PNMR Status Update

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Outline:

1. Introduction of PNMR
2. PNMR calibration during experiment
3. PNMR online results
4. PNMR offline analysis
5. Post experiment PNMR loss study
6. Future work

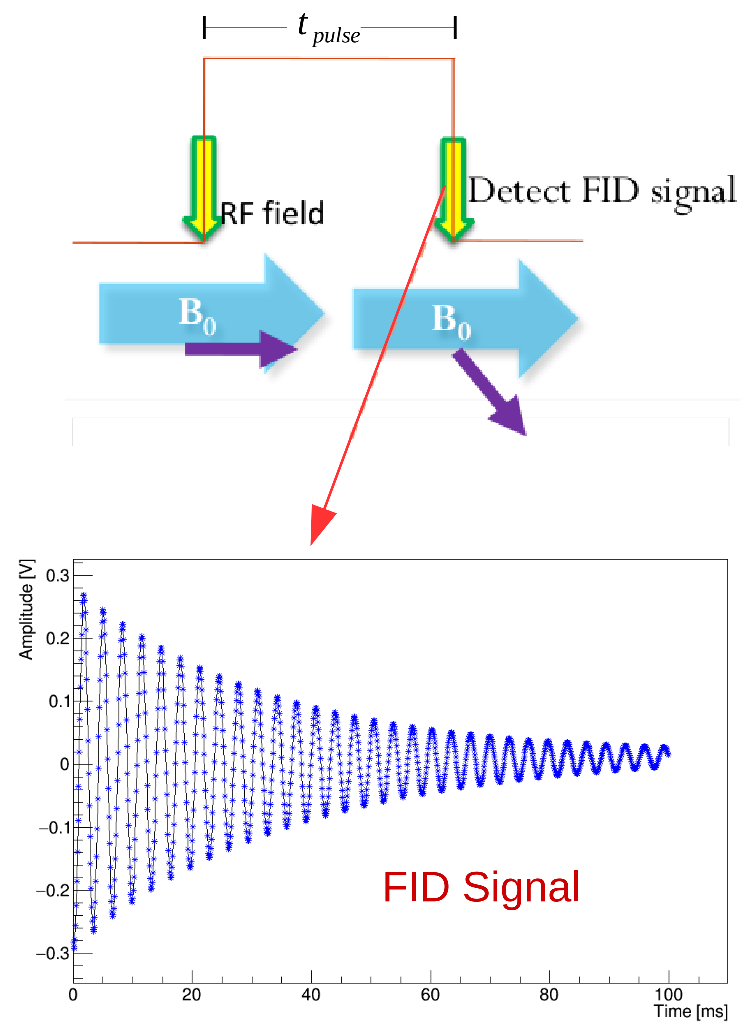
Pulse NMR Polarimetry

Advantage:

- Took shorter time to complete measurement, less depolarization compare to AFP-NMR.
- For future metallic end cells, provide local polarimetry at transfer tube.

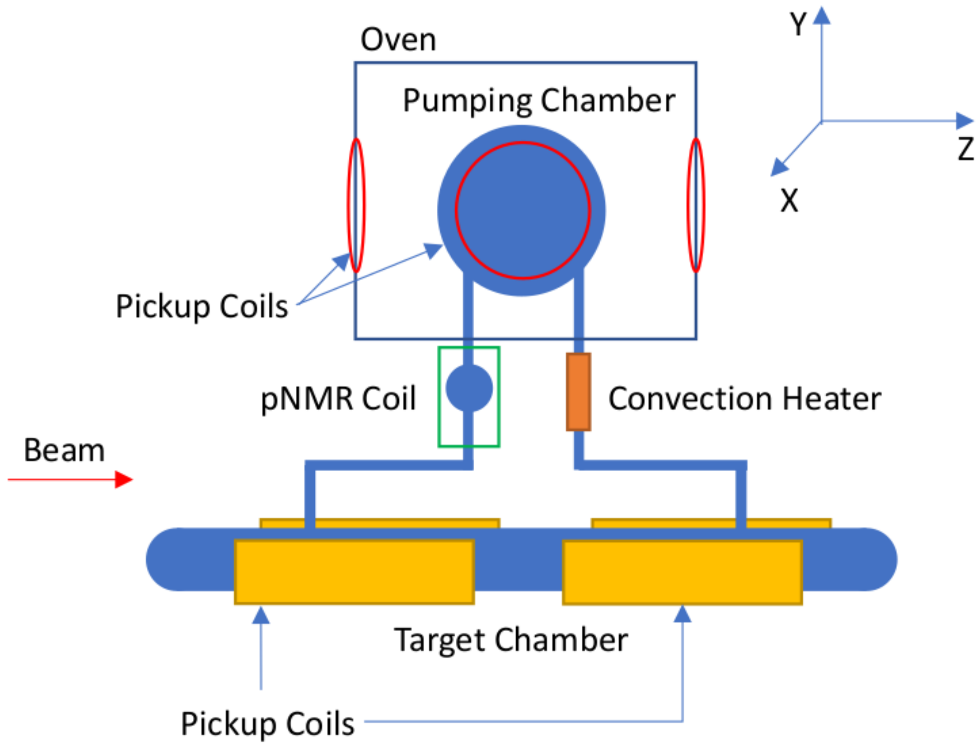
Principle:

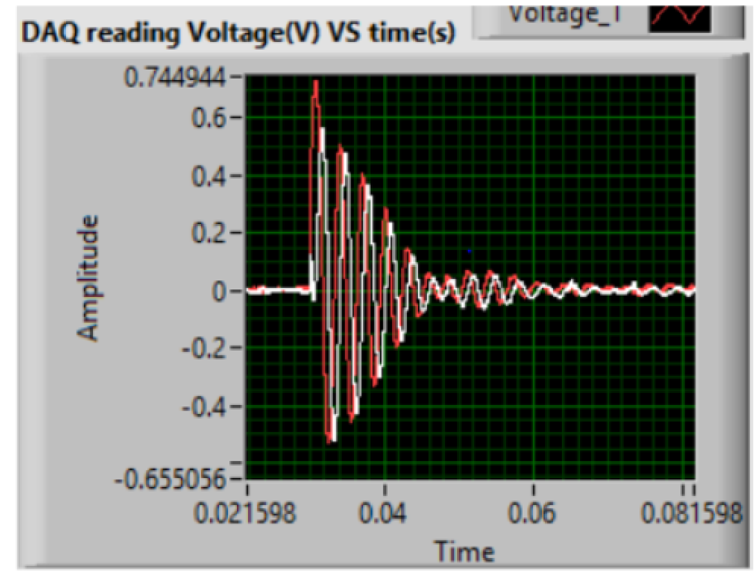
- Send a RF pulse at Larmor frequency which tips ³He spin away from holding field axis: $\theta_{tip} = \frac{1}{2}\gamma H_1 t_{pulse}$
- When pulse ends, the spin precesses back to its initial state and experience free induction decay (FID).
- FID signal is picked up by the PNMR coil. Measure the transverse component of magnetic moment proportional to ³He polarization.



$$S(t) \propto M_z \sin(\theta_{tip}) \cos(\omega t + \phi_0) e^{-t/T_2}$$

PNMR Calibration during Experiment





- With established EPR vs NMR calib, NMR gives ^{3}He polarization (%) at measurement location.
- PNMR was performed at transfer tube which was calibrated by AFP-NMR at pumping chamber.
- PNMR calibration sequence:
  1. PNMR measurement;
  2. Wait 1 min;
  3. NMR measurement
- For production run, PNMR calibration was performed every 4 or 5 hours for each production run condition (cell, SHMS kinematic)

- Current fit for the signal by the FID fitting function to obtain PNMR amplitude .

$$S(t)=FID(t)=A_0\cos(\omega t+\phi_0)e^{-t/T_2}+a*t+b$$

- Obtain PNMR$_{amp}$/NMR$_{amp}$ ratio in order to calibrate PNMR with NMR.

