Polarimetries for Polarized ³He Target at JLab

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Outline

- Effective polarized neutron target.
- Spin exchange optical pumping.
- Polarimetry:
  - Nuclear Magnetic Resonance (NMR): adiabatic fast passage.
  - Electron Paramagnetic Resonance (EPR).
    - Target polarization from previous experiments.
  - Pulse NMR.
- Future plan.

Polarized ³He Target

✓ $^3\overrightarrow{He}$ as an effective polarized neutron target.

- Neutron decay time ~ 15 mins (no free neutron target).

- Deuteron (1p+1n → uncertainty comes from extracting n and there is more than 50% contribution from p).

³He wavefunction =

S-wave 90%   S'-wave 1.5%   D-wave 8%
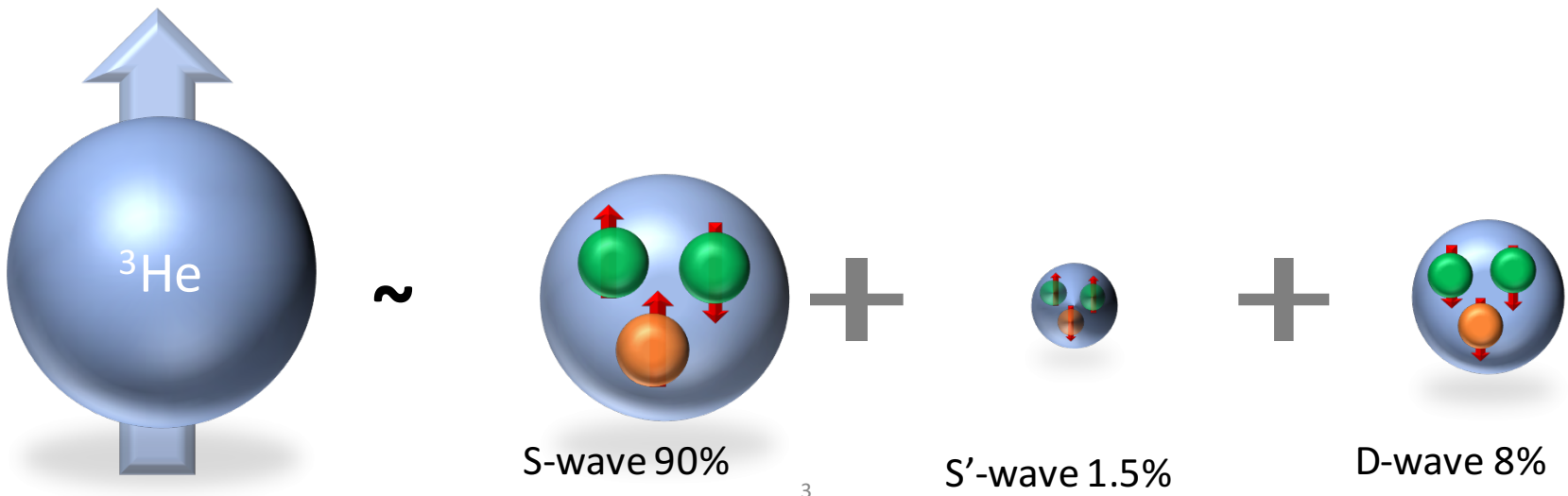
How to polarized ^{3}He

❑ We can polarized ^{3}He directly by metastability exchange optical pumping. Usually for low density gas.

❑ For our case, high density (use for electron scattering), we use spin exchange optical pumping. An indirect method: use electron from alkali atom.

Alkali electron   e ^{3}He   nucleus

Optical pumping   Spin-exchange alkali-^{3}He
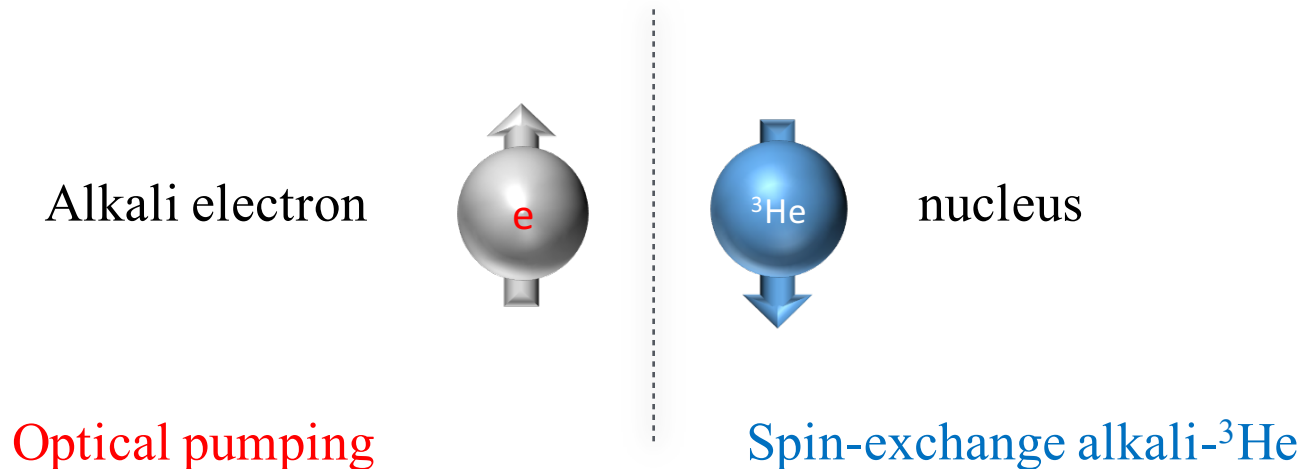
Optical pumping

- Apply magnetic field, energy split between $5S_{1/2}$ & $5P_{1/2}$.

