F2/EMC Collaboration Meeting

Live Time Calculations

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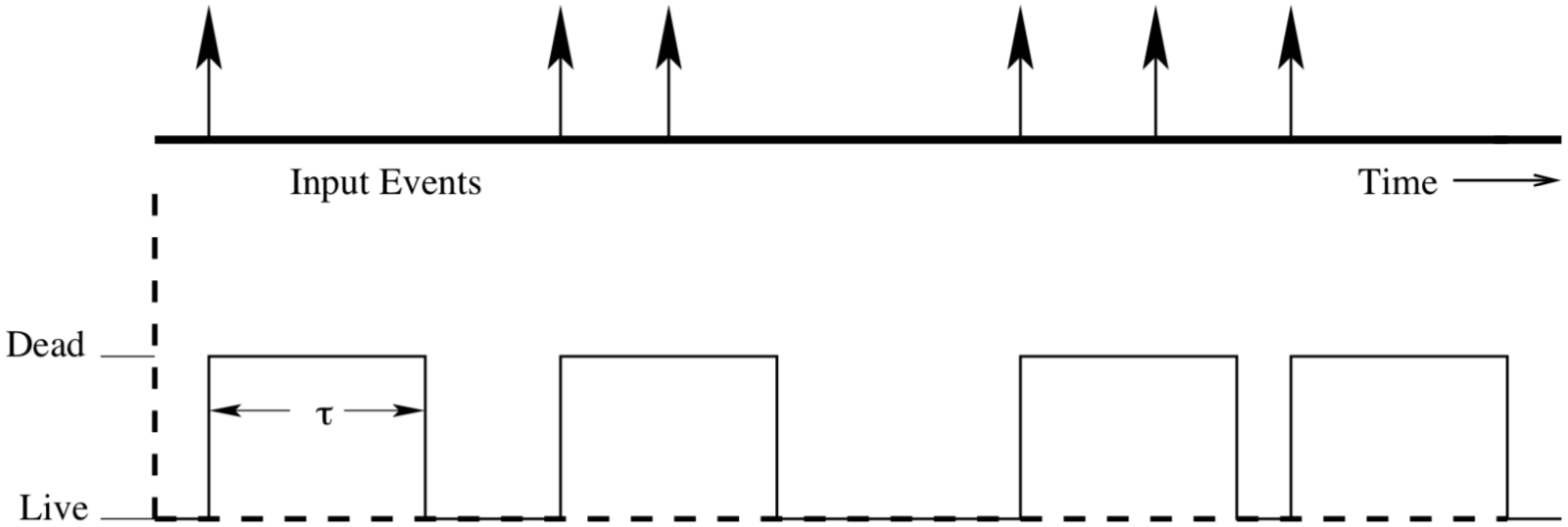
On Behalf of the DAQ Working Group

DAQ Live Time Formalism

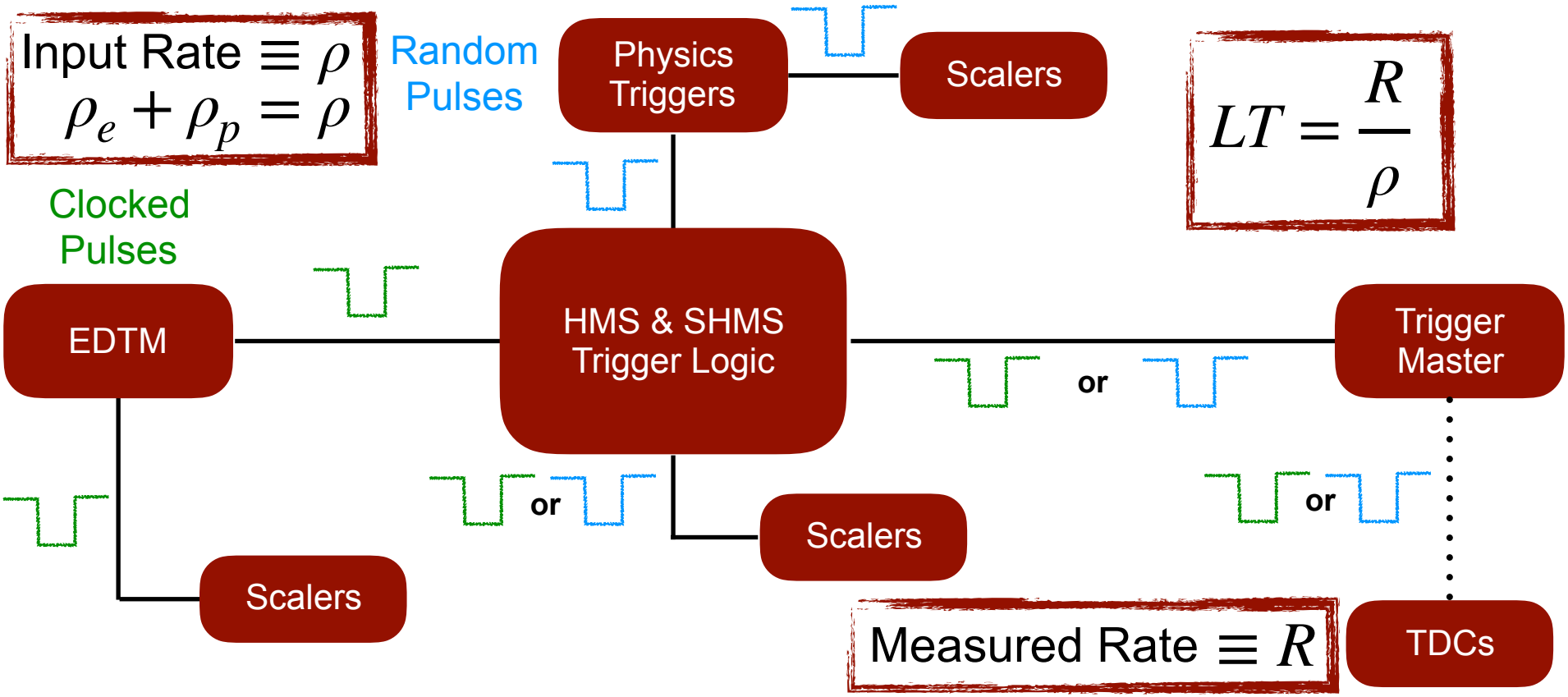
- There exists a minimum time interval by which events can be separated
- The DAQ is 'dead' for a time τ after each recorded trigger



- In 'ROC lock' mode, the DAQ is a 'non-extendable' system
  - Buffered mode does not behave in this manner
- TDC's account for the recorded events
- Scalers account for the total number of input events

Hall-C EDTM System

- Artificially inserted sequences of pulses allow for accurate corrections to be applied
- By design, the EDTM is a real trigger as observed by the electronics and readout system
- It is deployed into the circuit as close to the detectors for all components which are involved in the trigger legs



Slide Adapted from Carlos Yero

DAQ Live Time Formalism

- Define the following (Müller, NIM 112, 47-57 (1973)) :
  - $f(t) \equiv$ original interval density, $\rho \equiv$ input rate
  - $F(t) \equiv$ dead time modified interval density, $R \equiv$ output rate
- In general, the $F(t)$ for a given process must be known before the corresponding count rate can be evaluated:

$$R^{-1} = \int_0^\infty tF(t)dt$$

- The transformation from $f(t) \rightarrow F(t)$ for a non-extended system is:

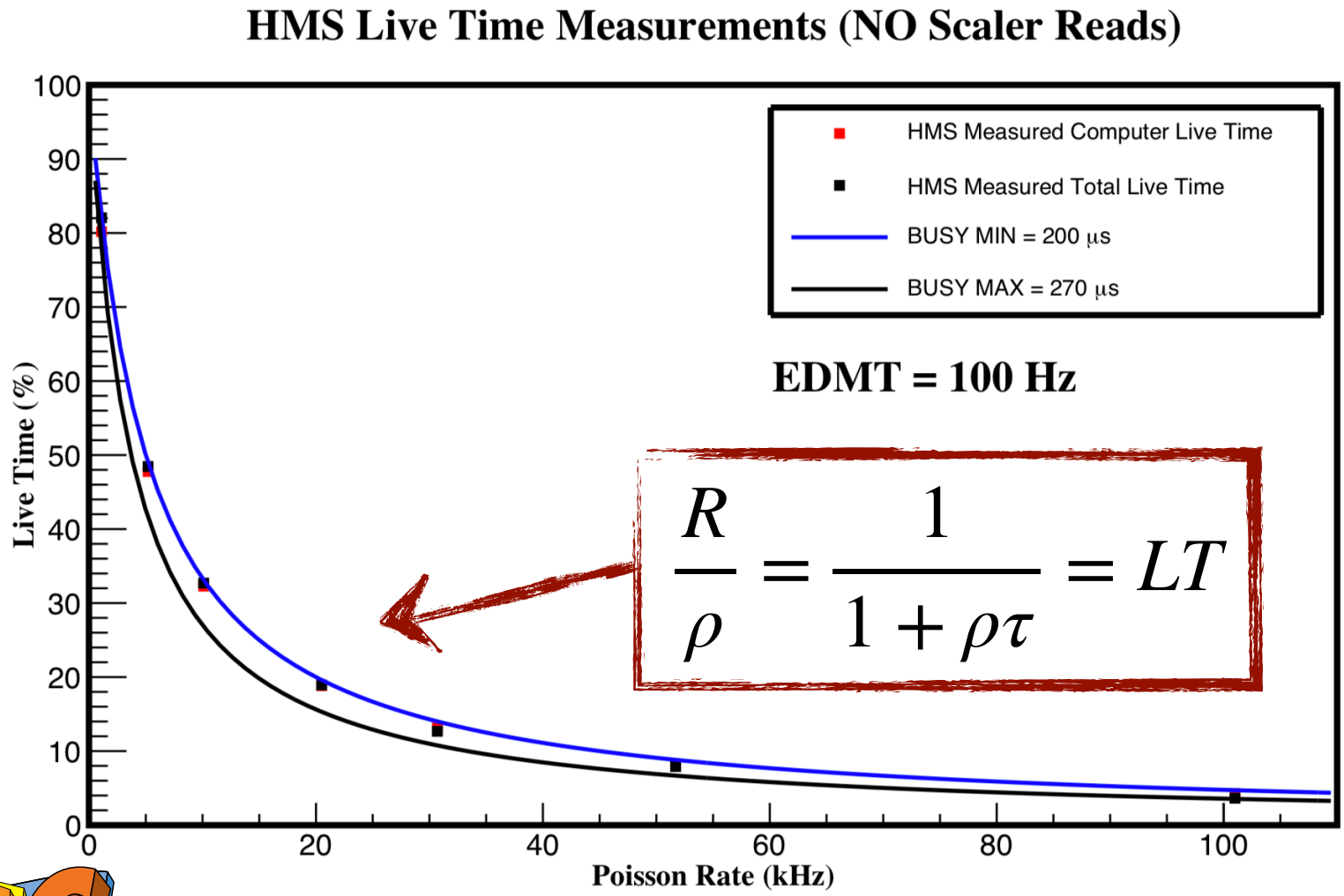
$$F(t) = U(t-\tau)\left\{ f(t) + \sum_{k=0}^{\infty} \int_0^\tau f_k(x) f(t-x)dx \right\}$$

- For a Poisson process of rate ρ we have the following:

$$R^{-1} = \int_\tau^\infty t\rho e^{-\rho(t-\tau)}dt = \rho^{-1} + \tau \qquad \therefore \qquad \boxed{\frac{R}{\rho} = \frac{1}{1+\rho\tau}}$$

DAQ Live Time Bench Test's

- Utilizing a Poisson pulse generator and the EDTM system, the non-extended dead time model well describes the data taken on the bench



Offline Analysis Method

- Previous study accurately determined the total live time as measured by the EDTM
  - Compared to the measured computer live time
  - Infer electronic live time
  - EDTM Rate = 100 Hz
- Live time 'scan' was taken during the Spring 2018 commissioning run
  - Vary rates via luminosity
- Singles runs were taken in both the HMS & SHMS
  - Single arm DAQ's
  - Single trigger type (PS1, 3/4)
  - No Pre-scale
  - ROC lock mode (buffer level 1)

HMS: $\theta = 22.0$, $p_c = -2.131$

Run #	I_{Beam} (μA)	PS1 Rate (Hz)
1437	65	7390
1438	40	4600
1439	30	3470
1440	20	2730
1441	10	1220
1442	5	680
1443	1	220
1444	40	4640
1445	50	5720
1446	60	6810

SHMS: $\theta = 17.1$, $p_c = +5.112$

Run #	I_{Beam} (μA)	PS1 Rate (Hz)
2014	30	970
2015	20	670
2016	10	370
2017	5	240
2018	1	130
2019	40	1350
2020	50	1730
2021	60	2130

Setting Up the Replay: Decode All Events

- Edit DEF-files to ensure that all events are decoded
  - DEF-files/(S)HMS/PRODUCTION/CUTS/
- Event type definitions:
  - (p)hstackana_rawdecode_cuts.def
- Definition of TDC cuts:
  - (p)hstackana_decode_cuts.def
- Decoding structure:
  - (p)hstackana_production_cuts.def
- By default, any events containing a hit in the EDTM TDC spectrum are not decoded
- Ensure that all events are being decoded so that EDTM events are present

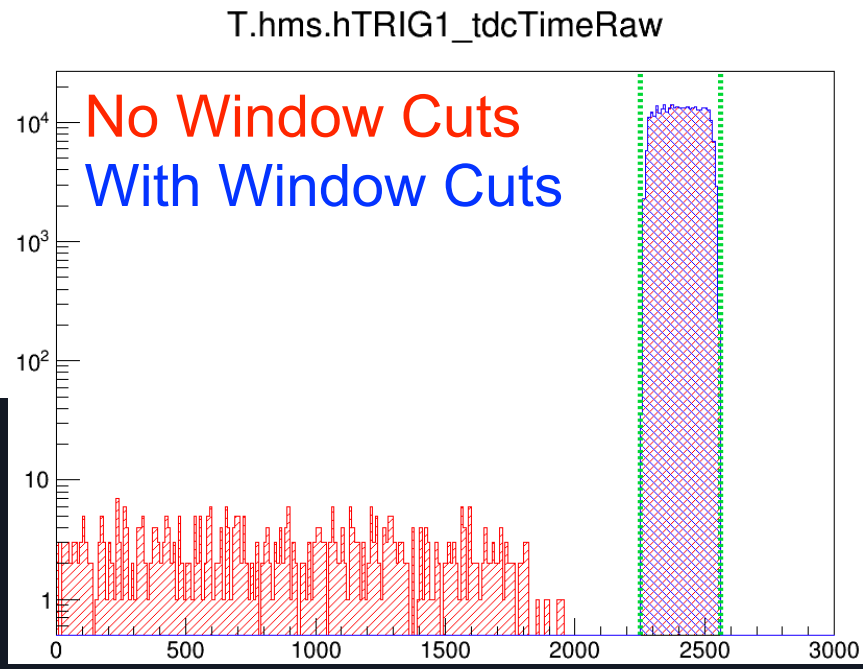
```
Block: RawDecode

Pedestal_event          g.evtyp == 99
SHMS_event              g.evtyp == 1
HMS_event               g.evtyp == 2
BOTH_SINGLES_event      g.evtyp == 3
COIN_ONLY_event         g.evtyp == 4
SHMS_COIN_event         g.evtyp == 5
HMS_COIN_event          g.evtyp == 6
COIN_ALL_event          g.evtyp == 7
ALL_events              SHMS_event || HMS_event  ||
ALL_HMS_events          HMS_event || BOTH_SINGLES_ev
```

```
hcut_TRIG1          T.hms.hTRIG1_tdcTimeRaw > 0
hcut_TRIG2          T.hms.hTRIG2_tdcTimeRaw > 0
hcut_TRIG3          T.hms.hTRIG3_tdcTimeRaw > 0
HMS_Pretrig         hcut_TRIG1 || hcut_TRIG2 || hcut_TRIG3

hms_trigs                 HMS_event
hcut_physics_accepted     T.hms.hEDTM_tdcTimeRaw == 0.0
ALL_HMS_NO_EDTM           ALL_HMS_events && hcut_physics_accepted
```

```
Block: RawDecode
#include "DEF-files/HMS/PRODUCTION/CUTS/hstackana_rawdecode_cuts.def"
RawDecode_master  1

Block: Decode
#include "DEF-files/HMS/PRODUCTION/CUTS/hstackana_decode_cuts.def"
Decode_master          ALL_events

Block: CoarseTracking
#include "DEF-files/HMS/PRODUCTION/CUTS/hstackana_coarsetracking_cuts.def"
CoarseTracking_master ALL_events

Block: CoarseReconstruct
CoarseReconstruct_master ALL_events

Block: Tracking
Tracking_master  ALL_events

Block: Reconstruct
#include "DEF-files/HMS/PRODUCTION/CUTS/hstackana_reconstruct_cuts.def"
Reconstruct_master ALL_events

Block: Physics
#include "DEF-files/HMS/PRODUCTION/CUTS/hstackana_physics_cuts.def"
Physics_master ALL_events
```

