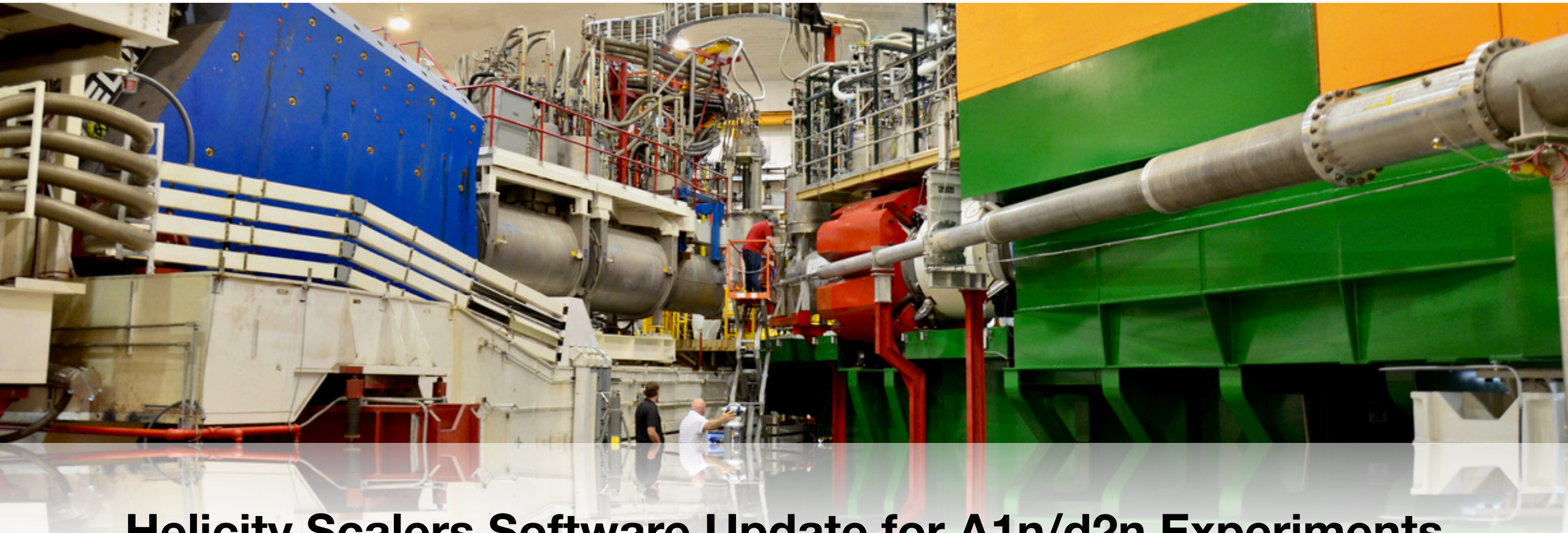


Helicity Scalers Software Update for A1n/d2n Experiments and Future Hall C Parity Experiments

Hall C Virtual Collaboration Meeting
January 28, 2021

Carlos Yero

OUTLINE

1. **How is polarized beam produced at JLab ?**
   Explain how beam is polarized and arrives at Hall C

2. **How Hall C Scalers register the beam helicity information ?**
   Explain how the hardware scalers get triggered

3. **Why is helicity scaler information needed?**
   Give reasons why helicity scaler information is needed for the A1n/d2n experiments and in general parity experiments

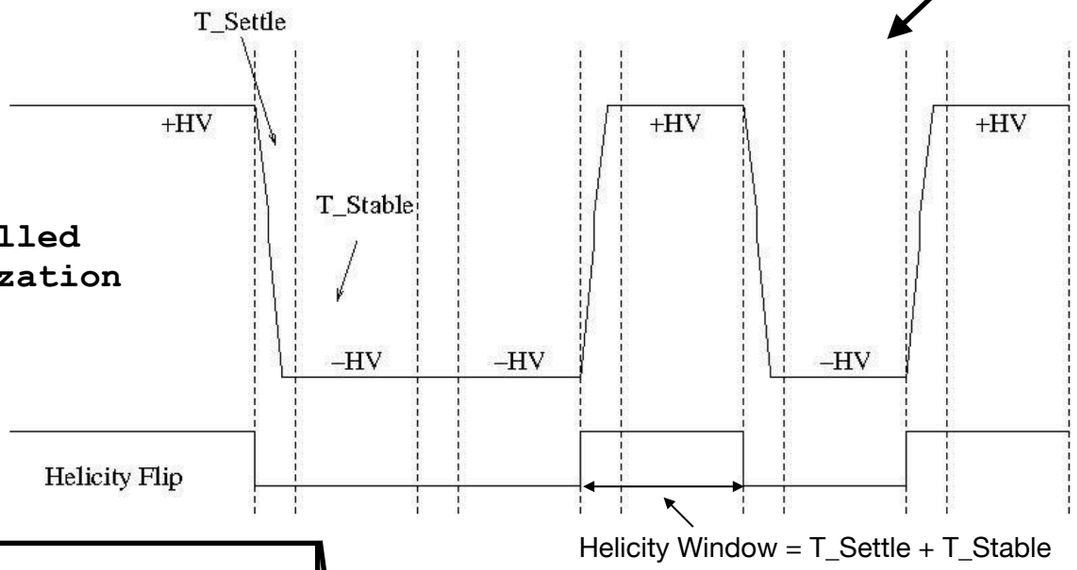
4. **Helicity Scalers Software Updates to** `HCANA` **and** `hallc_replay`
   Summarize the additions/updates made to the Hall C analysis software on helicity scalers

