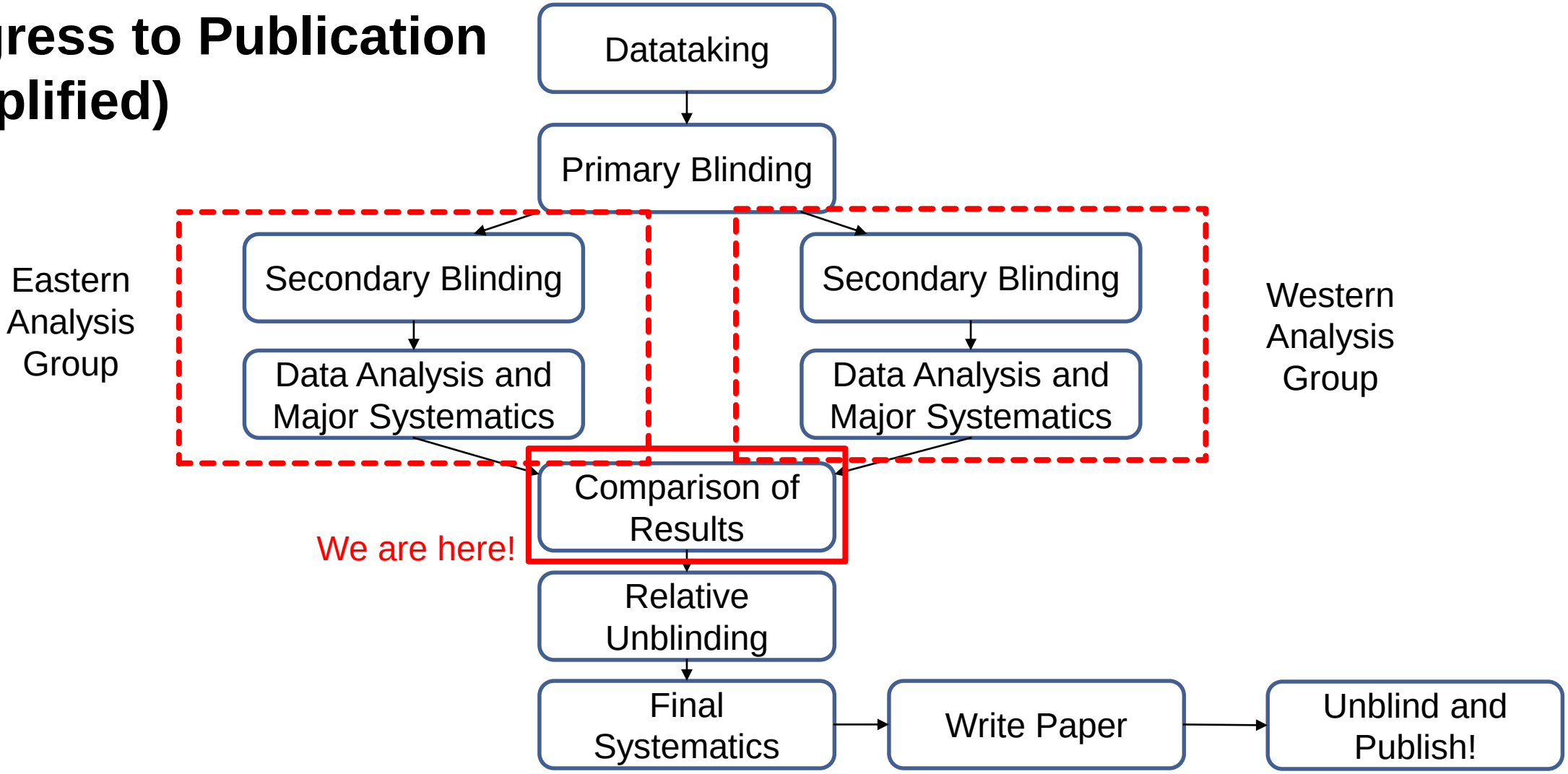
False EDMs and Crossing Lines Analysis

- Cesium magnetometer absolute accuracy too poor to use as sole measure of vertical gradient
- Idea: Use the gravitational shift to measure the vertical gradient
- Similar concept to that used on previous generation Sussex-RAL-ILL experiment