Setting Up the Replay: Hit Selection Windows

- Must define hit selection windows for all trigger apparatus variables associated with live time calculation
  - (p)hTRIGX_tdcTimeRaw
  - (p)hEDTM_tdcTimeRaw

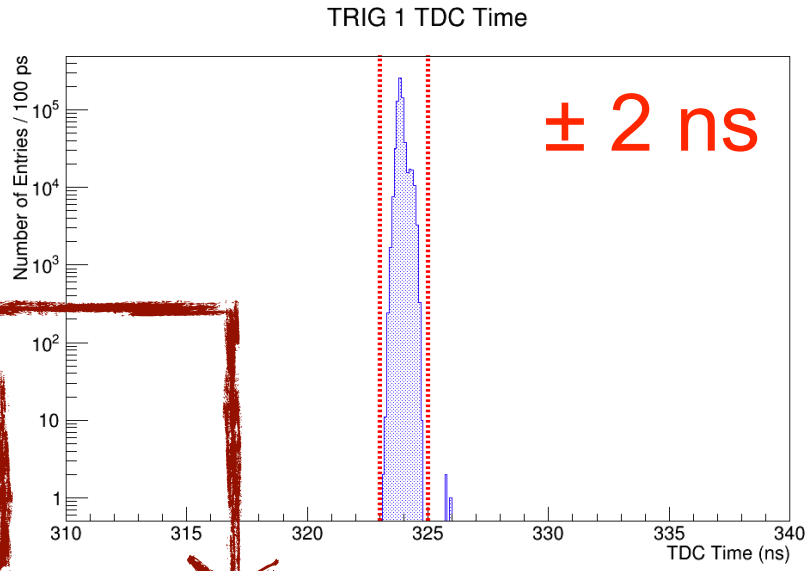


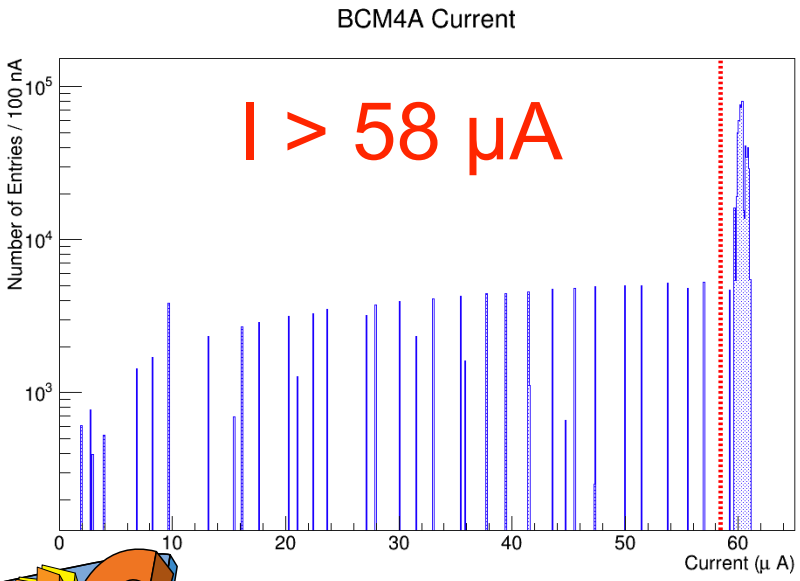
PARAM/TRIG/t(p)hms.param

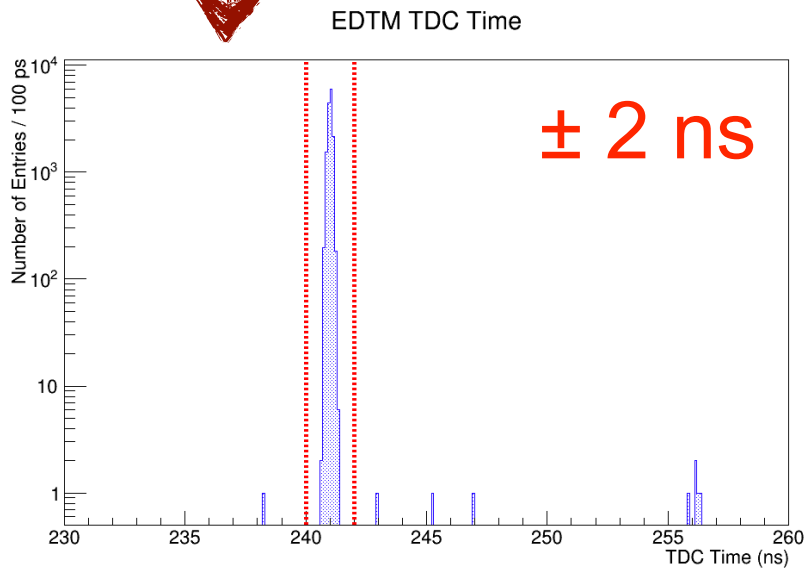
```
t_hms_numAdc = 9
t_hms_numTdc = 53
t_hms_tdcoffset=300.
t_hms_adc_tdc_offset=300.
t_hms_tdcchanperns=0.09766

t_hms_trig_adcrefcut = -4350
t_hms_trig_tdcrefcut = -2000

; bar num:          1     2     3     4     5     6     7     8         9
t_hms_adcNames = "hASUM hBSUM hCSUM hDSUM hPSHWR hSHWR hAER hCER hFADC_TREF_ROC1"

; bar num:          1   2   3   4   5   6   7    8     9     10    11   12    13    14    15    16  17    18      19      20      21      22      23
t_hms_tdcNames = "h1X h1Y h2X h2Y h1T h2T hT1 hASUM hBSUM hCSUM hDSUM hPRLO hPRHI hSHWR hEDTM hCER hT2 hDCREF1 hDCREF2 hDCREF3 hDCREF4 hTRIG1 hTRIG2

t_hms_TdcTimeWindowMin = -10000, -10000, -10000, -10000, -10000, -10000, -10000, -10000, -10000, -10000,
                         -10000, -10000, -10000, -10000, -10000,  1400., -10000, -10000, -10000, -10000,
                         -10000,  2250., -10000, -10000, -10000, -10000, -10000, -10000, -10000, -10000,
                         -10000, -10000, -10000, -10000, -10000, -10000, -10000, -10000, -10000, -10000,
                         -10000, -10000, -10000, -10000, -10000, -10000, -10000, -10000, -10000, -10000,
                         -10000, -10000, -10000

t_hms_TdcTimeWindowMax = 10000, 10000, 10000, 10000, 10000, 10000, 10000, 10000, 10000, 10000,
                         10000, 10000, 10000, 10000,  1710., 10000, 10000, 10000, 10000, 10000,
                         10000,  2560., 10000, 10000, 10000, 10000, 10000, 10000, 10000, 10000,
                         10000, 10000, 10000, 10000, 10000, 10000, 10000, 10000, 10000, 10000,
                         10000, 10000, 10000, 10000, 10000, 10000, 10000, 10000, 10000, 10000,
                         10000, 10000, 10000
```

Setting Up the Analysis: Diagnostic Histograms

- Create set of diagnostic histograms of variables that are included in the live time calculations
- Reference time subtracted TDC spectra
  - (p)hTRIGX_tdcTime
  - (p)hEDTM_tdcTime
- Beam current monitor read back
- Determine appropriate cuts in order to properly iterate both the TDC and scaler counters under beam on conditions







Live Time Definitions

- Live time (LT_E) as measured by the EDTM

$$LT_E = \frac{T_{EDTM}}{S_{EDTM}}$$

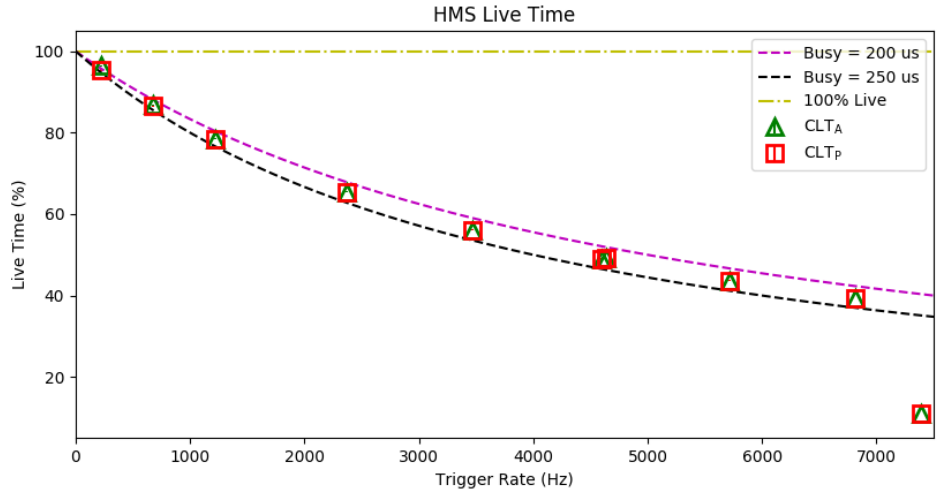
- Computer Live Time for all events (CLT_A) as measured by the trigger

