Polarized ^{3}He Target For Future Experiments

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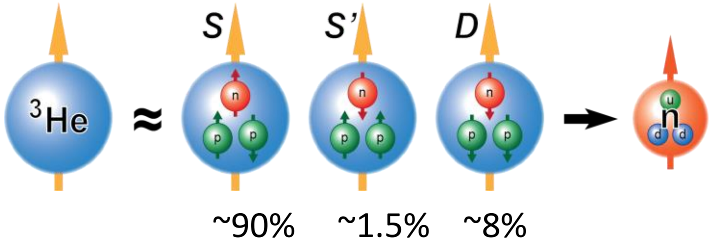
Hall C Winter Collaboration Meeting, January 20, 2017

- Introduction to polarized ^{3}He target
- Target upgrade plan
- Progress & Status
- Summary

Polarized ^{3}He Introduction

- ^{3}He: Effective polarized neutron target



- magnetic moment $\mu = \frac{e\hbar}{2m}$, $\mu_N \ll \mu_e$, more difficult to polarize nucleon.

- ^{3}He: 2 electrons in ground state 1S, cannot be directly polarized (Pauli Blocking)

Methods of polarization ^{3}He:

- 1. Metastability-Exchange Optical Pumping (MEOP)

➢ Excite one electron to metastable state, then can be polarized;
➢ Metastability-exchange collision to polarize ^{3}He nucleus;
➢ Metastable state lifetime decrease with high ^{3}He density;
➢ Low ^{3}He pressure(Mainz, 3atm), cannot reach high density(luminosity).

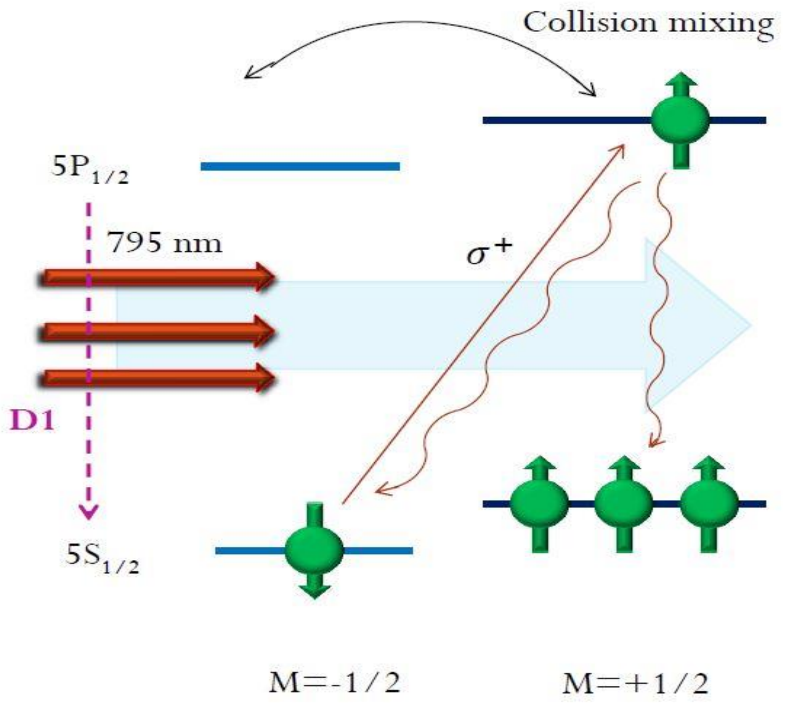
- 2. Spin-Exchange Optical Pumping(SEOP):

➢ Can be used to polarize high density ^{3}He target (10 atm), reach high luminosity(~10^{36}).

Polarized ^{3}He Introduction

1.Optical pumping :

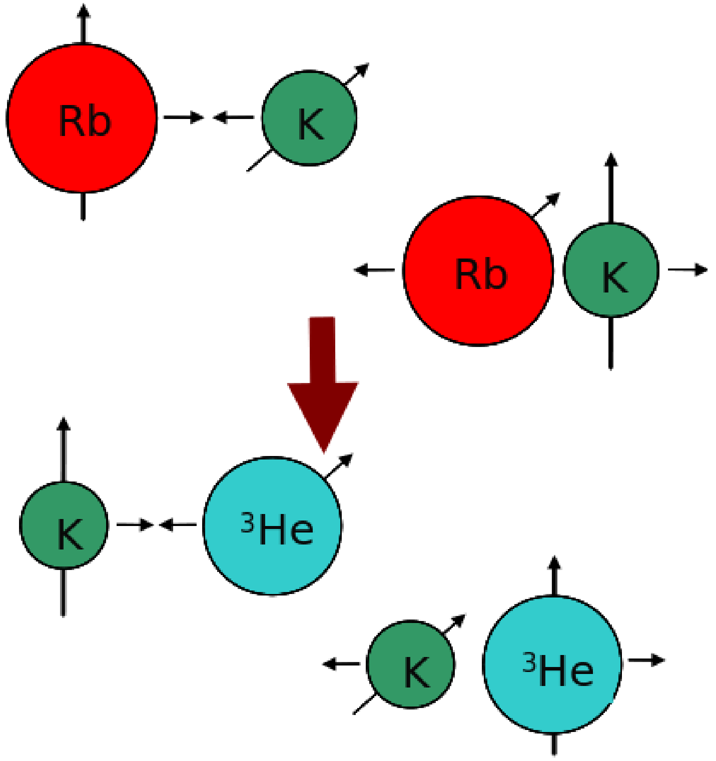
- Splitting of Alkali atomic state by B field;
- Polarized laser light excite electrons from $5S_{1/2}$ (M=-1/2)→ $5P_{1/2}$(M=1/2);
- Decay from excited state to ground states;
- Alkali atoms can reach ~ 100% polarization!



