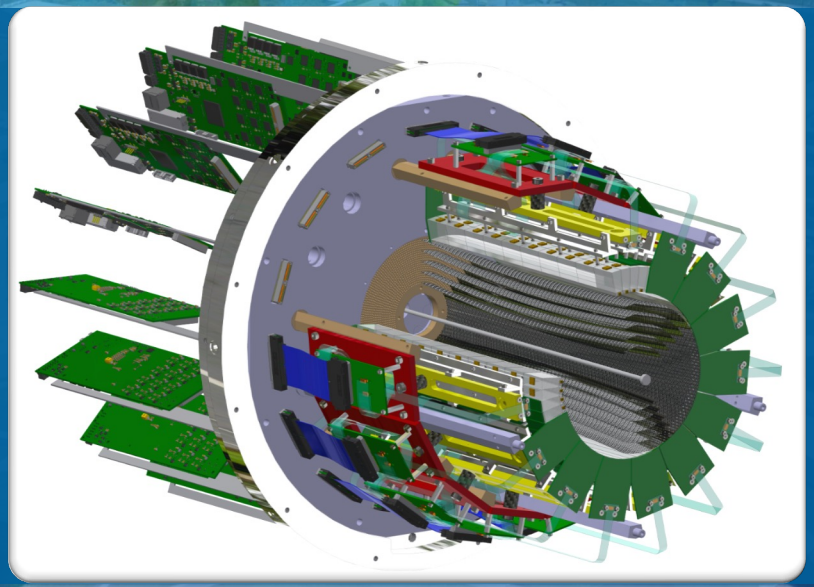
ALERT ATOF Calibration Update



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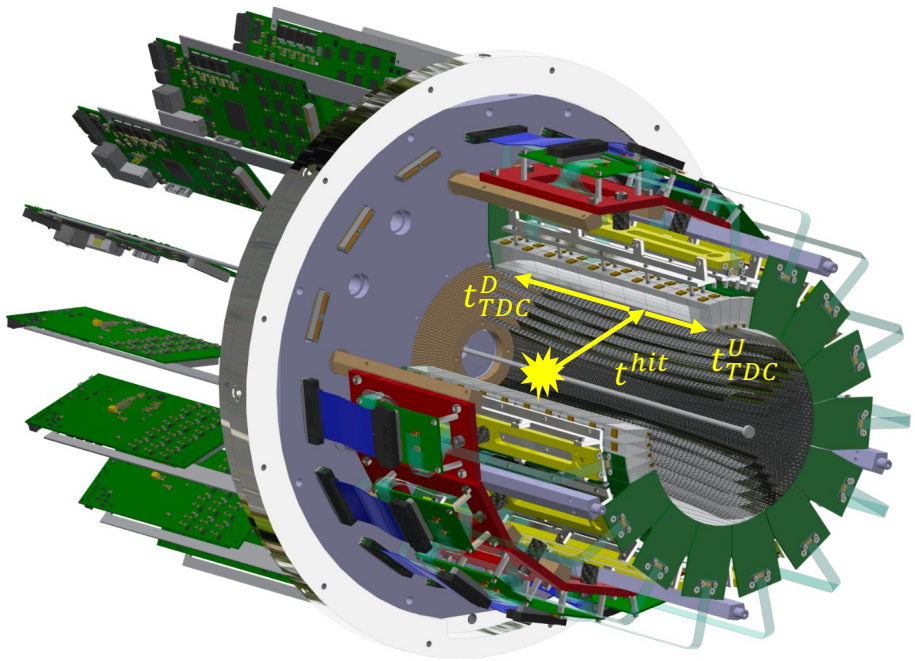
Argonne National Laboratory
06/30/25

ATOF Calibration

Calcode: https://code.jlab.org/hallb/clas12/calibration/calcode/-/tree/main

JLab gitlab:https://code.jlab.org/hallb/alert/atof/atof-timeline



- Bar & wedge hit time (t^{hit}) from Up/Downstream end (✓):
  - $t^{D(U)} = t^{D(U)}_{TDC} - t_{vertex} - t^{D(U)}_{TW} \mp t_{UD} - \frac{L-z}{v_{eff}}$
  - $t^{hit} = \frac{1}{2}(t^{U} + t^{D}) + c_{b2b}$
  - $z = (t^{U} - t^{D})v_{eff}$
- Wedge hit time (t^{hit}) has 10 z components (✓):
  - $t^{hit} = t^{w}_{TDC} - t_{vertex} - t^{w}_{TW} - \frac{h}{v_{eff}} + c_{w2w}$

★ Timeline calibration: 2nd iteration on CCDB constants.

— Wedge & Bar Time

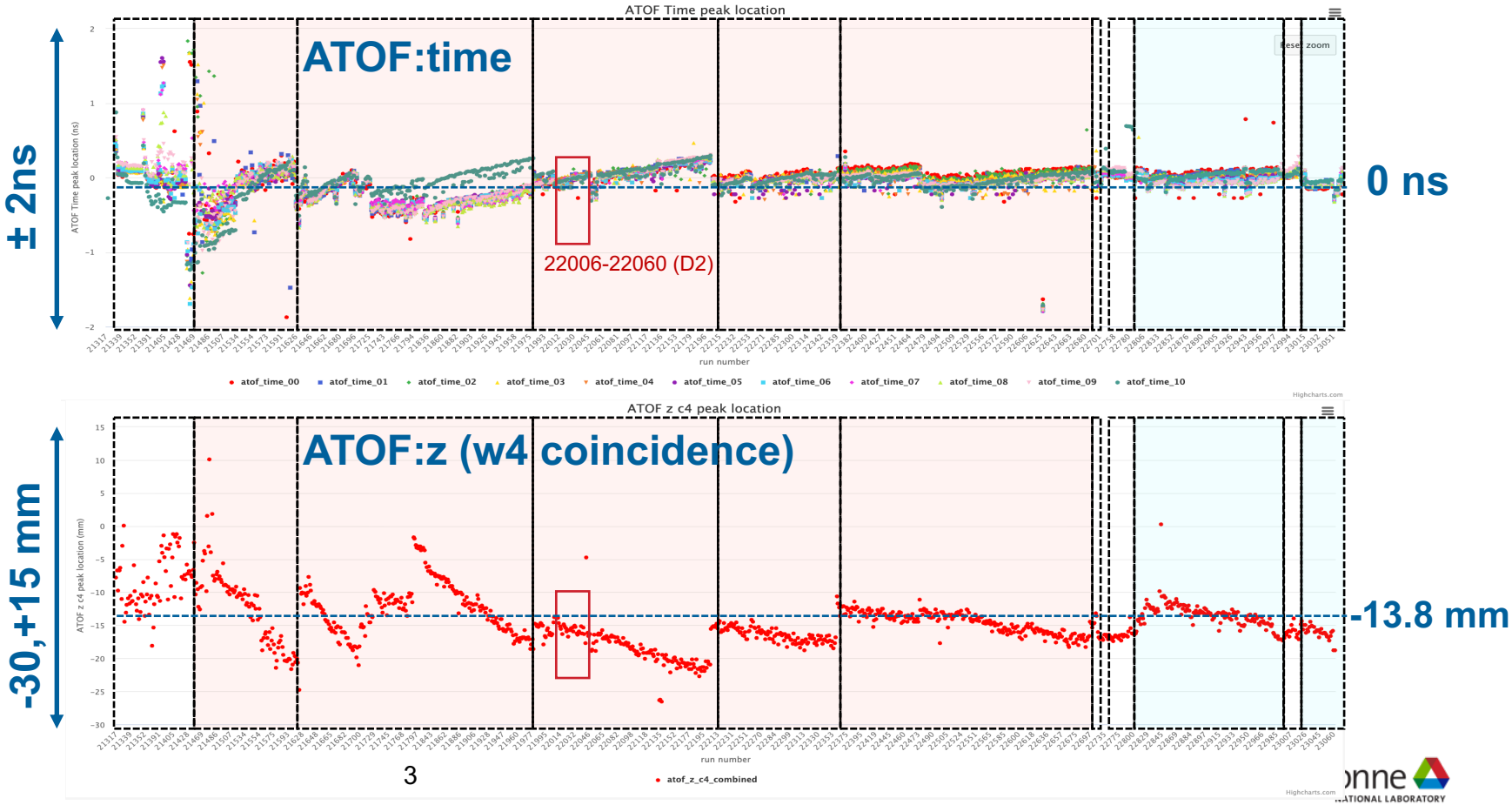
— Bar z

RG-L timeline

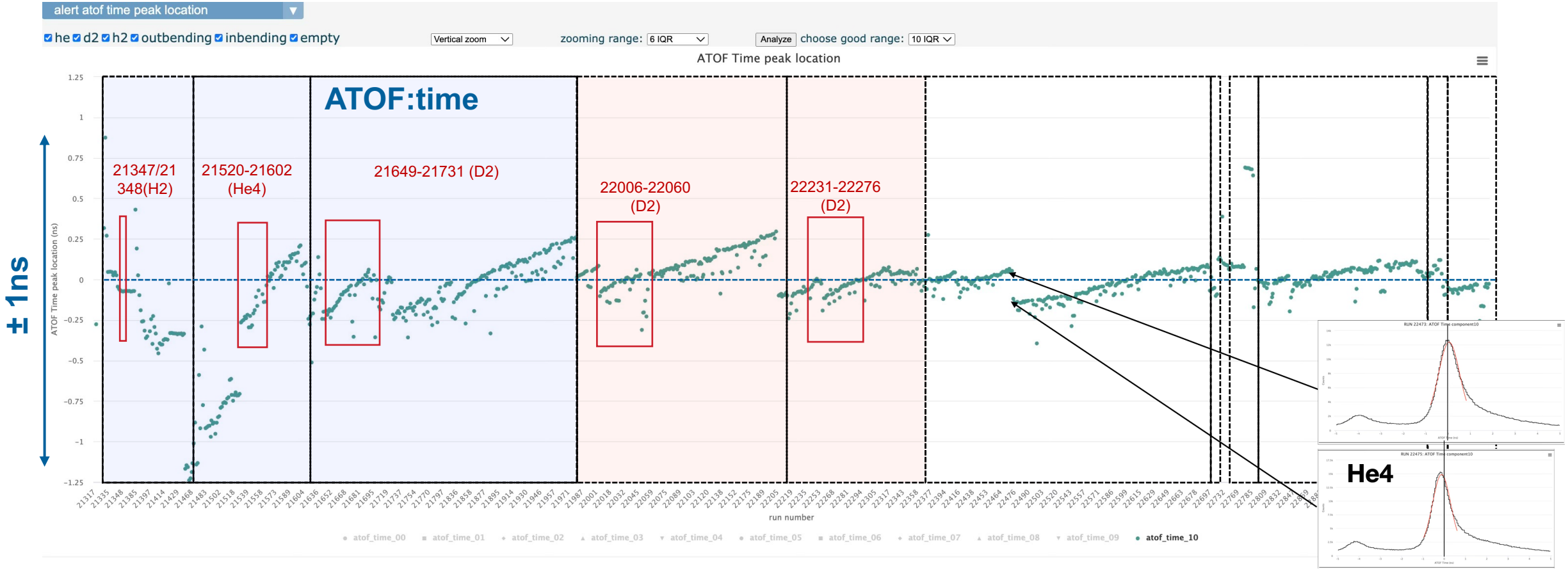
Timeline v10.3 (April) and CCDB constant

- Recall: The RG-L ATOF timeline was divided into **11 run periods**, each with its own set of CCDB constants.
- In reconstruction, we implemented CCDB constants to the **ATOF::time** bank for t^{hit} and bar z
  - These constants provide **a rough alignment** for bars and wedges in azimuthal slices

	Start	End	CCDB data
1	21310	21435	Full 21347, 21348 (H2)
2	21436	21611	21520-21602 (He4)
3	21612	21978	21649-21731 (D2)
4	21980	22204	22006-22060 (D2)
5	22205	22358	22231-22276 (D2)
6	22359	22693	22541-22610 (D2)
7	22694	22708	22697-22708 (H2)
8	22709	22791	Full 22784 (H2)
9	22792	22980	22795-22804 (H2)
10	22981	23015	Full 23012 (H2)
11	23016	23065	23028-23056 (He4)



Timeline for ATOF time peak



- Observed split points between subperiods, with increasing shift in each.
- The selected range for constant calculation remains ~0 ns.