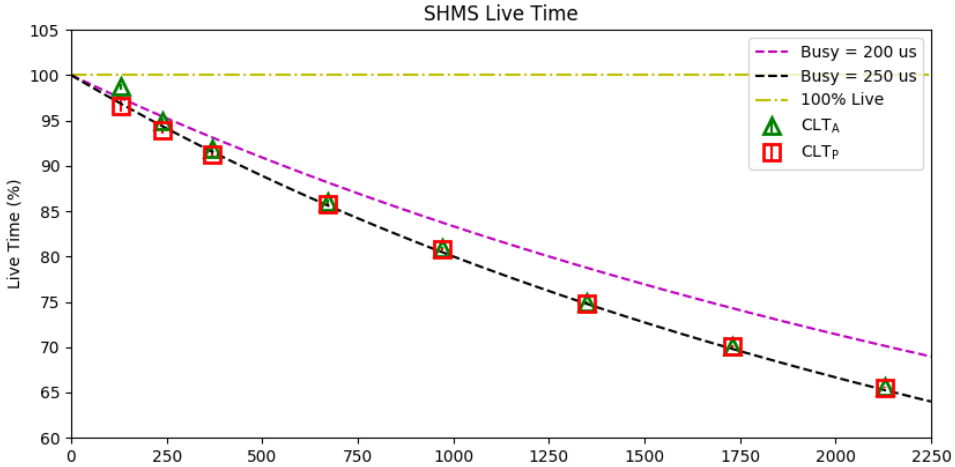
$$CLT_A = \frac{T_{TRIG}}{S_{TRIG}}$$

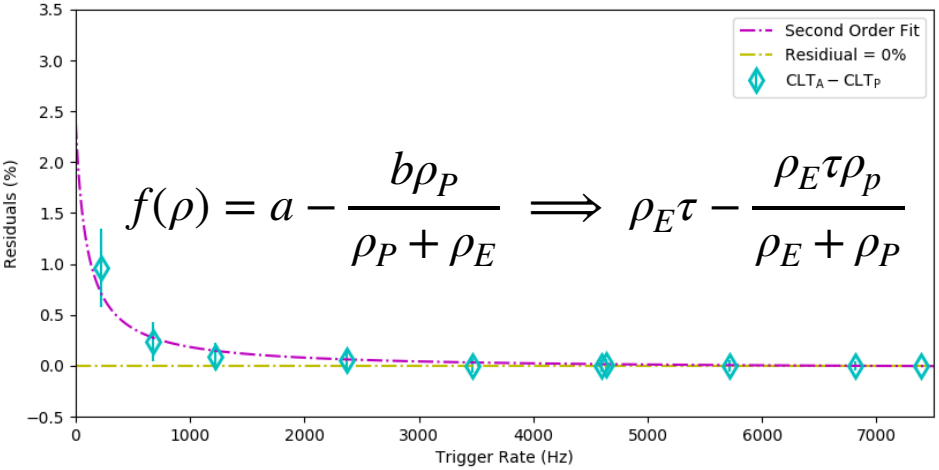
- Computer live time for physics events (CLT_P)