- Use circularly polarized laser with 795nm.

- $5S_{1/2}$ absorbs σ^+ → excited state.

- Decay back to m_s =+1/2 or m_s=-1/2 equally.

- Finally, electrons end up in m_s=1/2 state

Collision mixing

$5P_{1/2}$

795 nm
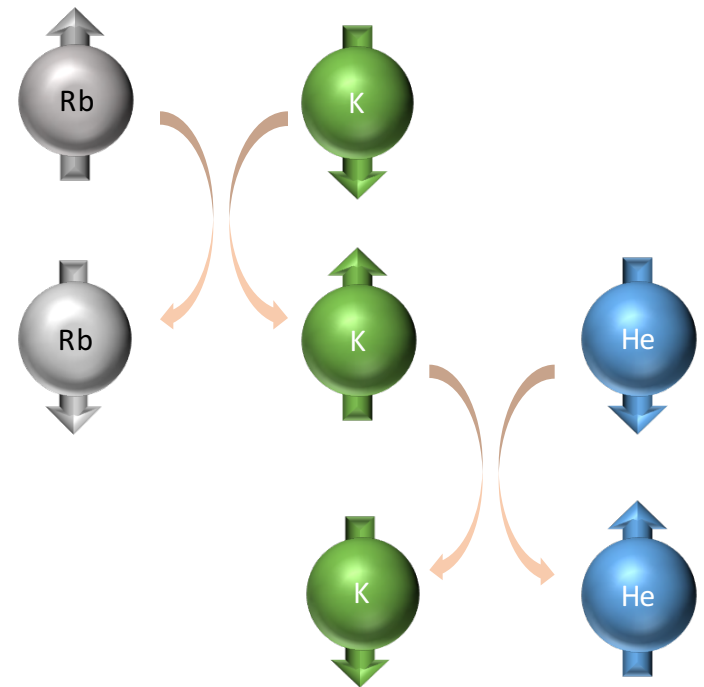
σ^+

D1

$5S_{1/2}$

M=-1/2   M=+1/2
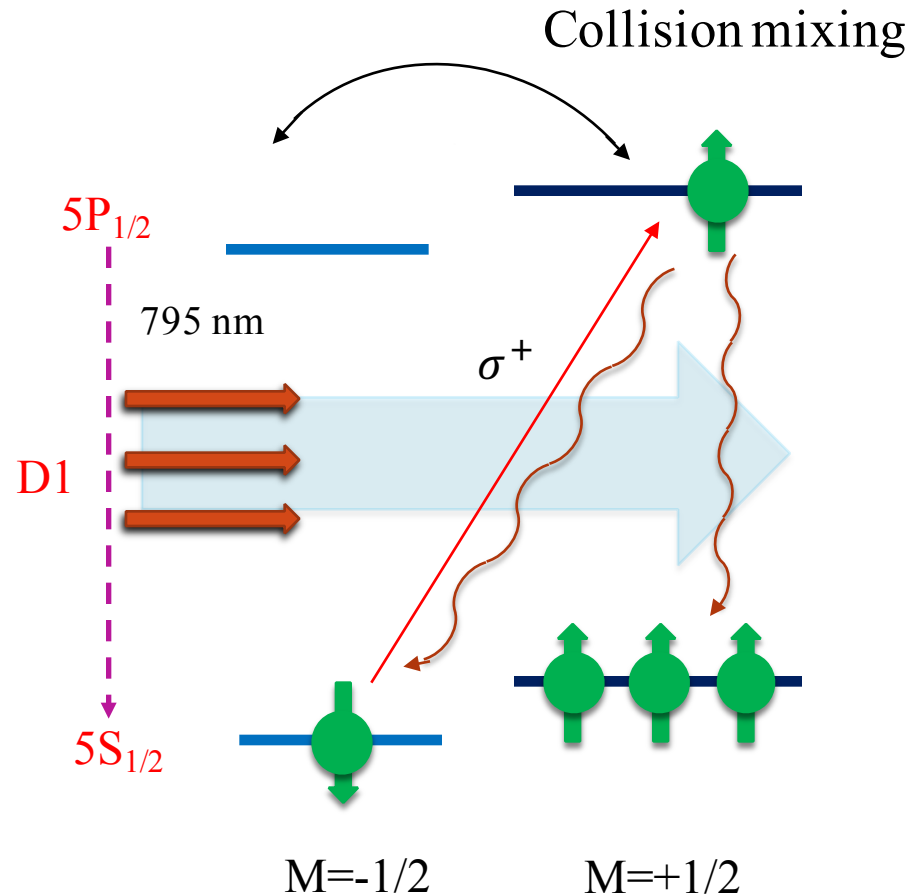
Spin-exchange

- Alkali-^{3}He interact through: hyperfine interaction.
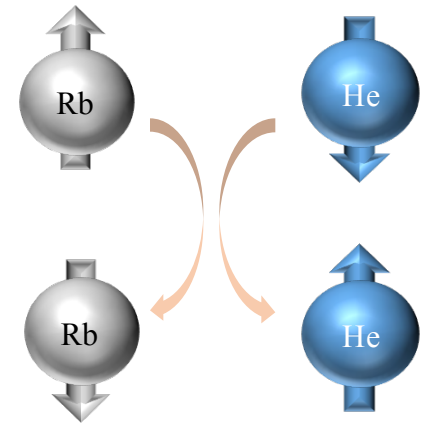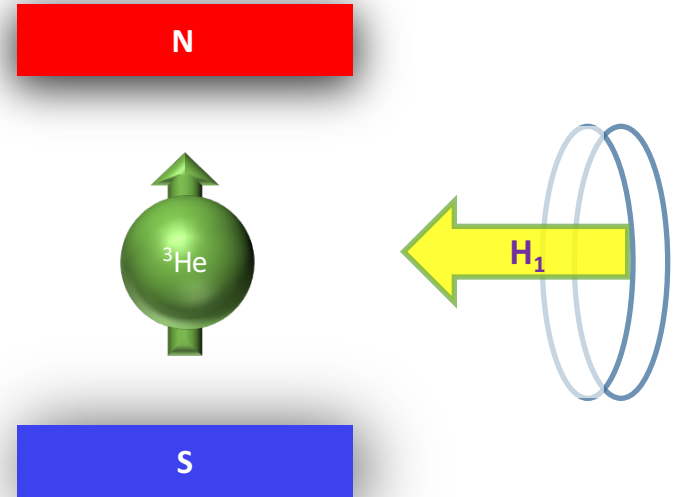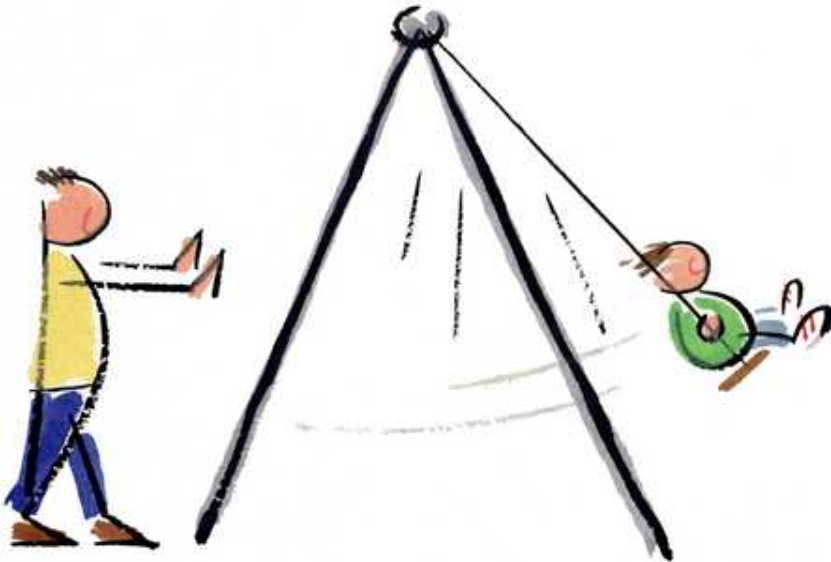
- Hybrid mixture (K-Rb) increases spin-exchange efficiency.

Polarimetry (polarization measurement)

❑   NMR: nuclear magnetic resonance (relative/absolute).

❑   EPR: electron paramagnetic resonance (absolute).

❑   Pulse NMR (relative).

NMR (nuclear magnetic resonance)

At the right frequency, resonance will happen.
Natural frequency of spin is the Larmor frequency: $\omega = \gamma \cdot B_0$
Where γ is the gyromagnetic magnetic ratio of ^{3}He

NMR cont.

- ❑ AFP(adiabatic fast passage): slow & fast.
- ❑ Measure the transverse component of magnetization which induces signal in pair of pick-up coils.
- ❑ Relative measurement, need to calibrate with EPR or with known thermal equilibrium polarization of water.

RF field

B_0 field sweep
(or frequency sweep)

