Measurements of the TUCAN vertical UCN source heat load response and UCN polarization

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TUCAN Collaboration

THE UNIVERSITY OF WINNIPEG

UNIVERSITY OF MANITOBA

TUCAN

The TUCAN collaboration, or

TRIUMF Ultra Cold Advanced Neutron source collaboration, is a Canadian-Japanese collaboration

TRIUMF

THE UNIVERSITY OF WINNIPEG

UNIVERSITY OF MANITOBA

名古屋大学 NAGOYA UNIVERSITY

RCNP

THE UNIVERSITY OF BRITISH COLUMBIA

UNBC UNIVERSITY OF NORTHERN BRITISH COLUMBIA

KEK

SFU SIMON FRASER UNIVERSITY ENGAGING THE WORLD

Motivation

Hamiltonian $\widehat{H}$ describes equations of motion of a neutron

$$\widehat{H} = -d\vec{E}\cdot\vec{S} - \mu\vec{B}\cdot\vec{S}$$
$$= \hbar\omega \quad \longleftarrow \text{General solution}$$

$$\hbar\omega_{1\upharpoonleft} = 2\,\mu B - 2dE$$
$$\hbar\omega_{1\downharpoonleft} = 2\,\mu B - 2dE$$

Trying to measure this

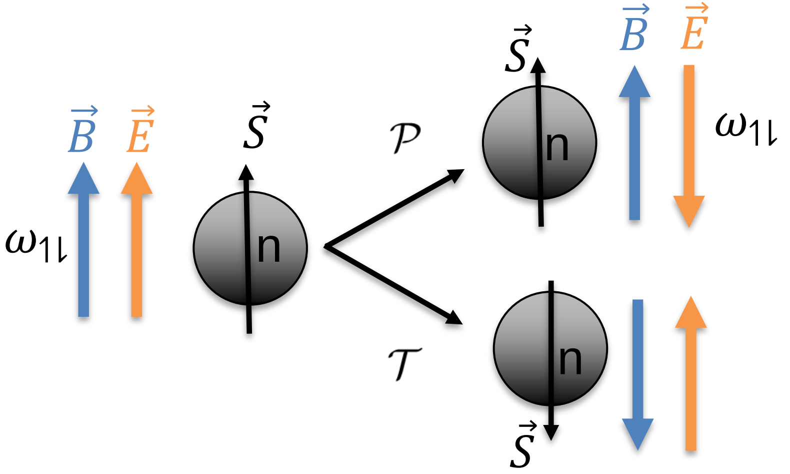
$$d = \frac{\hbar\Delta\omega}{4E}$$

$$\Delta\omega = \omega_{1\upharpoonleft} - \omega_{1\downharpoonleft}$$

Limits by Abel et al.(2020) is $|d_n| < 1.8 \times 10^{-26}$ e cm @ PSI, Switzerland

TUCAN's goal ultimate goal is $|d_n| < 10^{-27}$ e cm

$$\hat{H} \neq \mathcal{P}(\hat{H}) = -\vec{d}\cdot(-\vec{E}) - \vec{\mu}\cdot\vec{B}$$



$$\hat{H} \neq \mathcal{T}(\hat{H}) = -(-\vec{d})\cdot\vec{E} - (-\vec{\mu})\cdot(-\vec{B})$$

EDM $\vec{d} = d\vec{S}$
Time Reversal – violating
Parity – violating
therefore violating combined CP