Polarized ^{3}He Introduction

2.Exchange spin with ^{3}He:

- Collision with angular momentum conservation;
- Spin exchange: Alkali atom ↔ ^{3}He nucleus;
- Rb-K mixture Alkali gas(hybrid cell);
- Higher in-beam polarization 55-60%;



^{3}He Target Upgrade

- Stage I:

➢ I~30 μA, target L=40 cm, L~ 2.2X10^{36} $cm^{-2}s^{-1}$

➢ In beam polarization ~60%

➢ Glass cell, with convection flow, pumping chamber: 3.5”(optional to 4”)

➢ Polarimetry uncertainty~3%,

➢ Engineering: Hall A&C compatible

➢ Experiments: d2n in Hall C, A1n in Hall C, (A1n in Hall A)

- Stage II:

➢ I~60 μA, target L=60 cm, L~6.6X10^{36} $cm^{-2}s^{-1}$

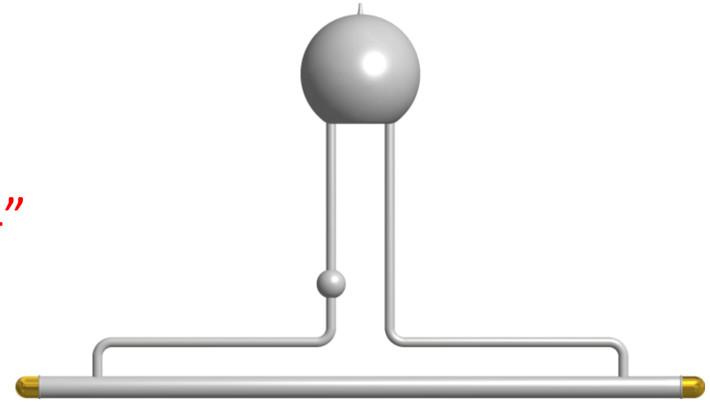
➢ In beam polarization ~60%

➢ Glass cell, with convection flow, metal window, pumping chamber: 4.4”

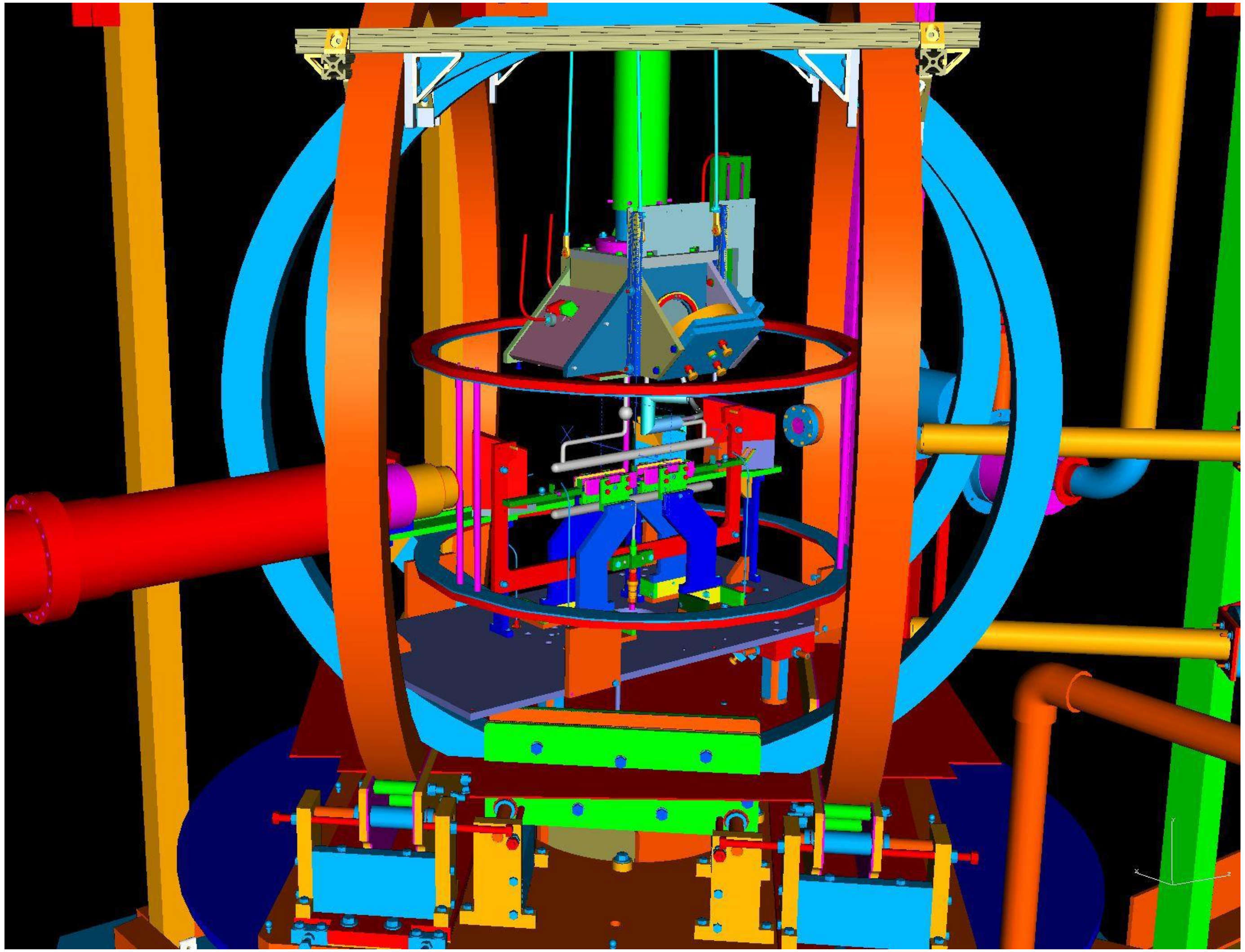
➢ Polarimetry uncertainty~3%

➢ Engineering: shield large field gradient from SBB fringe field

➢ Experiments: GEN in Hall A



Mechanical Design



- Raising Helmoholtz coils by 15 cm
- Oven modifications
- Oven support modifications
- Mirror arrangements
- EPR optics design
- Optics change
- Enclosure
- Fitting to Hall C : Pivot modifications
  Access Platform

Oven

- Oven design finished;
- Components of first oven have been manufactured and delivered to JLab;
- Assembling in progress, will be tested soon.