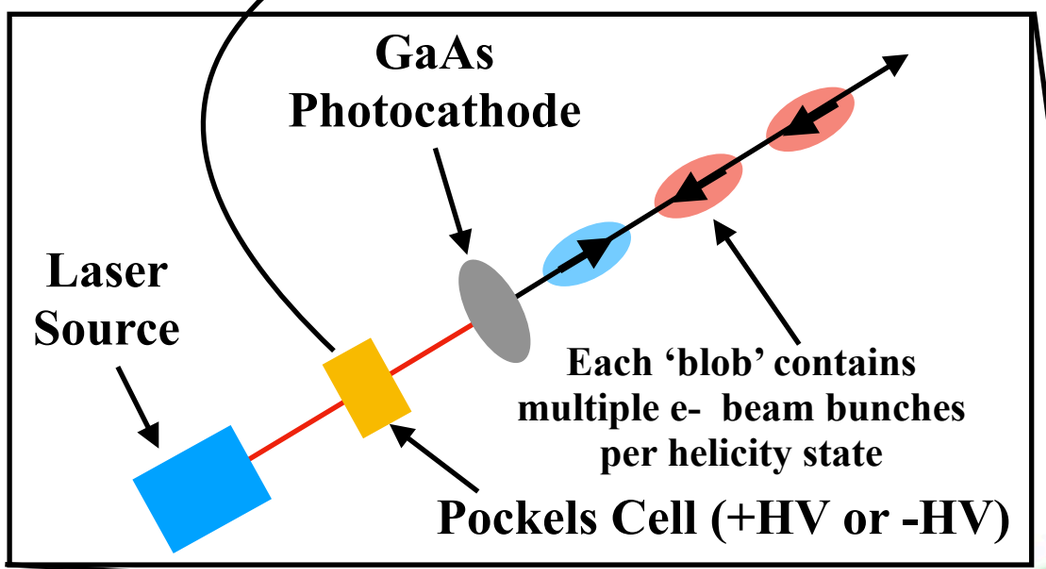
5. **A Brief Note on the Helicity Data Class,** `THcHelicity.cxx(.h)`
   Briefly mention how helicity states is determined for data events (physics triggers)

1. How is polarized beam produced at JLab ?

Source: https://wiki.jlab.org/ciswiki/images/3/32/Helicity_Board_UserGuide.pdf

- Pockels cells are voltage-controlled wave plates used to alter polarization of light.





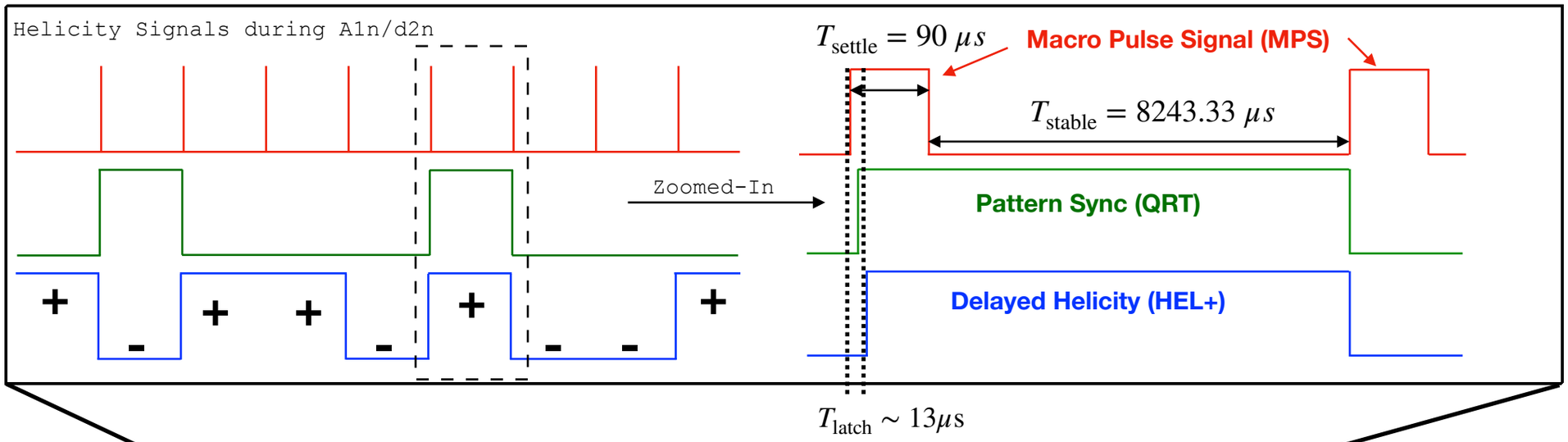
Negative(-) Helicity

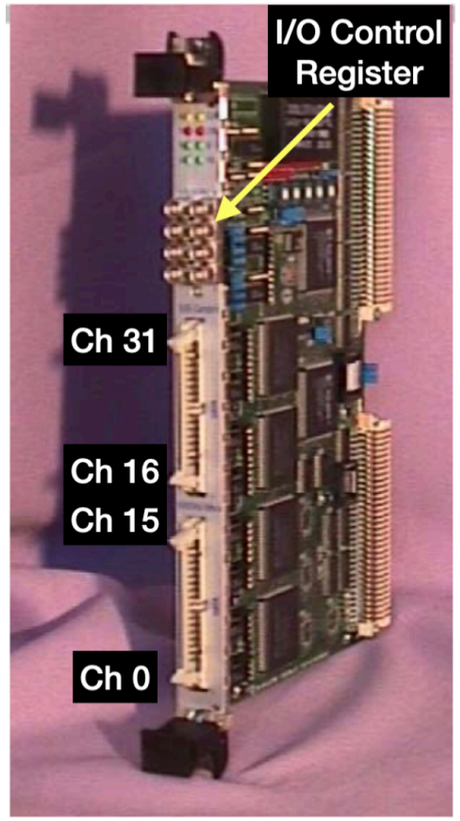
Positive(+) Helicity

- 499 (or 249.5) MHz Laser per Hall shines GaAs to generate 499 (or 249.5) MHz e- beam bunches
- Pockels Cell +/-HV flip reverses laser (photons) polarization and hence, the electron bunch helicity state
- During +/- HV flip, there is a settle time where the helicity is undetermined
- Hall C A1n/d2n configuration:

1. Pockels cell HV flip rate ~ 120 Hz
2. Quartet helicity pattern (+ - - + or - + + -)
3. Helicity reporting delayed by 8 Windows (2 quartets)

2. How Hall C Scalers register the beam helicity information ?





Hall C Moller Polarimeter DAQ
(in Hall C Counting Room)

Helicity Control Board (Injector)

Ch 31

HMS/SHMS pre-triggers [1-6]

Ch 16

Ch 15

BCMs Unser 1MHz clock

Ch 0

Control Register

DATA Register

Triggered by T_{settle} signal

FIFO

"First In First Out"

Memory buffer where counts are stored

Vetoed by T_{settle} signal

Data registers count signals ONLY in the T_{stable} part of the helicity window

SIS 3801 Scaler (side view)
(in Hall C Counting Room)

"FIFO acts as a ringbuffer to store helicity information"

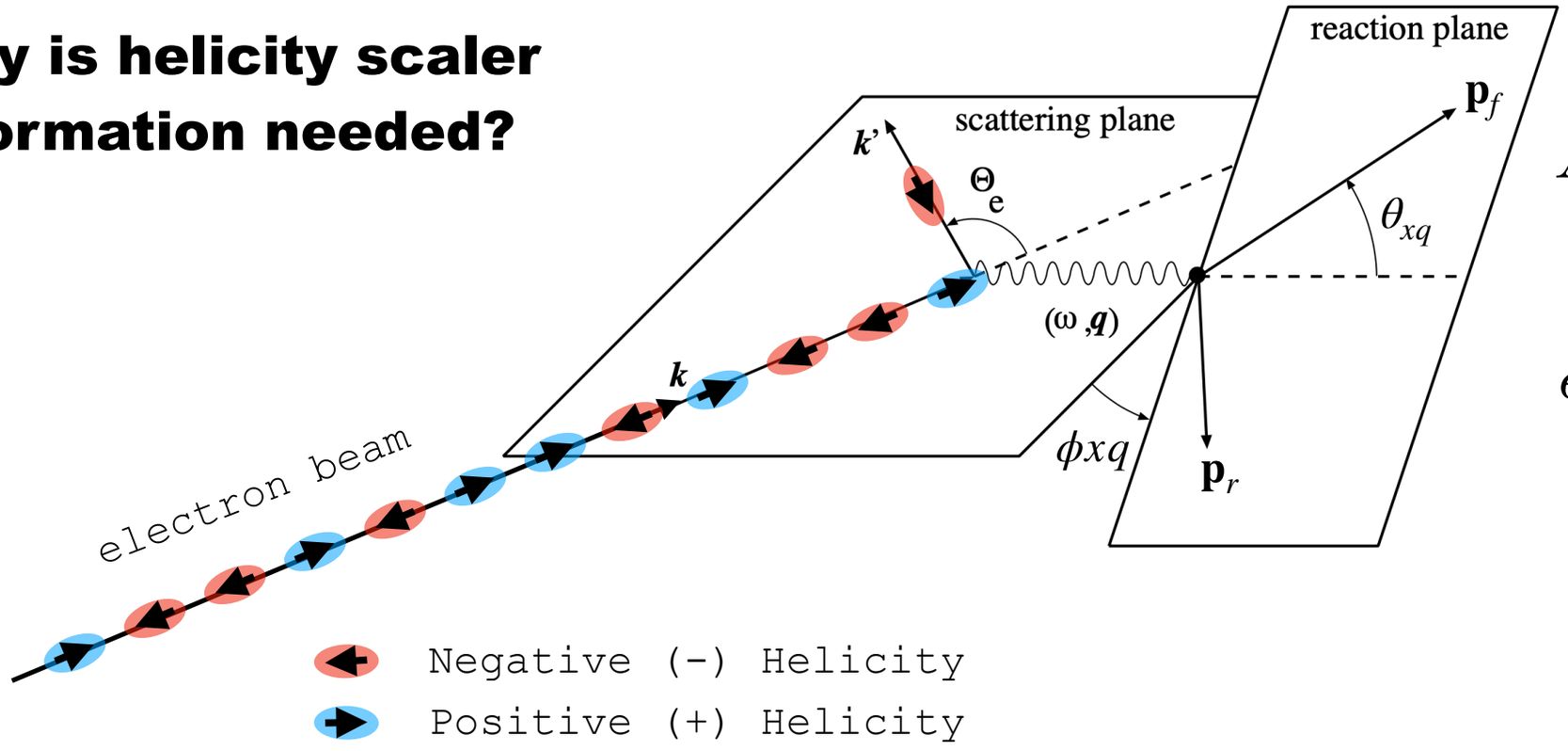
Helicity information written to raw .dat files to be saved in disk

$$f_{\text{HelicityBoard}} = \frac{1}{T_{\text{settle}} + T_{\text{stable}}}$$ (~120 Hz for A1n/d2n)

Reference (Chao Gu): Helicity Decoder for E08-027

Reference (Pengjia Zhu): Beam Charge Measurements for the g2p/GEp Experiments

3. Why is helicity scaler information needed?



$$A = \frac{N^+/\epsilon_i^+ - N^-/\epsilon_i^-}{N^+/\epsilon_i^+ + N^-/\epsilon_i^-}$$

$$\epsilon_i^{\pm} = Q_{\rm tot}^{\pm}, \epsilon_{\rm trk}^{\pm}, \epsilon_{\rm LT}^{\pm}, \text{etc.}$$

1. Check/Verify that helicity-correlated beam charge asymmetries from the injector are negligible for A1n/d2n experiments

2. Normalize the total number of helicity-gated physics triggers by the +/- helicity charge as well any inefficiency calculation that requires the +/- helicity states scaler counts (i.e., live time)

3. Apply a BCM current cut to select and analyze scalers and physics trigger events for beam-on conditions (usually > 5 uA cut is applied)

NOTE: Even though for A1n/d2n the beam charge asymmetries are expected to be negligible, for parity experiments in general, the beam charge asymmetries are no longer negligible and MUST be calculated from helicity scalers

4. Helicity Scalers Software Updates to HCANA and hallc_replay

The HCANA source code (hcana/src/) contains the helicity scalers class, THcHelicityScaler.cxx and corresponding header file, THcHelicityScaler.h. Modifications to this class were made to write the decoded raw helicity data variables to a ROOT scaler tree with the aid of a helicity scaler map (hallc_replay/MAPS/SCALERS).