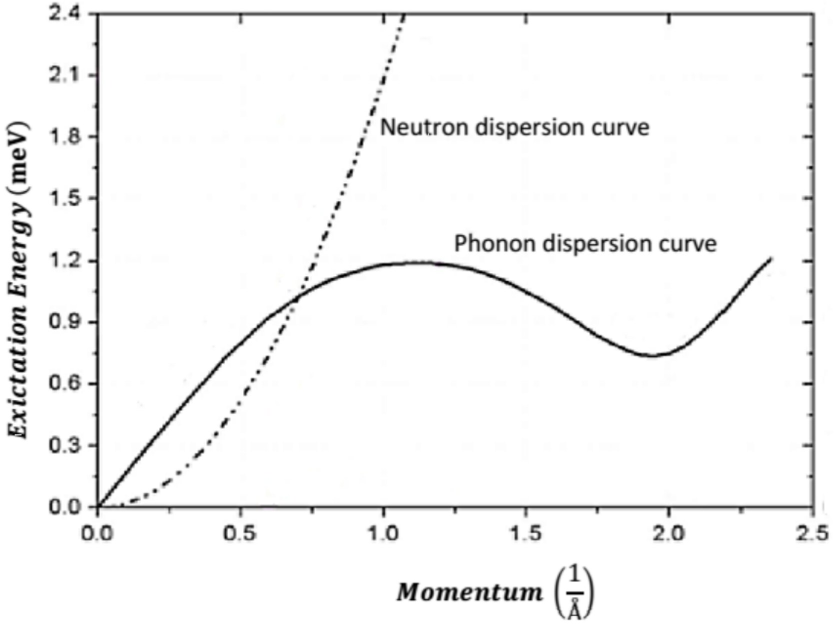
nEMD Experiment

- UCN Production
- Polarization
- Low field NMR sequence
- Detection of final polarization state

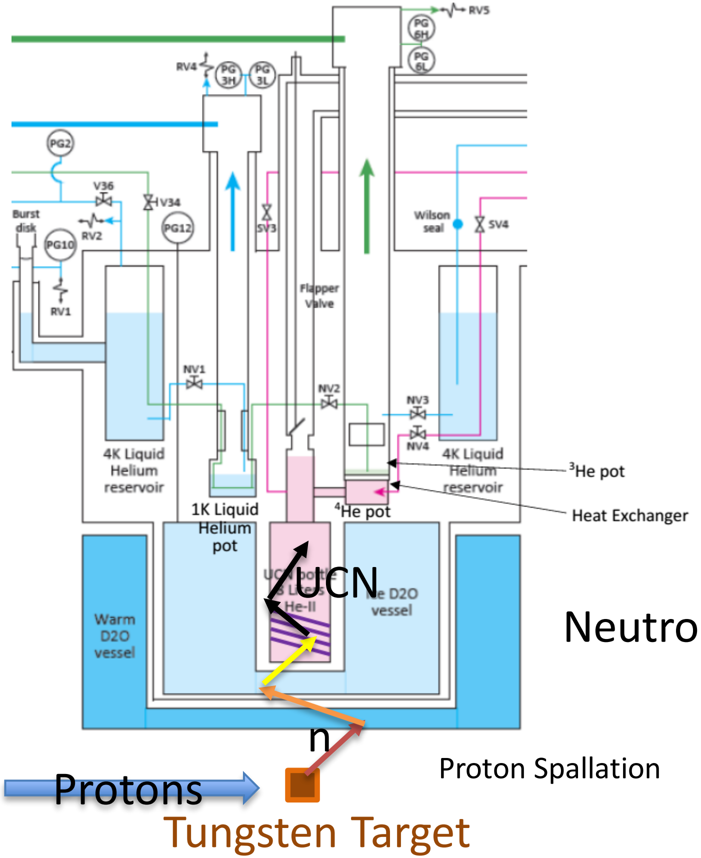
$$\sigma_d \cong \frac{\hbar}{2\alpha T E\sqrt{N}}$$

neutron – super fluid Helium interaction

- The neutrons can exchange energy and create phonon excitations in the superfluid helium



Ultracold Neutron Production



- Super fluid ^{4}He is cooled using a ^{3}He evaporation based heat exchanger in thermal contact
- ^{4}He is used since its low neutron cross section