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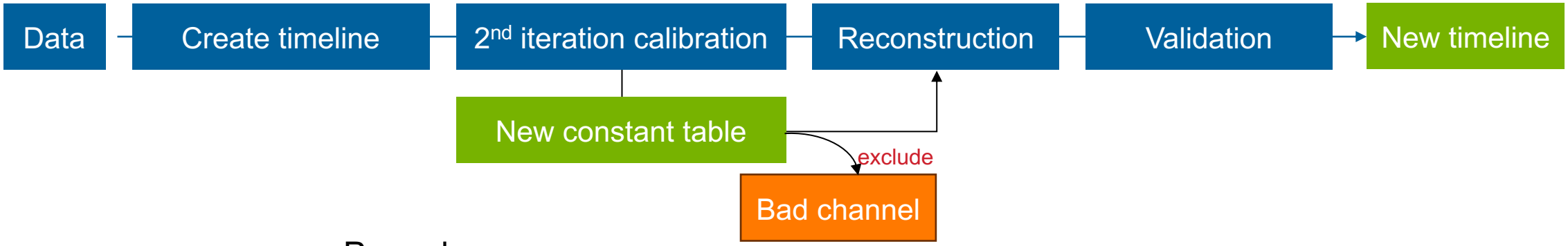
ATOF Calibration

2nd iteration on timeline calibration

- Possible source for increasing trend & split-point: (physics) radiation damage, (operation) run conditions, DAQ issues, or target changes, HV/gain change during the RG-L running, (QA) bad runs and restart.
- Approach: Develop an offline ATOF timeline calibration toolkit. https://code.jlab.org/hallb/alert/atof/atof-timeline



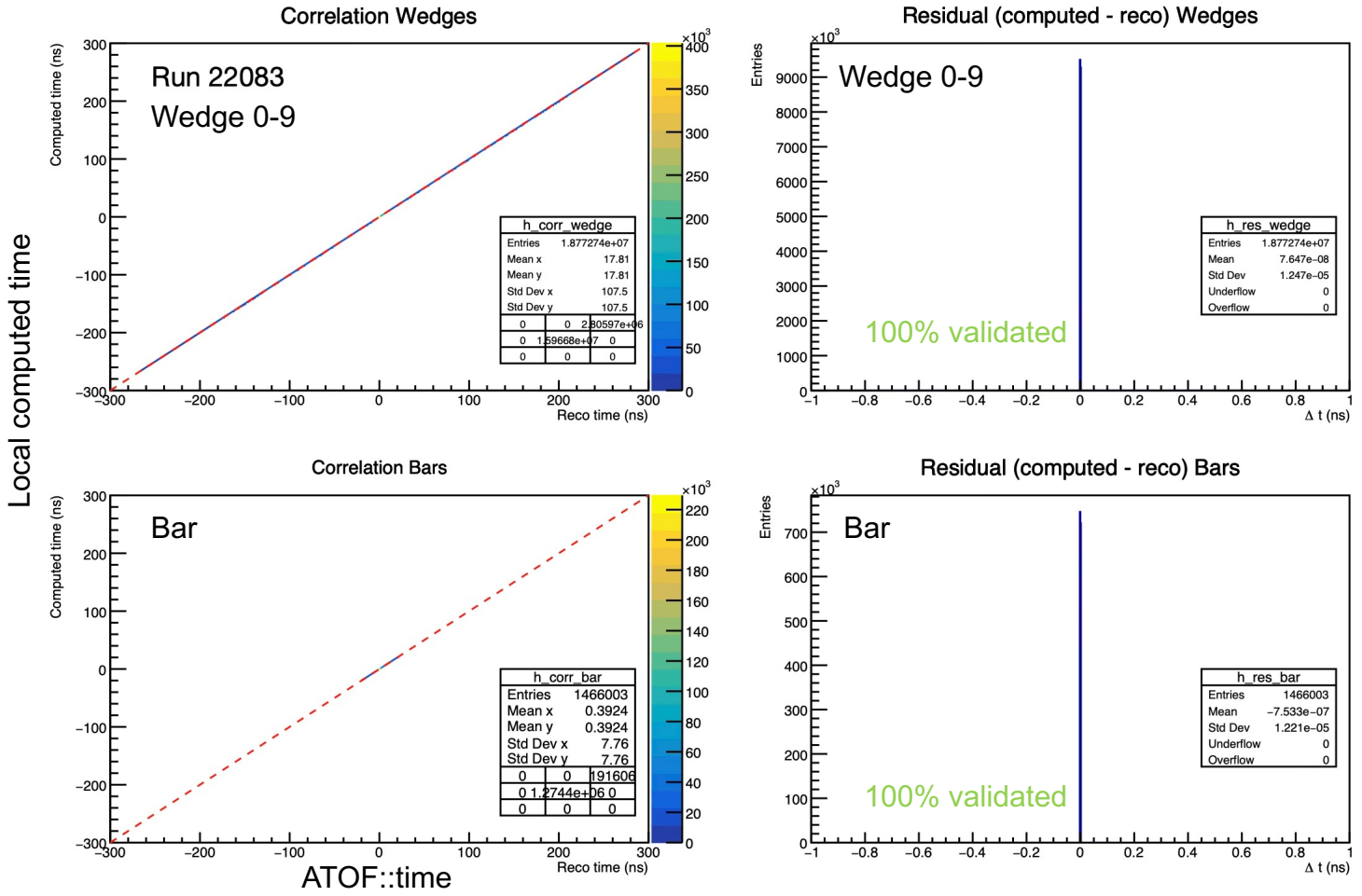
Procedure:

1. Reconstruct time (ATOF::time) based on TDC (ATOF::hit) the same as CJ.
2. Timeline from Crystal Ball function fitting can better locate the time peak.
3. Apply the timeline calibration inside each run subperiod with a linear function. Identify bad channels. Generate updated constant table in CCDB format.
4. Validate the new time under the new constants, then compare the new timeline with old version.

ATOF timeline Calibration

Offline ATOF timeline calibration toolkit

- Reconstruction function validated (✓): read in CCDB table, locally computed t_{bar} and t_{wedge} from the TDC.



ATOF::time Equations in the CJ:

$$t_{\text{raw}} = \alpha_{\text{TDC}} \cdot \text{TDC} - t_{\text{start}}$$

$$t_{\text{wedge}} = t_{\text{raw}} - \frac{d_{\text{wedge}}/2}{v_{\text{eff}}} - t_0$$

$$t_{\text{down}} = t_{\text{raw}} + \frac{t_{ud}}{2} - \frac{t_0}{2}$$

$$t_{\text{up}} = t_{\text{raw}} - \frac{t_{ud}}{2} - \frac{t_0}{2}$$

$$z = \frac{v_{\text{eff}}}{2}(t_{\text{up}} - t_{\text{down}})$$

$$t_{\text{bar}} = t_{d/u} \pm \frac{z}{v_{\text{eff}}}$$

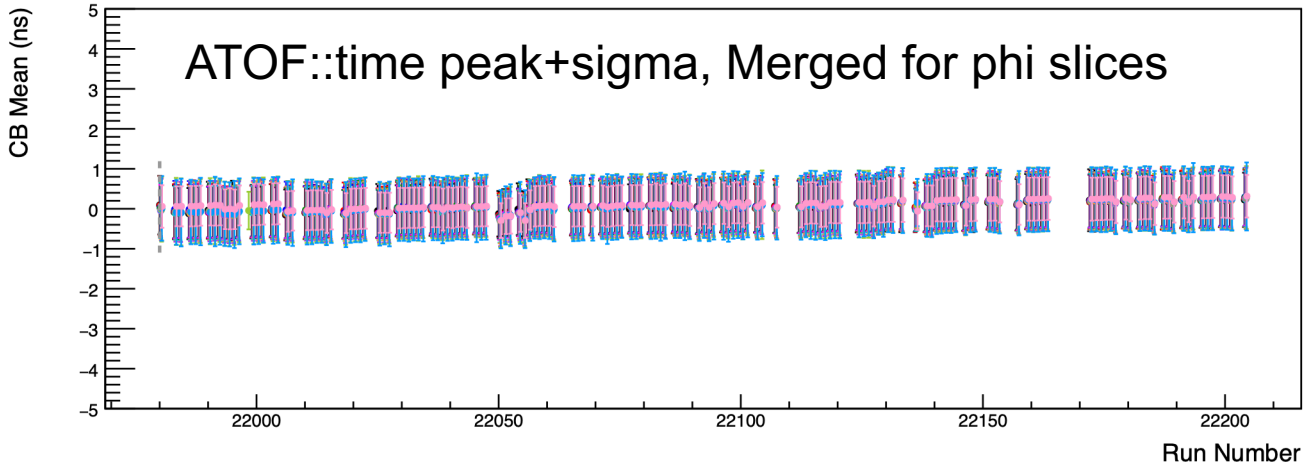
$$E_{\text{wedge}} = c_{\text{wedge}} \cdot \text{ToT} \cdot \exp\left(\frac{d_{\text{wedge}}/2}{\lambda}\right)$$

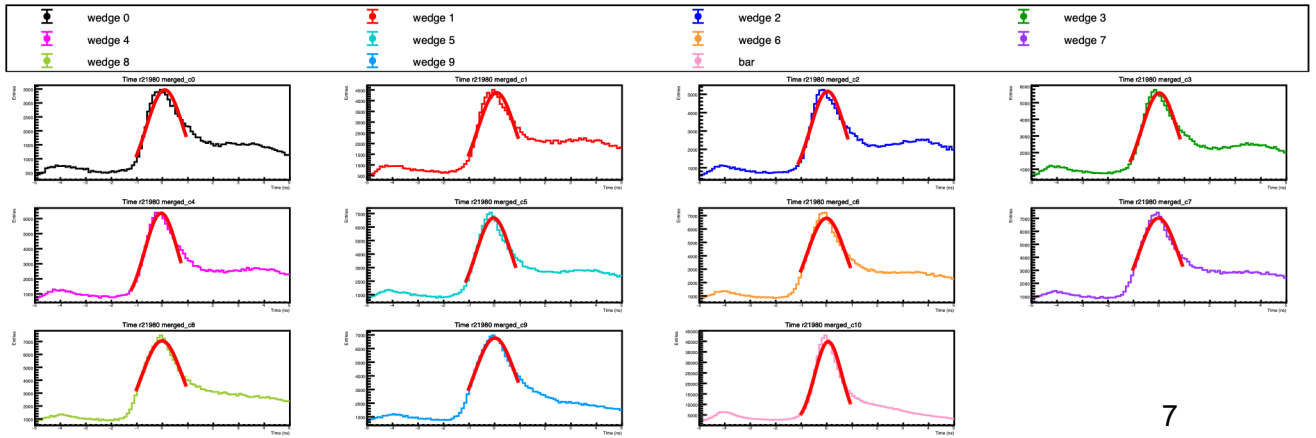
$$E_{\text{bar}} = c_{\text{bar}}\left[\text{ToT}_{\text{up}}\, e^{(L/2+z)/\lambda} + \text{ToT}_{\text{down}}\, e^{(L/2-z)/\lambda}\right]$$

ATOF timeline Calibration

1) Test 10 GeV run period (He4+D2): 21980-22204

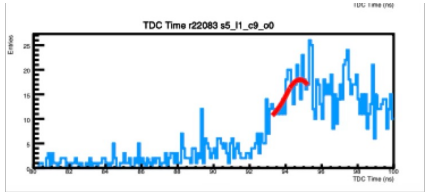
- Timeline function: Crystal Ball Function better describe the distribution.
- Still observe the increasing trend → Need timeline calibration.