The hallc_replay repository has also been modified in accordance with the changes made in HCANA. The modifications are summarized as follows:

- Added the relevant helicity scaler map files located at: hallc_replay/MAPS/SCALERS. The files are:
  - ◇ the input helicity scaler map file, scaler_hel.map, which describes the hardware location of the helicity scalers as well as the scaler input channels.
  - ◇ the script used to generate the output scaler map files, make_hel_scaler_db.py, which uses scaler_hel.map as input.
  - ◇ the output helicity scaler map files, db_helHScalevt.dat and db_helPScalevt.dat, are generated by the make_hel_scaler_db.py script. These files are symbollically linked to hallc_replay/DBASE, where they are read by the THcHelicityScaler.cxx class.
- Modified all the PRODUCTION and SCALERS directory replay scripts located at:
  - ◇ hallc_replay/SCRIPTS/COIN,
  - ◇ hallc_replay/SCRIPTS/SHMS, and
  - ◇ hallc_replay/SCRIPTS/HMS

  to initialize the helicity scaler class. This initialization is necessary for the helicity scaler ROOTTree (TSHelP or TSHelH) to be generated in the output ROOTfile.
- Added a new helicity scaler template file for both single and coincidence mode replay scripts located at:
  - ◇ hallc_replay/TEMPLATES/COIN/SCALERS/coin_hel_scalers.template,
  - ◇ hallc_replay/TEMPLATES/SHMS/SCALERS/phelscalers.template, and
  - ◇ hallc_replay/TEMPLATES/HMS/SCALERS/hhelscalers.template

  These template files have the relevant helicity scaler information for beam current monitors (BCMs) as well as the physics pre-triggers for HMS and SHMS single-arm or coincidence mode DAQ.

The full helicity software documentation can be found below:
Hall C Doc DB Reference: https://hallcweb.jlab.org/doc-private/ShowDocument?docid=1105

4. Helicity Scalers Software Updates to HCANA and hallc_replay

Fig. 1 shows an example of helicity scalers initialization in a replay script. This block of code must be added to the user's replay script to access the helicity scaler tree

replay_shms_scalers.C

Fig. 1

```
// Add handler for EPICS events
THaEpicsEvtHandler *hcepics = new THaEpicsEvtHandler("epics", "HC EPICS event type 180");
gHaEvtHandlers->Add(hcepics);
// Add handler for scaler events
THcScalerEvtHandler *pscaler = new THcScalerEvtHandler("P","Hall C scaler event type 1");
pscaler->AddEvtType(1);
pscaler->AddEvtType(129);
pscaler->SetDelayedType(129);
pscaler->SetUseFirstEvent(kTRUE);
gHaEvtHandlers->Add(pscaler);

/*
//Add event handler for helicity scalers
THcHelicityScaler *phelscaler = new THcHelicityScaler("P", "Hall C helicity scaler");
//phelscaler->SetDebugFile("PHelScaler.txt");
phelscaler->SetROC(8);
phelscaler->SetUseFirstEvent(kTRUE);
gHaEvtHandlers->Add(phelscaler);
*/

// Add event handler for DAQ configuration event
```

SHMS Helicity Scalers Initialization

-:--- replay_shms_scalers.C 34% L48 Git-carlos_helicity_work (C/*l +2 Abbrev)

Fig. 2 shows an example of how to load the helicity scalers TEMPLATE file to create a REPORT_FILE with the relevant helicity scaler information