$$CLT_P = \frac{T_{TRIG} - T_{EDTM}}{S_{TRIG} - S_{EDTM}}$$

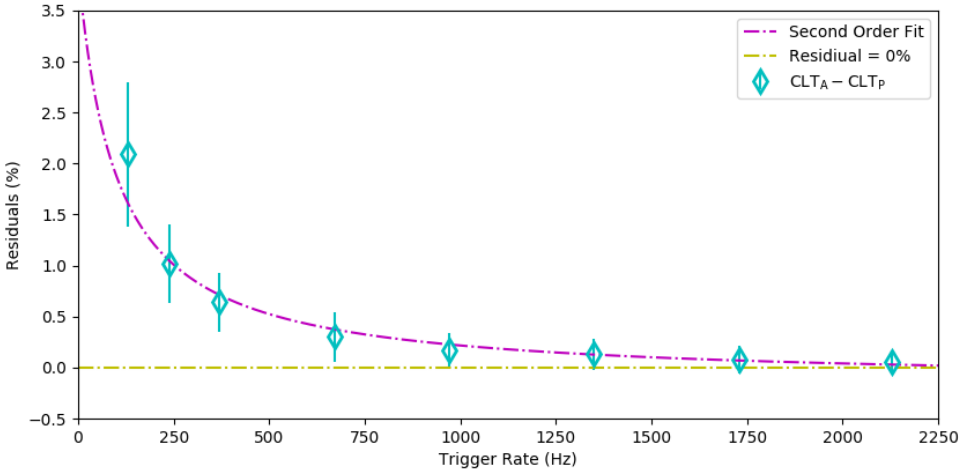
Live Time Results: CLT_P & CLT_A



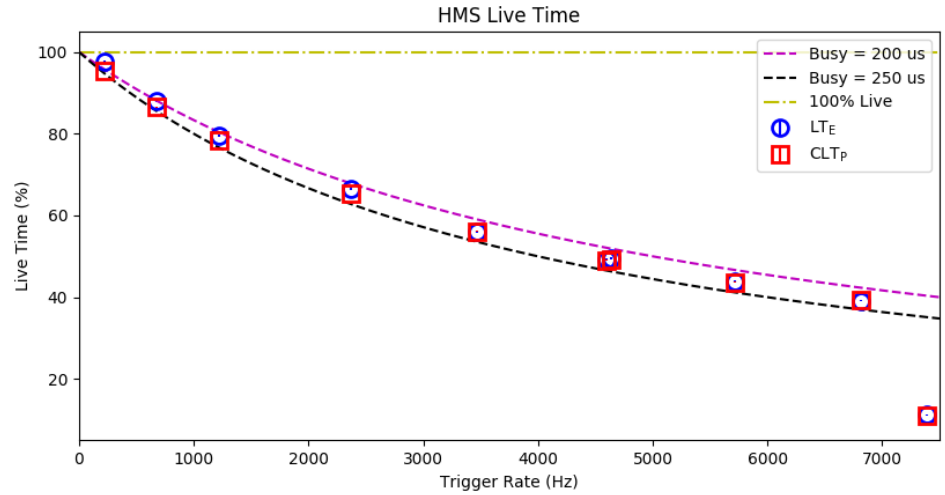


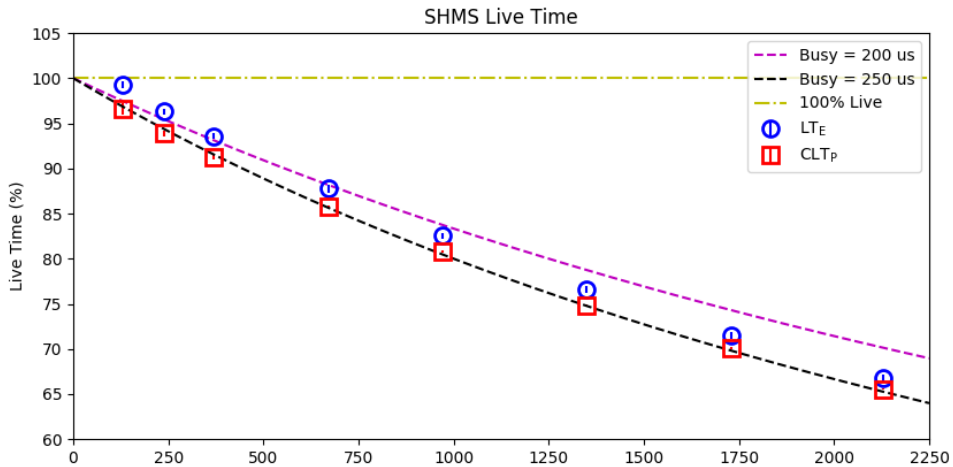


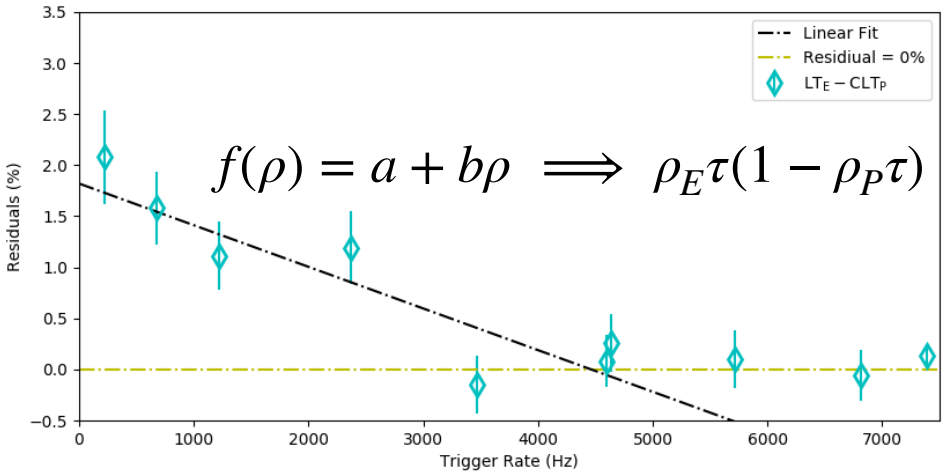
$$f(\rho) = a - \frac{b\rho_P}{\rho_P + \rho_E} \Longrightarrow \rho_E\tau - \frac{\rho_E\tau\rho_p}{\rho_E + \rho_P}$$



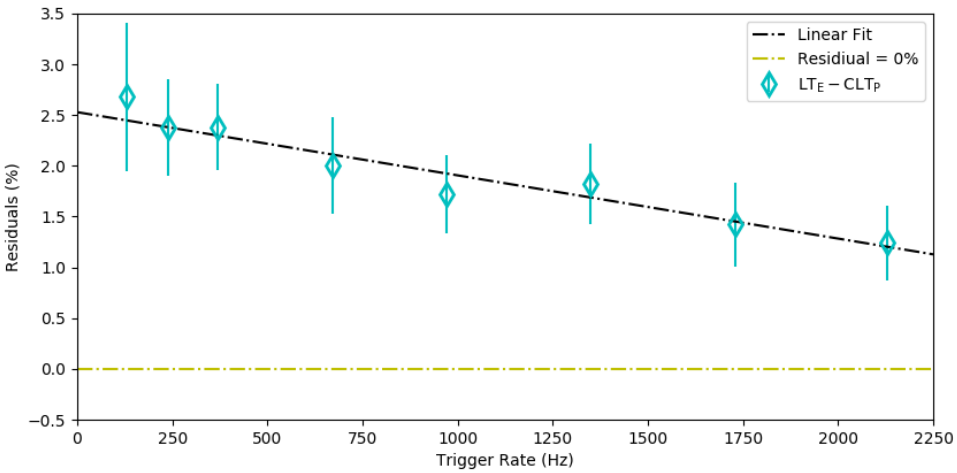
Live Time Results: LT_E & CLT_P







$$f(\rho) = a + b\rho \implies \rho_E \tau (1 - \rho_P \tau)$$



Offline Analysis: 0e595e7

- Scripts to conduct offline analysis of the live time calculations are now in the hallc-replay-f2xem repo
- CALIBRATION/dead_time
- README.md
- These scripts were developed specifically for the live-time studies conducted during the Fall 2017 commissioning period
- Will not work right out of the box for F2 although minimally invasive changes are required

Macros to calculate the various components of the live time

1. Begin with creating diagnostic histograms in order to define the cuts to be utilized.
   - python runHistos.py spec run-nums edtmRate
     - spec = **hms** or **shms**
     - run-nums = run range in form of **a-b** or comma sepataed ranges **a-b,c-d,f**
     - edtmRate = rate of the EDTM pulser
   - Example (hms) = python runHistos.py hms 1437-1446 100
   - Example (shms) = python runHistos.py shms 2014-2021 100
2. Once the EDTM and trigger TDC self timing cuts have been determined, the dead time can be calculated.
   - python runDeadTime.py spec run-nums edtmTdcLowCut edtmTdcHighCut trigTdcLowCut trigTdcHighCut > specOutput.txt
     - spec = **hms** or **shms**
     - run-nums = run range in form of **a-b** or comma sepataed ranges **a-b,c-d,f**
     - edtmTdcLow(High)Cut = cuts on the EDTM timing spectra to iterate counters for total live time calculation
     - trigTdcLow(High)Cut = cuts on the trig timing spectra to iterate counters for computer live time calculation
     - > specOutput.txt = pipes output to **hmsOutput.txt** or **shmsOutput.txt** so that it can be parsed for populating python dictionaries which are later used for plotting
   - Example (hms) = python runDeadTime.py hms 1437-1446 240 242 323 325 > hmsOutput.txt
   - Example (shms) = python runDeadTime.py shms 2014-2021 123 125 272 275 > shmsOutput.txt
3. Make plots to compare the total live time to the computer live time (for low rates) and plot the electronic live times
   - python makePlots.py

F2/EMC/X>1 Computer Live Time

- CLT in the report file is calculated in two ways at the moment
- Most recently added method (36f3d4c) utilizes software scalers that are predicated on the event type contained in the CODA file
- The event type associated with a physics trigger is unique to the trigger configuration present for that run
- If only one trigger type is present, then only one event type associated with a physics trigger will exist
- The TI firmware version present during F2 produced unreliable event types when more than one trigger type was active
- Prevents using ETs in CLT calculations when more than one trigger type was being utilized ➛ **Not the case for F2/EMC/X>1**

```
SHMS_event              g.evtyp == 1
HMS_event               g.evtyp == 2
```

```
shms_trigs              SHMS_event
pcut_edtm_accepted      T.shms.pEDTM_tdcTimeRaw != 0.0
pcut_physics_accepted   T.shms.pEDTM_tdcTimeRaw == 0.0
```

```
PS1 SHMS Computer Live Time (ET) : {(shms_trigs.npassed / (P.pTRIG1.scaler/gpconfig_ti_ps_factors[0])):%3.4f}
PS2 SHMS Computer Live Time (ET) : {(shms_trigs.npassed / (P.pTRIG2.scaler/gpconfig_ti_ps_factors[1])):%3.4f}
PS3 SHMS Computer Live Time (ET) : {(shms_trigs.npassed / (P.pTRIG3.scaler/gpconfig_ti_ps_factors[2])):%3.4f}
```

F2/EMC/X>1 Computer Live Time

- The other method utilizes a software scaler which applies a one sided cut on raw TDC variables as configured via the trigger apparatus and then calculates the CLT in the usual manner ➛ **Currently not correct**
- To calculate the CLT via TDCs in the report file correctly:
  1. Define hit selection window around self timing raw TDC distributions
  2. Define "cut" variables associated with self timing cuts around reference time subtracted TDC variables and beam on conditions
  3. Define ratio of software and hardware scalers in report file
  4. Calculate CLT in the usual manner

$$CLT = \frac{T_{TRIG}}{S_{TRIG}}$$

DEF-files/SHMS/PRODUCTION/CUTS/pstackana_decode_cuts.def

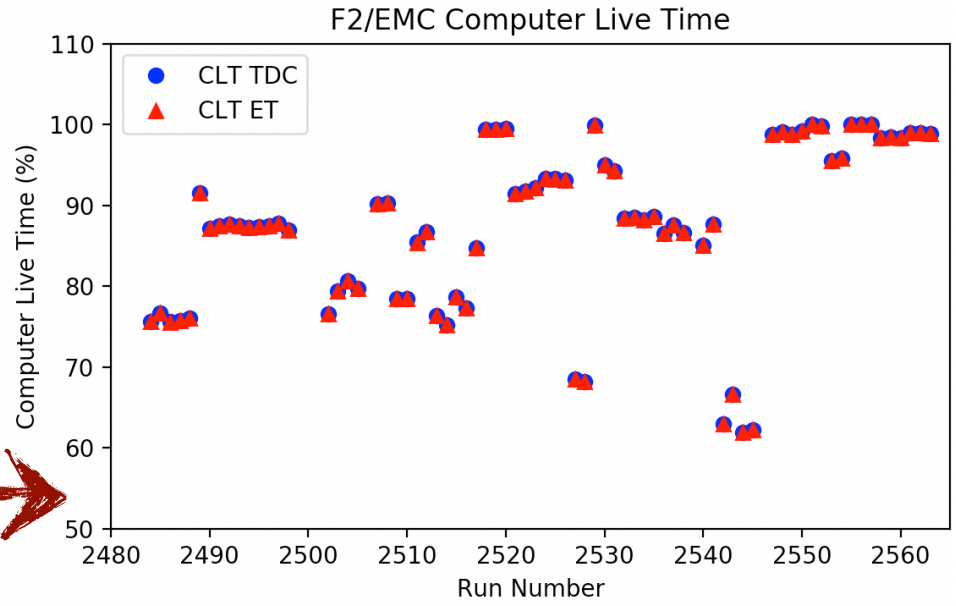
```
pcut_TRIG1          T.shms.pTRIG1_tdcTimeRaw > 0
pcut_TRIG2          T.shms.pTRIG2_tdcTimeRaw > 0
pcut_TRIG3          T.shms.pTRIG3_tdcTimeRaw > 0
```