Neutrons cool to UCN

Production of UCN $\propto T^{-7}$

Cryostat Model

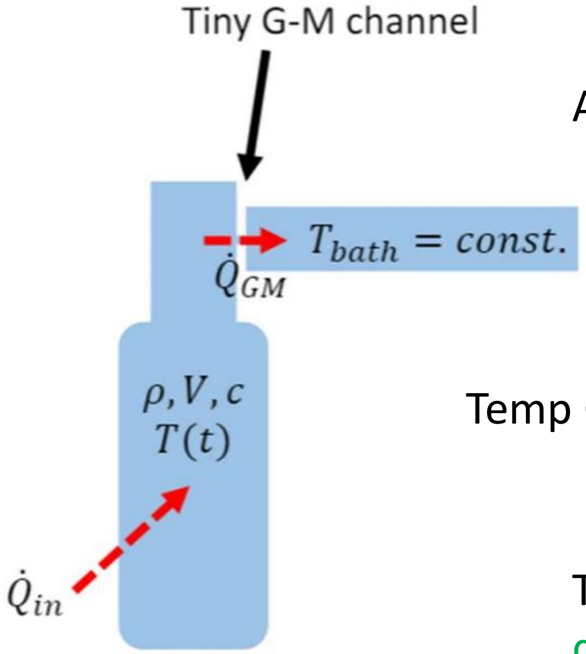
$$\frac{\partial T}{\partial t} = \frac{q_V}{\rho c} + \alpha \Delta T$$

Standard Heat equation

Temp Change

Heat input

How the material reacted to heat changes



A time dependent modified Gorter-Mellink equation

$$\frac{\partial T}{\partial t} = \frac{(\dot{Q}_{in}/V)}{\rho c} - \frac{1}{\rho V c}\left[\frac{A}{l}\int_{T_{bath}}^{T(t)} dT' f^{-1}(T', SVP)\right]^{1/3}$$

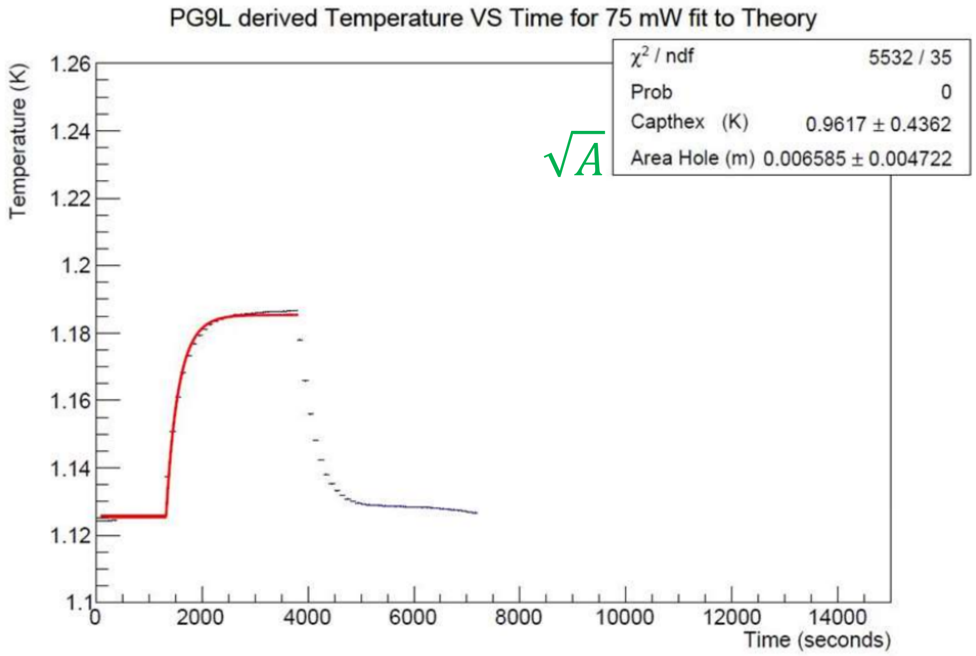
Temp Change

Heat input

Model how helium reacted to heat changes

To test model we can solve numerically and predict the dimensions of the channel and compare to real life

Heater Tests



Heating with a coil to mimic beam heating during irradiation from proton beam

Conclusions

The model is able to produce slow temperature rise

The dimensions of the hole qualitatively close

nEMD Experiment

- UCN Production
- Polarization
- Low field NMR sequence
- Detection of final polarization state