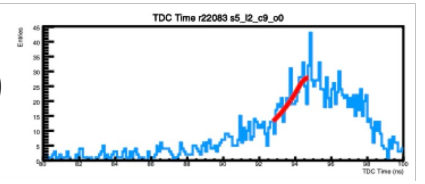


- Problematic channels (background peak dominated):

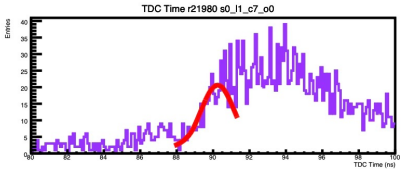
S5L1C9



S5L2C9



S0L1C7



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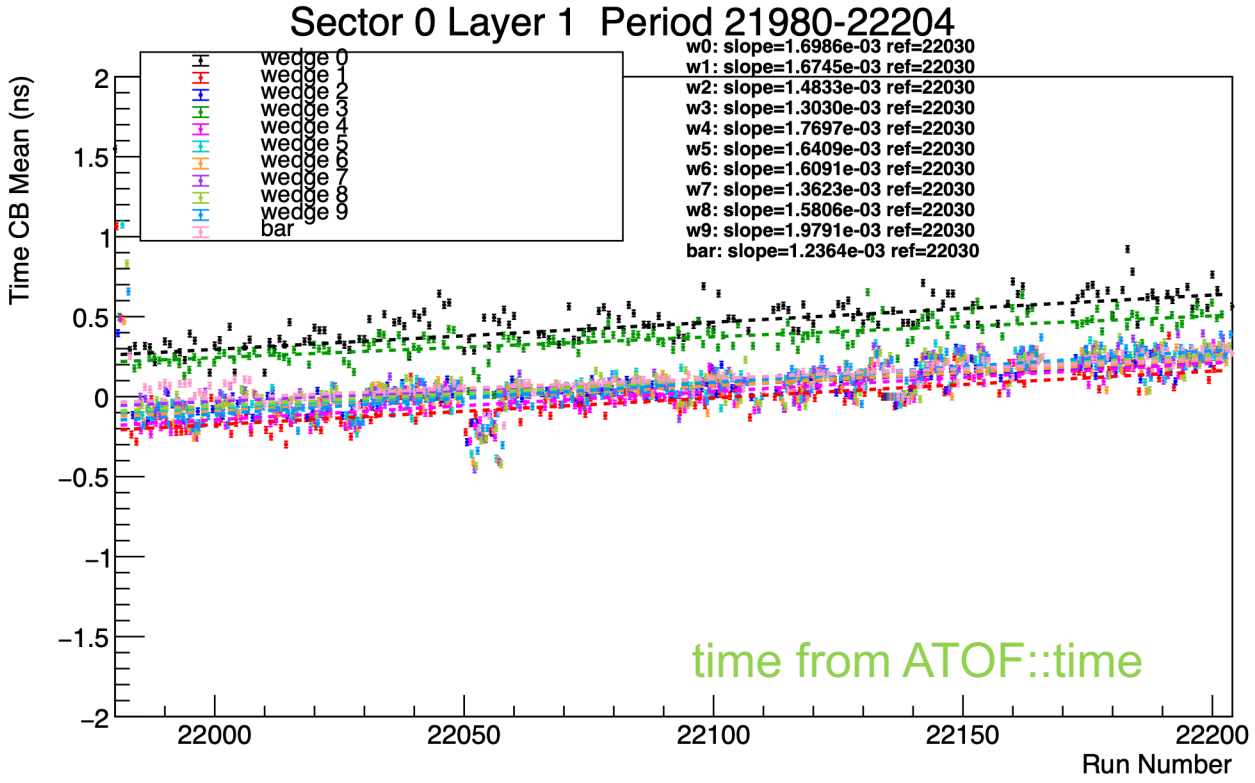
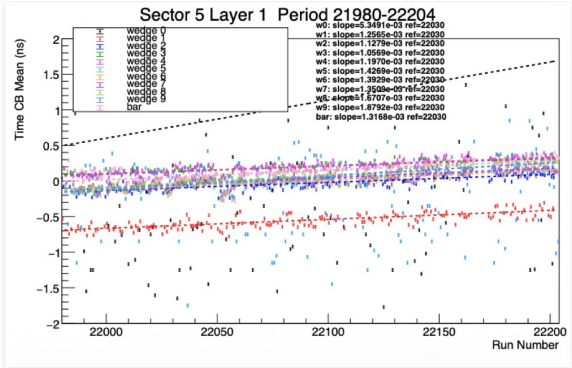
ATOF timeline Calibration

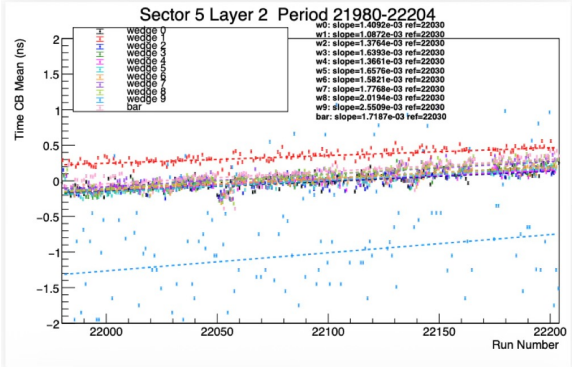
1) Test 10 GeV run period (He4+D2): 21980-22204

- Linear fit for each (sector, layer, component) channel: y= $k(N_i - N_{ref}) + b$



- Bad channels excluded:





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ATOF timeline Calibration

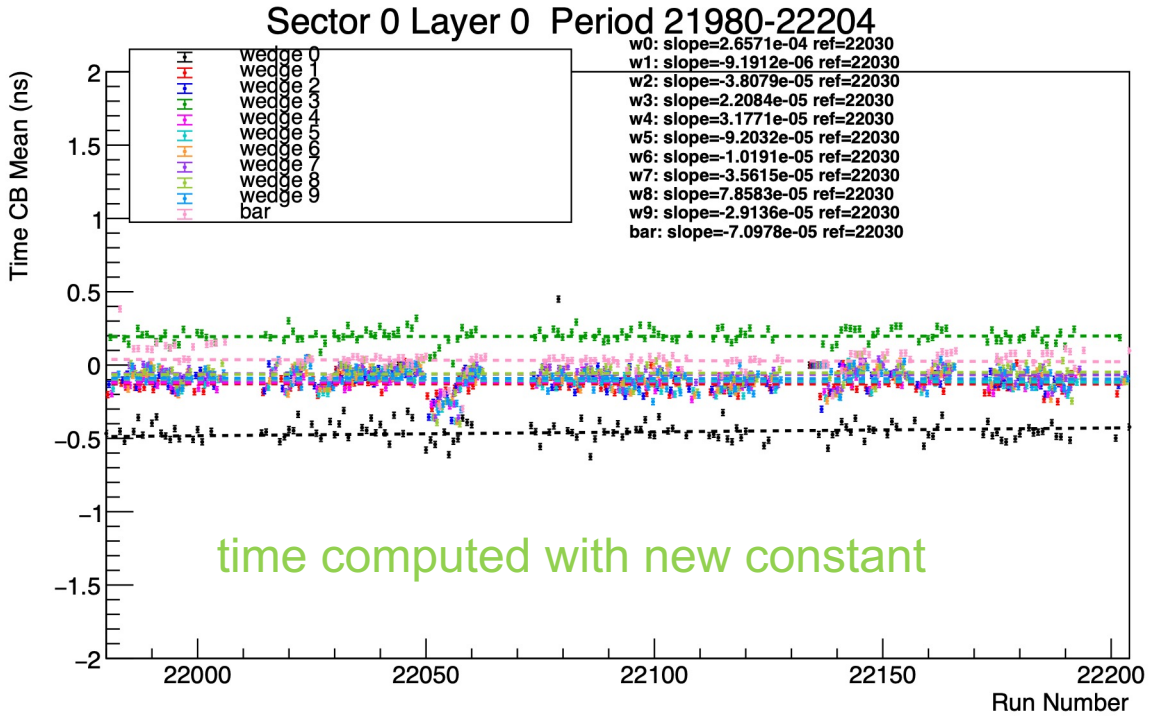
1) Test 10 GeV run period (He4+D2): 21980-22204

- 2 new constants (N_{ref} and slope k) updated to CCDB in last 2 column (extra1 extra2)
- Apply a Δt calibration: $t_{TDC}^{DUw} = t_{TDC}^{DUw}\big|_{old} + k(N_i - N_{ref})$
- Validation of the constants (✓): reconstruction from TDC + new timeline production: flat as expected.

```
=== Original CCDB (first 5) ===
0 0 10 0 182.937 2.006 0.000 0.879 1.154
0 0 10 1 182.937 2.006 0.000 0.879 1.154
0 1 10 0 183.744 3.141 0.000 0.933 1.128
0 1 10 1 183.744 3.141 0.000 0.933 1.128
0 2 10 0 181.202 1.964 0.000 1.078 1.596

=== Updated (first 5) ===
0 0 10 0 182.937 2.006 0.000 0.00124434 22030
0 0 10 1 182.937 2.006 0.000 0.00124434 22030
0 1 10 0 183.744 3.141 0.000 0.00123643 22030
0 1 10 1 183.744 3.141 0.000 0.00123643 22030
0 2 10 0 181.202 1.964 0.000 0.00095819 22030

=== Original wedge ===
0 0 0 0 88.116 0.000 0.000 0.942 0.000
0 0 1 0 89.132 0.000 0.000 0.725 0.000
0 0 2 0 89.320 0.000 0.000 0.693 0.000
=== Updated wedge ===
0 0 0 0 88.116 0.000 0.000 0.00101335 22030
0 0 1 0 89.132 0.000 0.000 0.00092901 22030
0 0 2 0 89.320 0.000 0.000 0.00096250 22030
```



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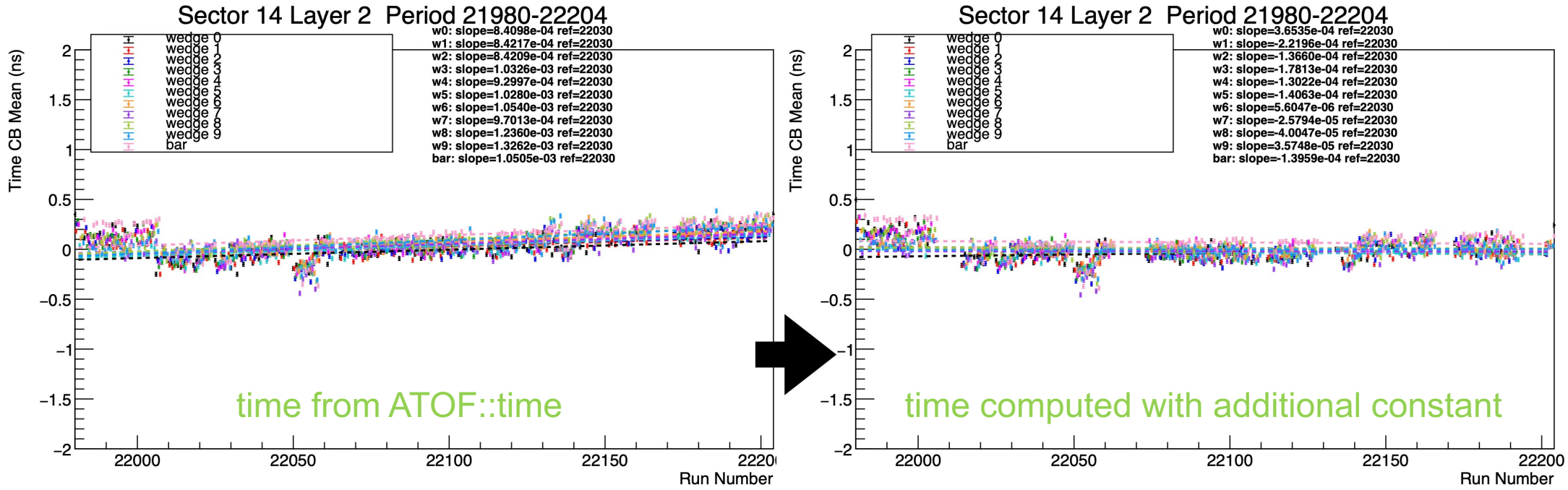
ATOF timeline Calibration

1) Test 10 GeV run period (He4+D2): 21980-22204

- Some modules present a jumpy sub-period: S14L1/2/3 S8-L0.
  The Run log shows: changing target from D2→He4 at ~ 22000.
- The small dip at 22050 are low luminosity runs from run log.
- Still, the vast majority is brought to flat.