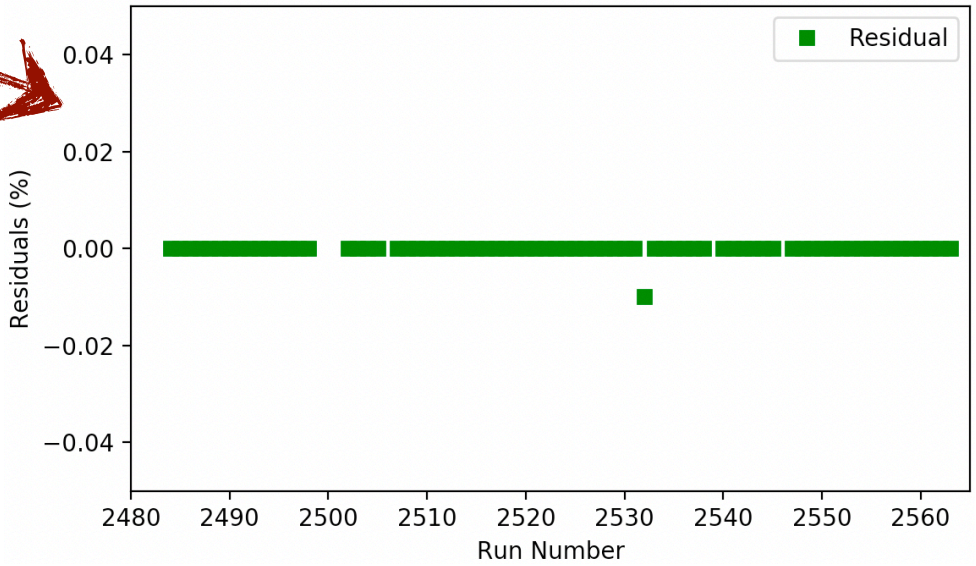
```
Pre-Scaled Ps1 SHMS Computer Live Time : {(pcut_TRIG1.npassed / (P.pTRIG1.scaler/gpconfig_ti_ps_factors[0]))*100.0:%3.4f} %
Pre-Scaled Ps1 SHMS Computer Dead Time : {100.0 - (pcut_TRIG1.npassed / (P.pTRIG1.scaler/gpconfig_ti_ps_factors[0]))*100.0:%3.4f} %

Pre-Scaled Ps2 SHMS Computer Live Time : {(pcut_TRIG2.npassed / (P.pTRIG2.scaler/gpconfig_ti_ps_factors[1]))*100.0:%3.4f} %
Pre-Scaled Ps2 SHMS Computer Dead Time : {100.0 - (pcut_TRIG2.npassed / (P.pTRIG2.scaler/gpconfig_ti_ps_factors[1]))*100.0:%3.4f} %

Pre-Scaled Ps3 SHMS Computer Live Time : {(pcut_TRIG3.npassed / (P.pTRIG3.scaler/gpconfig_ti_ps_factors[2]))*100.0:%3.4f} %
Pre-Scaled Ps3 SHMS Computer Dead Time : {100.0 - (pcut_TRIG3.npassed / (P.pTRIG3.scaler/gpconfig_ti_ps_factors[2]))*100.0:%3.4f} %
```

TEMPLATES/SHMS/PRODUCTION/pstackana_production.template

F2/EMC/X>1 Computer Live Time

- F2/EMC/X>1 all ran with single trigger type
  - EL-REAL ➛ p(h)TRIG2
  - EL-CLEAN ➛ p(h)TRIG3
- Extremely convenient as it greatly simplifies the CLT calculation
- SHMS 21° degree data look good
- No difference observed in the ET and TDC (albeit incomplete) calculation of the CLT
- Any high rate runs should be carefully investigated if utilizing the TDC method
- Any short, low rate runs should be checked for EDTM biasing

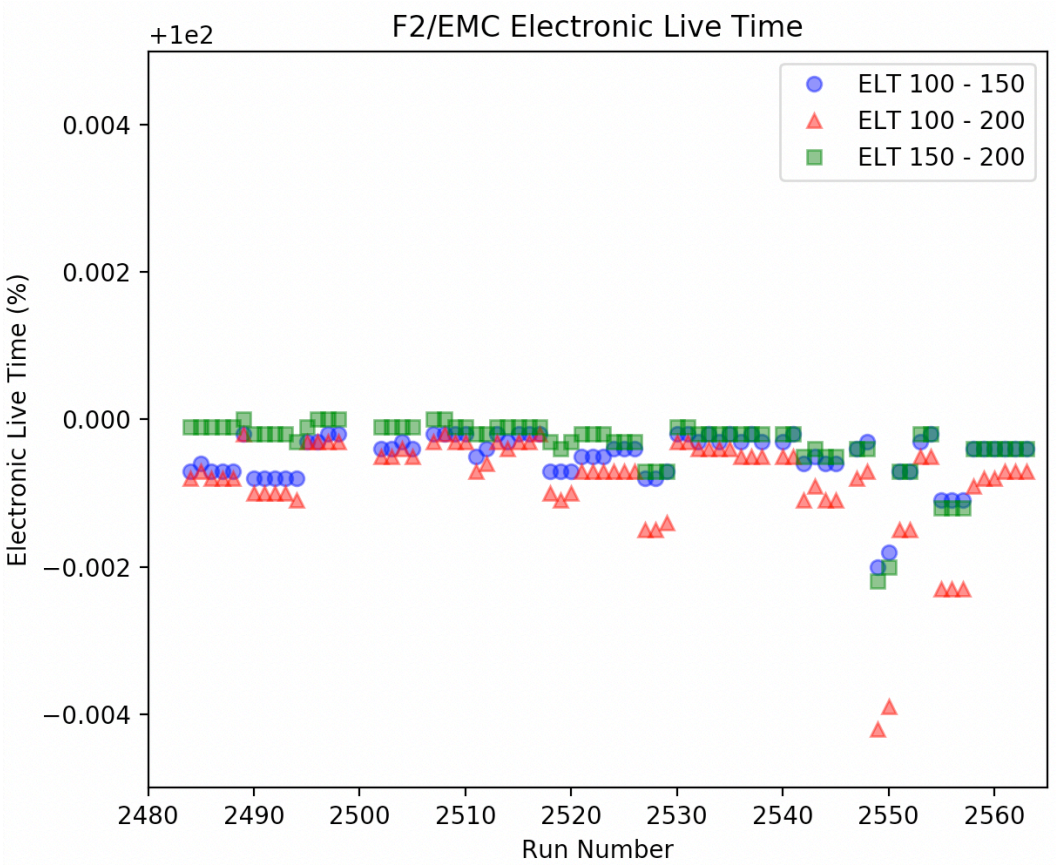




F2/EMC/X>1 Electronic Live Time

- Currently, the ELT is calculated utilizing a method utilized in the 6 GeV era
  - Vahe's Thesis, 2010
- Trigger scalers of varying gate widths (50, 100, 150, 200 ns) are recorded
- A linear extrapolation back to zero gate width gives the total number of triggers that were incident to the electronics
- Rates during F2/EMC were not high enough for the ELT to contribute to the overall dead time

$$\frac{N_{measured}}{N_{total}} = \frac{\left(PRE_{100} - PRE_{150}\right)}{PRE_{100}} \approx 1 - R\tau$$