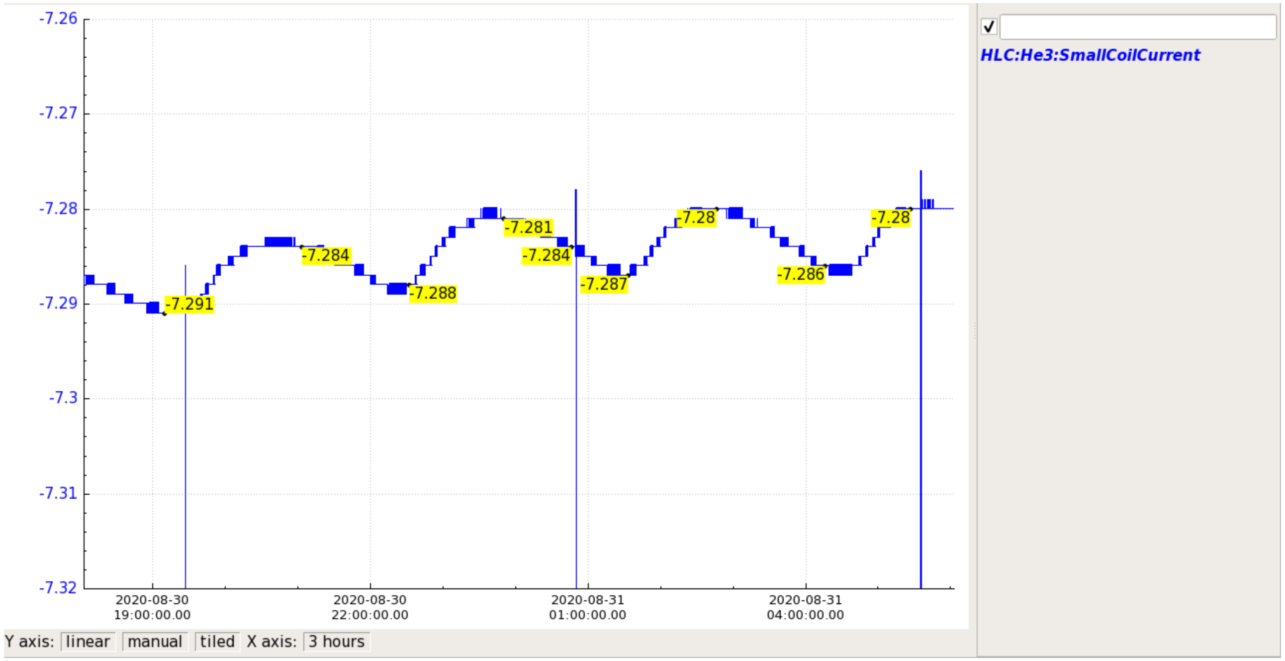
Note:

- Have 4 or 5 sets of PNMR vs. NMR measurements in order to determine PNMR calibration constant (in %/mV)
- For offline analysis will also study PNMR vs. NMR at target chamber calibration.

Holding Field Stability

- Different SHMS HB kinematics results different Holding field gradient around the PNMR coil region, thus PNMR vs NMR calibration need to be done for each SHMS HB kinematics setting.
- For same Holding field direction and same SHMS HB kinematics, the Holding field coil current still drifts (with 0.01 A level) after wait several hours to let the coil warm up.

  (this is main due to the power supplies for holding field coils are in voltage control mode)
- Holding field current can only be fine tune at ±0.02 A level due to limitation of voltage control mode of the power supplies.



Example:

- 180 deg with HB at 14.5 deg, -6.4 GeV. HS current varies from -7.288 A to -7.280 A.
- pNMR_He_20200831_004832: HS=-7.284A; Pulse freq=82.265 kHz, Reference freq=81.98 kHz; FID freq=101.199 Hz (Larmor freq ~82.081 kHz)
- pNMR_He_20200831_053435: HS=-7.280A; Pulse freq=82.045 kHz, Reference freq=81.76 kHz; FID freq=163.842 Hz (Larmor freq ~81.923 kHz)
- Will have about 316 Hz FID freq shift due to holding field coil current drift over time.

FID Freq Correction On Signal Amp

(with respect to PNMR Pulse freq)

- For ^{3}He Larmor freq in Holding field H:

$$\omega = -\gamma H$$

where γ=-3.2434 kHz/G is ^{3}He gyro-magnetic ratio.

- This means for holding field drift be about 30 mG around PNMR coil region, we will have about 100 Hz freq shift for ^{3}He Larmor freq.
- The usage of a Lock-in amplifier makes the frequency for obtained FID signal becomes difference between Larmor freq and Lock-in amplifier reference freq.
- From initial PNMR vs NMR calibration, noticed PNMR FID signal amp become higher when FID signal frequency become lower due to ^{3}He tipping angle change.
- Tried to use a linear model to correct amplitude for different FID signal frequency.

$$A_{corr} = A_0 * \left(1 + c\frac{f_{FID} - \Delta f}{\Delta f}\right)$$

Where A_0 is the fitted FID amp, f_{FID} is FID signal freq, Δf is the difference between pulse freq and reference freq. Constant c is the factor for signal amp change.

Note: for PNMR system set up, set the reference freq ~335 Hz below the pulse freq.

PNMR vs NMR Calibration Results

(Cell Briana: 08/26 180 deg with HB 18 deg, -5.6 GeV)

PNMR Time-stamp	PNMR amp (mV)	NMR Time-stamp	NMR PC Long (mV)	PNMR/NMR PC Long Ratio	Time between PNMR and NMR	Comments
20200826_095908	2795.09	20200826_100002	5.3259	524.811	1 min	Fit from 5ms to 10ms
20200826_152749	2528.69	20200826_152827	5.1297	492.951	1 min	
20200826_203527	2672.24	20200826_203609	5.1284	521.063	1 min	
20200827_003148	2608.09	20200826_003211	5.0648	514.940	1 min	

Number of Measurements	PNMR FID fitted freq (Hz)	vs. PC Long uncertainty (%)	PNMR/NMR PC Long Ratio Avg
1	207.246	2.214	513.441
2	252.345	-3.991	513.441
3	208.91	1.484	513.441
4	207.09	0.292	513.441
Avg freq (Hz)	218.898		

Condition pulse freq= 81.975 kHz, RF freq=81.69 kHz, t_pulse=1 ms, df=285 Hz

180deg_with_HB_VL_5.2A_VS_7.0A_conv_7V_oventemp_205C_PNMR_Calib

Holding Field: HL=0.0A, HS=-7.280A for phi=180.6deg, Field=25.6G

Fit PNMR FID from 5 ms to 11 ms after the end of trigger signal, at pick-up coil position

For PNMR/ NMR PC signal ratio

Number	PNMR FID fitted freq (Hz)	PNMR amp Corr (mV)	Freq Corr ratio	Average freq (Hz)	Freq away from pulse freq (Hz)	Freq Corr ratio uncertainty (%)	Freq Corr ratio average	PNMR Calib (%/mV)
1	207.246	2566.322	481.8569972	218.898	-77.754	0.918	477.475	0.01801
2	252.345	2441.770	476.0063178	218.898	-32.655	-0.308	477.475	Corr. Constant C
3	208.91	2458.208	479.3285366	218.898	-76.09	0.388	477.475	0.30
4	207.09	2394.199	472.7097335	218.898	-77.91	-0.998	477.475	

PNMR vs NMR Calibration Results

(Cell Tommy: 09/08 270 deg with HB 18 deg, -5.6 GeV)

PNMR Time-stamp	PNMR amp (mV)	NMR Time-stamp	NMR PC Tran (mV)	PNMR/NMR PC Tran Ratio	Time between PNMR and NMR	Comments
20200908_212618	1535.89	20200908_212654	7.2912	210.651	1 min	
20200909_021019	1542.59	20200909_021052	7.4882	206.004	1 min	
20200909_051148	1637.13	20200909_051222	7.4585	219.498	1 min	
20200909_104810	1595.57	20200909_104858	7.2469	220.173	1 min	

Number of Measurements	PNMR FID fitted freq (Hz)	vs. PC Tran uncertainty (%)	PNMR/NMR PC Tran Ratio Avg	Fitted T2 (msec)
1	531.823	-1.602	214.082	5.070
2	567.095	-3.773	214.082	4.989
3	521.703	2.530	214.082	5.001
4	495.767	2.846	214.082	5.125

Condition pulse freq= 82.935 kHz, RF freq=81.60 kHz, t_pulse=1 ms, df=335 Hz

270deg_with_HB_VL_4.8A_VS_6.6A_conv_7V_oventemp_205C_PNMR_Calib

Holding Field: HL=-7.392 A, HS=-0.239A for phi=268.2deg, Field=25.05G

Fit PNMR FID from 5 ms to 10 ms after the end of trigger signal, at pick-up coil position

For PNMR/ NMR PC signal ratio

Number	PNMR FID fitted freq (Hz)	PNMR amp Corr (mV)	Freq Corr ratio	Average freq (Hz)	Freq away from pulse freq (Hz)	Freq Corr ratio uncertainty (%)	Freq Corr ratio average	PNMR Calib (%/mV)
1	531.823	1987.082	272.5333805	529.097	196.823	-1.217	275.892	0.01827
2	567.095	2076.959	277.3654034	529.097	232.095	0.534	275.892	Corr. Constant C
3	521.703	2093.335	280.6639128	529.097	186.703	1.730	275.892	0.50
4	495.767	1978.428	273.0041359	529.097	160.767	-1.047	275.892	

PNMR vs NMR Calibration Results

(Cell Tommy: 09/20 0 deg with HB 13 deg, -2.1286 GeV)

