Update:
2020 Intensity Analysis and Simulation chi2

UT/ORNL n → n’ Group Meeting
08/31/2023
Cary Rock

Previously Identified Problems

1) Calibration data fits with 6 data points show a large chi2/DOF.

2) Corresponding PHITS simulations show a chi2/DOF that is too small.

1.) Measurement Data Used for Fit

All measurements were made in the FROI of the 18-24 PC runs.

Each run was ~20 minutes with an integrated proton intensity of ~1.7 C and the “4-Fit” background subtraction scheme.

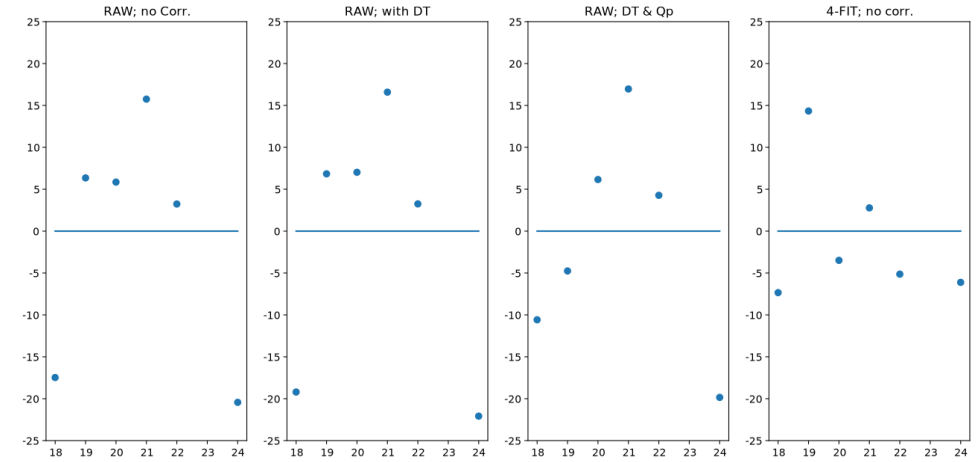
Measured rates are corrected for beam charge and detector deadtime.

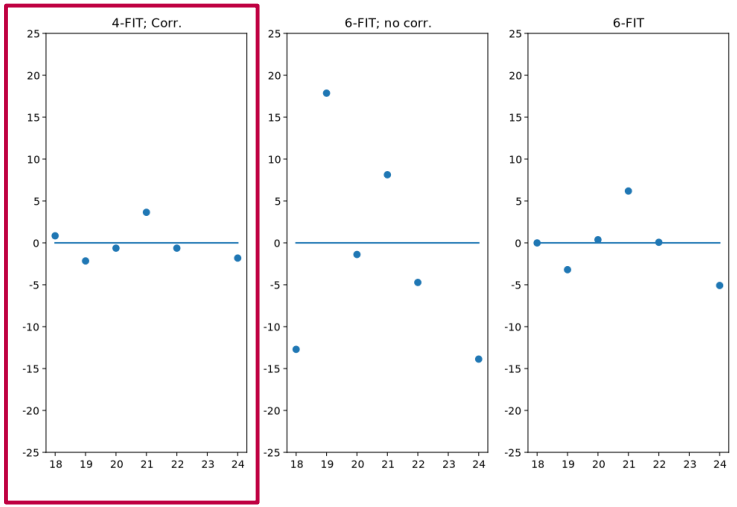
Errors include: statistical, systematic of the background subtraction, and the RMS of the beam intensity.

We think that the correction for detector efficiency is not necessary since the calibration and detection were made with the same detector, provided that the spectrum for the calibration and the spectrum for the measurements are the same (“which is almost true”).

# PC	Rate / C	Total Err / C
18	1697895.2	2900.1
19	1137354.1	2500.2
20	754367.2	1841.0
21	495483.4	1697.2
22	334968.3	1567.2
24	150457.2	1344.6

Residues of the Measured Fits





Best fit

Observation: 21 PC point is consistently high
Conclusion: 21 PC measurement is an outlier

Two possible scenarios to remedy:

1.) Remove this point and use 5 points to fit instead of 6

2.) Increase all fit errors by a factor of ~1.22 as “unaccounted factor” in systematic contributions.

5-Point (no 21 PC) Fit & 6-Point Fit

			χ^2/DOF	F_0 n/C	$\pm$ n/C	η	$\pm$
	6 points	Minuit	5.63	2.5798×10^9	0.0402×10^9	0.66569	0.00054
	6 points	Likelihood	5.64	2.5780×10^9	0.04×10^9	0.66572	not calc
	6 points	Interval 68%		$(2.541\text{-}2.580\text{-}2.621) \times 10^9$			
	5 points	Minuit	1.51	2.5002×10^9	0.0429×10^9	0.66684	0.00060
(1)	5 points	Likelihood	1.51	2.5000×10^9	0.0425×10^9	0.66684	Not calc
	5 points	Interval 68%		$(2.460\text{-}2.501\text{-}2.545) \times 10^9$			
	6 points >σ	Minuit	1.02	2.5001×10^9	0.0524×10^9	0.66684	0.00073
(2)	6 points >σ	Likelihood	1.02	2.5000×10^9	0.0520×10^9	0.66684	Not calc
	6 points >σ	Interval 68%		$(2.451\text{-}2.501\text{-}2.545) \times 10^9$			

For bottom set of 6-Points, increase of error terms by 1.22x

Either option 1) or 2) yields identical fit results and nearly identical confidence intervals.