F2/EMC/X>1 Total Live Time

- The EDTM can be utilized to measure the total live time of the system
- With knowing the CLT, one can infer the ELT $\rightarrow TLT = CLT \cdot ELT$
- The TLT can be measured offline or in the report file
- Measured in identical way as the CLT was measured utilizing TDCs
  1. Ensure that EDTM events are being decoded
  2. Define hit selection window for the EDTM variable T.(s)hms.(p)hEDTM_tdcTimeRaw in PARAM/TRIG/t(p)hms.param
  3. Define a "cut" variable in DEF-files/SHMS/PRODUCTION/CUTS/pstackana_decode_cuts.def on the self timing peak in the reference time subtracted distribution T.(s)hms.(p)hEDTM_tdcTime
  4. Be sure to place cut so as to include only beam on conditions
  5. Define ratio of software scaler to hardware scaler to calculate the TLT

$$TLT = \frac{T_{EDTM}}{S_{EDTM}}$$

Looking Forward

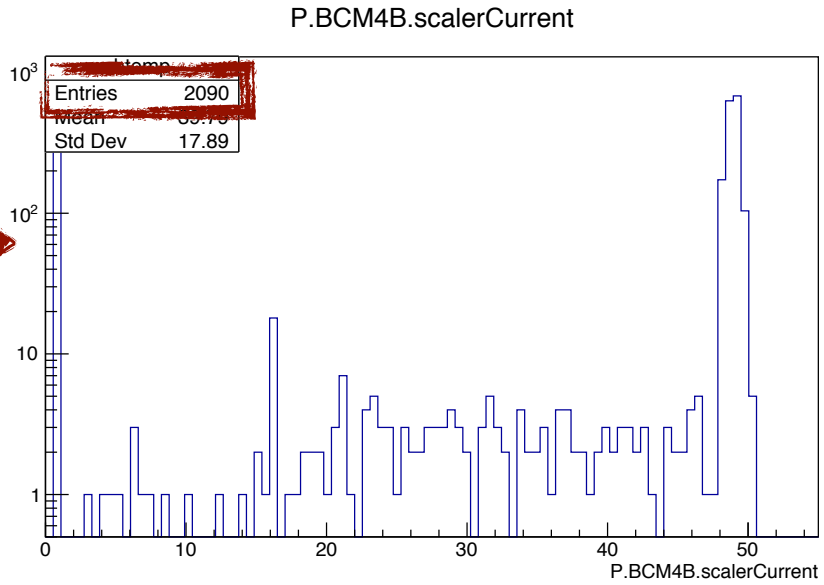
- The CLT as calculated from ETs gives identical result to that of the CLT as calculated from TDCs albeit the TDC calculation is incomplete at the moment
  - Relatively low rates and a clean trigger simplified things greatly
- The ELT reported in the report file is calculated in the identical manner as it was done during the 6 GeV era
  - Given the rates for F2/XEM/X>1, EDT should not be an issue
- Any high rate runs should be sanity checked for EDT
- Any short, low rate runs where the EDTM could have biased the CLT measurement should be sanity checked
- Overall, the live time measurements look good to first order
- So long and thanks for all the fish!

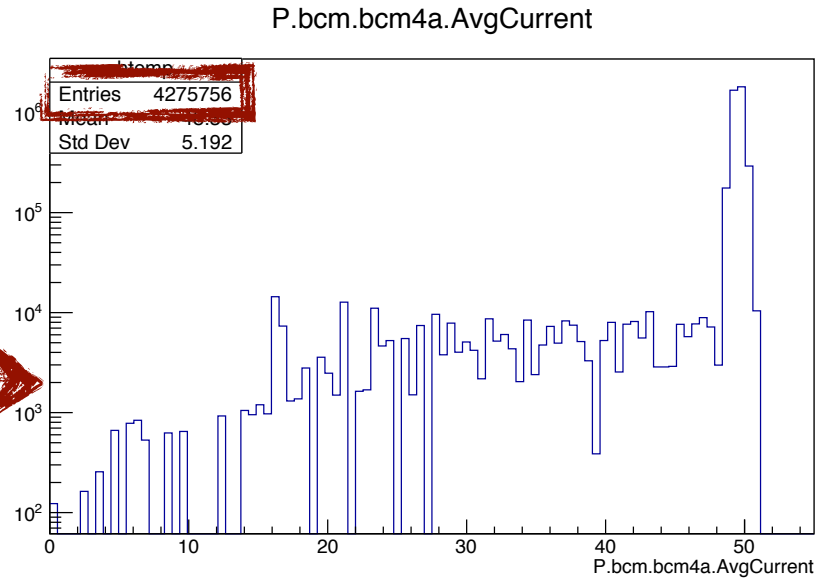
HaII-C F2/EMC Collaboration Meeting

Backup Slides

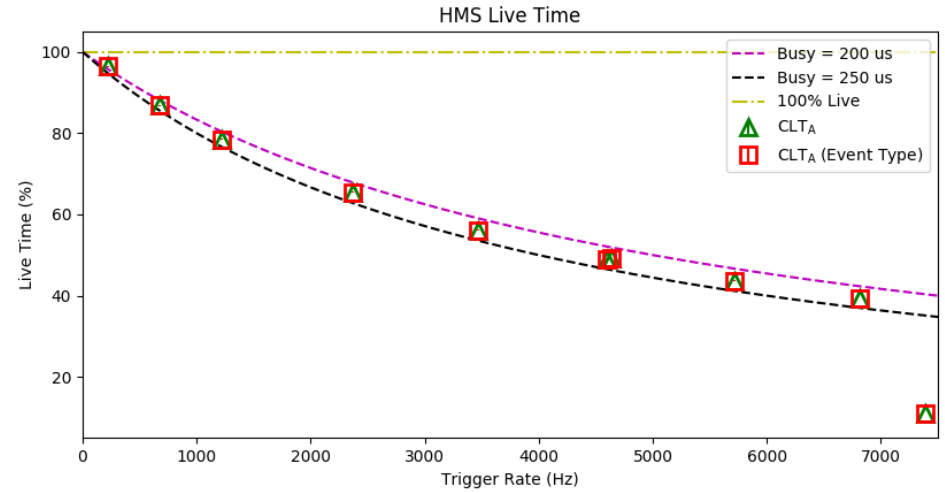
Setting Up the Replay: BCM Module

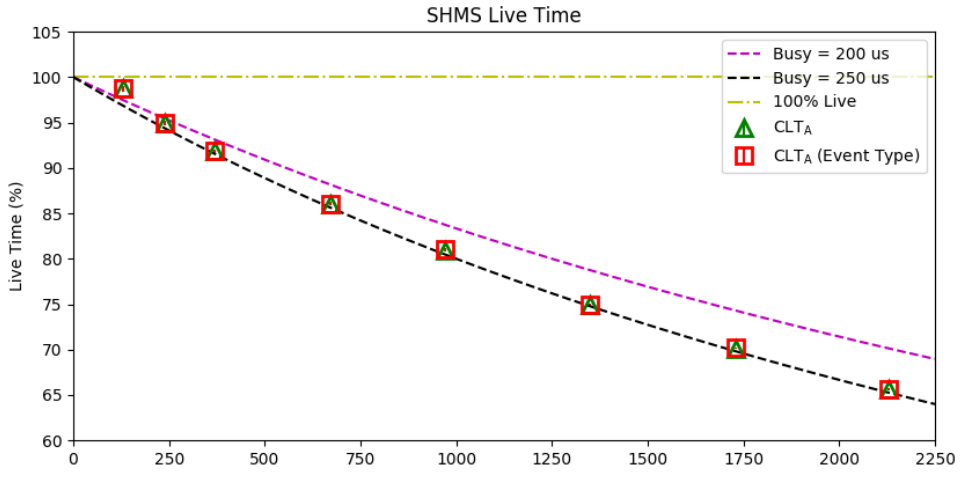
- Add average BCM current values into the event tree (T)
- Execute full scaler replays to obtain BCM current values in scaler tree (TSP or TSH)
- Create BCM parameter files
- Include BCM parameter file in DEF-file (P.bcm.* or H.bcm.*)
- Include path to the BCM parameter files in replay script
- Add BCM module to replay scripts
- Replay data to include average BCM values into event tree
- Sanghwa's Slides