mV

Gauss
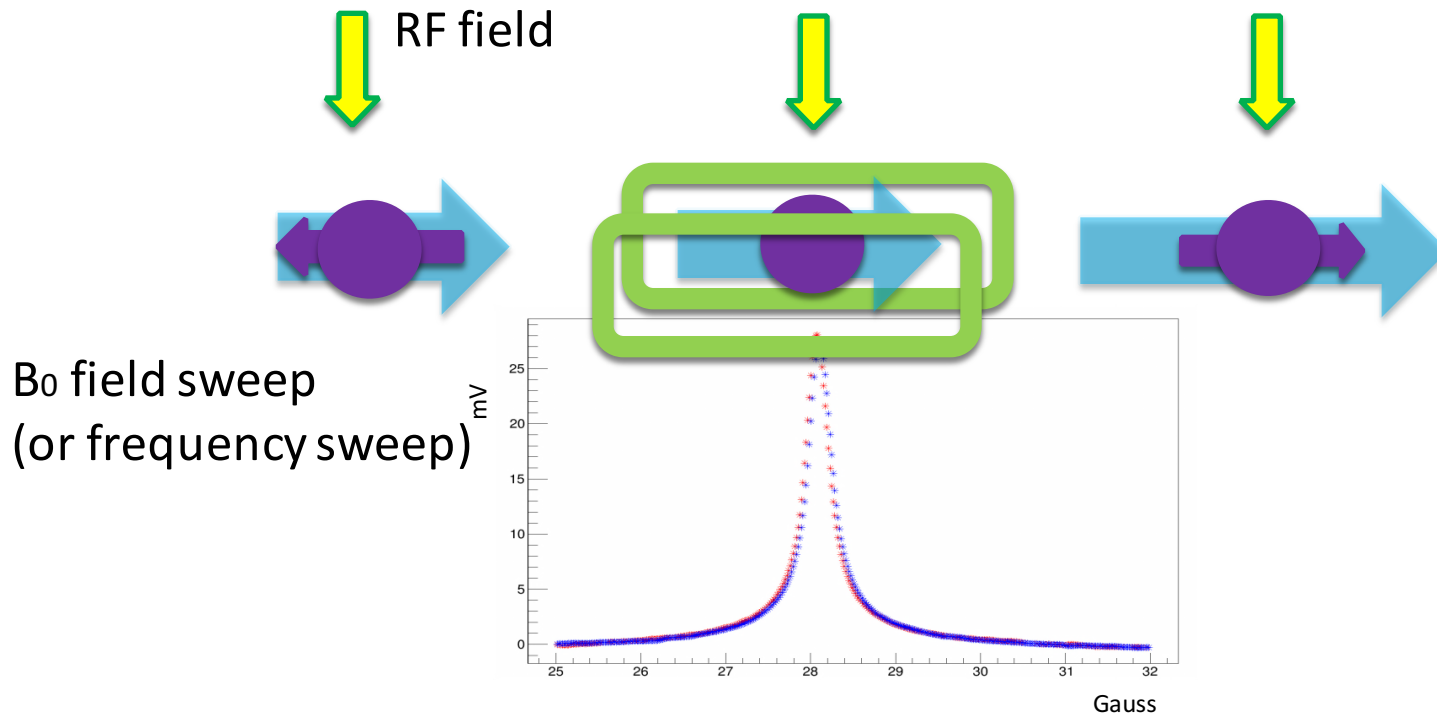
EPR (electron paramagnetic resonance)

❑ **Principle**: Use Alkali EPR resonance frequency and the shift in frequency due to small contribution from ^{3}He field.
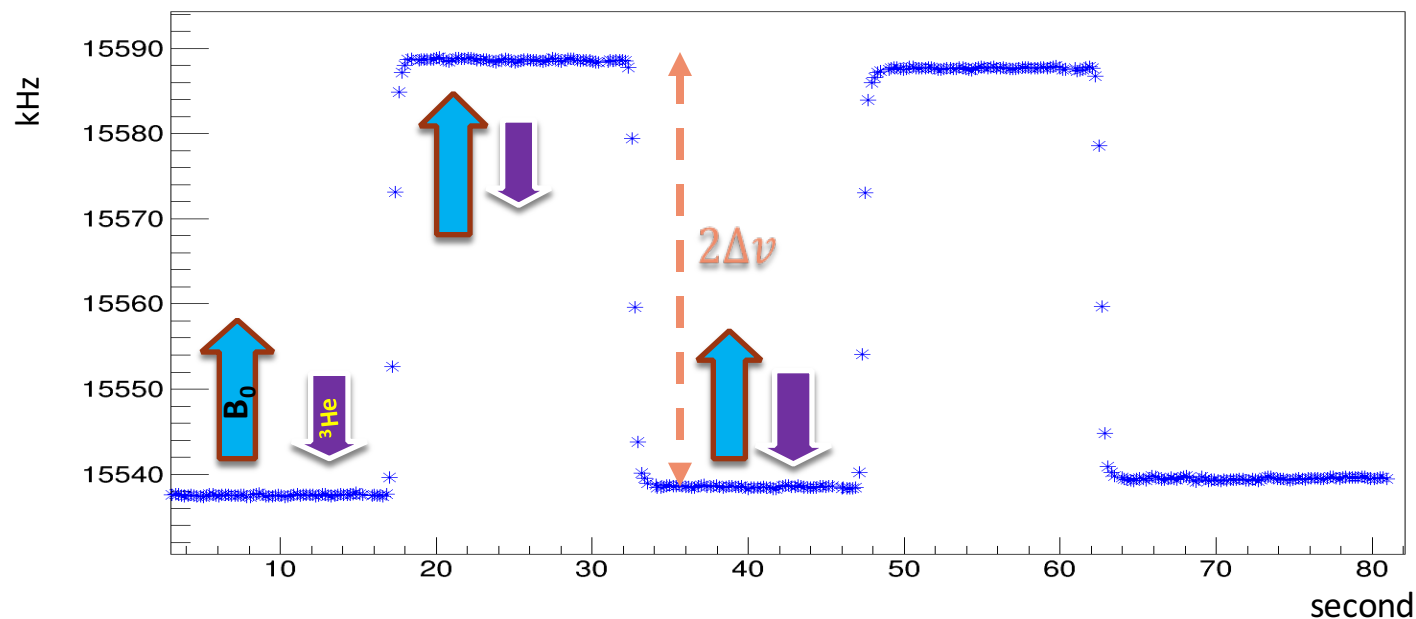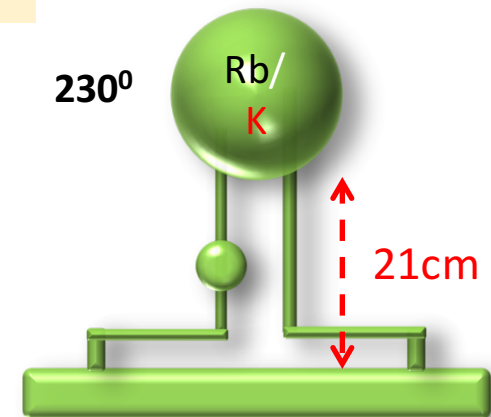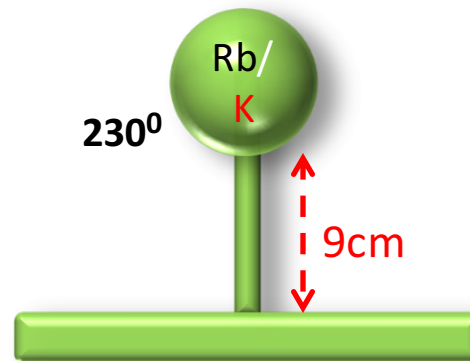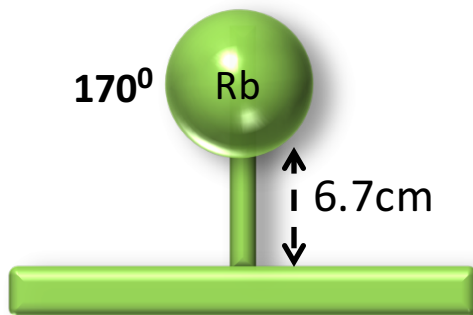