Statistical uncertainty of *d*

$$\sigma_d \cong \frac{\hbar}{2\alpha T E \sqrt{N}}$$

$$\alpha = \frac{n_\uparrow - n_\downarrow}{n_\uparrow + n_\downarrow}$$

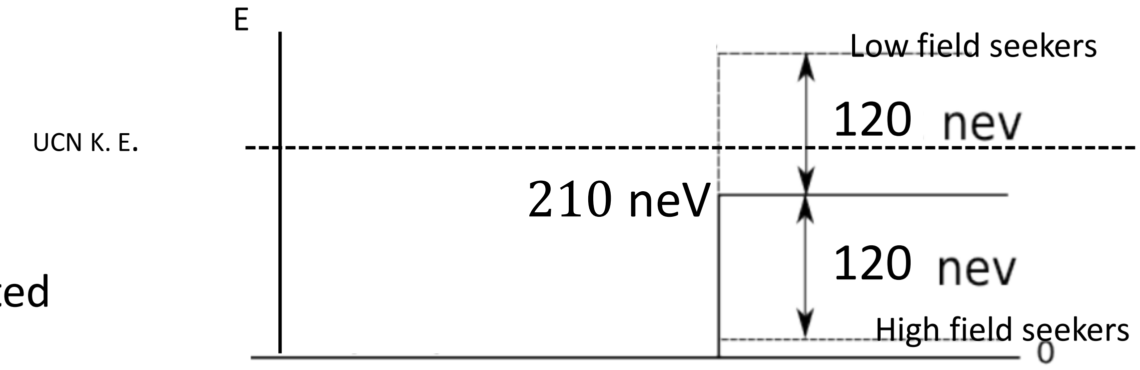
Polarizing Foils and SCM

$$V_{F,eff} = V_{F,\,Fe} \pm 60\ \text{neV/T} \cdot \text{B}$$

Magnetic field changes potential due to spins

Thin iron foils saturate magnetization

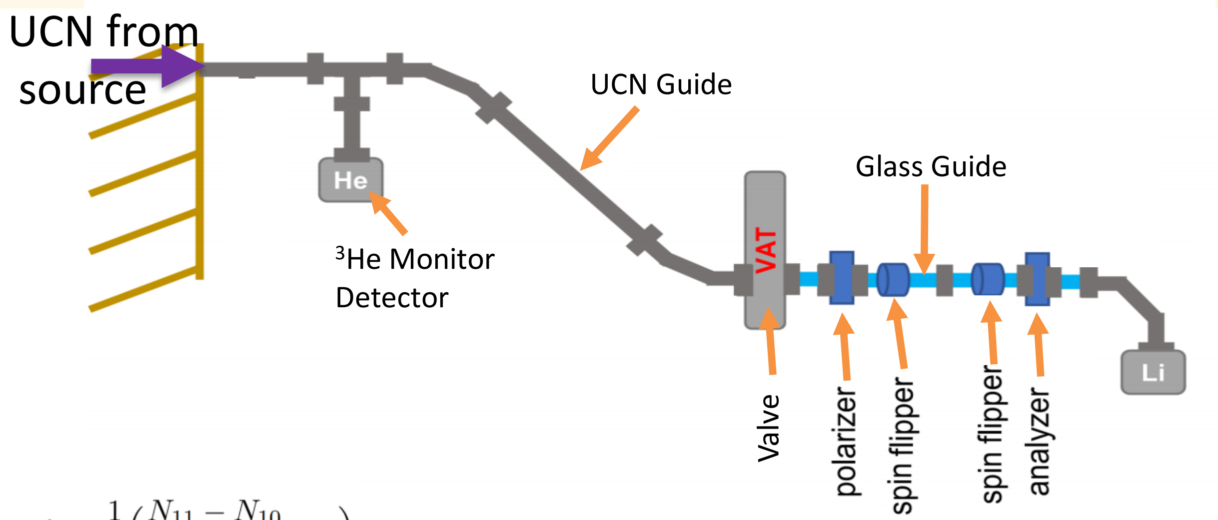
- Have internal field 2 T

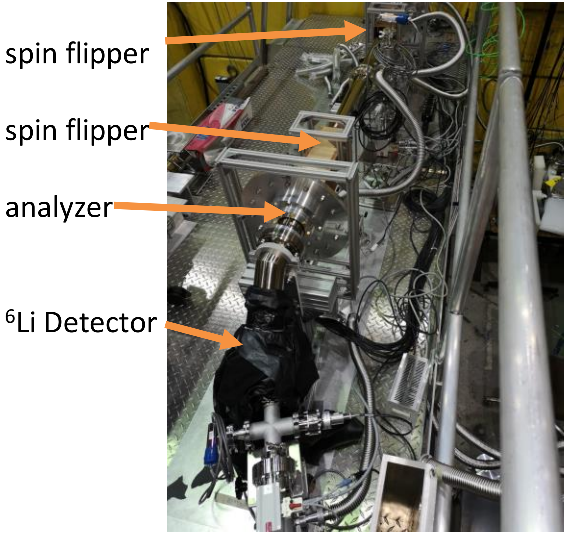


One Polarization state will be let through, the other will be reflected

Super Conducting Magnet provides large enough B field to polarize