Fig. 2

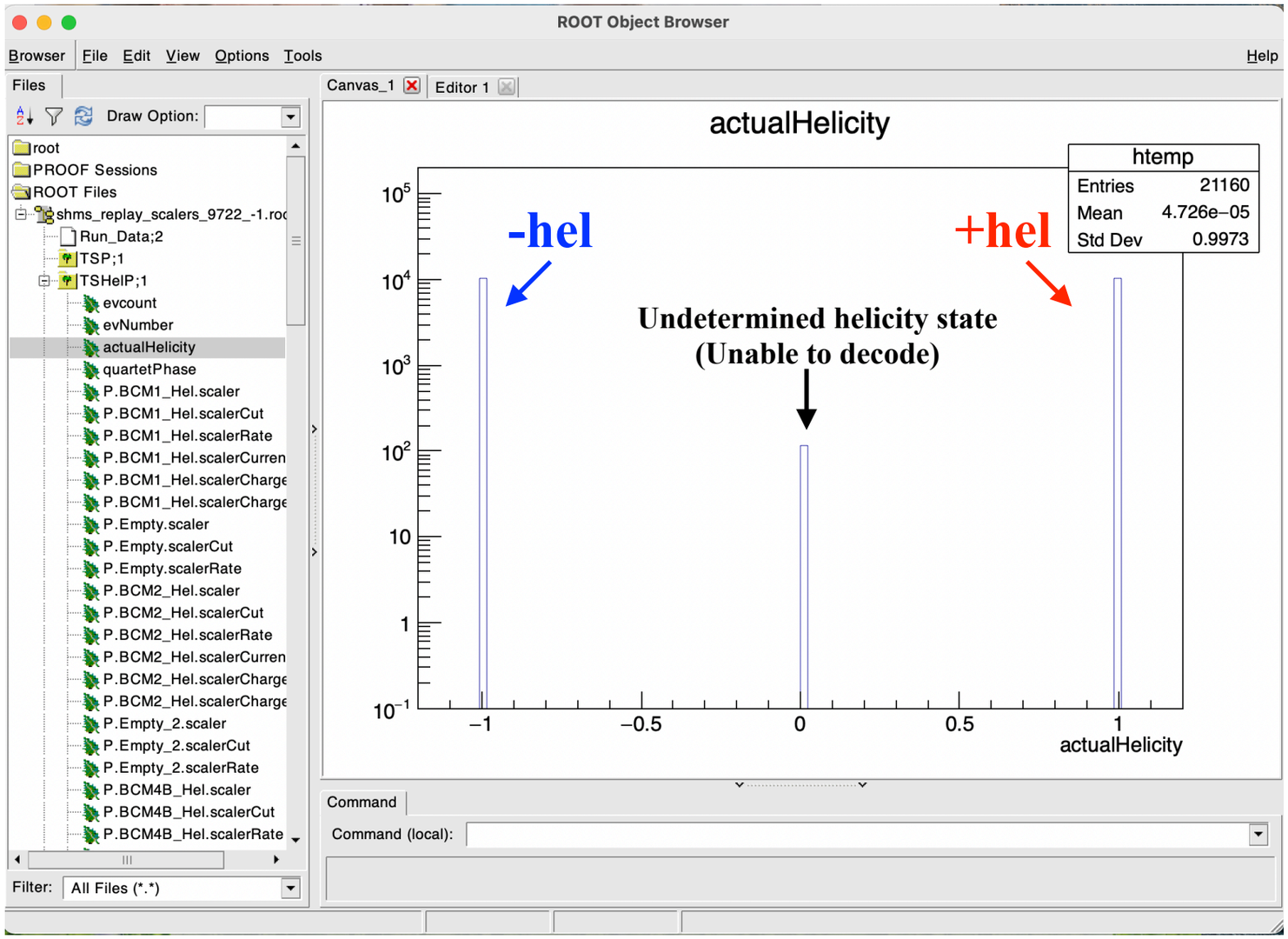
```
// Create report file from template
analyzer->PrintReport("TEMPLATES/SHMS/SCALERS/pscalers.template",
                      Form("REPORT_OUTPUT/SHMS/SCALERS/replay_shms_scalers_%d_%d.report", RunNumber, MaxEvent));  // optional

// Create report file from template for helicity scalers
analyzer->PrintReport("TEMPLATES/SHMS/SCALERS/phelscalers.template",
                      Form("REPORT_OUTPUT/SHMS/SCALERS/replay_shms_hel_scalers_%d_%d.report", RunNumber, MaxEvent));  // opti

}
```

Set TEMPLATE and REPORT_FILE for helicity scalers

-:--- replay_shms_scalers.C Bot L116 Git:carlos_helicity_work (C/*l +2 Abbrev)

4. Helicity Scalers Software Updates to HCANA and hallc_replay

Example of Helicity Scaler Tree



- Helicity scaler tree is separate from standard scaler tree (clocks are not in sync as their trigger is different)

- Decoded events are "tagged" by either +hel, -hel. If the event was unable to be decoded, it is set to 0. **NOTE: this is different from MPS signal.

- The number of +/- helicity states for all other variables can be determined by making a software cut on 'actualHelicity'

- The asymmetry calculations for each variable are done on a '*per quartet*' basis in hcana.
  ** the asymmetry is calculated in the last cycle of each quartet, and averaged over all quartets
  See Note on Hall C Doc-DB Ref: https://hallcweb.jlab.org/doc-private/ShowDocument?docid=1105

- The '*per quartet*' asymmetry calculations are also done independently on a helicity scaler analyzer script written for users to use as a starting point in the helicity scaler analysis. This script has also been uploaded to Hall C Doc-DB Ref: https://hallcweb.jlab.org/doc-private/ShowDocument?docid=1105

4. Helicity Scalers Software Updates to `HCANA` and `hallc_replay`

Example of a helicity scaler REPORT_FILE showing the relevant information.