From frequency difference, ^{3}He polarization is extracted.

Target Polarization from Previous Experiments

Experiment	<PC > %	<TC > %	Relative uncertainty	$<\Delta P = P_{pc} - P_{tc}>\%$
A1n	42.97	41.90	3%	1.07
Transversity	60.4	55.4	5%	5

Larger distance, larger polarization gradient between PC & TC

170^0 Rb   6.7cm

230^0 Rb/K   9cm

230^0 Rb/K   21cm

K_0 for Rb is known up to 300^0C but for K only up to 200^0C. UVa and W&M group are studying this calibration constant

With convection, reduce polarization gradient.

Overview of ^{3}He target upgrade plan
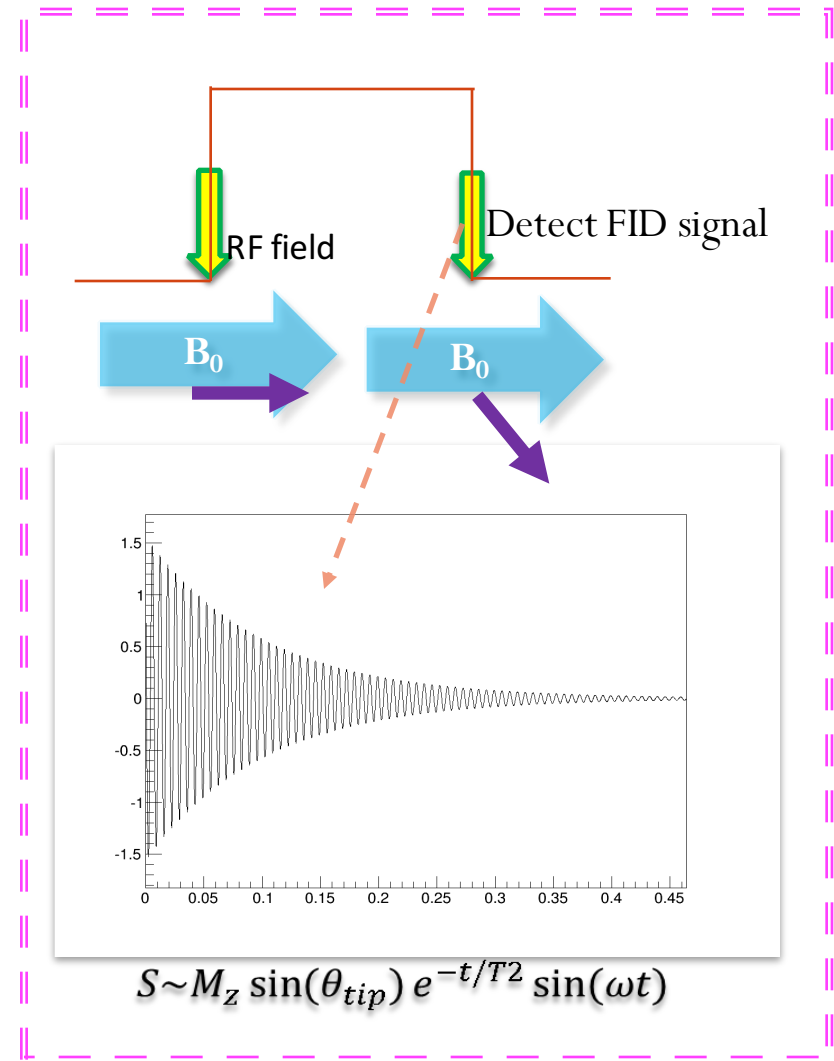
- Target will take 30 uA beam current with glass cell.