PNMR Time-stamp	PNMR amp (mV)	NMR Time-stamp	NMR PC Long (mV)	PNMR/NMR PC Long Ratio	Time between PNMR and NMR	Comments
20200920_101857	1580.83	20200920_101917	5.8739	269.129	1 min	
20200920_164215	765.511	20200920_164333	3.1703	241.460	1 min	
20200920_222208	1049.1	20200920_222316	3.9204	267.601	1 min	
20200921_025635	1209.33	20200921_025755	4.4207	273.560	1 min	
20200921_070626	1234.33	20200921_070705	4.8564	254.168	1 min	

Number of Measurements	PNMR FID fitted freq (Hz)	vs. PC Long uncertainty (%)	PNMR/NMR PC Long Ratio Avg	Fitted T2 (msec)
1	559.861	3.042	261.184	6.673
2	589.397	-7.552	261.184	7.036
3	550.253	2.457	261.184	6.982
4	553.069	4.739	261.184	6.865
5	572.674	-2.686	261.184	7.198

Condition pulse freq= 81.465 kHz, RF freq=81.13 kHz, t_pulse=1 ms, df=335 Hz

0deg_with_HB_VL_0.0A_VS_0.0A_conv_7V_oventemp_208C_PNMR_Calib

Holding Field: HL=0.0 A, HS=7.230 A for phi=358.86deg, Field=25.14G

Fit PNMR FID from 5 ms to 11 ms after the end of trigger signal, at pick-up coil position

For PNMR/ NMR PC signal ratio

Number	PNMR FID fitted freq (Hz)	PNMR amp Corr (mV)	Freq Corr ratio	Average freq (Hz)	Freq away from pulse freq (Hz)	Freq Corr ratio uncertainty (%)	Freq Corr ratio average	PNMR Calib (%/mV)
1	559.861	3596.912	612.358	565.051	224.861	1.883	601.039	0.01271
2	589.397	1870.028	589.851	565.051	254.397	-1.861	601.039	Corr. Constant C
3	550.253	2329.881	594.298	565.051	215.253	-1.122	601.039	1.90
4	553.069	2705.041	611.902	565.051	218.069	1.807	601.039	
5	572.674	2898.209	596.786	565.051	237.674	-0.708	601.039	

PNMR vs NMR Calibration Table

Cell Briana from 08/23 to 08/31:

SHMS angle (deg)	HB momentum (GeV)	Field Direction (deg)	Oven Temp (deg C)	Laser Power (W)	Corr. Coil VL (A)	Corr. Coil VS (A)	Convection PS (V)	Target Position	Calibration Constant (%/mV)	Pulse Freq (kHz)	Reference Freq (kHz)	FID fitting range (msec)
18	5.6	180	205	80	5.2	7.0	7	Pick-up Coils	0.01801	81.975	81.69	5 ms to 11 ms
18	5.6	270	205	80	4.8	6.6	7	Pick-up Coils	0.02489	82.935	82.65	5 ms to 11 ms
11	7.5	180	205	80	4.7	6.9	7	Pick-up Coils	0.04260*	82.265	81.98	5 ms to 11 ms
14.5	6.4	180	205	80	4.9	7.0	7	Pick-up Coils	0.03259*	82.045	81.76	5 ms to 11 ms

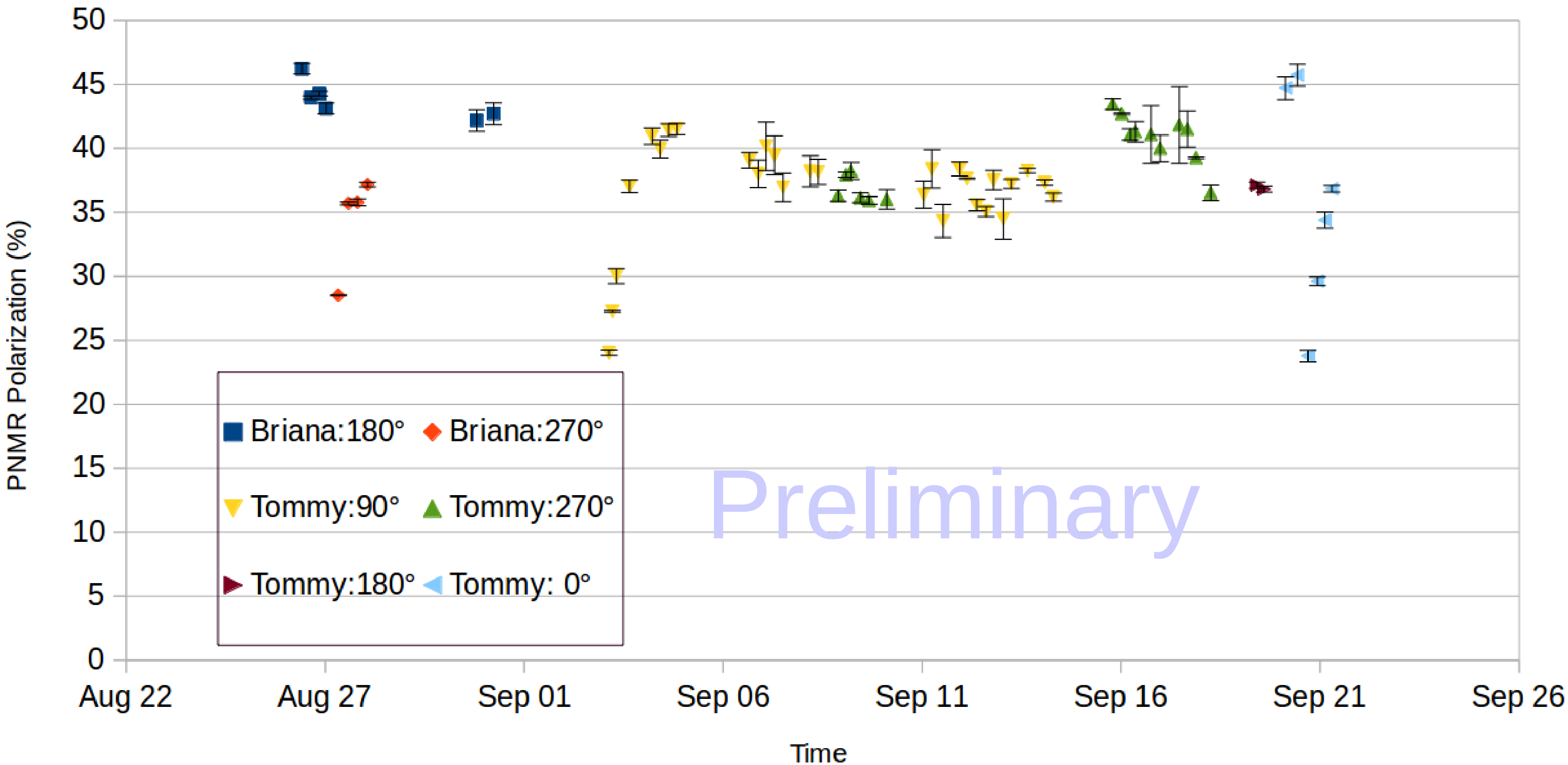
Cell Tommy from 09/03 to 09/21:

SHMS angle (deg)	HB momentum (GeV)	Field Direction (deg)	Oven Temp (deg C)	Laser Power (W)	Corr. Coil VL (A)	Corr. Coil VS (A)	Convection PS (V)	Target Position	Calibration Constant (%/mV)	Pulse Freq (kHz)	Reference Freq (kHz)	FID fitting range (msec)
11	7.5	90	200	80	4.0	6.0	7	Pick-up Coils	0.01423	82.565	82.23	5 ms to 11 ms
18	5.6	90	205	80	4.4	6.0	7	Pick-up Coils	0.01451	82.385	81.98	5 ms to 11 ms
18	5.6	270	205	80	4.8	6.6	7	Pick-up Coils	0.01827	82.935	82.6	5 ms to 10 ms
11	7.5	270	208	80	4.1	6.0	7	Pick-up Coils	0.01986*	82.265	81.93	5 ms to 11 ms
8.5	2.1286	180	208	80	3.6	4.5	7	Pick-up Coils	0.02056*	83.595	83.26	3 ms to 7 ms
8.5	2.1286	0	208	80	0.0	0.0	7	Pick-up Coils	0.01798*	81.465	81.130	5 ms to 11 ms
13	2.1286	0	208	80	0.0	0.0	7	Pick-up Coils	0.01271	81.465	81.130	5 ms to 11 ms
18	5.6	0	208	80	2.8	4.1	7	Pick-up Coils	0.01877	82.795	82.46	5 ms to 11 ms

Note: “*” means only have one or two sets of PNMR vs. NMR measurement, maybe not enough to determine calibration constant.