Analyzer and Spin Flipper Experiment





$$f_1 = \frac{1}{2}\left(\frac{N_{11} - N_{10}}{N_{00} - N_{01}} + 1\right)$$

f_1 is the spin flipping efficiency of spin flipper 1

$$p_A = \sqrt{\frac{N_{00} - N_{10}}{N_{00} + N_{10}}}$$

N_{nm} is the neutron counts

n denotes the power state of the first spin flipper, m the second spin flipper,with $n, m = 0$ (off) or 1 (on).

Polarizing foil $p_A = 60 \pm 2$ %
Spin flipper efficiency is $f_{1,2} = 97 \pm 3$ %

Monte Carlo Simulations

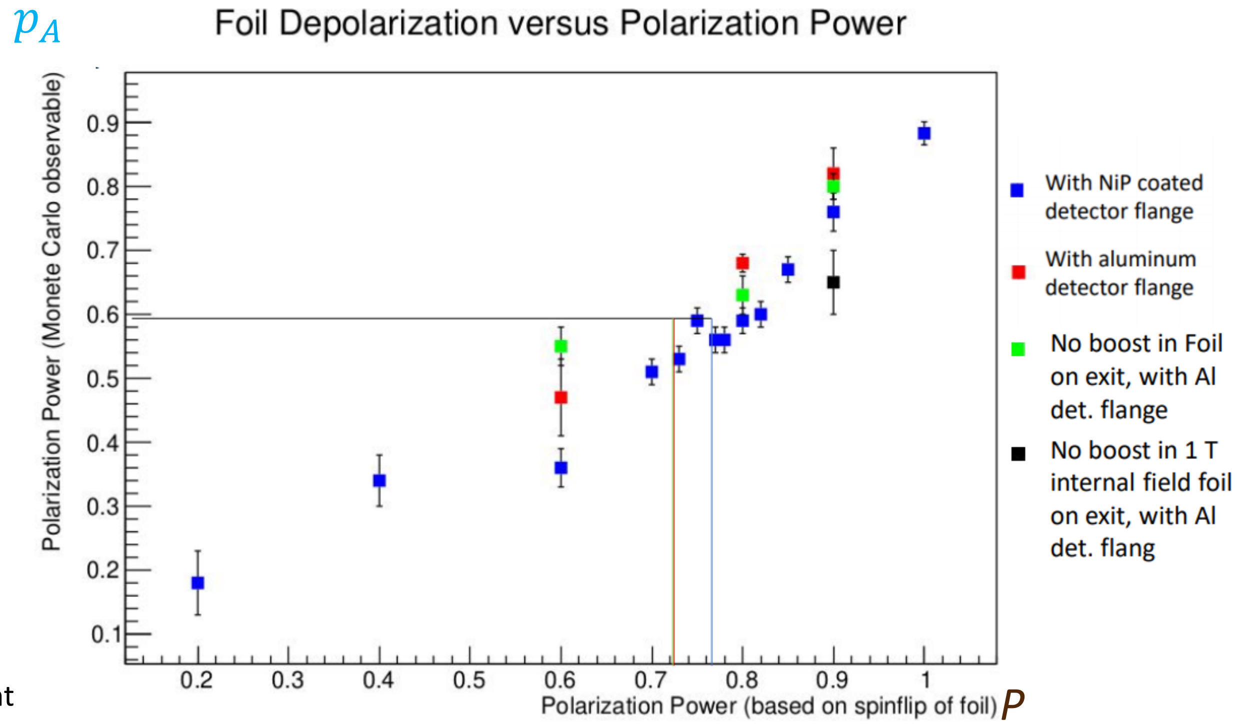
A UCN Monte Carlo is used to get the strict internal polarization power of the foils