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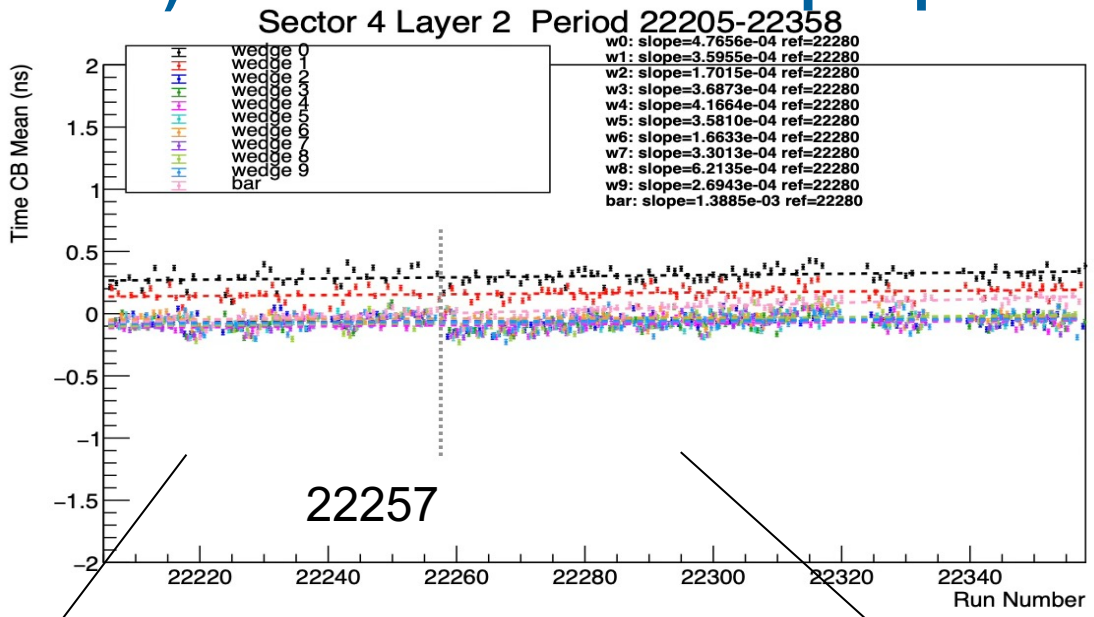
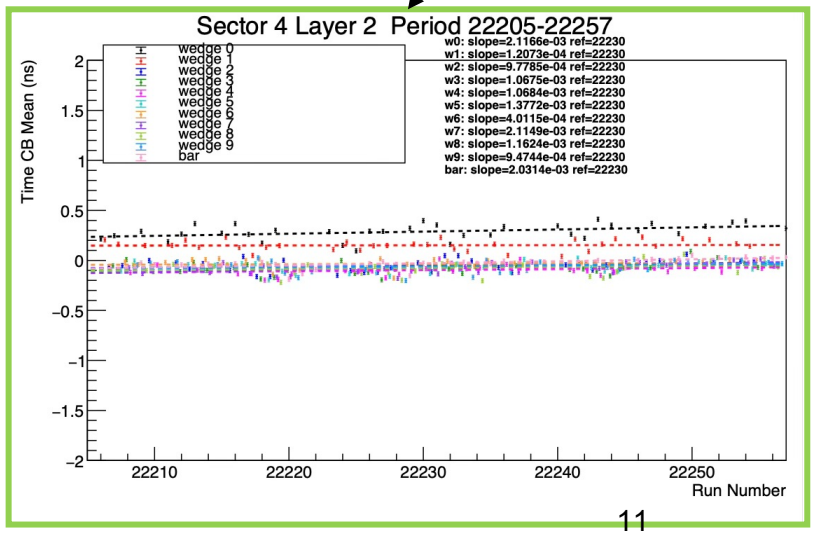
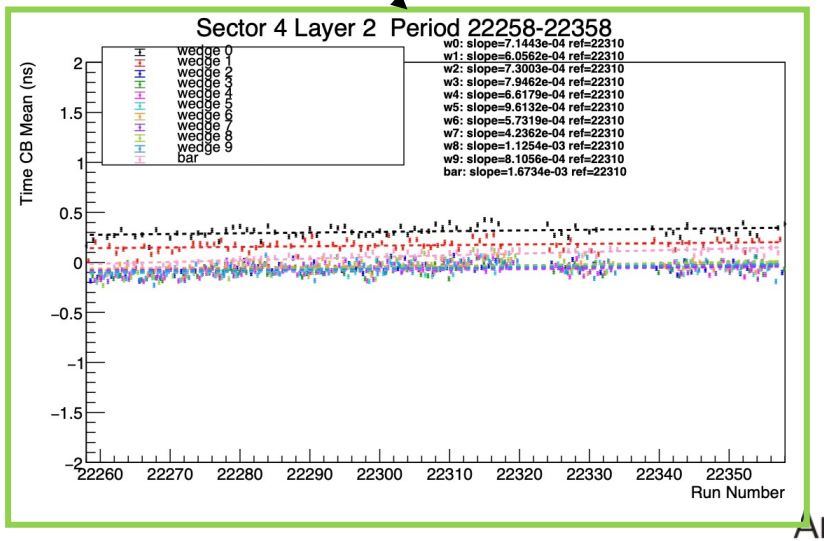
ATOF timeline Calibration

2) Test 10 GeV run period (He4+D2): 22205-22358 with split point

- Split point at 22257, run log shows a long down time happened.
- To process the calibration, split into 2 sub-period for linear fitting.
- The time_offset constant table is further separated to two sets.
- **Here, Ref=22230, 22310**



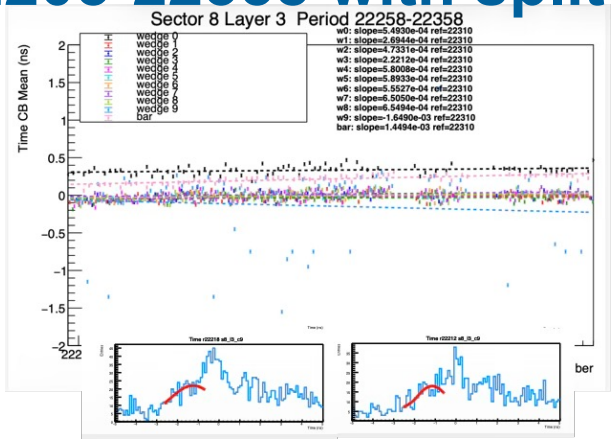


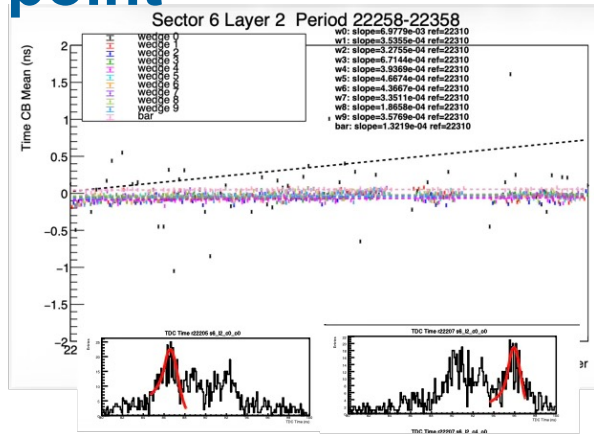


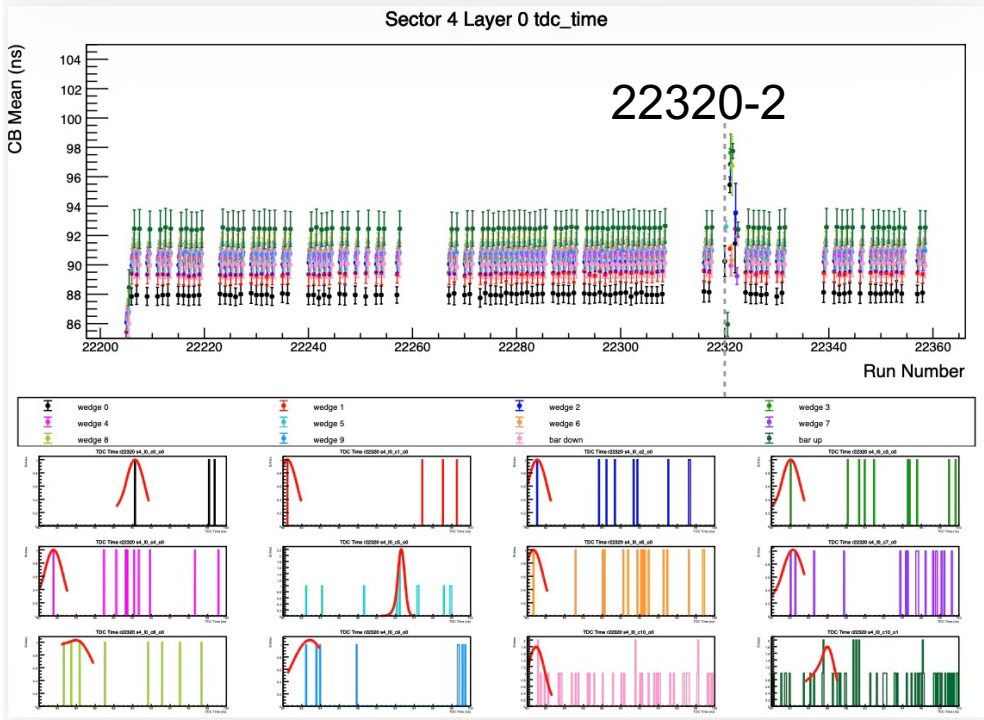
ATOF timeline Calibration

2) Test 10 GeV run period (He4+D2): 22205-22358 with split point

- Problematic channels identified: S5L1/2 C9, (new) S8L3C8, (new) S6L2C0.
- The background in wedge grows with time. Possible source from radiation damage, run condition change, or HV gain change.
- Problematic runs found: 22320, 22321, 22322, all show start.time=-1000.
  In run log, it shows DAQ issue.







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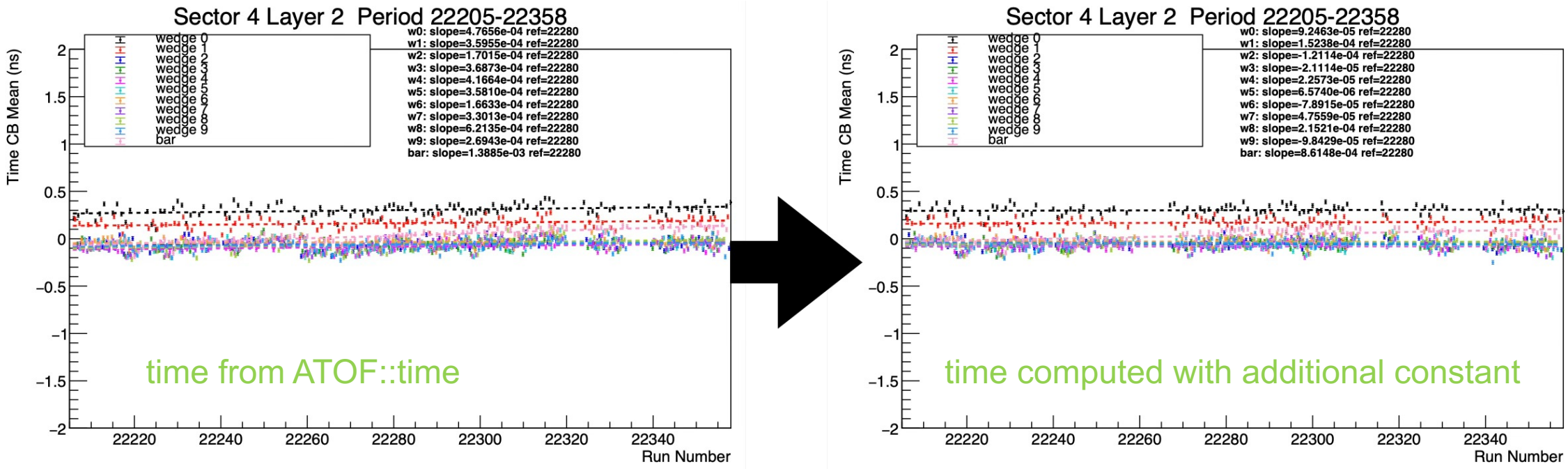
ATOF timeline Calibration

2) Test 10 GeV run period (He4+D2): 22205-22358 with split point

- Validation: apply the 2 new constant tables for sub-period separately, new timeline of computed time is flat, no jumping point.