PNMR Online Analysis

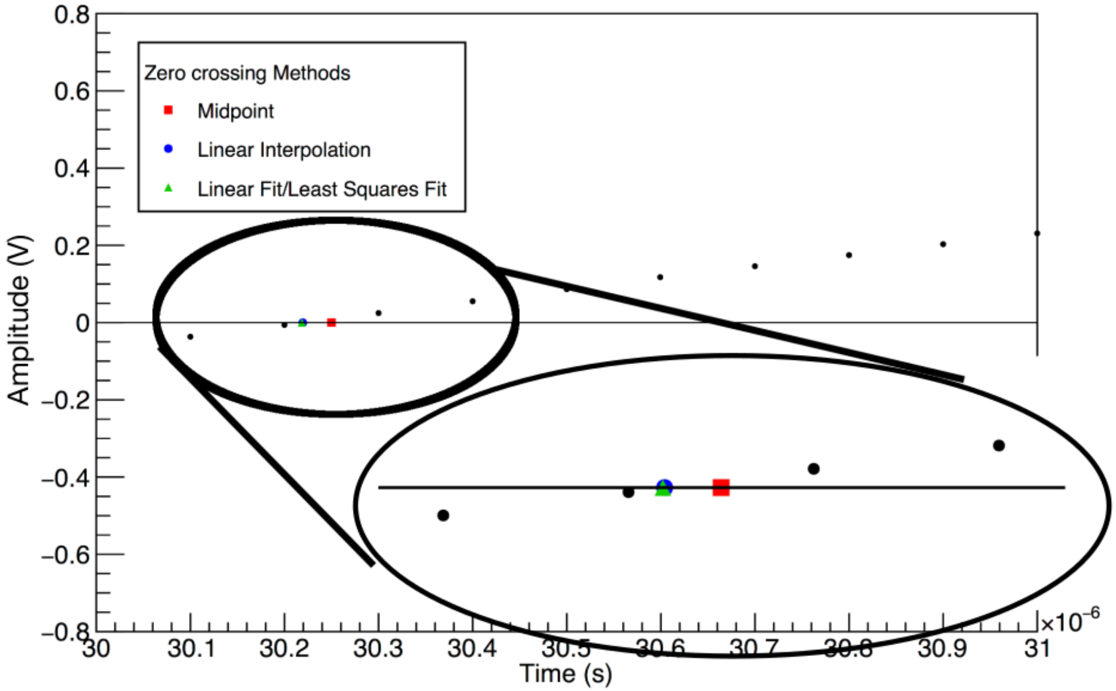
(for d_2^n experiment E12-06-121)



- PNMR was performed at transfer tube which was calibrated by AFP-NMR at pumping chamber. For most of the measurements, polarization from PNMR agrees with NMR within ±2%.
- However, due to the limitation of holding field power supply, the drift of holding field magnitude over time changed PNMR signal amplitude and introduce additional uncertainty.
- Still need to do detailed analysis to characterize this effect on PNMR signal and determine the systemic uncertainty for PNMR.

Zero-Crossing Algorithm

(with "Umass-ZC" program)



- Midpoint: Take the average time of samples before and after the zero crossing
- Linear interpolation: Compute the zero crossing time based on linearly-interpolating across the zero crossing region
- Least squares: Perform a least-squares fit to the samples in the immediate vicinity (~1/8 of a period) of a given zero crossing. This tends to be the best result (that is, more accurate).

Count number of zero crossings of the PNMR signal between given start and stop times to determine FID freq:

$$f = \frac{N_{zc} - 1}{2\Delta t}$$

Where N_{zc} is number of zero crossings and $\Delta t = t_{end} - t_{start}$

phase fit:

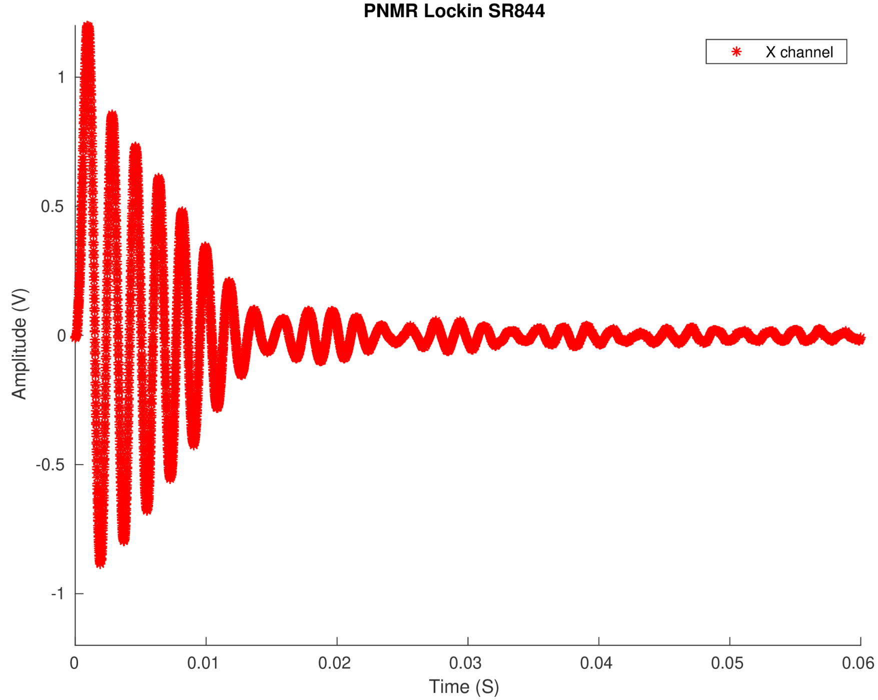
- plot determined zero crossings against time of crossing. Then the slope of line gives frequency at t=0 msec.

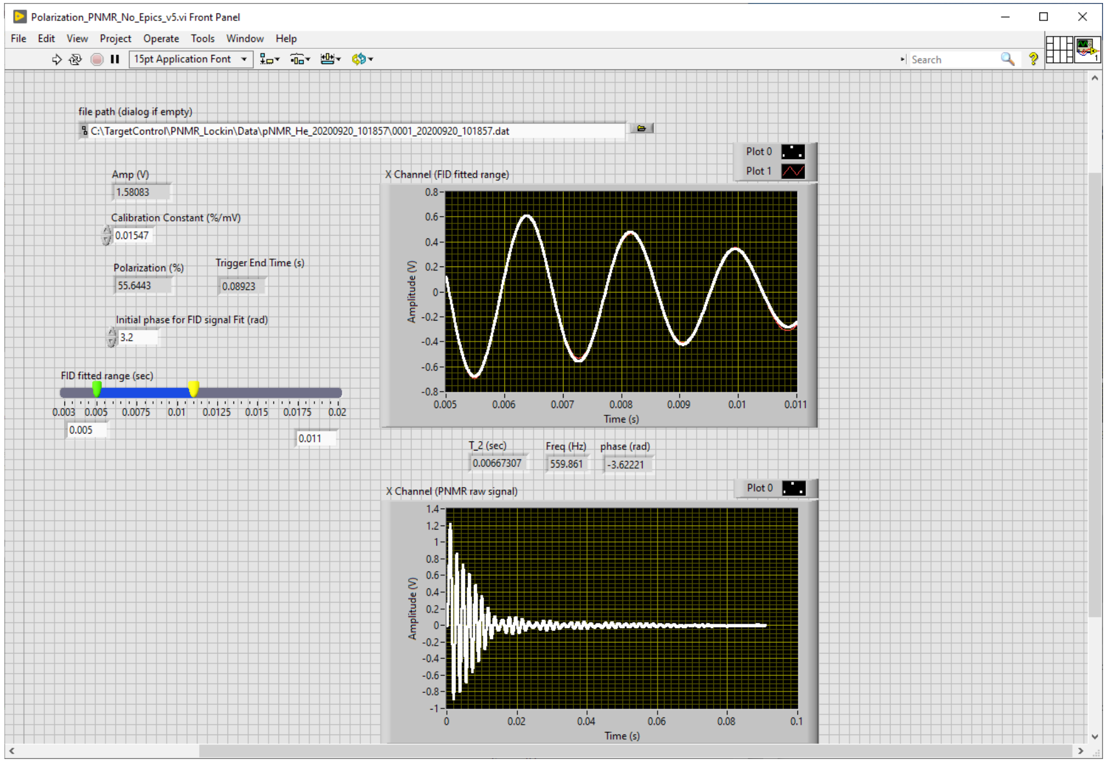
Determine PNMR freq:

- Using Least-squares (with phase fit) to determine the PNMR freq

PNMR FID Signal Freq

(on Cell Briana 09/20)





- File_name:pNMR_He_20200920_101857
- Holding field at 0 deg with SHMS HB at 13 deg, -2.1286 GeV
- Correction coils: VL=0.0A, VS=0.0A; Pulse freq=81.465 kHz, Ref freq=81.13 kHz
- FID Freq=558.228 Hz (from UMass-ZC)

Goal: Help characterize drift of holding field magnitude. Since PNMR FID signal freq is Larmor freq of ^{3}He at time of measurement.