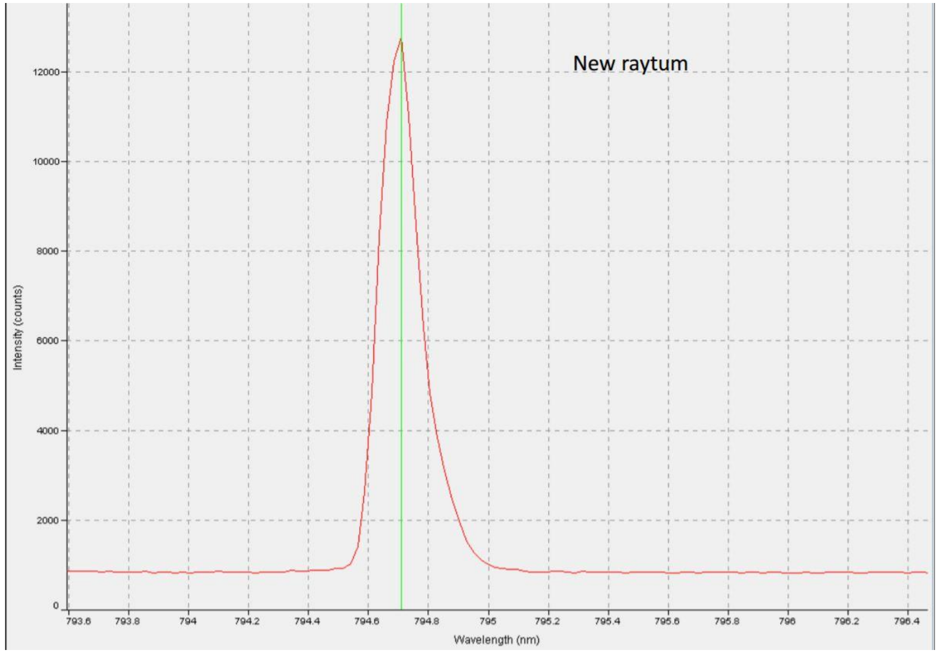
Lasers & Optical Fibers

- 7 Raytum lasers(3 upgrade, 4 new) :

➢ Power 30 W, wavelength 794.71 nm, width 0.2 ~0.3 nm;

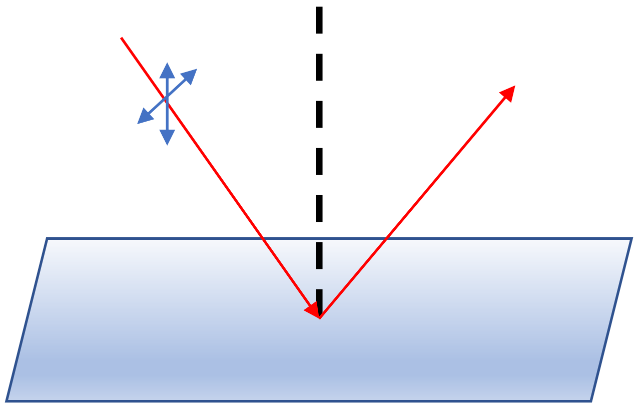
➢ Worked with Raytum to improve laser quality.

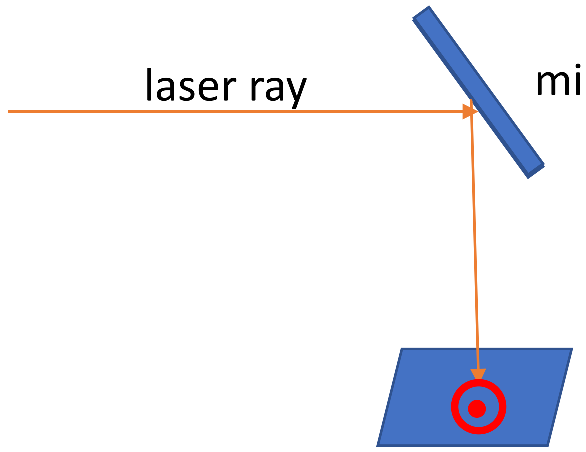
- 10 new fibers arrived, have been tested.



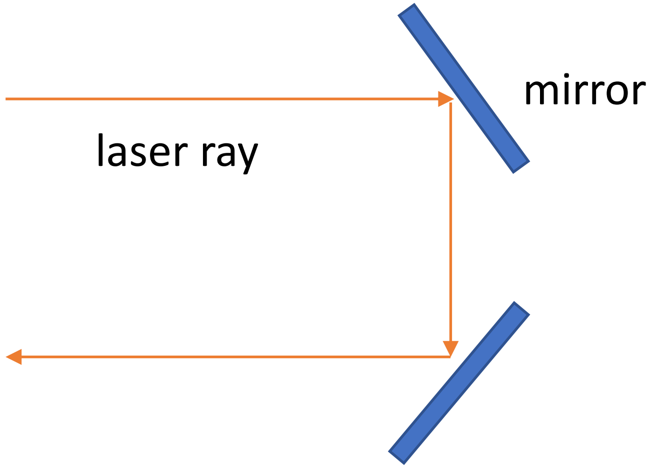
Beam Compensation

- Dielectric mirror has relative phase shift between S & P wave of laser;
- For longitudinal pumping, mirror which redirect laser to cell is not in polarization preserving configuration;
- Laser circular polarization ~ 70%, not suitable for ^{3}He pumping;
- Add quarter waveplates: extra phase difference to compensate.





polarization preserving



non-polarization preserving

Testing of Stage I Cell

- not thin window cell:

➢ Protovec-I (tested @ Jlab)