2.) PHITS Simulations – Too Small Chi2

Previous fits to simulation data were resulting in suspiciously good chi2 values for F0 and eta.

chi2/(6-2 DoF) = 0.078 => prob = 0.0235 → suspicious

To check: something in the pRNG-aspect of PHITS is not behaving as we expect (not Poisson-like behavior).

Random Number Generation in PHITS: `batch.out`

```
0 <--- number of remaining batches

------------------------------------------------------------------------------
bat[       1] ncas =     1000000000.
 bitrseed = 11111001011101100110000100000001011110111000010110001110000010110
          cpu time =  72 h. 31 m. 32.47 s.

 date = 2023-08-30
 time = 00h 27m 38s

------------------------------------------------------------------------------
next initial random seed:
 bitrseed = 10010110110011101100100101000010100010101111110101000101011010 10
```

PHITS reports the seed that was used to generate the “batch” (either the piece of the total desired runs, or the entirety of the run). Consecutive batches use the “next initial random seed”.

First clue: *this output seed was always the same.* If we’re always starting from the same initial seed, there may be correlations across runs.

100 Runs of Sequential Seeds – 24 PC

Question to answer: what is the behavior of consecutive seeds?

- PHITS has the capability of running in “batches”: the output seed from the previous bunch of neutrons will be used as the initial seed of the next bunch of neutrons.
- Ran 1e9 neutrons in 100 batches (1e7 / batch) and recorded the generated seeds.
- 100 individual, separate runs were then started with those seeds as their individual starting seeds.

The number of neutrons in the FROI of each of these runs was recorded. The average and standard deviation were then computed, as well as the errors in each, and then compared.

100 Runs of Sequential Seeds – 24 PC

```
ave           = 104.53 +/- 0.941
var of ave    =              0.941
stddev        = 9.409
```

sqrt(ave) ~= 10.224,
stddev / sqrt(2 * 100) ~= 0.665 => 9.409 + 0.665 = 10.071

10.224 – 10.071 > 0 => More than 1 sigma difference

The average is ~100x smaller than usual values for 24 PC at 1e9 initial neutrons, including error in average.

Conclusion: Still follows Poisson behavior. This is not the confounding factor

Final check: sequential seeds for each simulation.

Full Simulation Run: 18 – 24 PC with Unique Seeds

Instead of running simulations with the same initial seed for all 6 trials as had been done previously, do as the 100 Seeds runs and use sequential seeds for each.

Each run uses the “next initial random seed” of the previous (i.e., 18 → 19 → 20, etc.) as if the number of PC plates was changing in one large simulation of 6e9 initial neutrons in 6 batches of 1e9.

Full Simulation Run: 18 – 24 PC with Sequential Seeds

PC	FROI Count	Error
18	109715.000	331.232544
19	74567.0000	273.069580
20	50084.0000	223.794556
21	33702.0000	183.581039
22	22731.0000	150.768036
24	10369.0000	101.828293

```
 FUNCTION MUST BE MINIMIZED BEFORE CALLING MINOs
PARAM  1-2          1.312256E+08      0.674641
ERRORS 1-2          3.041079E+06    0.000990
CHI^2                 0.686416
```

Sequential Initial Seeds

PC	FROI Count	Error
18	109232.000	330.500000
19	73706.0000	271.500000
20	49692.0000	222.899994
21	33452.0000	182.899994
22	22637.0000	150.399994
24	10327.0000	101.599998

```
 FUNCTION MUST BE MINIMIZED BEFORE CALLING MINOs
PARAM  1-2          1.303096E+08      0.674639
ERRORS 1-2          3.037020E+06    0.000994
CHI^2                 0.078947
```

Same Initial Seed

Prob. of chi2/DoF = 0.686 ~= 0.609

Starting hypothesis: for the same seeds, the first 18 PC of any given run will simulate “statistically” the same (in a loose sense of “statistical”). Likewise, all 19 PC and later runs are all similarly correlated. Thus, correlation is artificially suppressing chi2 / DoF.

Conclusion: a larger chi2 is seen for the simulations that do not share the same initial seed.

00PC Correction Factor

One last 00PC run was performed using the output seed from the 24PC run and the number of noninteracting points taken @ 1e9 initial neutrons:

162,442,447 in 00PC FROI

131,225,600 F0 from Fitting

sqrt(00PC + Fitting) Error / (F0 from fitting) => 0.00013

Ratio: 00 PC / Fit F0 = 1.23787 +/- 0.00013

Normally this would have been done @ 1e8 initial neutrons, but I accidentally left the setting @ 1e9.

Initial Intensity

For the experiment data's F0 fit of 2.500, and using a factor of 1.23787, the initial intensity is:

3.09468e9

Using 6 PC error (0.0524), the error is:

+/- 0.05240e9

Using 5 PC error (0.0429), the error is:

+/- 0.04290e9

END