- 3% systematic uncertainty for polarimetry.

- Using convection cell: decrease polarization gradient.

- Pulse NMR calibrated with EPR/NMR.
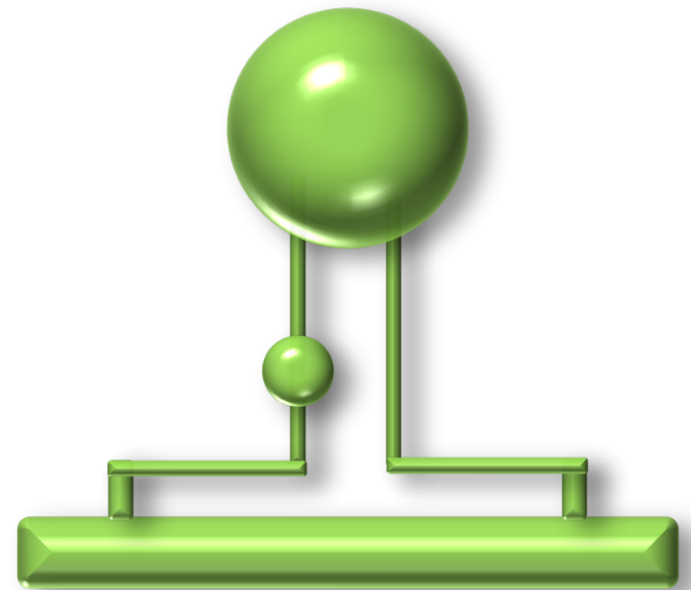
Convection cell

Pulse NMR

❑ **PNMR**: metal windows target chamber, can't send RF field through metal. (end of target chamber).

❑ **Principle:**

❑ Send a pulse at Larmor frequency (81kHz).

❑ ^{3}He spin precesses and tips away from main field.

❑ Detect free-induction-decay signal (FID). Measure the transverse component of magnetic moment.