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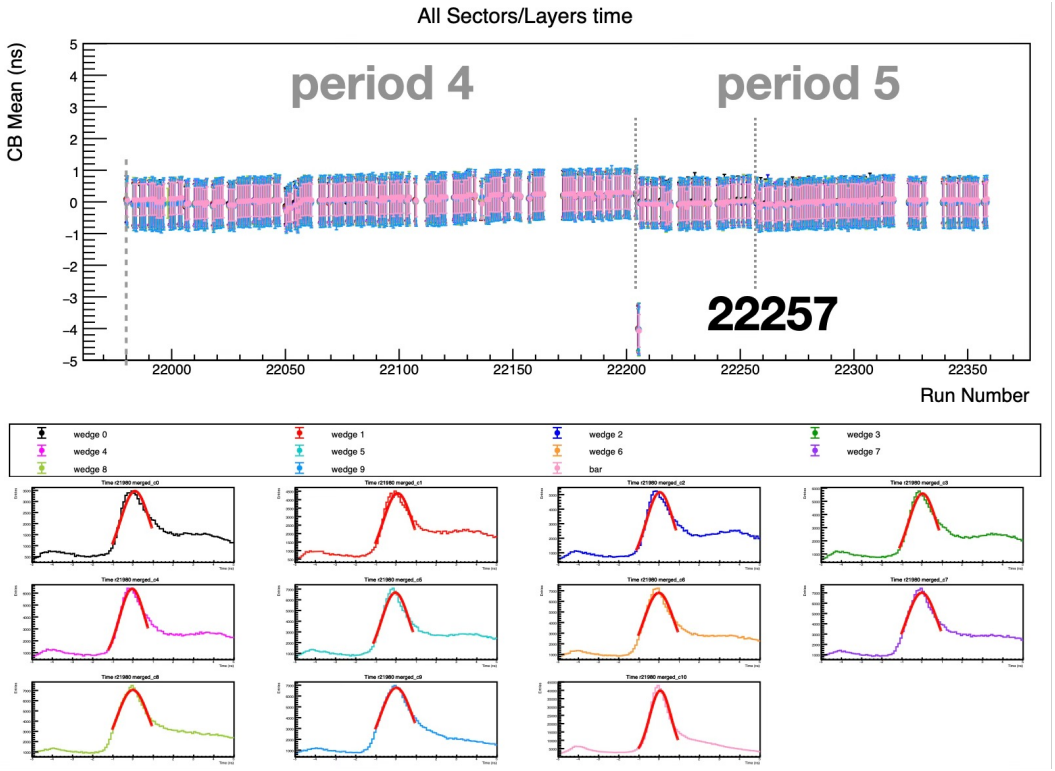
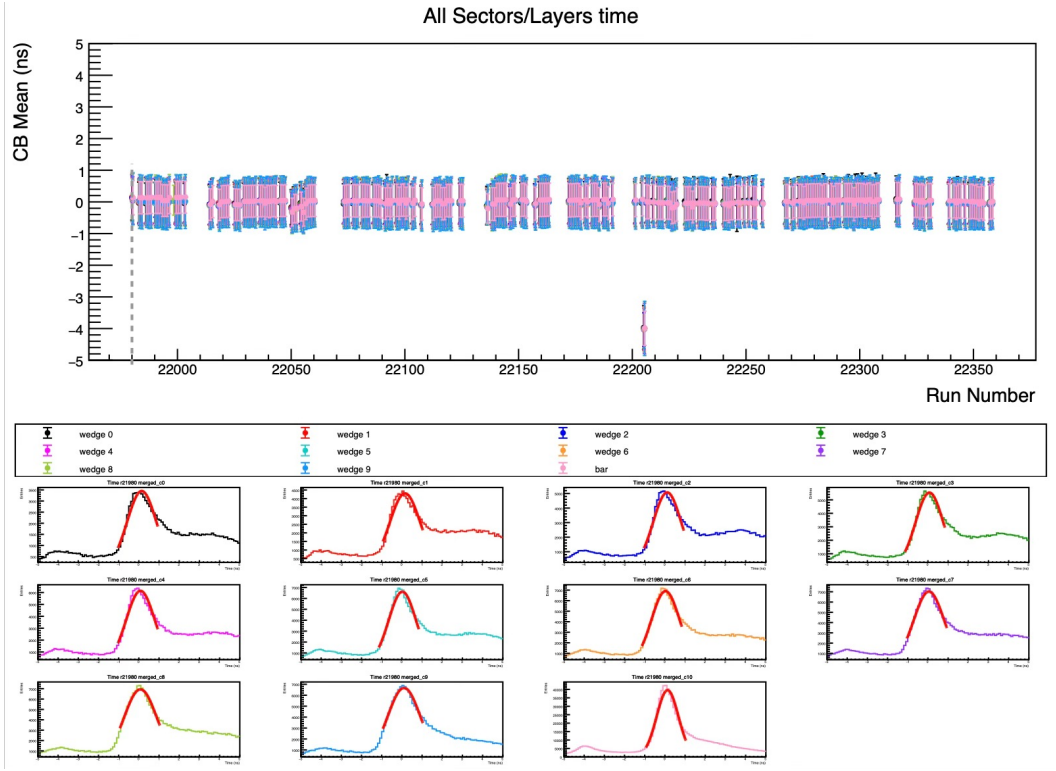
ATOF timeline Calibration

1) + 2) timeline

- Validation for 10 GeV (30% statistics)





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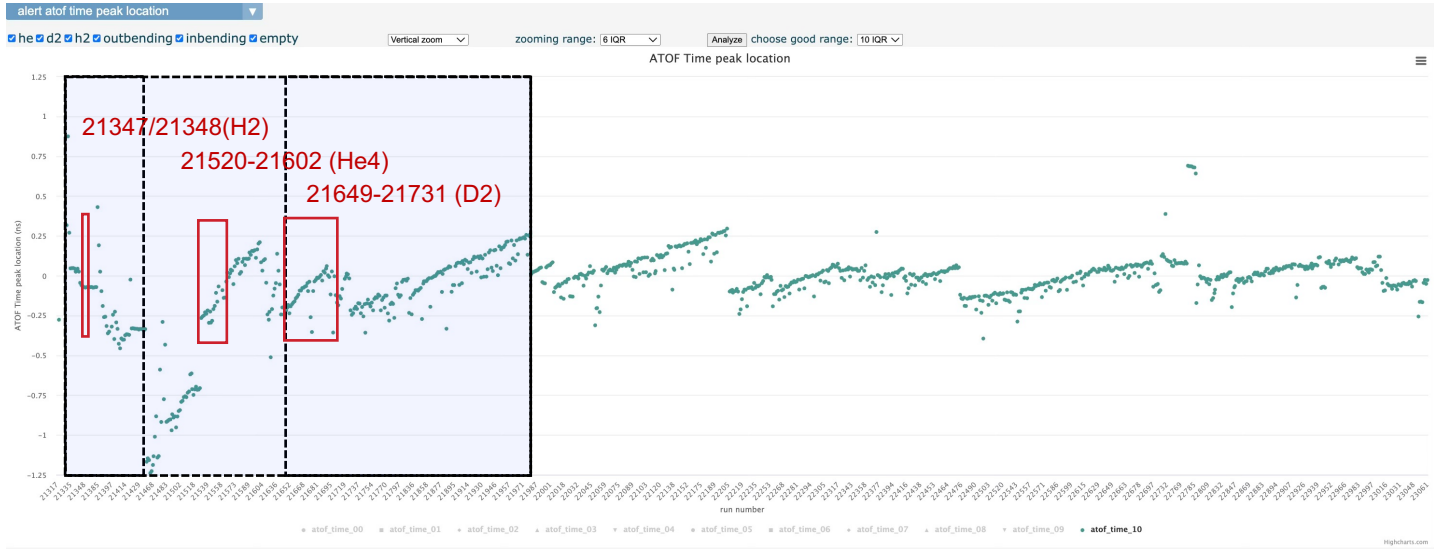
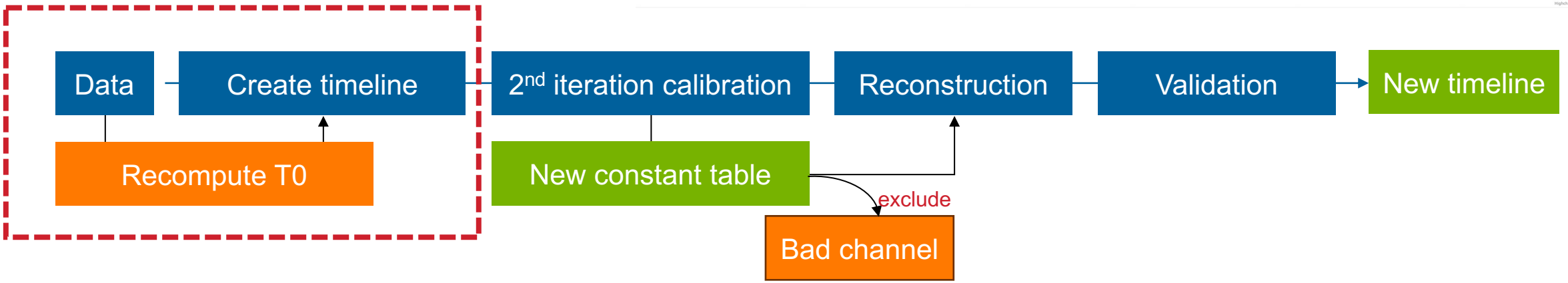
ATOF timeline Calibration

3) Stress test in complicated case: Commissioning period

- The commissioning period are jumpy, perform bad on existing table.
- Add a function to recompute time_offset
  - TSpectrum + Crystal Ball
  - Gaussian peak for comparison

  Works the same as Calcode in Java





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ATOF timeline Calibration

3) Stress test in complicated case: Commissioning period

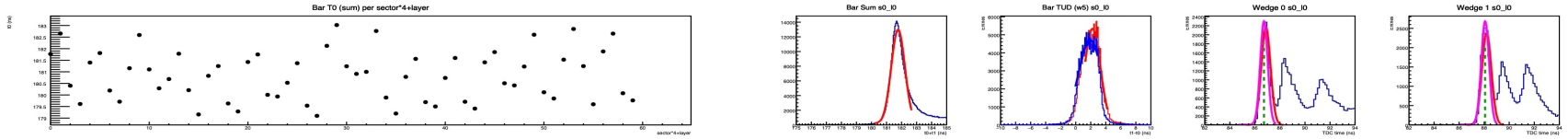
- Use more detailed sub-period:

Begin	End	New split point & sub-period
21310	21435	21335-21360, 21385-21386, 21395, 21396-21422, 21423-21435
21436	21611	21436-21479, 21480-21525, 21526-21549, 21550-21611
21612	21978	21612-21690, 21691-21729, 21730-21810, 21811-21869, 21870-21948, 21949-21978

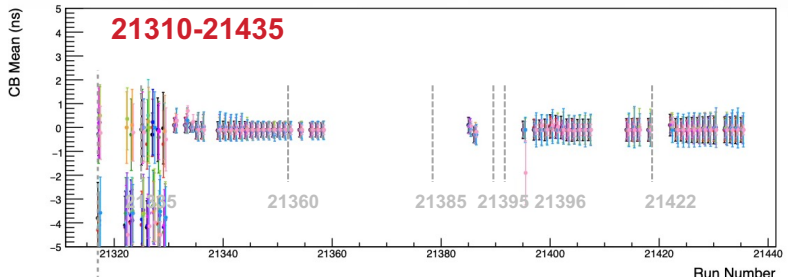
Run<=21329: bad run

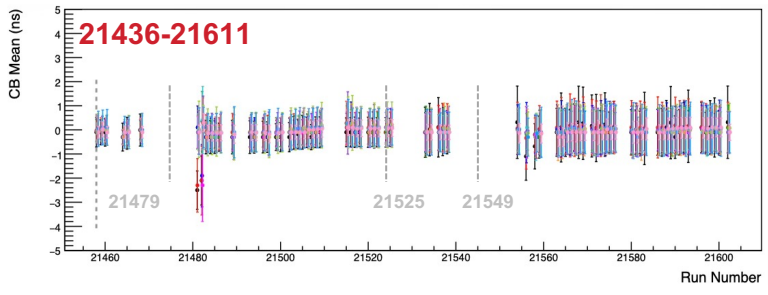
Missing data S7L1,S7L3 in 21710-21810.