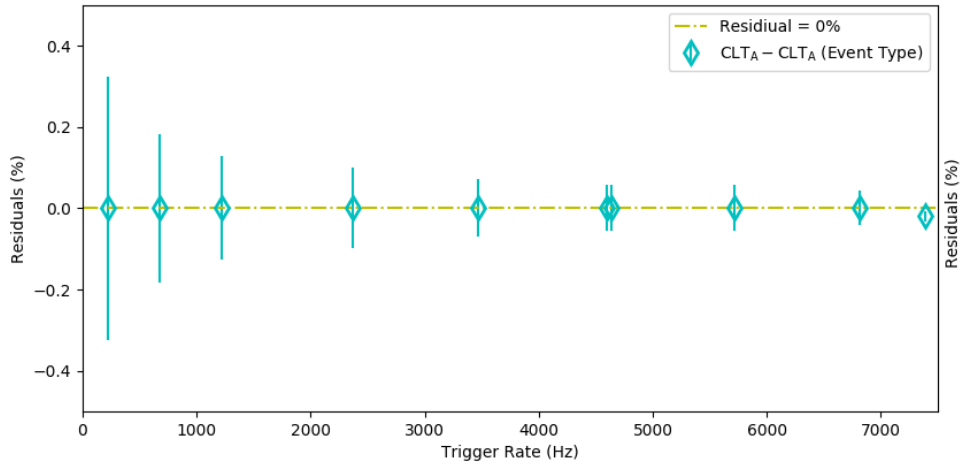


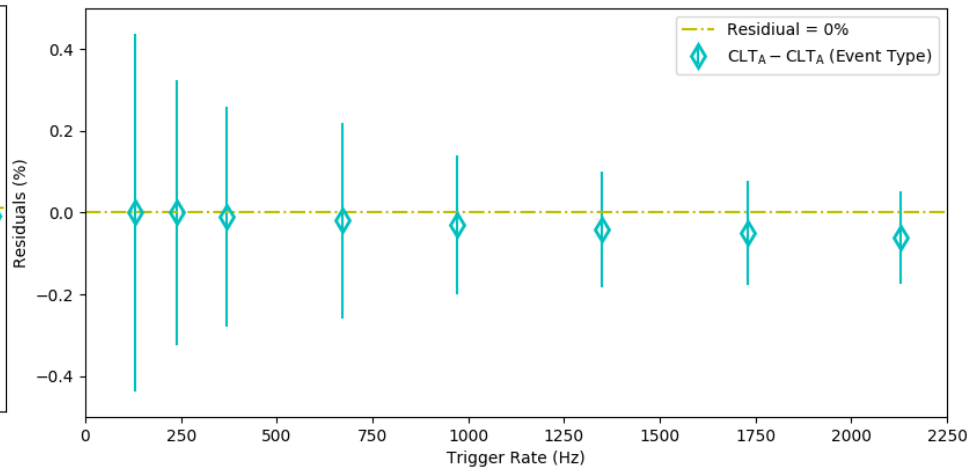


Live Time Results: CLT_A & CLT (Event Type)

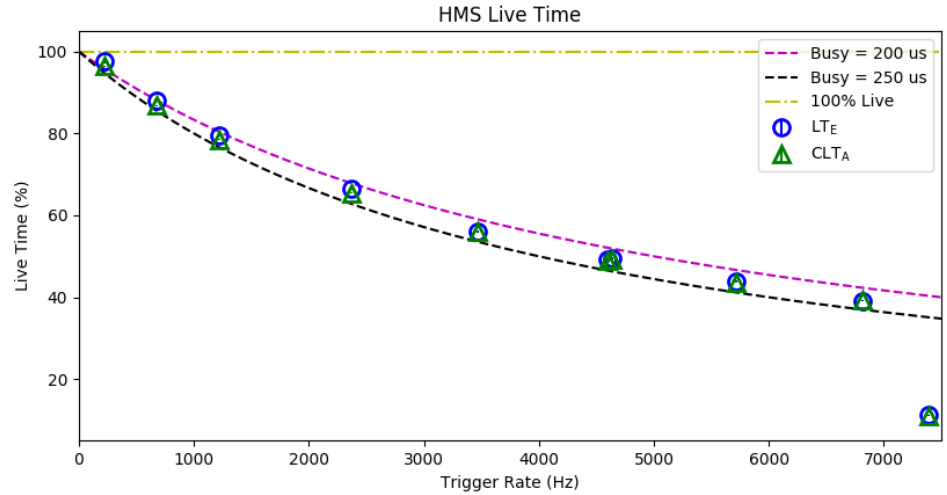


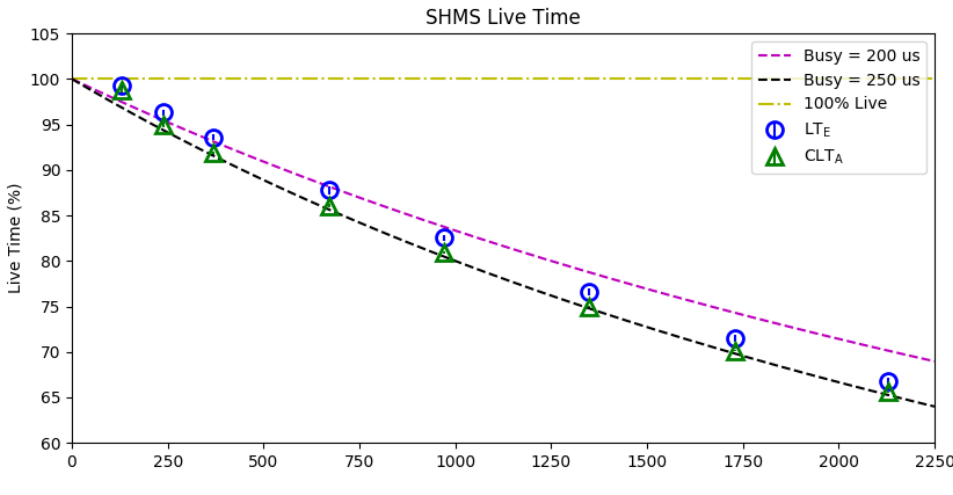


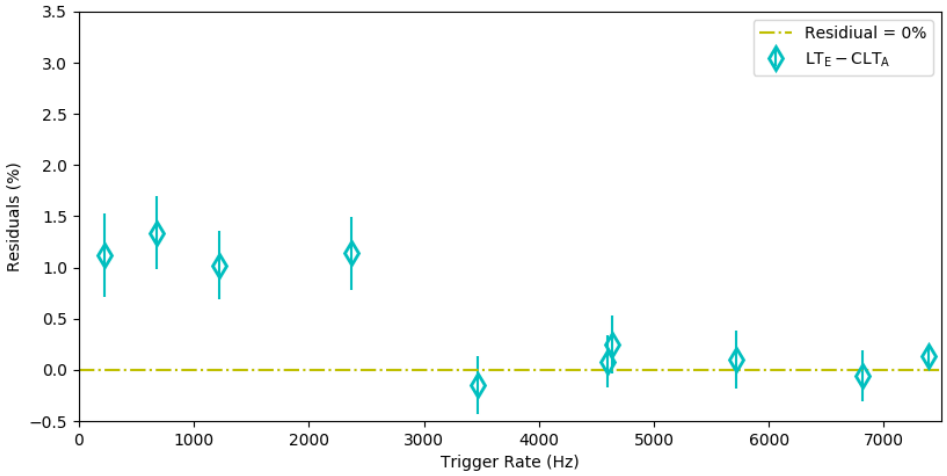


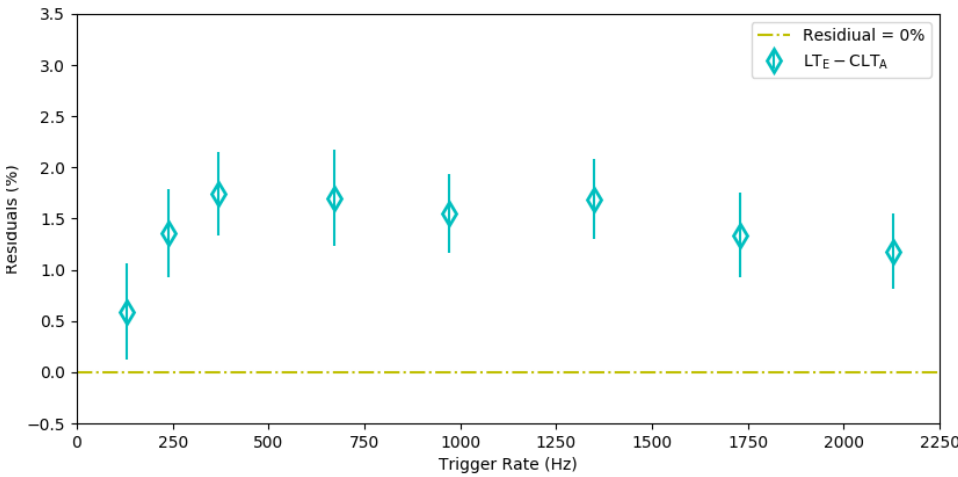


Live Time Results: LT_E & CLT_A









Slide Title