RF field

Detect FID signal

B_0

B_0

$$S \sim M_z \sin(\theta_{tip})\, e^{-t/T2} \sin(\omega t)$$

PNMR setup

Send RF signal

Receive signal

Gate gen

Fun gen
81 kHz

50Ω

L

H

C=45nF

Coil
R=0.9Ω
L=87µH

50Ω

H

L

Oscilloscope

Amp

Mixer

Pre amp

Fun gen
Ref freq
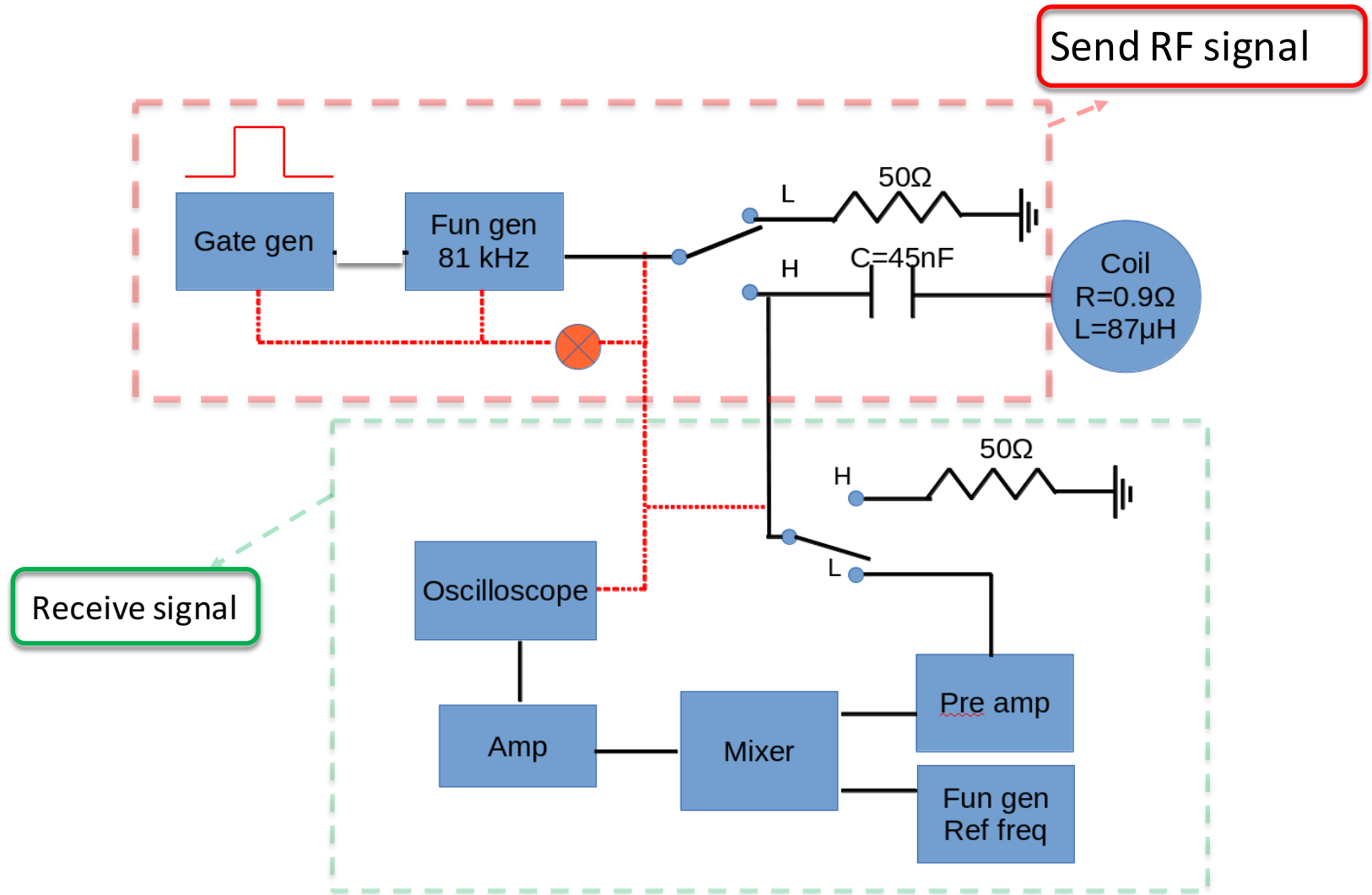
PNMR vs NMR in target chamber
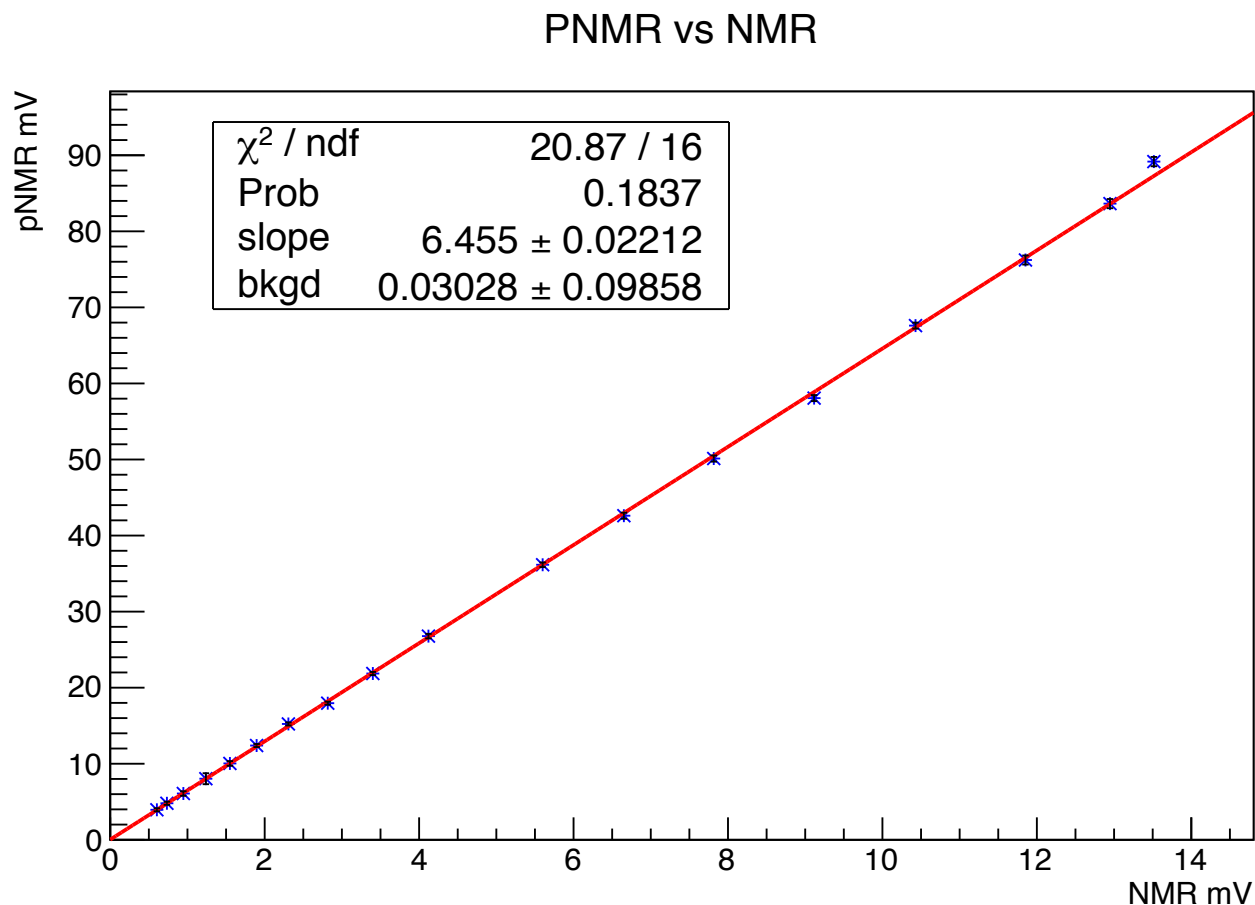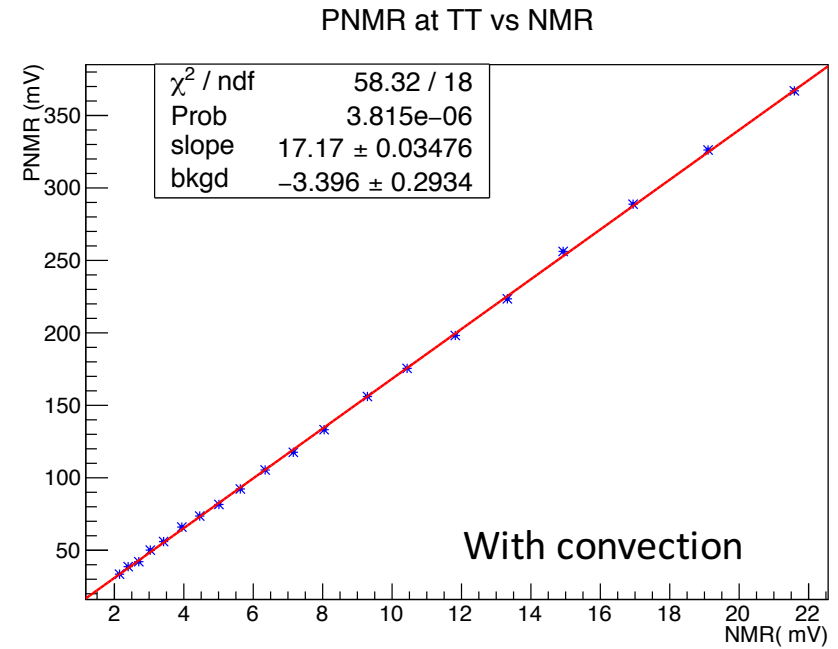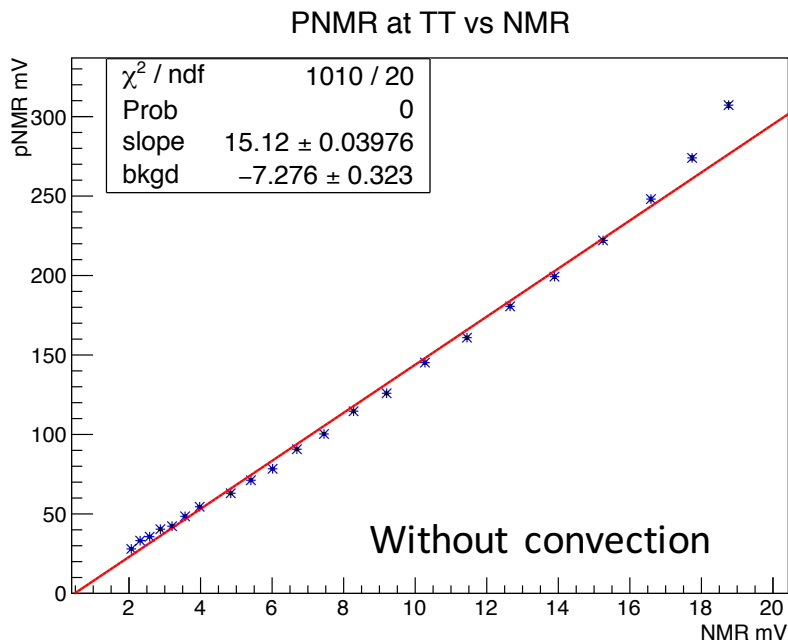
PNMR vs NMR