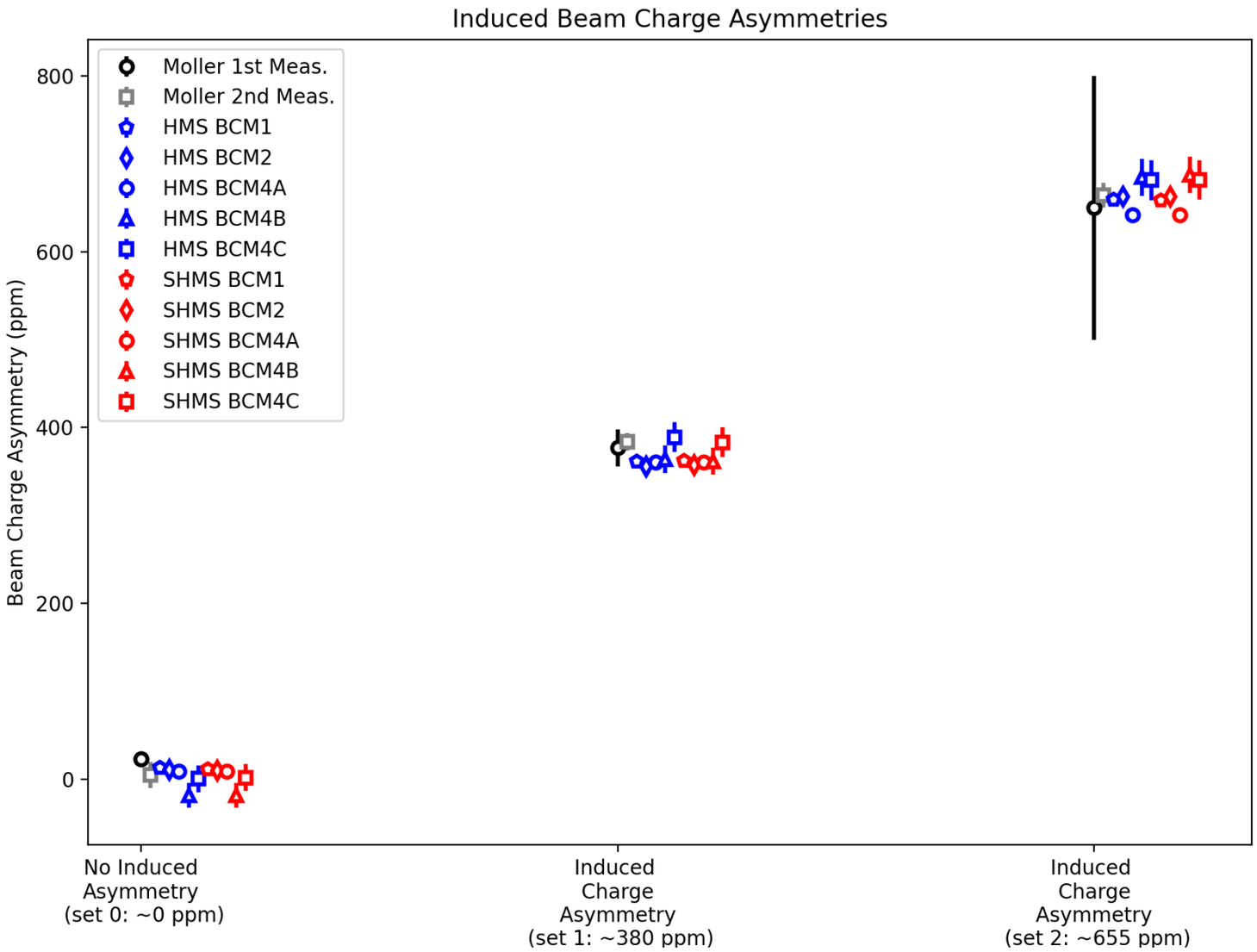
```
For information on the helicity channels and indices, refer to:
Helicty Scaler Channel Map: hallc_replay/MAPS/SCALERS/scaler_hel.map
BCM number index map: hallc_replay/PARAM/GEN/gscalers.param

The relevant helicity information from this file may be copied to
the user's template file, or it may be loaded as a separate template
file in the replay script.

------------------------------------------------------------------------

Run #: 9721

**************************
* General Run Information
**************************

=:=:=:=:=:=:=:=:=:=:=:=:
= Helicity Gated Scalers
=:=:=:=:=:=:=:=:=:=:=:=:

NOTE: (Helicity Gated refers to ONLY '+' or '-' helicity states being counted.
       MPS states (undefined helicity) are no counted)

1 MHz Pulses (hel)          : 253860109.999988
Run Length (hel)            : 253.860 sec

************************************************
* Helicity Scalers Information (ecluding MPS)
************************************************

=:=:=:=:=:=:=:=:=:=:=:=:=:=:=:=:=:=:=:=:=:
= Helicity Scaler Trigger (no bcm cut)
=:=:=:=:=:=:=:=:=:=:=:=:=:=:=:=:=:=:=:=:=:
Total Helicity Scaler Triggers (# of MPS signals) : 3.092100E+04
Positive Helicity Scaler Triggers                 : 1.540200E+04
Negative Helicity Scaler Triggers                 : 1.540000E+04
Undetermined Helicity Triggers                    : 119.000
Helicity Trigger Asymmetry                        : 6.493085E-05 (64.931 ppm)

The variables below were calculated with BCM4 current > 5 uA.

=:=:=:=:=:=:=:=:=:=:=:=:
= Helicity Scaler Time
=:=:=:=:=:=:=:=:=:=:=:=:
Helicity Gated Time           : 253.860       sec
Helicity Gated Time Asymmetry : 1.103022E-07 +-  3.397469E-07 (0.110 +- 0.340 ppm)


=:=:=:=:=:=:=:=:=:=:=:=:=:=:=:
= Helicity Gated Charge
=:=:=:=:=:=:=:=:=:=:=:=:=:=:=:
BCM1  Helicity Gated Charge: 2654.107 uC
BCM2  Helicity Gated Charge: 2686.289 uC
Unser Helicity Gated Charge: -858.055 uC
BCM4A Helicity Gated Charge: 2689.604 uC
BCM4B Helicity Gated Charge: 2687.313 uC
BCM4C Helicity Gated Charge: 731.759 uC

=:=:=:=:=:=:=:=:=:=:=:=:=:=:=:=:=:=:
= Helicity Gated Charge Asymmetries
=:=:=:=:=:=:=:=:=:=:=:=:=:=:=:=:=:=:
BCM1  Helicity Gated Charge Asymmetry: 3.625709E-04 +- 5.671178E-06 (362.571 +- 5.671 ppm)
BCM2  Helicity Gated Charge Asymmetry: 3.571441E-04 +- 5.724609E-06 (357.144 +- 5.725 ppm)
Unser Helicity Gated Charge Asymmetry: -2.445780E-03 +- 9.646142E-04 (-2445.780 +- 964.614 ppm)
BCM4A Helicity Gated Charge Asymmetry: 3.603474E-04 +- 5.865950E-06 (360.347 +- 5.866 ppm)
BCM4B Helicity Gated Charge Asymmetry: 3.618692E-04 +- 1.542844E-05 (361.869 +- 15.428 ppm)
BCM4C Helicity Gated Charge Asymmetry: 3.831336E-04 +- 1.695269E-05 (383.134 +- 16.953 ppm)
```

```
=:=:=:=:=:=:=:=:=:=:=:=:=:=:=:=:
= Helicity Gated Beam Current
=:=:=:=:=:=:=:=:=:=:=:=:=:=:=:=:
BCM1  Helicity Gated Current: 10.455 uA
BCM2  Helicity Gated Current: 10.582 uA
Unser Helicity Gated Current: -3.380 uA
BCM4A Helicity Gated Current: 10.595 uA
BCM4B Helicity Gated Current: 10.586 uA
BCM4C Helicity Gated Current: 2.883 uA

=:=:=:=:=:=:=:=:=:=:=:=:
=Trigger Scaler Counts
=:=:=:=:=:=:=:=:=:=:=:=:
pTRIG1  Helicity Scaler Counts:  1440682.000
pTRIG2  Helicity Scaler Counts:  1003709.000
pTRIG3  Helicity Scaler Counts:  279971.000
pTRIG4  Helicity Scaler Counts:  1607658.000
pTRIG5  Helicity Scaler Counts:  6577.000
pTRIG6  Helicity Scaler Counts:  5579.000

=:=:=:=:=:=:=:=:=:=:=:=:=:=:=:
= Trigger Scaler Asymmetries
=:=:=:=:=:=:=:=:=:=:=:=:=:=:=:
pTRIG1  Helicity Scaler Asymmetry    : -7.040753E-04 +- 8.364465E-04 (-704.075 +- 836.447 ppm)
pTRIG2  Helicity Scaler Asymmetry    : -8.924546E-04 +- 9.957538E-04 (-892.455 +- 995.754 ppm)
pTRIG3  Helicity Scaler Asymmetry    : -7.103399E-04 +- 1.945579E-03 (-710.340 +- 1945.579 ppm)
pTRIG4  Helicity Scaler Asymmetry    : -1.648486E-03 +- 7.999982E-04 (-1648.486 +- 799.998 ppm)
pTRIG5  Helicity Scaler Asymmetry    : -NAN +- 0.000000E+00 (-nan +- 0.000 ppm)
pTRIG6  Helicity Scaler Asymmetry    : -NAN +- 0.000000E+00 (-nan +- 0.000 ppm)

=:=:=:=:=:=:=:=:=:=:
=  Trigger Rates
=:=:=:=:=:=:=:=:=:=:
pTRIG1  Helicity Scaler Rates:  5.675E+00 kHz
pTRIG2  Helicity Scaler Rates:  3.954E+00 kHz
pTRIG3  Helicity Scaler Rates:  1.103E+00 kHz
pTRIG4  Helicity Scaler Rates:  6.333E+00 kHz
pTRIG5  Helicity Scaler Rates:  2.591E-02 kHz
pTRIG6  Helicity Scaler Rates:  2.198E-02 kHz
```