P

Comparison the observable polarization power

$$p_a = \sqrt{\frac{(N_{11}-N_{10})^2}{N_{11}N_{00}-N_{01}^2}}$$

Taking spin flippers f_1 and f_2 into account



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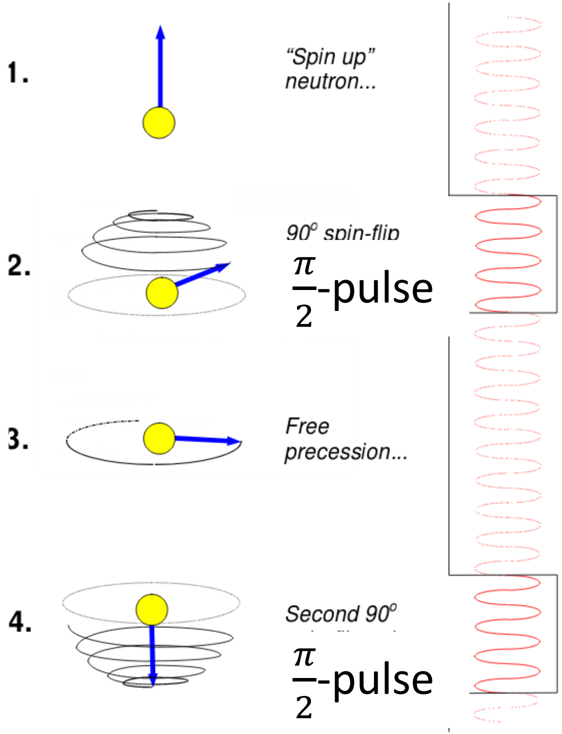
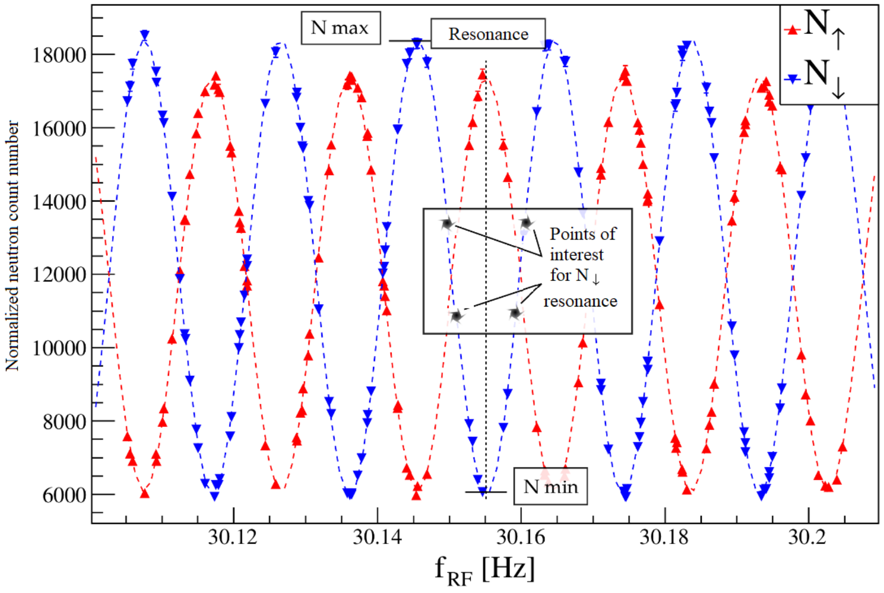
Question time