PNMR FID Frequency Results

(with UMass-ZC)

SHMS angle (deg)	HB momentum (GeV)	Field Direction (deg)	Oven Temp (deg C)	Cell Name	Corr. Coil VL (A)	Corr. Coil VS (A)	Convection PS (V)	PNMR Freq from UMass-ZC (Hz)	Pulse Freq (kHz)	Reference Freq (kHz)	File Name
18	5.6	180	205	Briana	5.2	7.0	7	217.815	81.975	81.69	pNMR_He_20200826_095908
18	5.6	270	205	Briana	4.8	6.6	7	215.663	82.935	82.65	pNMR_He_20200827_080148
11	7.5	180	205	Briana	4.7	6.9	7	324.976	82.265	81.98	pNMR_He_20200830_192539
14.5	6.4	180	205	Briana	4.9	7.0	7	159.375	82.045	81.76	pNMR_He_20200831_053435
11	7.5	90	200	Tommy	4.0	6.0	7	394.659	82.565	82.23	pNMR_He_20200903_031203
18	5.6	90	205	Tommy	4.4	6.0	7	364.903	82.385	81.98	pNMR_He_20200904_050907
18	5.6	270	205	Tommy	4.8	6.6	7	528.725	82.935	82.6	pNMR_He_20200908_212618
18	5.6	90	205	Tommy	4.4	6.0	7	300.526	82.385	81.98	pNMR_He_20200912_090252
18	5.6	90	205	Tommy	4.4	6.0	7	413.117	82.385	81.98	pNMR_He_20200913_005603
11	7.5	90	205	Tommy	4.0	6.0	7	426.602	82.565	82.23	pNMR_He_20200913_153458
11	7.5	270	208	Tommy	4.1	6.0	7	398.183	82.265	81.93	pNMR_He_20200915_185950
18	5.6	270	208	Tommy	4.8	6.6	7	519.134	82.935	82.6	pNMR_He_20200916_180420
8.5	2.1286	180	208	Tommy	3.6	4.5	7	294.188	83.595	83.26	pNMR_He_20200919_100205
8.5	2.1286	0	208	Tommy	0.0	0.0	7	421.667	81.465	81.13	pNMR_He_20200920_031201
13	2.1286	0	208	Tommy	0.0	0.0	7	558.228	81.465	81.13	pNMR_He_20200920_101857

PNMR FID Amplitude Analysis

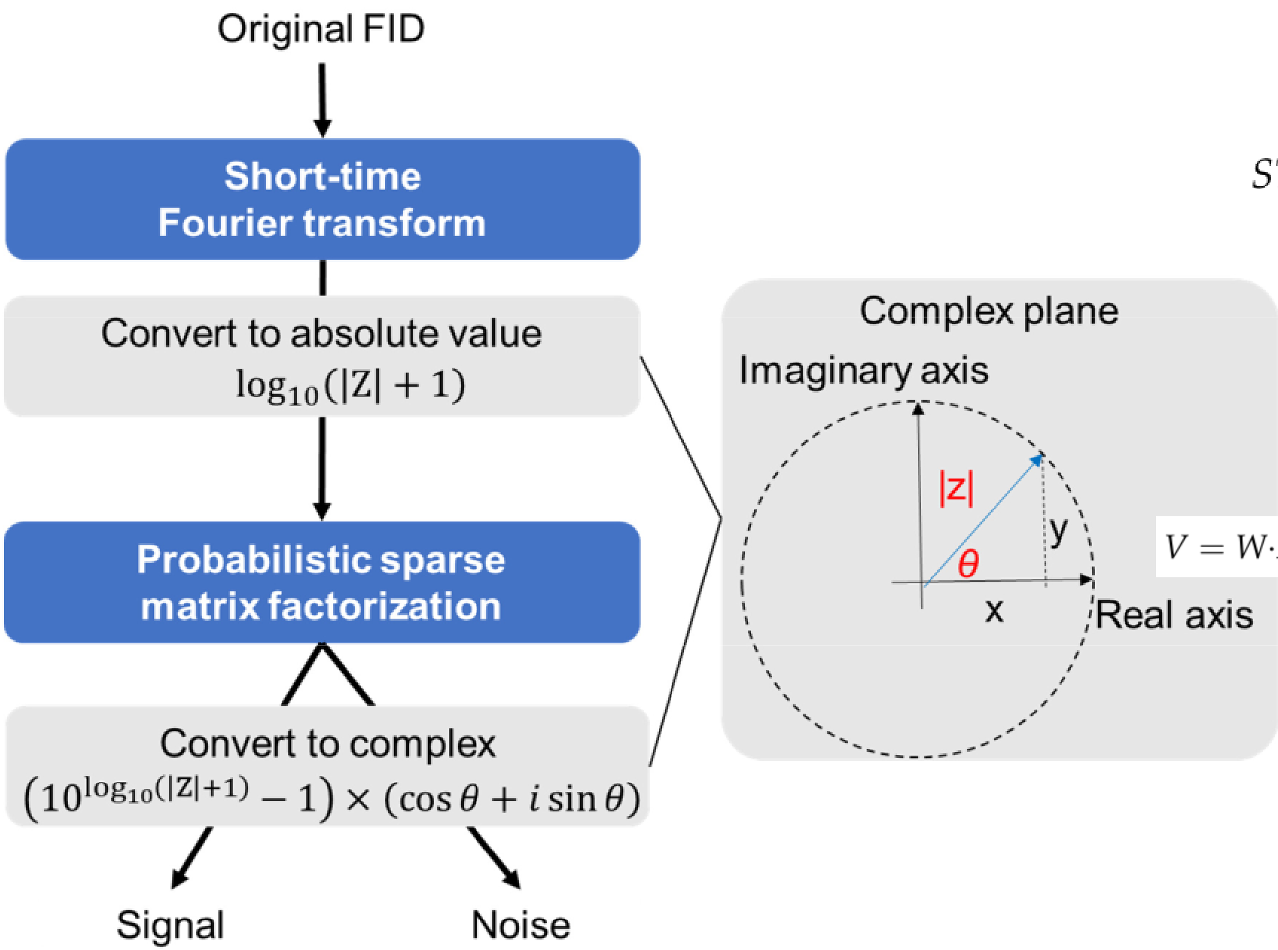
(Signal Deconvolution by Probabilistic Sparse Matrix Factorization)

- For PNMR FID raw signal, it contains a signal component which decays exponentially with time, while the noise component is a random or flat value.
- Then after applying short time Fourier transform (STFT) to the raw signal, we could perform probabilistic sparse matrix factorization (PSMF) to separate the noise from signal.
- Finally, do inverse Fourier transform (inverse STFT) of the signal component to obtain the deconvoluted signal.

Goal: separate noise component from signal component; determine FID amp for signal component only to reduce uncertainty.

- Signal Deconvolution and Noise Factor Analysis Based on a Combination of Time–Frequency Analysis and Probabilistic Sparse Matrix Factorization (by Shunji Yamada etal)

Flow Chart of Signal Deconvolution Method



$$S(t) = S_{signal}(t) + S_{noise}(t)$$

$$STFT_S(\tau,\omega) = \int_{-\infty}^{\infty} S(t)g(t-\tau)\exp(-i\omega t)dt$$

$$Re = \gamma\cos\omega\tau,$$

$$Im = \gamma\sin\omega\tau\,.$$

$$|z| = \sqrt{Re^2 + Im^2}.$$

$$V = \log_{10}(|z|+1)$$

$$V = W\cdot H + residuals = W_{signal}\cdot H_{signal} + W_{noise}\cdot H_{noise} + residuals$$

$$S_{inv}(t) = \int_{-\infty}^{\infty}\sum_{m=-\infty}^{\infty} V(\omega)\exp(i\omega t)d\omega.$$