Trigger Scaler Asymmetries

Helicity-Gated Charge Asymmetries

4. Helicity Scalers Software Updates to `HCANA` and `hallc_replay`



1. On Dec. 2019, two short (~2 min.) Moller and HMS/SHMS runs were taken at 3 induced beam charge asymmetry configurations

2. To check the hcana asymmetry calculations, the beam charge asymmetries for three different configurations were calculated and compared to the Moller results.

3. The numerical results of this plot are tabulated in the next slide.

A summary of the Moller, HMS and SHMS runs can be found in log-entry:
https://logbooks.jlab.org/entry/3755962

4. Helicity Scalers Software Updates to `HCANA` and `hallc_replay`

Table 1: No Induced Charge Asymmetry (set 0: ~0 ppm)

Moller Run	Moller Run		HMS Run 2548	SHMS Run 9720
23 ± 8	5 ± 15	BCM1	12.97 ± 5.18	11.88 ± 5.22
		BCM2	10.74 ± 5.29	10.13 ± 5.33
		BCM4A	8.76 ± 5.36	8.81 ± 5.40
		BCM4B	−18.56 ± 14.13	−18.33 ± 14.22
		BCM4C	0.766 ± 15.34	2.02 ± 15.47

Table 1: The numerical values for beam charge asymmetries in units of parts-per-million or ppm

Table 2: Induced Charge Asymmetry (set 1: ~380 ppm)

Moller Run 1332	Moller Run 1333		HMS Run 2549	SHMS Run 9721
377 ± 21	384 ± 10	BCM1	361.23 ± 5.66	362.57 ± 5.67
		BCM2	355.95 ± 5.68	357.14 ± 5.73
		BCM4A	360.98 ± 5.87	360.35 ± 5.87
		BCM4B	363.89 ± 15.39	361.87 ± 15.43
		BCM4C	388.89 ± 16.93	383.13 ± 16.95

Table 2: The numerical values for beam charge asymmetries in units of parts-per-million or ppm

Table 3: Induced Charge Asymmetry (set 2: ~655 ppm)

Moller Run 1334	Moller Run 1335		HMS Run 2550	SHMS Run 9722
650 ± 150	644 ± 14	BCM1	659.42 ± 7.58	658.68 ± 7.53
		BCM2	662.38 ± 7.70	662.73 ± 7.65
		BCM4A	642.29 ± 8.06	642.23 ± 8.04
		BCM4B	684.53 ± 20.72	687.65 ± 20.60
		BCM4C	681.29 ± 22.48	681.83 ± 22.32

Table 3: The numerical values for beam charge asymmetries in units of parts-per-million or ppm

`A summary of the Moller, HMS and SHMS runs can be found in log-entry:`
https://logbooks.jlab.org/entry/3755962