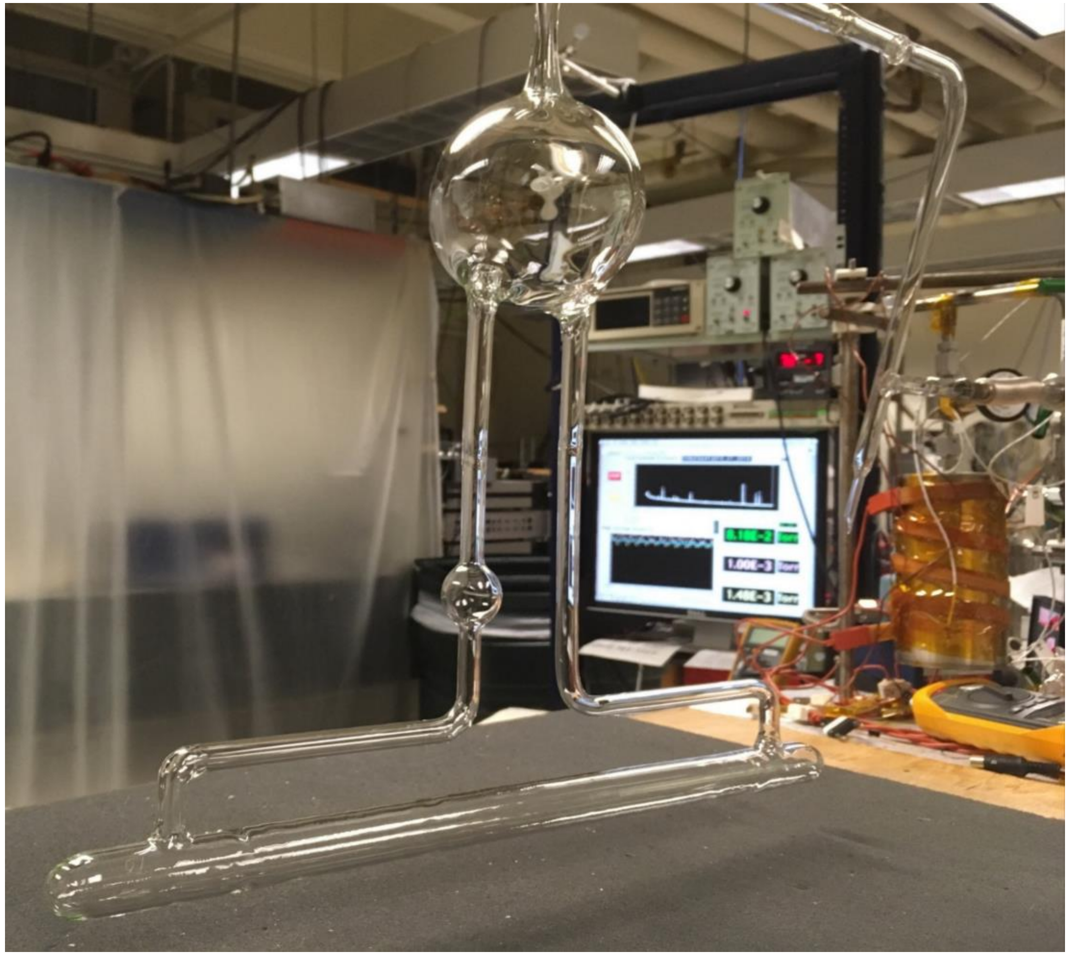
➢ Protovec-II (tested @ UVA)

- thin window cell:

➢first 2 cells broke

➢New Stage I cell “Savior” being tested @ UVA full characterization will be done@JLab.

- More cells will be made afterwards;
- GE180 Glass production was discontinued, already bought enough for Stage I&II, or more.



new cell “Savior”