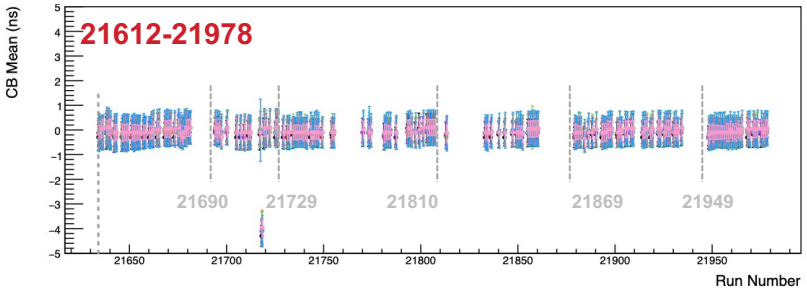
- Recompute Time Constant



- Result: commissioning runs' time peaks are now corrected near 0 ns







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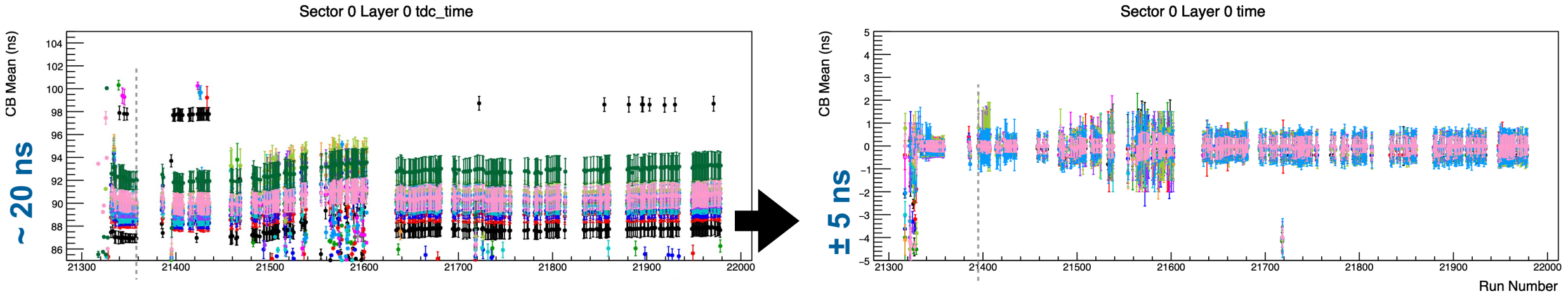
ATOF timeline Calibration

3)Stress test in complicated case: Commissioning period

- Identified problematic channels (more than physics run) and run split points associated with Detector Gain changes, run restarts, beam changes, and other operating conditions.
- With recompute T0, and slope calibration, updated time distribution looks much improved



Different colors represent different wedge/bar channels.

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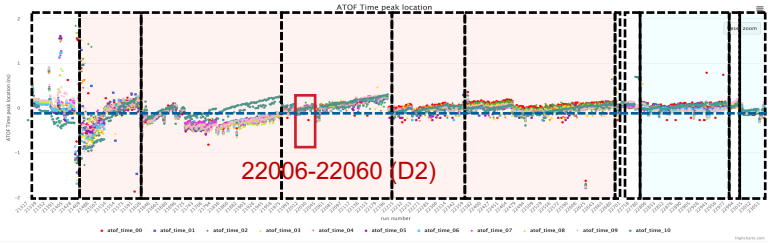
ATOF timeline Calibration

Apply to full timeline

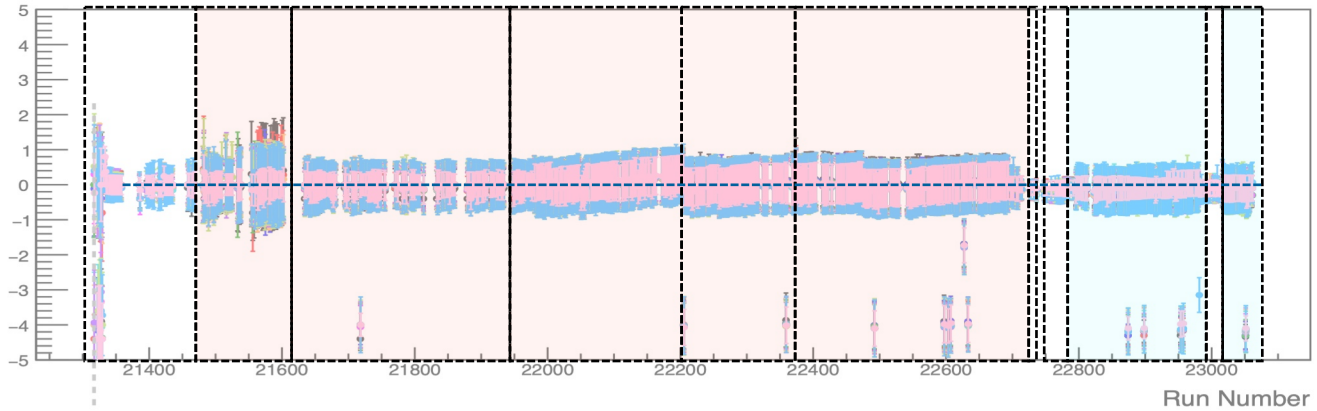
- Result for RG-L

Period	Range	Constant File
1	21310-21360	constant_time_offsets_21335_21360_updated.txt
	21361-21386	constant_time_offsets_21385_21386_updated.txt
	21387-21395	constant_time_offsets_21395_21395_updated.txt
	21396-21422	constant_time_offsets_21396_21422_updated.txt
	21423-21435	constant_time_offsets_21423_21435_updated.txt
2	21436-21479	constant_time_offsets_21436_21479_updated.txt
	21480-21525	constant_time_offsets_21480_21525_updated.txt
	21526-21549	constant_time_offsets_21526_21549_updated.txt
	21550-21611	constant_time_offsets_21550_21611_updated.txt
3	21612-21689	constant_time_offsets_21612_21689_updated.txt
	21690-21727	constant_time_offsets_21690_21727_updated.txt
	21728-21809	constant_time_offsets_21728_21809_updated.txt
	21810-21868	constant_time_offsets_21810_21868_updated.txt
	21869-21947	constant_time_offsets_21869_21947_updated.txt
	21948-21978	constant_time_offsets_21948_21978_updated.txt
4	21980-22204	constant_time_offsets_21980_22204_updated.txt
5	22205-22257	constant_time_offsets_22205_22257_updated.txt
	22258-22358	constant_time_offsets_22258_22358_updated.txt
6	22359-22409	constant_time_offsets_22359_22409_updated.txt
	22410-22474	constant_time_offsets_22410_22474_updated.txt
	22475-22693	constant_time_offsets_22475_22693_updated.txt
7	22694-22708	constant_time_offsets_22694_22708_updated.txt
8	22709-22777	constant_time_offsets_22709_22777_updated.txt
	22778-22791	constant_time_offsets_22778_22791_updated.txt
9	22792-22812	constant_time_offsets_22792_22812_updated.txt
	22813-22980	constant_time_offsets_22813_22980_updated.txt
10	22981-23015	constant_time_offsets_22981_23015_updated.txt
11	23016-23051	constant_time_offsets_23016_23051_updated.txt
	23052-23065	constant_time_offsets_23052_23065_updated.txt

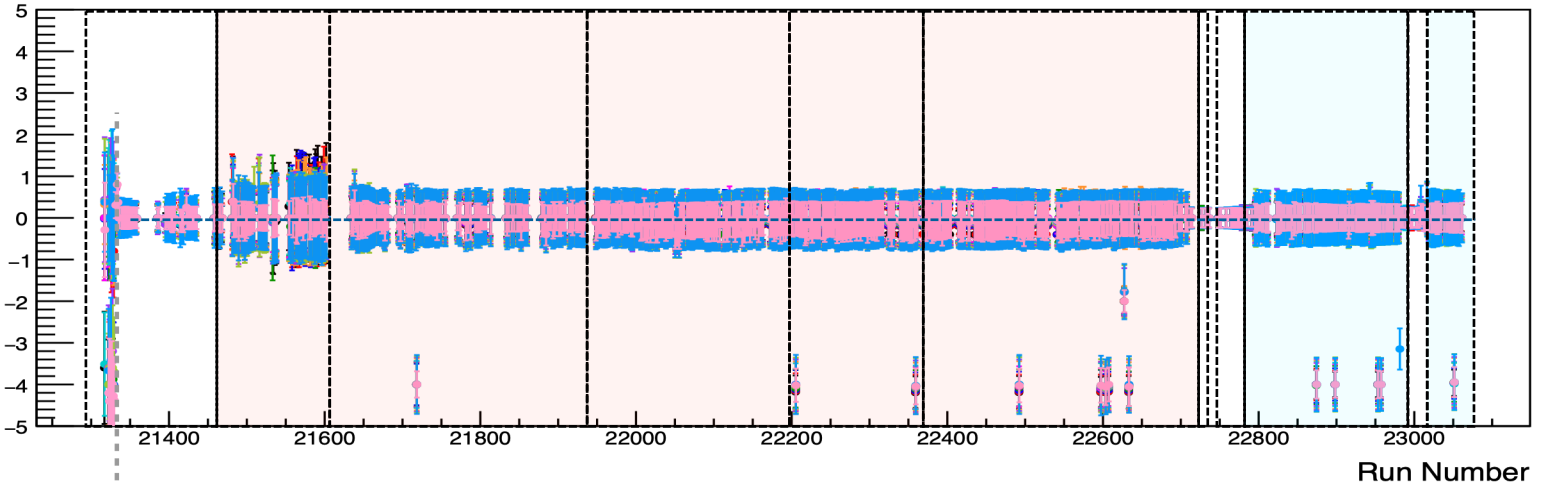
Original



Before



After



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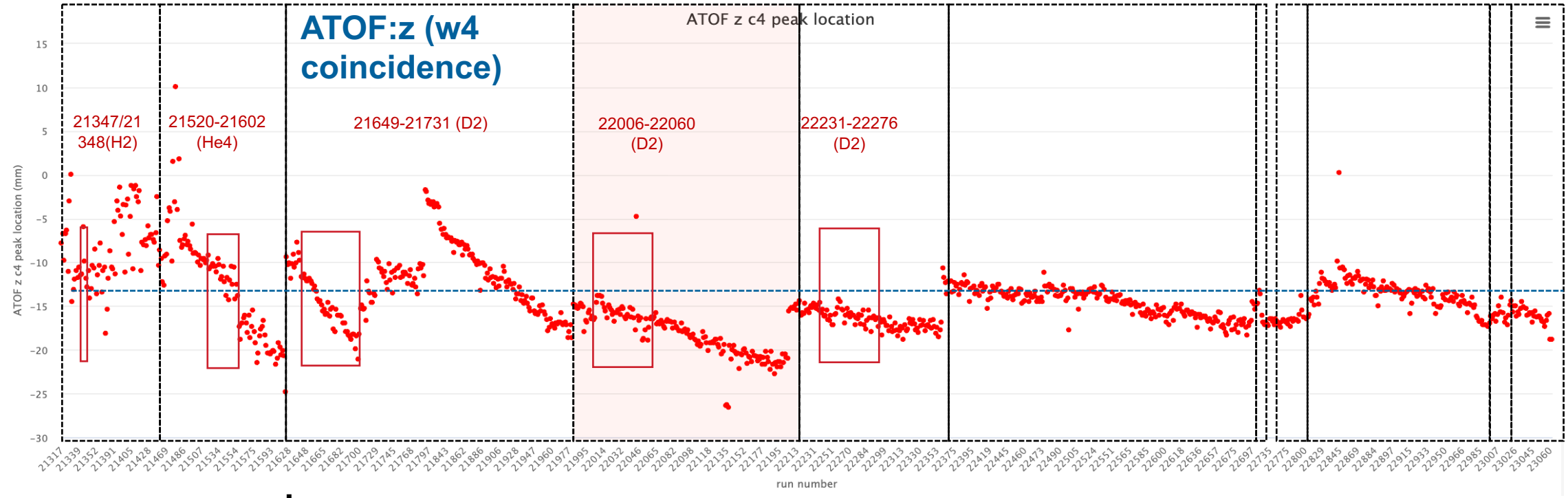
Timeline for ATOF z prediction from bar