5. A Brief Note on the Helicity Data Class, `THcHelicity.cxx (.h)`

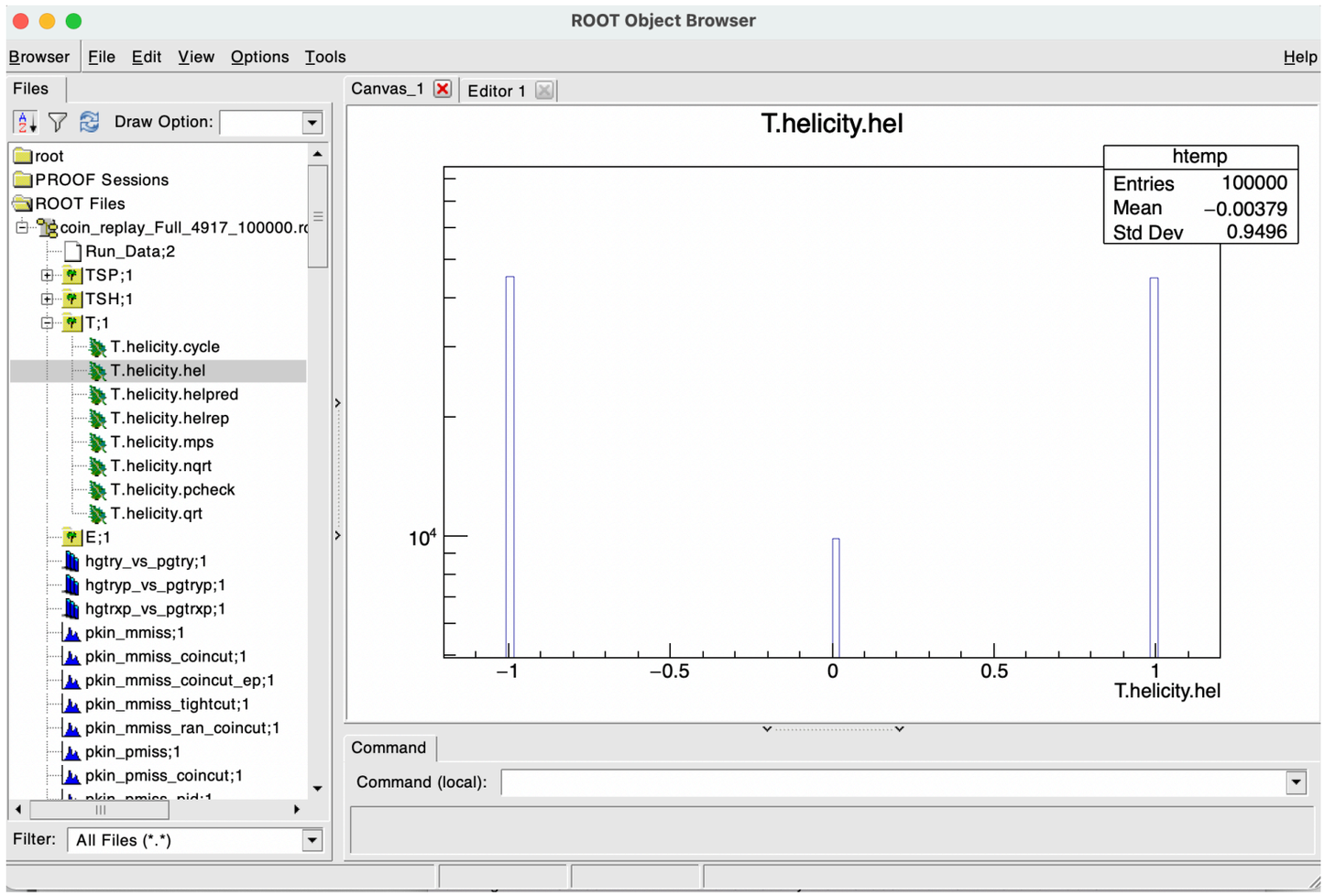
Replay script snippet

```
// Add handler for scaler events
THcScalerEvtHandler *pscaler = new THcScalerEvtHandler("P","Hall C scaler event type 1");
pscaler->AddEvtType(1);
pscaler->AddEvtType(129);
pscaler->SetDelayedType(129);
pscaler->SetUseFirstEvent(kTRUE);
gHaEvtHandlers->Add(pscaler);

THcHelicityScaler *phelscaler = new THcHelicityScaler("P", "Hall C helicity scaler");
//phelscaler->SetDebugFile("PHelScaler.txt");
phelscaler->SetROC(8);
phelscaler->SetUseFirstEvent(kTRUE);
gHaEvtHandlers->Add(phelscaler);

// Add helicity detector to trigger apparatus
THcHelicity* helicity = new THcHelicity("helicity","Helicity Detector");
TRG->AddDetector(helicity);
helicity->SetHelicityScaler(phelscaler);
```

Standard Scaler Initialization

Helicity Scaler Initialization

Helicity Data Initialization



- Helicity information is decoded (in `THcHelicity.cxx(.h)`) for every physics trigger accepted by the DAQ and written to the data tree

- Helicity data class must be initialized in the replay script to access the helicity data variables

- Similarly to helicity scaler, data are 'tagged' with either +/- helicity or undetermined(0) for every trigger and the number of +/- states can be determined via a cut on 'T.helicity.hel'

- **NOTE:** It is important to set the 'helicity_freq' parameter to the correct MPS frequency used in the experiment. By default, it is set to ~120 Hz in hcana, however, this may change per experiment.

  **The parameter can be set in the standard.kinematic file for a given run range if preferred.

Summary

- The helicity scalers source code (THcHelicityScalers.cxx (.h)) has been updated and has been merged with the official hcana repository.
  Refer to the official hcana git repository to see updates from the commit:
  >> https://github.com/JeffersonLab/hcana/commit/7b337a1a35216a29a7edc4ad6ede256e6ad350f7

- The helicity scalers replay scripts have been updated to initialize the helicity scalers. (Need to be uncommented by the user in the replay scripts.)

  The official hallc_replay repository is yet to be updated with the changes, as these need to be fully checked for any errors/inconsistencies. Refer to the unofficial hallc_replay branch or pull request to checkout updates (under revision before merging):
  >> unofficial repository: https://github.com/Yero1990/hallc_replay/tree/carlos_helicity_work
  >> git pull request: https://github.com/JeffersonLab/hallc_replay/pull/532

- A helicity scaler analysis script has been completed, and is intended to be used as a starting point for the A1n/d2n scaler analysis. The script can (and should) be incorporated in the main A1n/d2n analysis code. The script has also been uploaded to the Hall C Doc DB (see reference below).

The full helicity software documentation can be found below:
Hall C Doc DB Reference: https://hallcweb.jlab.org/doc-private/ShowDocument?docid=1105

Thank You !