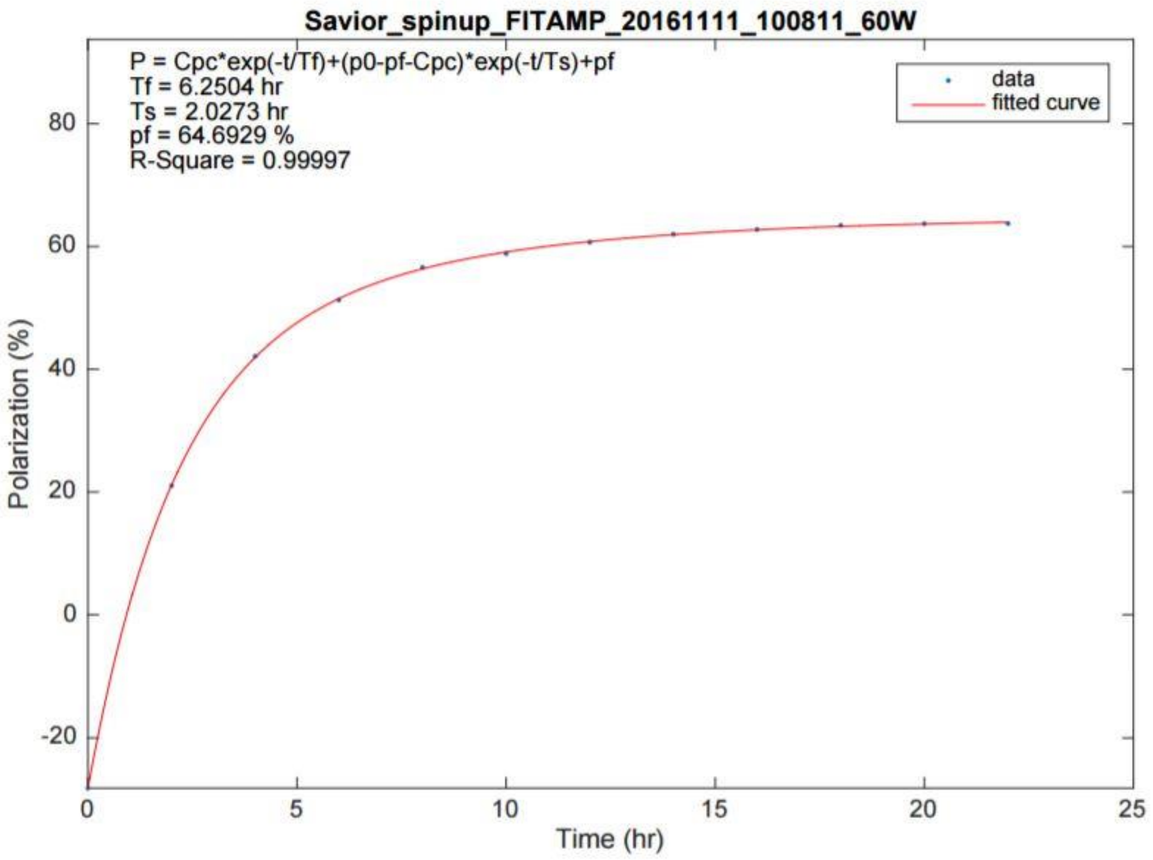
Cell test for Protovec-1

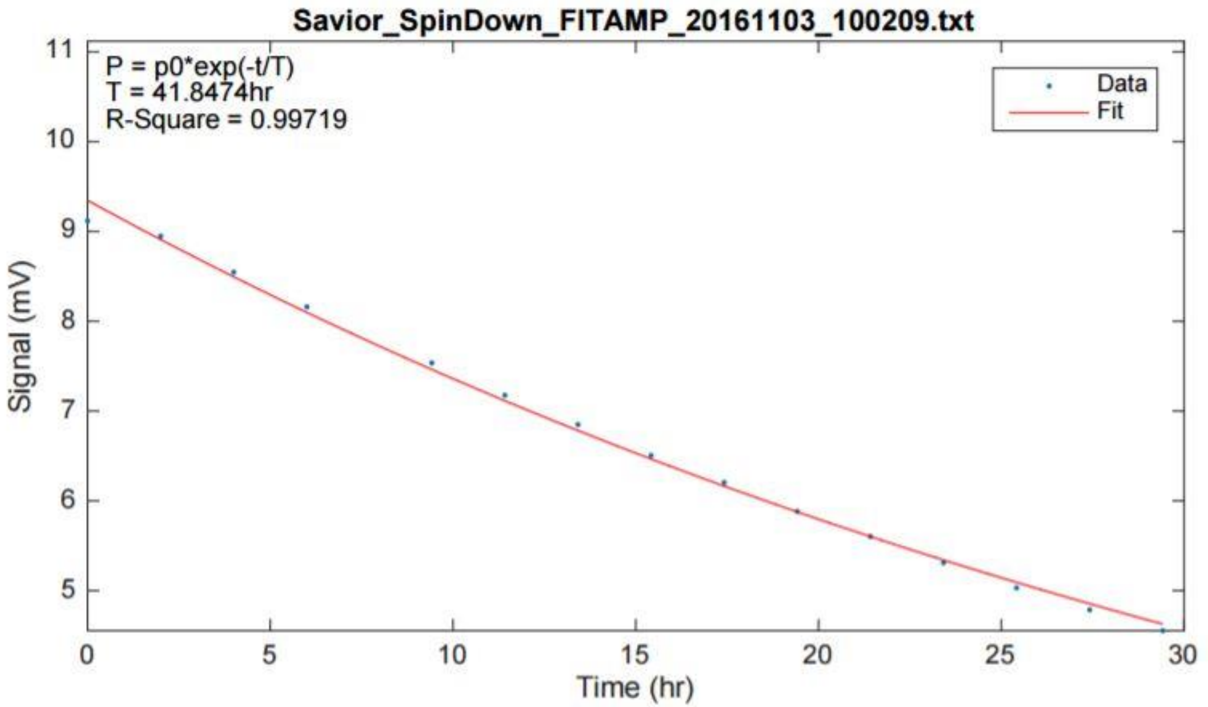
AFP loss(single flip)	Pumping chamber(%)	Target chamber(%)
Cool without convection	1.18	0.21
Hot without convection	0.95	0.37
Hot with convection	1.43	1.44

Lifetime	Pumping chamber(hr)	Target chamber(hr)
Cool without convection	26.57	23.11
Hot without convection	13.49	15.97
Hot with convection	14.56	14.54

Characterization of new cell “Savior”

plots from Sumudu Katugampola @ UVA

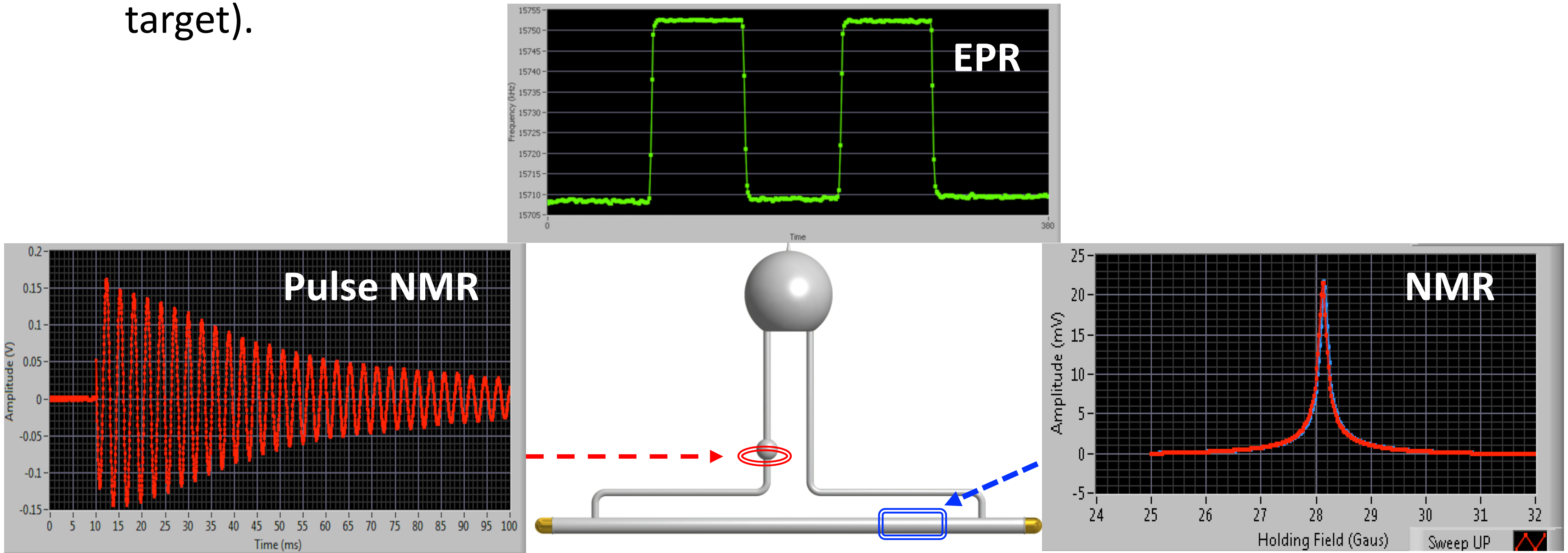




- Maximum polarization: 64%
- Lifetime: 41 hours

Polarimetries of ^{3}He target

- AFP-NMR (nuclear magnetic resonance):
  - Field sweep (frequency sweep).
  - Calibrated with water NMR or EPR.
- EPR (electron paramagnetic resonance): absolute measurement.
- Pulse NMR: need to be calibrated against EPR/NMR (new polarimetry at target).



NMR

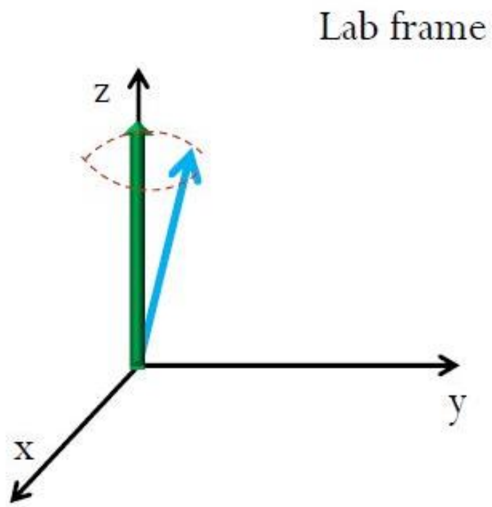
- Principle:

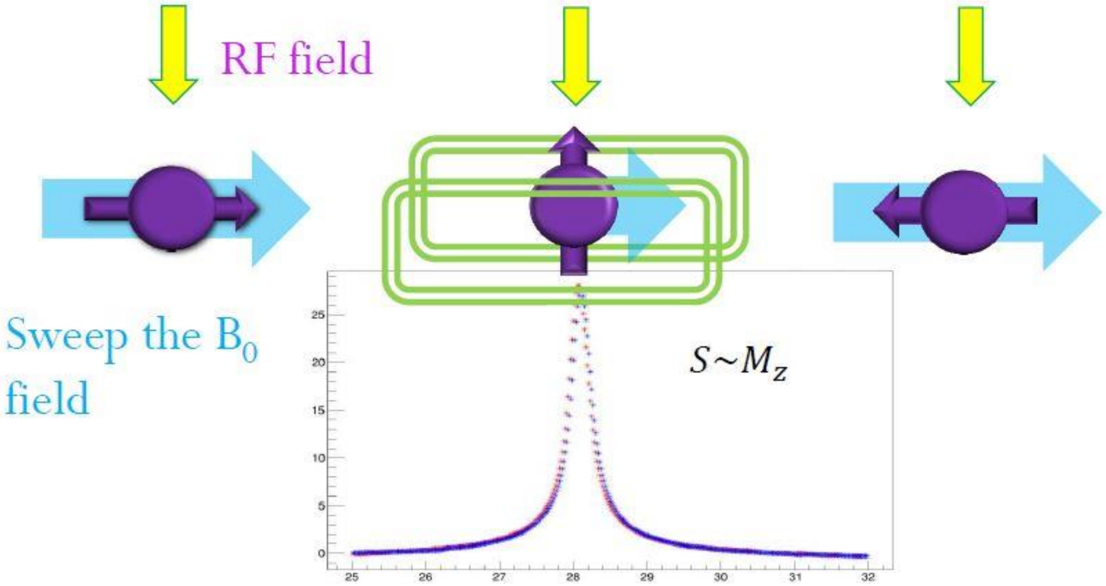
➢ ^{3}He in holding field H along z axis, $\frac{dM}{dt} = \gamma M \times H$, ^{3}He nuclei magnetic moment precessing around holding field;

➢ Add an RF field H_1 along x axis;

➢ Sweep holding field across resonance (Adiabatic Fast Passage), reverse spin of ^{3}He nuclei;

➢ Induce an electromagnetic field and a signal in pickup coils.





EPR

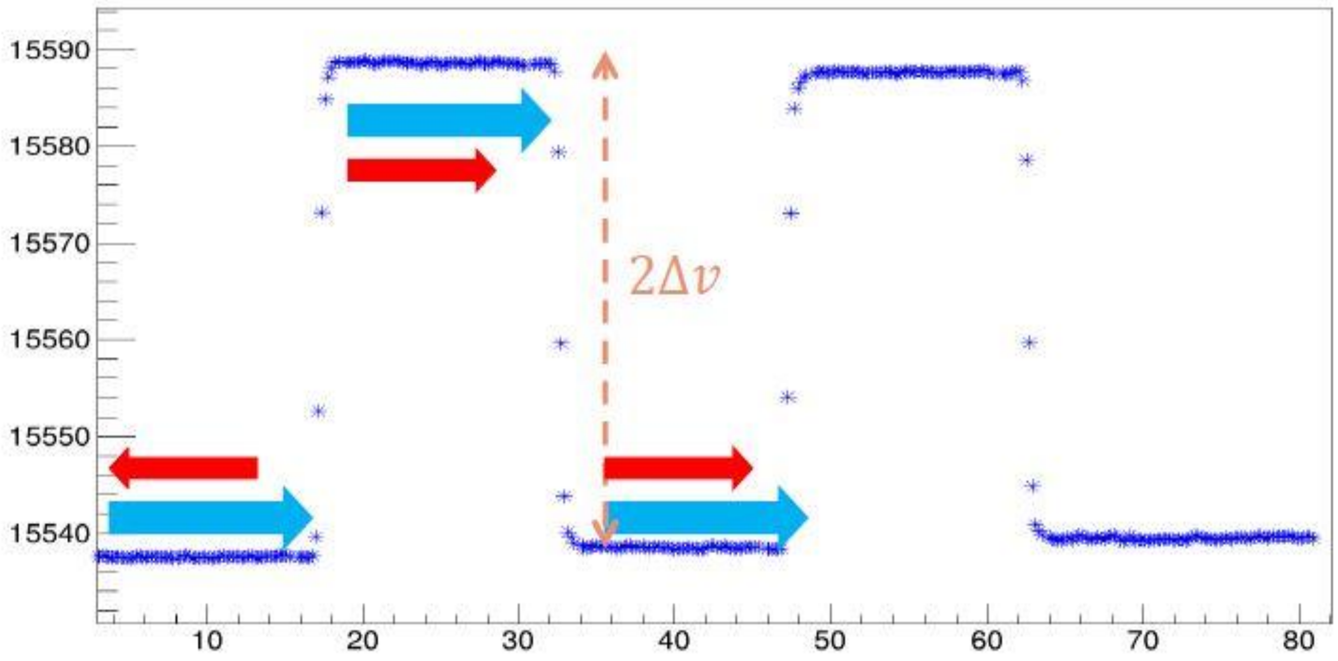
- Principle: use Alkali EPR resonance frequency and the shift in frequency due to small contribution from 3He polarization;

➢polarized ^{3}He nuclei generate $\mathrm{B}_{^3\mathrm{He}} \sim 0.1$ G

➢Rb's Zeeman splitting $\upsilon_{EPR} \propto \mathrm{B} = \mathrm{B_H} + \mathrm{B}_{^3\mathrm{He}}$

➢AFP reverse ^{3}He polarization->$\Delta\upsilon_{EPR} \propto \mathrm{B}_{^3\mathrm{He}} \propto \mathrm{P}_{^3\mathrm{He}}$

- Measure absolute polarization;
- Uncertainty: ~ 3%.