Issues

- Calcode computes constant with a limited run range, which is inadequate for commissioning runs.
- Calcode assumes a wedge length of **3.0 cm**; elastic data indicate **2.75 cm**.
- Timeline v10.3 did not apply the wedge-leading-peak selection (|t| < 1 ns), allowing cross-talk noise to contaminate the z distribution.

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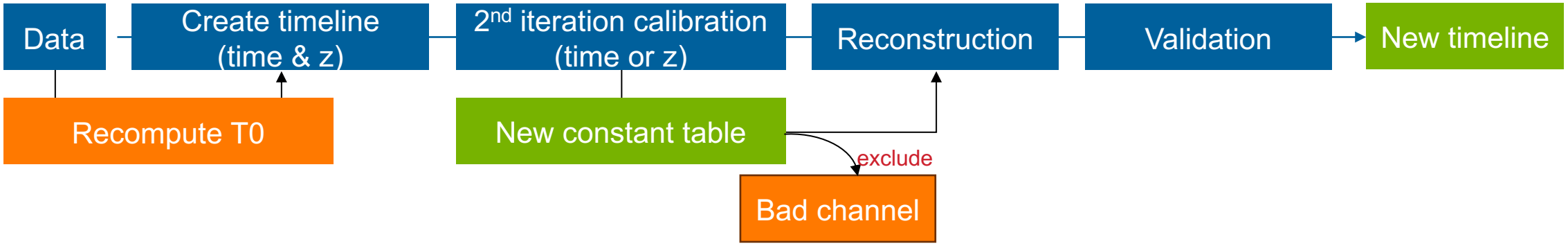
ATOF Calibration

2nd iteration on timeline calibration for bar-z

- Offline ATOF timeline calibration toolkit for z (v_{eff} and t_{UD} constant).



$$t_{\text{down}} = t_{\text{raw}} + \frac{t_{ud}}{2} - \frac{t_0}{2}$$

$$t_{\text{up}} = t_{\text{raw}} - \frac{t_{ud}}{2} - \frac{t_0}{2}$$

$$z = \frac{v_{\text{eff}}}{2}(t_{\text{up}} - t_{\text{down}})$$

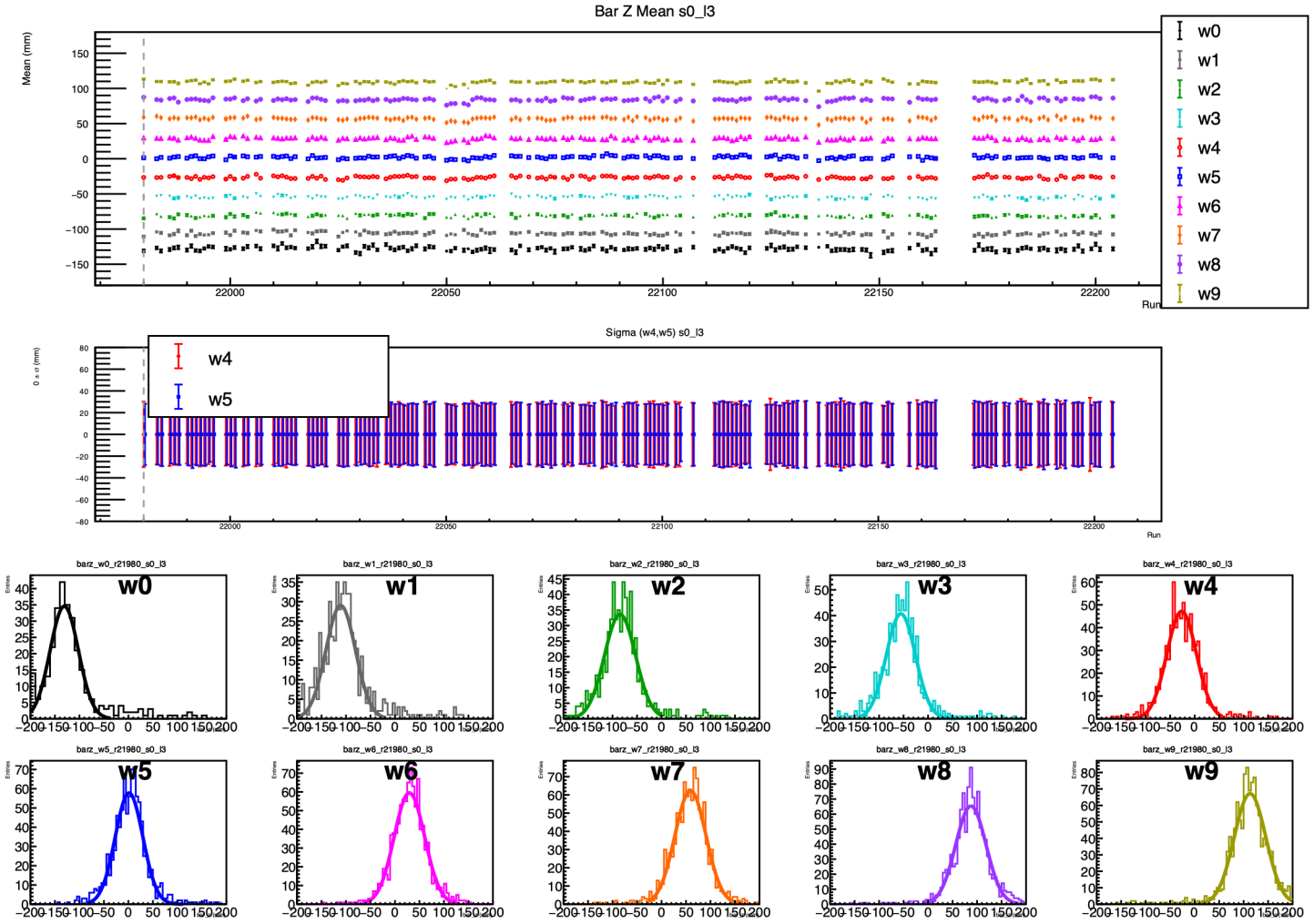
$$t_{\text{bar}} = t_{d/u} \pm \frac{z}{v_{\text{eff}}}$$

Notes:

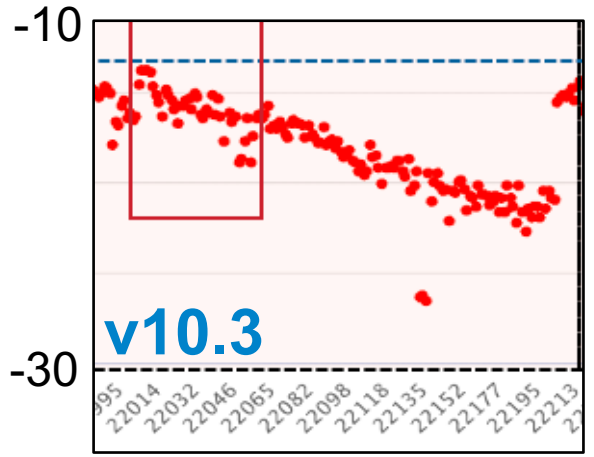
1. Reconstruct z (ATOF::time) based on TDC (ATOF::hit) the same as CJ.
2. Build the bar-z timeline using Gaussian fits to z-distribution under the coincidence within leading peak (|t| < 1 ns) of the 10-wedge.
3. Apply a linear fit on (z-peak, wedge#) to extract the slope and intercept.
4. Perform bar-z calibration for each run sub-period:
    1. Scale V_{eff} using the corrected wedge length.
    2. Update t_{UD} to shift the intercept to 0 mm (ATOF geometric center).
5. Validate the new time under the new constants

ATOF timeline Calibration

1) Test 10 GeV run period (He4+D2): 21980-22204



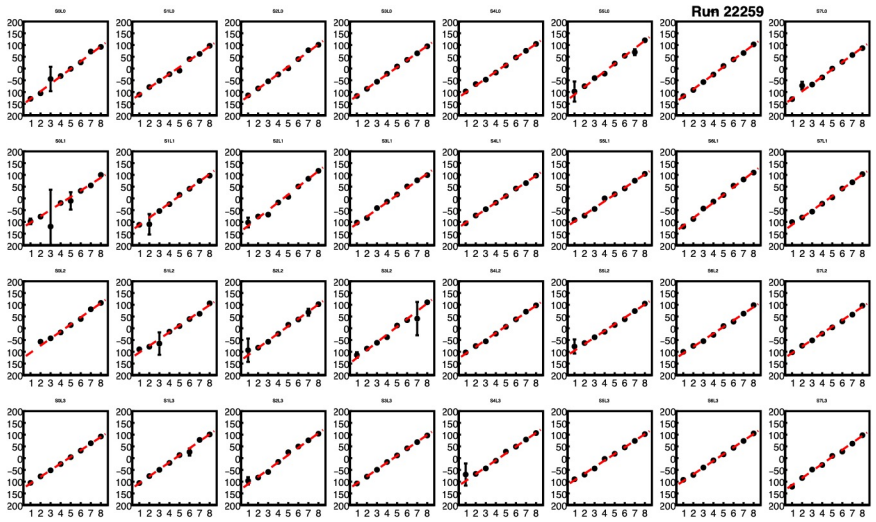
- With leading peak selection (|t| < 1 ns), z is flat across 200 runs with a small global offset.
- It suggests that the decreasing trend seen in v10.3 originated from non-leading peaks' noise.