POLARIZATION MEASUREMENT OF UCN

Ramsey Sequence for nEDM measurement

$$P(\uparrow;\downarrow) = P(\omega_{RF}, T, B_o, B_1)$$





Frequency Detection

$$\hat{H} = -d\frac{\vec{J}}{J}\cdot\vec{E} - \mu\frac{\vec{J}}{J}\cdot\vec{B}$$

EDM Measurement is a frequency difference measurement between polarized atoms in E-field

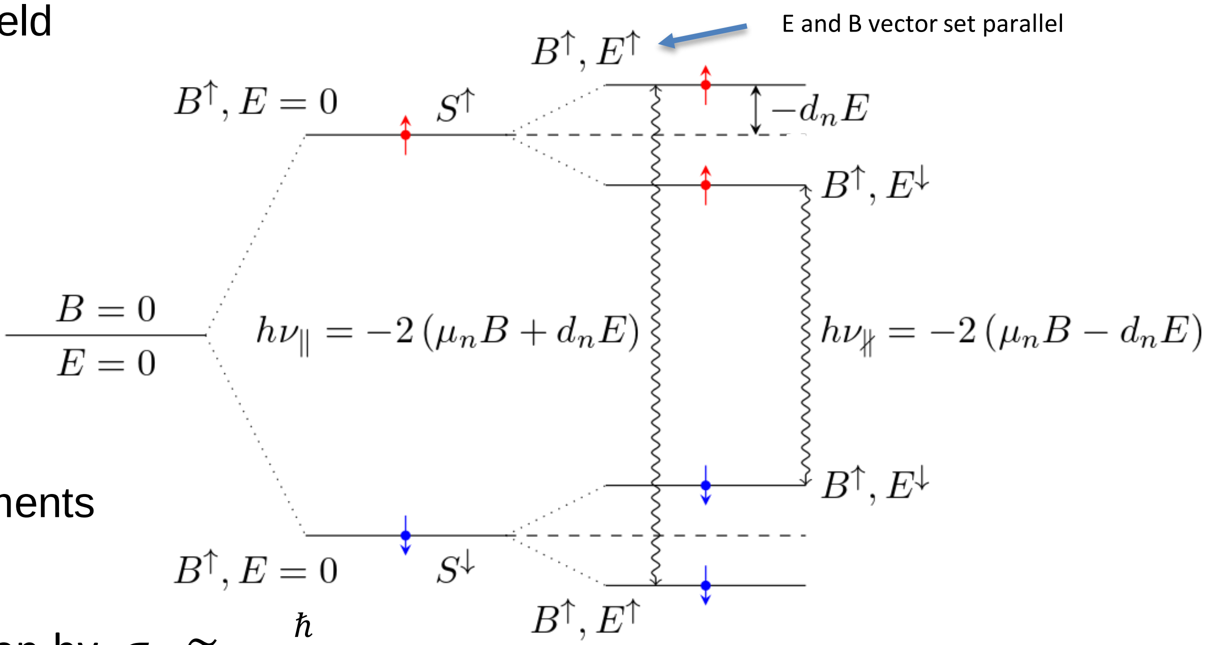
- Zeeman levels due to μ in B-field
- Shift due to d in E-field

$$\hbar\nu_{\parallel} - \hbar\nu_{\parallel} = 4\ d\ E$$

$$\hbar\Delta\nu = 4\ d\ E$$

$$d_n = \frac{\hbar\Delta\nu}{4E}$$

- Change in frequency from E-field is d the measurements



Error from the experiment is given by $\sigma_n \cong \frac{\hbar}{2\alpha TE\sqrt{N}}$