Pulse NMR

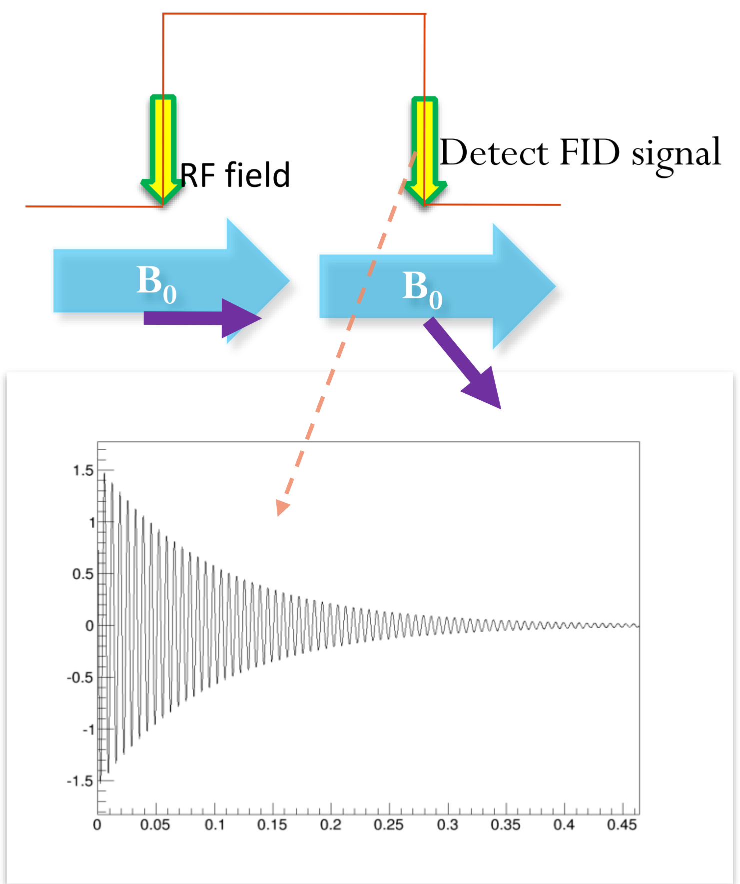
- **PNMR:** metal windows target chamber, can't send RF field through metal. (end of target chamber).

- **Principle:**

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

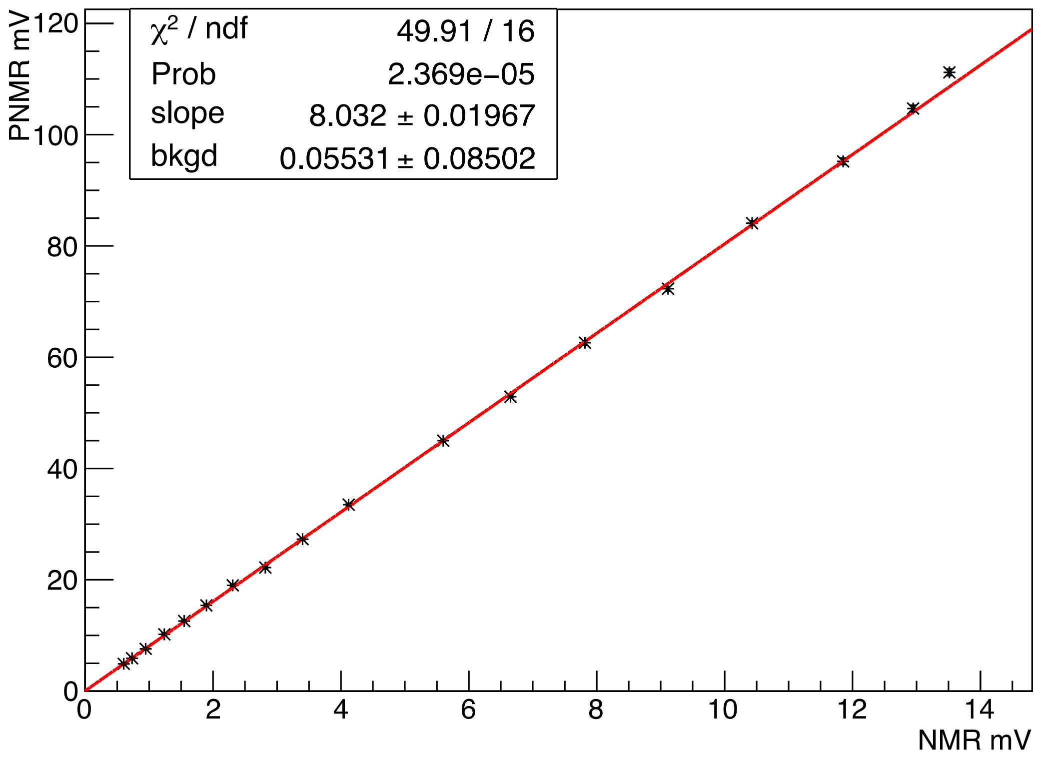
- ^{3}He spin precesses and tips away from main field.

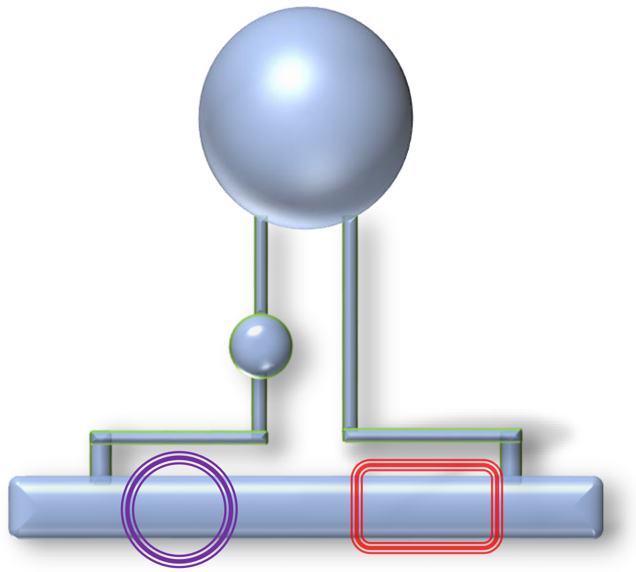
- Detect free-induction-decay signal (FID). Measure the transverse component of magnetic moment.