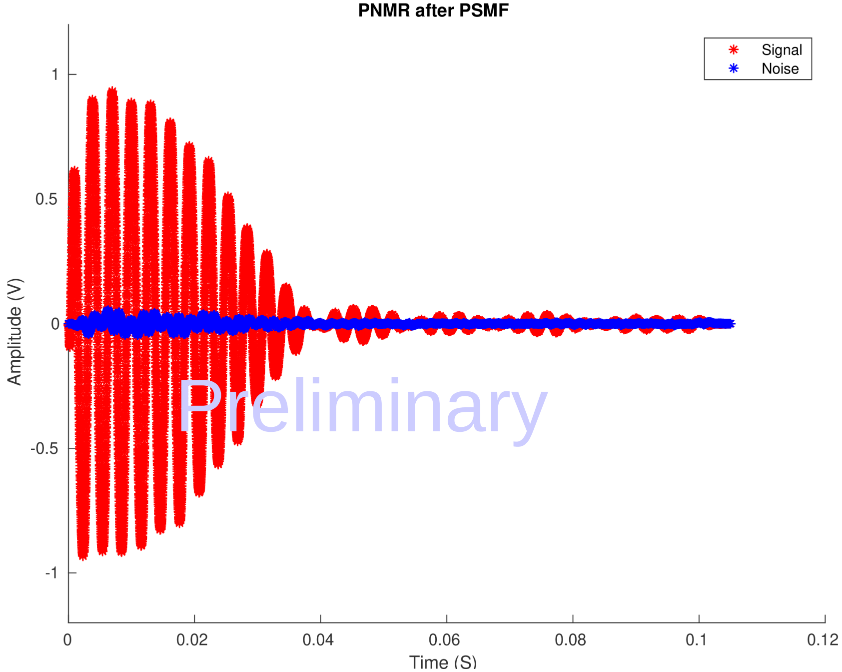
$$SNR = \frac{Signal\ \ peak\ \ intensity}{Noise\ \ value}.$$

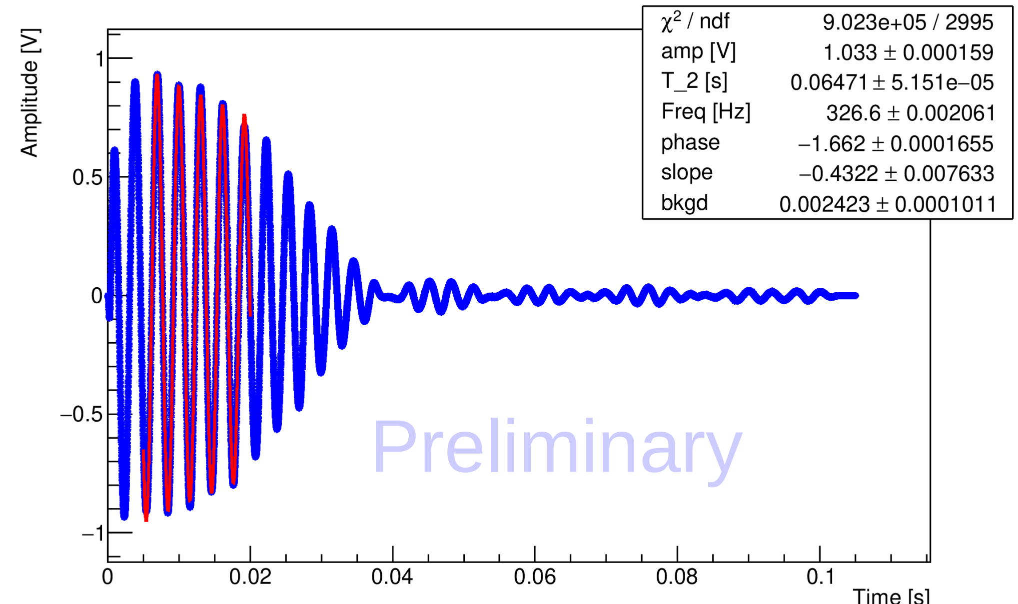
$$Noise\ \ value = \sqrt{\frac{\sum_{i=1}^{N}(S(t)_i - S(t)_m)^2}{N-1}},$$

- Signal Deconvolution and Noise Factor Analysis Based on a Combination of Time–Frequency Analysis and Probabilistic Sparse Matrix Factorization (by Shunji Yamada etal)

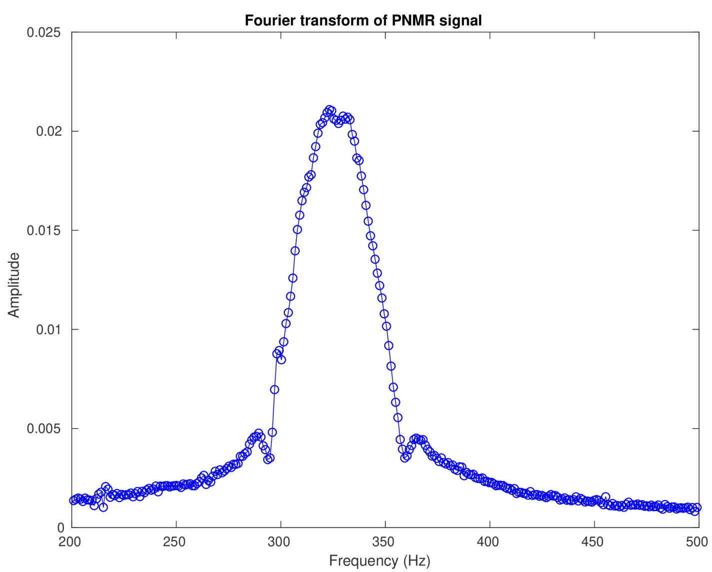
PNMR FID Amplitude Analysis

(Signal Deconvolution by Probabilistic Sparse Matrix Factorization)





$$S(t) = FID(t) = A_0 \cos(\omega t + \phi_0) e^{-t/T_2} + a * t + b$$



- Fitted FID amp: A_0=1.033 V (PNMR signal component; t=5 ms to 20 ms)

Note:
- Take raw PNMR signal up to 1.0 sec; Should extract noise after signal decays away.
- Could apply a FFT cut on low freq to improve the PNMR signal.

PNMR Loss Study During the Experiment

(on Cell Austin and Cell Tommy)

PNMR Loss study:

SHMS angle (deg)	HB momentum (GeV)	Field Direction (deg)	Oven Temp (deg C)	Laser Power (W)	Corr. Coil VL (A)	Corr. Coil VS (A)	Convection PS (V)	Target Position	PNMR Loss per Measurement (%)	Pulse Freq (kHz)	Reference Freq (kHz)	Cell Name
11	7.5	180	210	80	4.7	6.9	9	Pick-up Coils	1.03*	80.57	80.28	Austin
8.5	2.1286	0	208	80	0.0	0.0	7	Pick-up Coils	3.90*	81.465	81.13	Tommy
8.5	2.1286	180	208	80	3.6	4.5	7	Pick-up Coils	2.93*	83.595	83.26	Tommy
11	7.5	270	208	80	4.1	6.0	7	Pick-up Coils	4.25*	82.265	81.93	Tommy
11	7.5	90	208	80	4.0	6.0	7	Pick-up Coils	4.13*	82.565	82.23	Tommy
18	5.6	90	208	80	4.4	6.0	7	Pick-up Coils	3.53*	82.385	81.93	Tommy

Note: “*” means that PNMR loss is not finalized yet.

Goal: Help determine the in beam ^{3}He polarization after PNMR and NMR measurements.

1) Since PNMR loss per measurement depends on the PNMR ^{3}He spin tip angle, the holding field magnitude drift will affect the PNMR loss.
2) PNMR loss study during the experiment is not ideal for determine PNMR loss.
3) Need to do additional post experiment PNMR loss study at EEL target lab to finalize the PNMR loss per measurement during the experiment.

Post Experiment PNMR Loss Study

(plan at EEL Target Lab)

PNMR Loss Measurement: during Hot spin down with convection

a) NMR measurement at 0 min: $P_0=\beta^2 P_a$

b) 10 PNMR measurements take within 1 sec at 1 min: (for T2 ~7 msec)

c) NMR measurement at 30 min: $P(t)=P_c$

d) NMR measurement at 60 min: P_d

For τ be Hot spin down time constant and known $\beta=1-AFP_{Loss}$ (NMR AFP loss per sweep)

Then from c), d) get P_0' after all PNMR measurement: (Δt=0.5 hr)

$$\boxed{P_0'=P_c e^{-\Delta t/\tau}}$$

$$\boxed{P_d=P_c \beta^2 e^{-\Delta t/\tau}}$$

$$\longrightarrow \boxed{P_0'=\frac{P_c^{\,2}\beta^2}{P_d}}$$

Polarization time evolution:

$$\boxed{P(t)=P_0 e^{-t/\tau}}$$

Using a), c) to found out PNMR ^{3}He spin tip angle: (n=10)

$$\boxed{P_0'=(1-\cos(\theta_{tip}))^n * P_0}$$

Thus PNMR loss per measurement is:

$$\boxed{\alpha_{loss}=1-\cos(\theta_{tip})=\left(\frac{P_0'}{P_0}\right)^{1/n}}$$

Future Work

- For PNMR analysis, still in the process of offline detailed analysis with main effort focused on obtain PNMR FID amplitude and determine PNMR systemic uncertainty.
- In addition, post experiment PNMR loss tests are planned to perform in EEL target lab to help determine the PNMR loss per measurement during the experiment.