Hot spin down measurement (2hours). No convection.

Pulse NMR measure at target chamber.

Pulse NMR works for spin up, hot spin down with and without convection.

PNMR vs NMR at transfer tube

PNMR at TT vs NMR

χ^2 / ndf	1010 / 20
Prob	0
slope	15.12 ± 0.03976
bkgd	−7.276 ± 0.323

Without convection

PNMR at TT vs NMR

χ^2 / ndf	58.32 / 18
Prob	3.815e−06
slope	17.17 ± 0.03476
bkgd	−3.396 ± 0.2934

With convection

➢ During cold spin down without convection, the first several points have strong diffusion effect. With convection on, the diffusion effect become smaller and we can get the linear curve.

➢ Systematic study is in progress.

Future plan

- Continue PNMR systematic uncertainty.

- Study PNMR for real condition in the Hall with large gradient.

- Characterize protovec-2 cell.

Thanks!

- People at JLab:
  - Supervisor: Jian-ping Chen.
  - Graduate student: Jie Liu, Kai Jin.
  - Undergraduate: Caleb Fogler.
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  - UVa: Gordon Cate, Maduka Kaluarachchi, Yunxiao Wang, Daniel Matyas.
  - UVa: Xiaochao Zheng, Vincent Sulkosky.
  - W&M: Todd Averett.

Back up slide

Target polarization from previous experiment

- Systematic uncertainty come from: K-^{3}He EPR calibration constant, PC density, NMR signal fit, PC temperature, density fluctuation, diffusion rate, TC intrinsic lifetime, beam depolarization, transfer tube depolarization, spin flip loss.

- Average polarization for PC and TC are:
  - <PC>= 60.4%±0.5%(average stat. per NMR) ±2.1%(sys.)
  - <TC>=55.4%±0.4%%(average stat. per NMR) ±2.7%(sys.)

How the target look like