NB: old incomplete data, for illustration purposes only

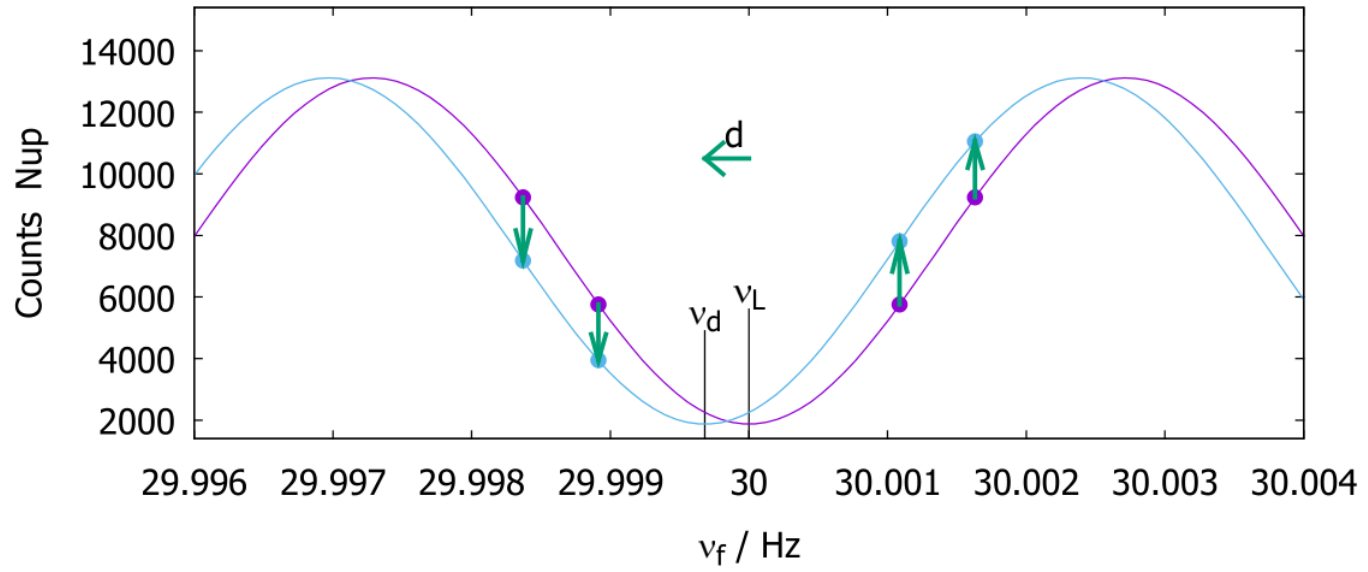
Progress to Publication (simplified)

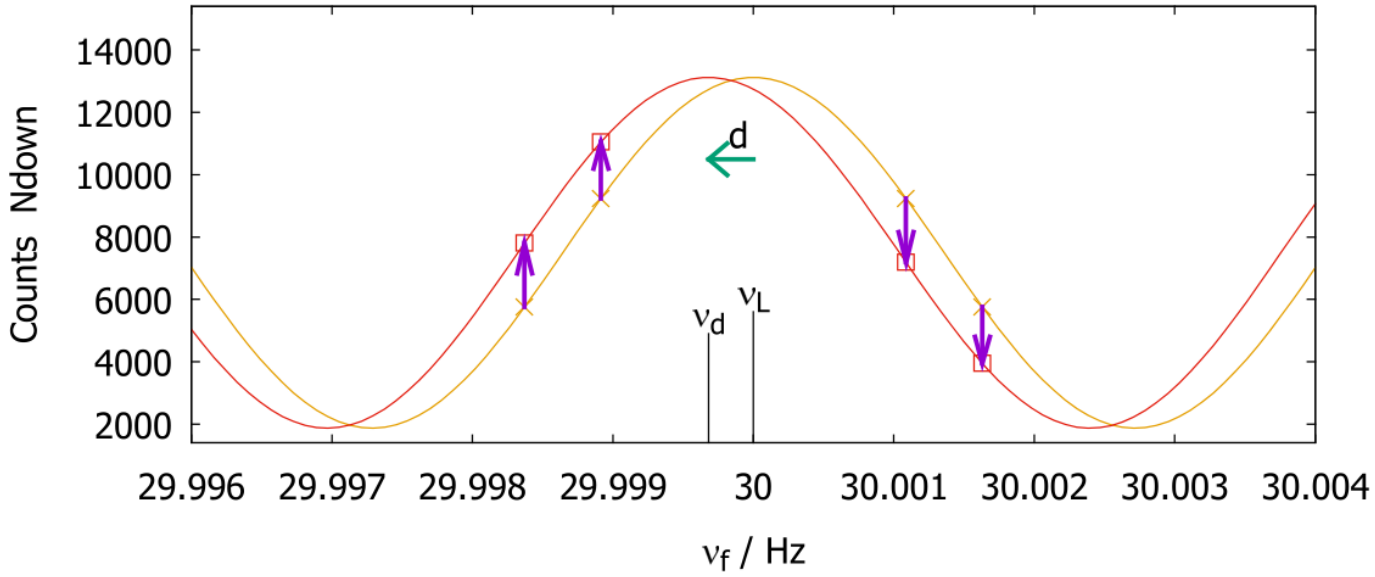


Conclusion

- Analysis of PSI nEDM experimental data is nearing completion
- Statistical and systematic uncertainties substantially reduced compared to previous best measurement
- First fully blinded EDM analysis, and most rigorous experiment yet
- New limit expected soon, with a final uncertainty on the d_n ~ a few * 10^{-26} e cm level

Data Blinding





Concept: add an *E*-field dependant shift to the neutron frequency by moving counts between detectors

$$N_{\uparrow,i} = \bar{N}_{\uparrow}\left(1 - \alpha\cos\phi_i\right), \quad (1)$$

$$N_{\downarrow,i} = \bar{N}_{\downarrow}\left(1 + \alpha\cos\phi_i\right), \quad (2)$$

$$\phi_i = \frac{\left(\nu_{\mathrm{F},i} - \nu_{\mathrm{L}}\right)}{\Delta\nu}\pi, \quad (3)$$

$$\Delta\nu = \frac{1}{2\left(T + 4t/\pi\right)}, \quad (4)$$

$$\delta\nu_{\mathrm{L}} = 2\vec{d}\cdot\vec{E}/h. \quad (5)$$

Sensitivity to other types of new physics

- The EDM is the most popular measurement, but high precision experiments lend themselves well to being used to test for other physics
- Advertisement: Talk Michal Rawlik, 1400 Thursday

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Search for Axionlike Dark Matter through Nuclear Spin Precession in Electric and Magnetic Fields

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