Backup Slides

PNMR Loss Study During the Experiment

(On Cell Austin and Cell Tommy)

PNMR Loss Measurement:

a) NMR measurement at 0 min: $P_0=\beta^2 P_a$

b) 5 PNMR measurements take every min: (from 1 min till 5 min)

c) NMR measurement at 15 min: $P(t)=P_c$

d) NMR measurement at 30 min: P_d

For τ be Hot spin up time constant and $\beta=1-AFP_{Loss}$ (NMR AFP loss per sweep)

Then from c), d) get P_{max}: (t=0.25 hr)

$$P_{max}=\frac{P_d-\beta^2 P_c e^{-t/\tau}}{1-e^{-t/\tau}}$$

Polarization time evolution:

$$P(t)=P_0+(P_{max}-P_0)(1-e^{-t/\tau})$$

Using a), c) to found out PNMR loss. (n=5)

$$P_0'=\frac{P(t)-P_{max}(1-e^{-t/\tau})}{e^{-t/\tau}}$$

$$P_0'=(1-\alpha_{loss})^n * P_0$$

Thus PNMR loss is:

$$\alpha_{loss}=1-(P_0'/P_0)^{1/n}$$

PNMR System Setup

(for PNMR Loss Study at EEL target Lab)

1) Modify the current Labview program for PNMR measurement to be able to perform 10 PNMR measurements within 1 sec. (send 10 PNMR RF pulses with t_{pulse}=1 msec with dt=100 msec)

2) Use Agilent power supply with current control mode to provide similar holding field coil current level during d_2^n experiment. (Holding field magnitude will not be exactly at 25.0 G)

3) Use horizontal correction coils to add holding field gradient up to ~30 mG/cm at PNMR coil region.

4) Establish similar convection condition (for cell Austin convection heater at 9 V; for cell Tommy convection heater at 7 V)

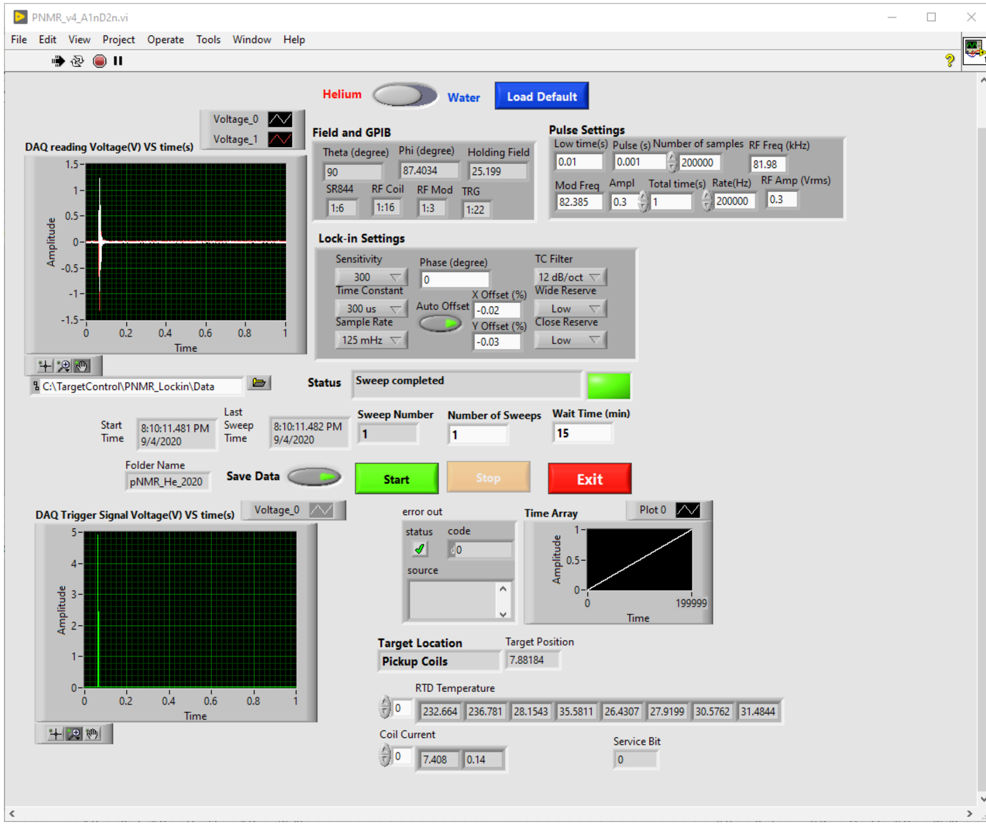
5) Test with different PNMR RF pulse freq (different df away from ^{3}He Larmor freq) to determine the effect of df on ^{3}He spin tipping angle θ_{tip}.

Note:

With established relation between df and θ_{tip}, we could determine PNMR loss for all the PNMR measurements during d_2^n experiment. (with known Fitted PNMR FID freq)

Typical PNMR FID Signal

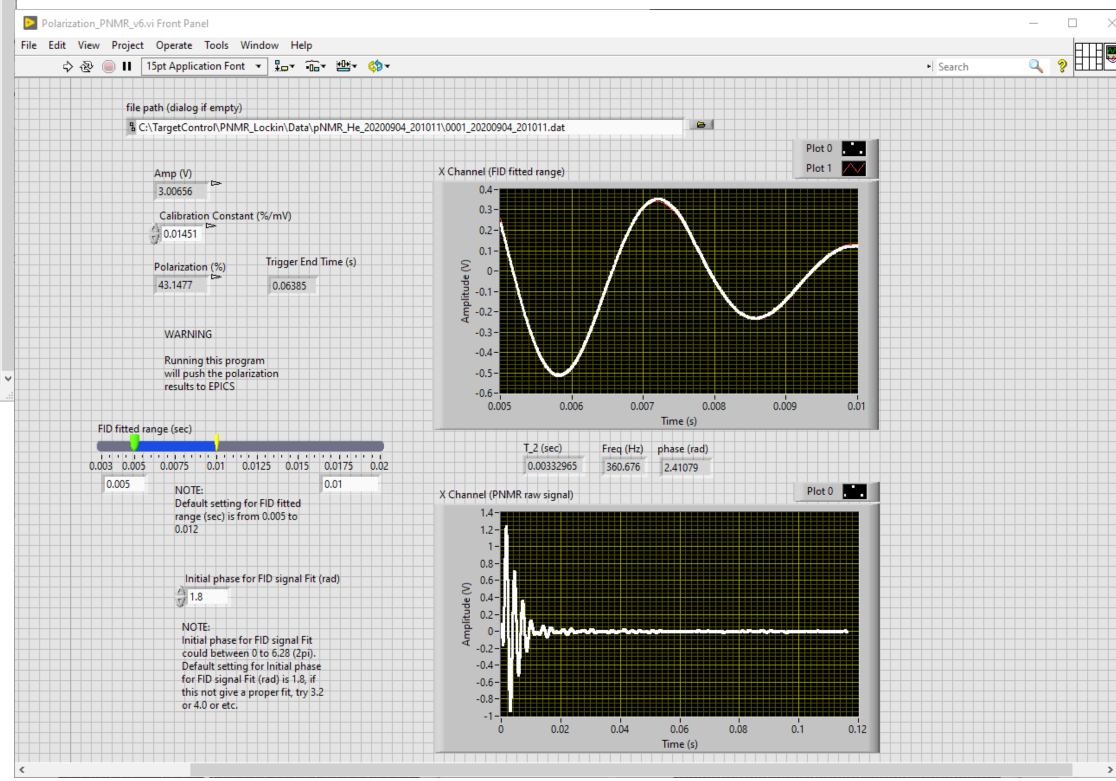
(with PNMR coil on Cell Tommy)



- Current fit for the signal by the FID fitting function to obtain PNMR amplitude A_0 .