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

PNMR vs NMR in target chamber

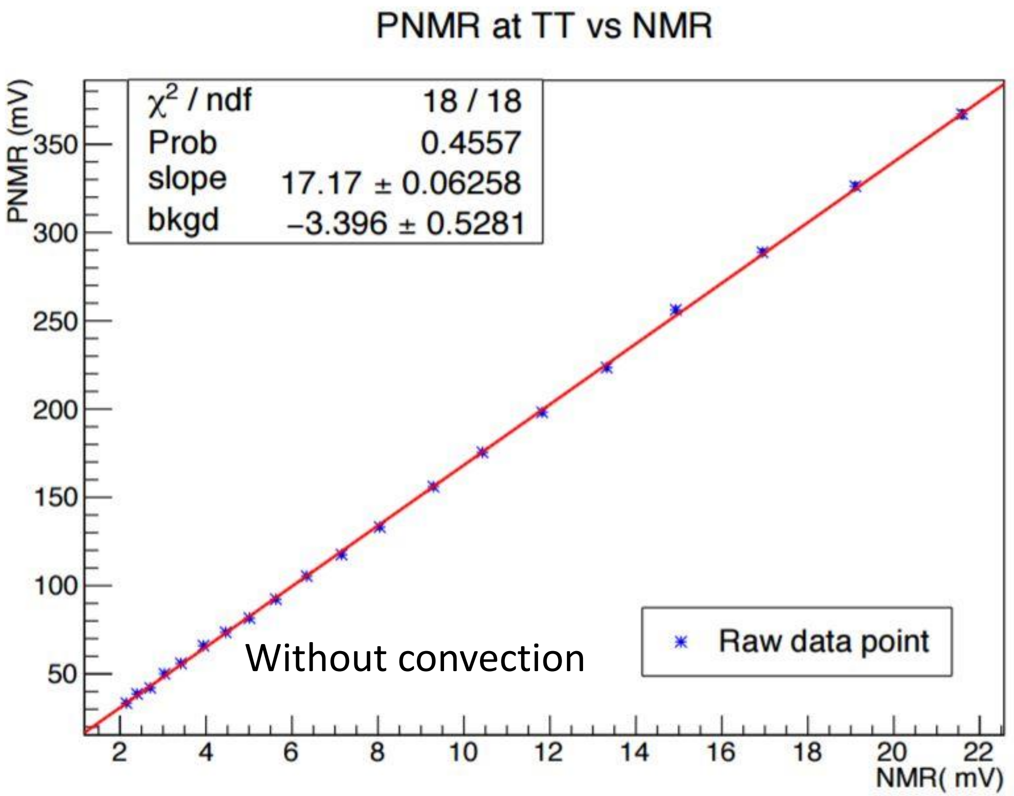


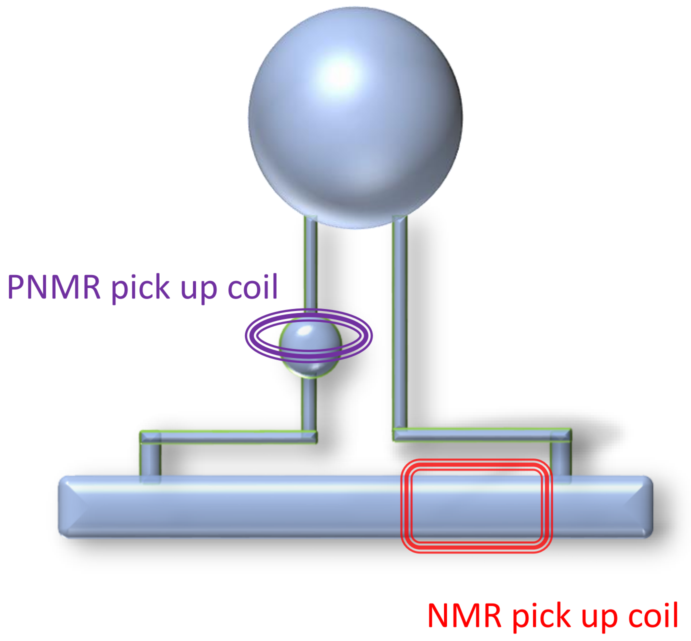


Hot spin down measurement (2hours). No convection.
Pulse NMR measure at target chamber.

✓ Reach 1% uncertainty

PNMR (at transfer tube) vs NMR (at target chamber)





Hot spin down measurement (2hours). No convection.
Pulse NMR measure at transfer tube.

Summary

- Two steps upgrade of polarized 3He target system;

- Progress & Status:

❑Stage I: Can be ready in a few months for Hall C & A experiments

➢ Mechanical Design: finished;

➢ Laser & Fiber: already have in house enough to start experiment;

➢ Cell: made 1 thin window cell, with reasonable performance, production will follow;

➢ Polarimetry: PNMR systematic study ongoing; convection cell polarization study;

➢ Full characterization of cells;

➢ Testing oven, lasers, fibers;

➢ EPR κ_0 study(at W&M , UVA);

❑Stage II:

➢ Mechanical Design: started: optics platform, shielding structure…

➢ Cell: metal window R&D in progress

Thanks!

- **People@JLab:**

➢ Supervisor: Jian-ping Chen

➢ Graduate student: Nguyen Ton, Kai Jin

➢ Engineering/Design: Al Gavalya, Bert Metzeger

➢ **Help from**: Jie Liu, Jin Huang, JLab electronics group ……

- **Collaborators University:**

➢ UVa: Gordon Cate's Group

➢ W&M: Todd Averett's Group

- UVa: Xiaochao Zheng(My Advisor)

Back Up

Experiment Requirements

Experiment	Spectro	target		Density	Length	Pol.	Current	Lumi	Polarimetry
d2n-Hall C	HMS/SHMS	Stage I	proposed	10 amg	60 cm	55%	30 uA	$3x10^{36}$	3%
			accepted	10 amg	40 cm	55%	15 uA	$1x10^{36}$	3%
A1n-Hall C	HMS/SHMS	Stage I	proposed	10 amg	60 cm	60%	60 uA	$6x10^{36}$	3%
			accepted	10 amg	40 cm	60%	30-40 uA	$3x10^{36}$	3%
A1n-Hall A	Big Bite/HRS	Stage I	proposed	10 amg	60 cm	55%	30 uA	$3x10^{36}$	3%
			accepted	10 amg	40 cm	55%	30 uA	$2x10^{36}$	3%
GEN-Hall A	SBS	Stage II	proposed	10 amg	60 cm	60%	60 uA	$6x10^{36}$	3%
SIDIS	Big Bite/SBS	Stage II	proposed	10 amg	60 cm	60%	40 uA	$4x10^{36}$	3%

Metal windows:

- Tests of metal test cells completed;
- Glass to metal seals(“Housekeeper seals”) work very well;
- OFHC copper metal end windows, with gold electroplating on inner surface;
- good spin relaxation properties:

relaxation contribution from metal windows < 1/100 hr^{-1};

- Have not produced an actual window yet;