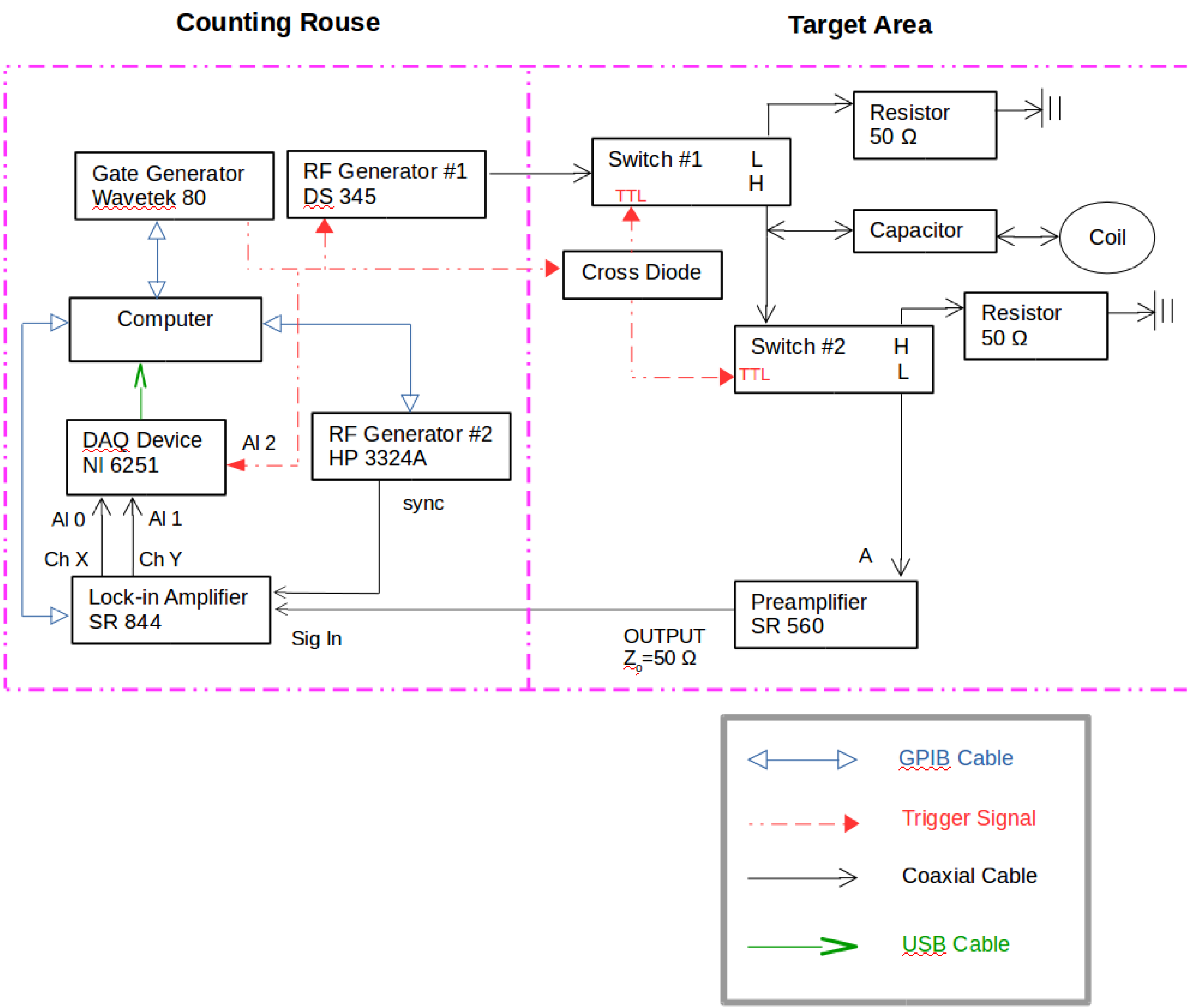
$$S(t)=FID(t)=A_0\cos(\omega t+\phi_0)e^{-t/T_2}+a*t+b$$

- Obtain PNMR_amp/NMR_amp ratio in order to calibrate PNMR with NMR.



- Typical PNMR signal and signal fit
- Condition: pulse freq= 82.385 kHz, RF freq=81.98 kHz, t_pulse=1 ms, df=405 Hz
- Target spin 90deg with HB on for 18 deg, -5.6 GeV
- VL=4.4 A, VS=6.0 A with convection at 7V

PNMR with Lockin SR844 and DAQ Setup

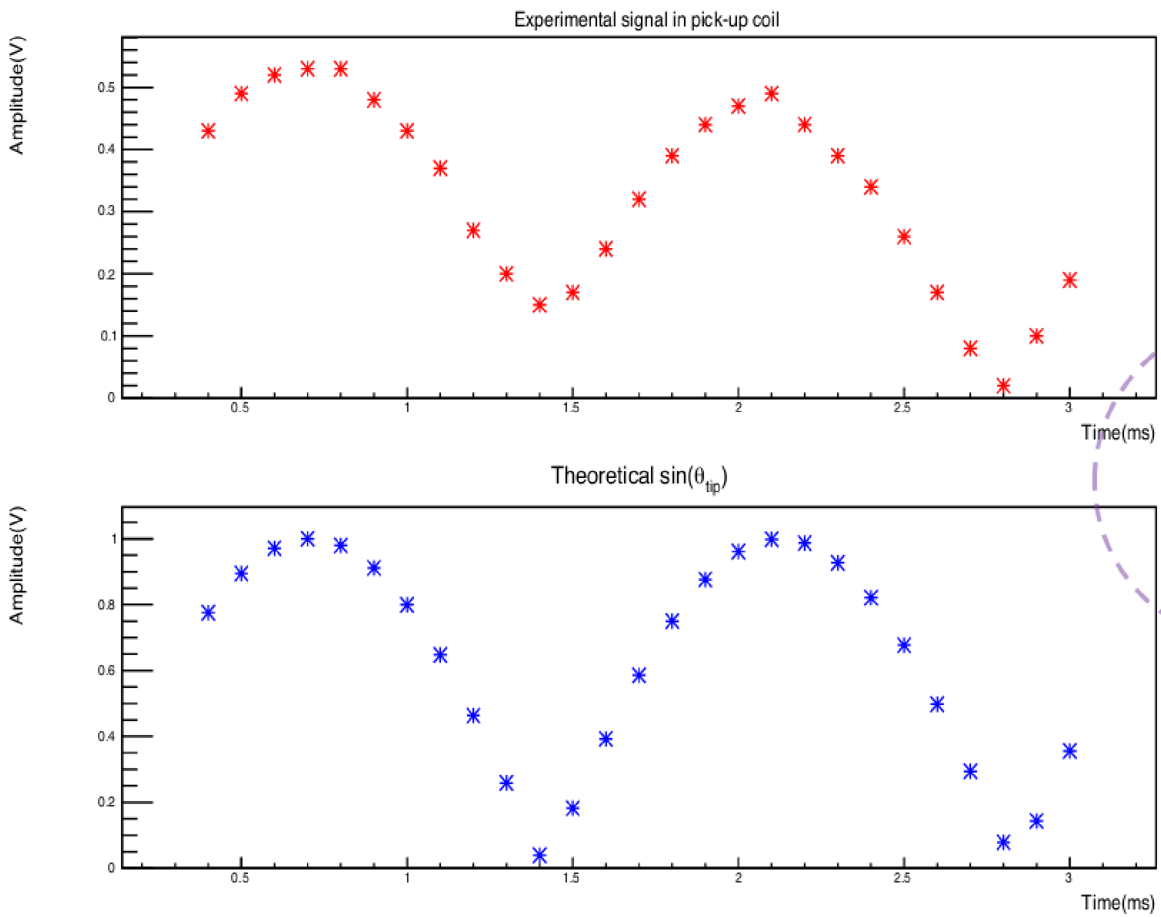


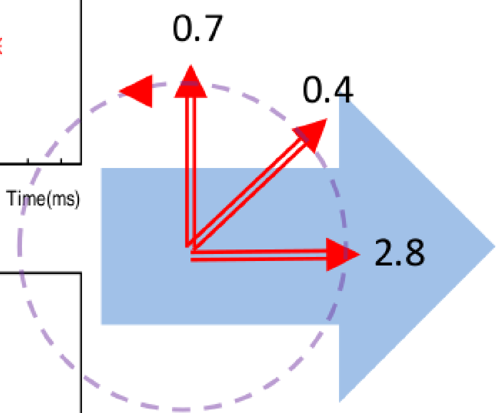
- Keep Holding filed at 25G along z-direction (along beam direction) by Helmholtz coil.
- For Preamplifier the bandpass is 10 kHz to 100 kHz; the preamplifier has gain of 20 times.
- The input pulse sine wave signal from DS 345 has f_{in}=81.085 kHz, V_{rms}=0.3 V with t_{pulse}=1.0ms; while the reference signal for Lockin is from the sync of HP3324A with f_R=80.8 kHz.
- RF switches: ZYSWA-20-50DR controlled by TTL low/ high signal. If TTL signal is high, function generator will send the input pulse to the PNMR coil. When the TTL is low, FID signal from the PNMR coil will pass the second RF switch, then go through the rest setup.

^{3}He Tipping Angle

(From Nguyen Ton's presentation 05/23/2016)

Red: experiment, Blue: theory





Conclusion: for this coil, 90^o pulse is at t_{pulse} ~ 0.7 ms. 360^o pulse at t_{pulse} = 2.8 ms.

Note: Map of t_{pulse} from 0.4 msec to 3.0 msec with step 0.1 msec.

$$\theta_{tip} = \frac{1}{2} \gamma H_1 t_{pulse}$$