ATOF timeline Calibration

1) Test 10 GeV run period (He4+D2): 21980-22204

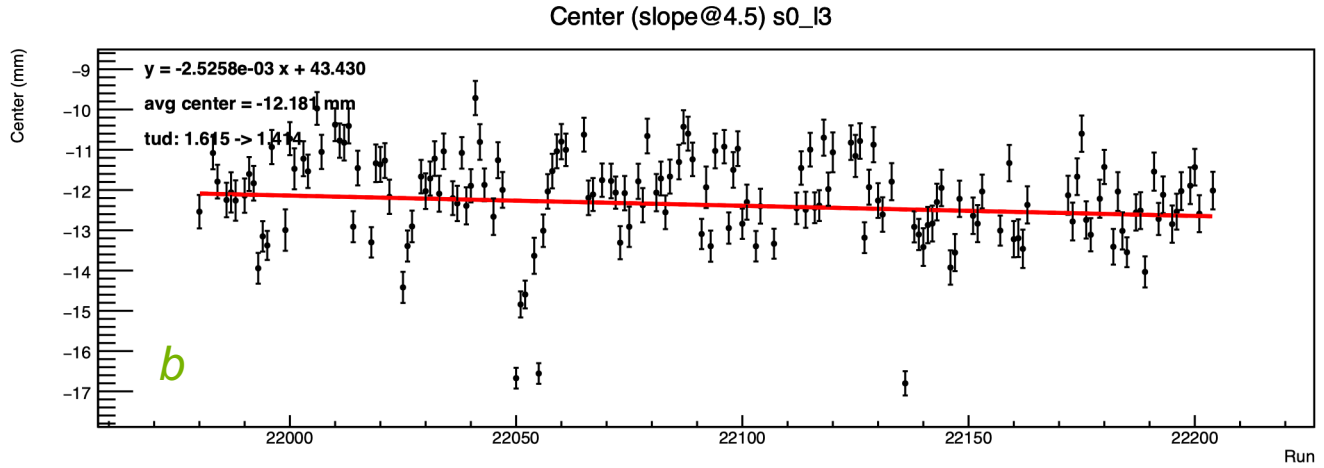
- Apply liner fit for z distribution vs wedge number

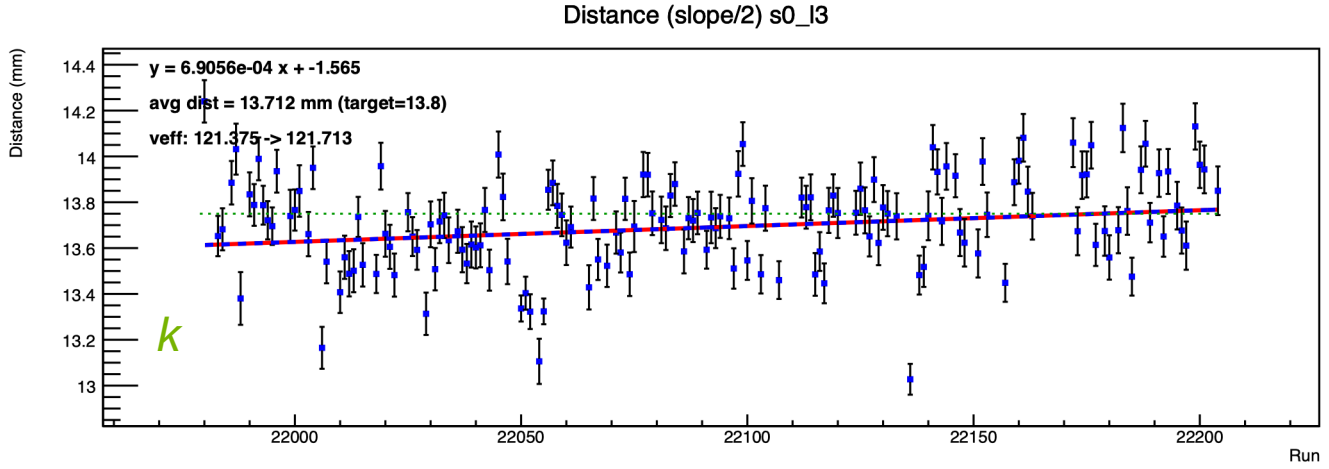


$y=k(x-4.5)+b$

$$t_{ud}^{bar} = t_{ud}^{bar}\big|_{old} + \frac{2\langle b\rangle}{v_{eff}|_{old}}.$$

$$v_{eff} = \frac{2.75\ cm}{\langle L\rangle} \times v_{eff}\big|_{old},\ L=k*1$$

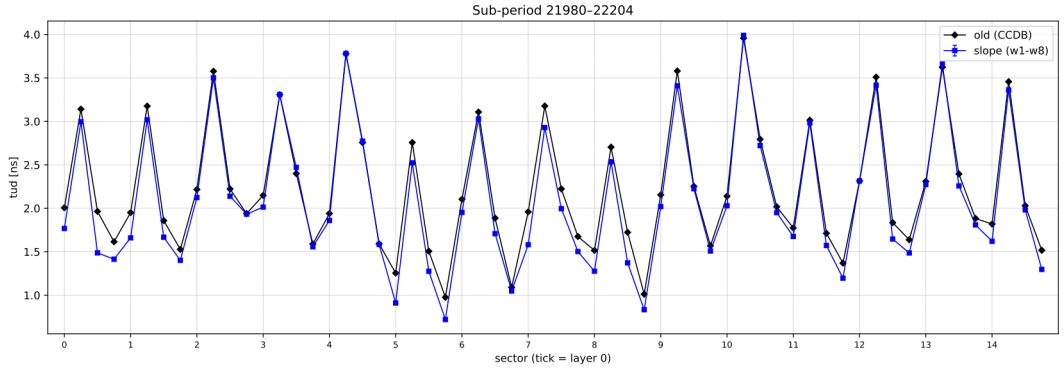


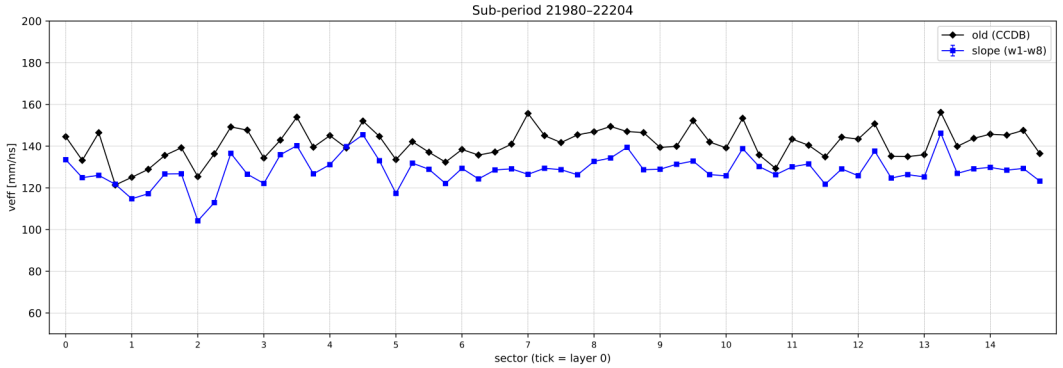


ATOF timeline Calibration

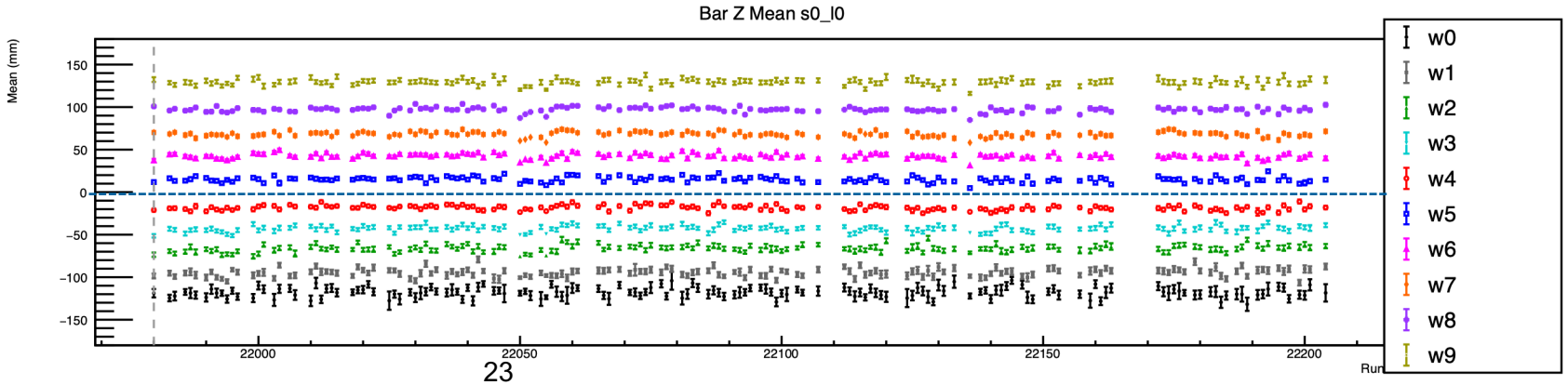
1) Test 10 GeV run period (He4+D2): 21980-22204

- Comparison of calibration constants:
  - t_{UD} is nearly unchanged
  - v_{eff} decreases by ~10% due to the updated wedge length (2.75 cm).





- New bar z distribution



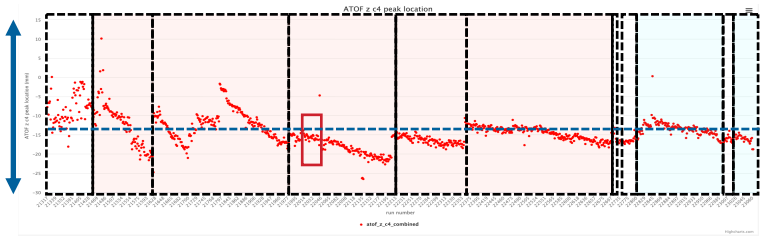
ATOF timeline Calibration

Apply to full timeline

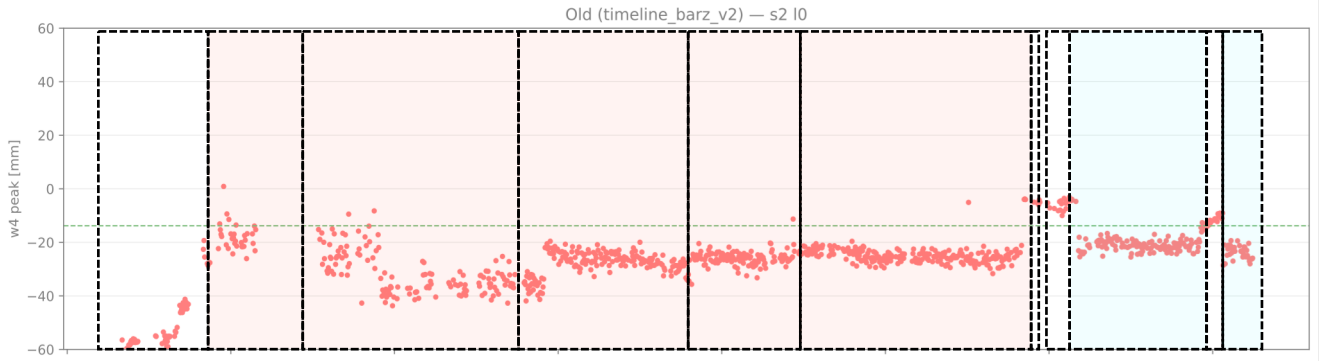
- Result for RG-L

Period	Range	Constant File
1	21310-21360	constant_veff_21335_21360_updated.txt
	21361-21386	constant_veff_21385_21386_updated.txt
	21387-21395	constant_veff_21395_21395_updated.txt
	21396-21422	constant_veff_21396_21422_updated.txt
	21423-21435	constant_veff_21423_21435_updated.txt
2	21436-21479	constant_veff_21436_21479_updated.txt
	21480-21525	constant_veff_21480_21525_updated.txt
	21526-21549	constant_veff_21526_21549_updated.txt
	21550-21611	constant_veff_21550_21611_updated.txt
3	21612-21689	constant_veff_21612_21689_updated.txt
	21690-21727	constant_veff_21690_21727_updated.txt
	21728-21809	constant_veff_21728_21809_updated.txt
	21810-21868	constant_veff_21810_21868_updated.txt
	21869-21947	constant_veff_21869_21947_updated.txt
	21948-21978	constant_veff_21948_21978_updated.txt
4	21980-22204	constant_veff_21980_22204_updated.txt
5	22205-22257	constant_veff_22205_22257_updated.txt
	22258-22358	constant_veff_22258_22358_updated.txt
6	22359-22409	constant_veff_22359_22409_updated.txt
	22410-22474	constant_veff_22410_22474_updated.txt
	22475-22693	constant_veff_22475_22693_updated.txt
7	22694-22708	constant_veff_22694_22708_updated.txt
8	22709-22777	constant_veff_22709_22777_updated.txt
	22778-22791	constant_veff_22778_22791_updated.txt
9	22792-22812	constant_veff_22792_22812_updated.txt
	22813-22980	constant_veff_22813_22980_updated.txt
10	22981-23015	constant_veff_22981_23015_updated.txt
11	23016-23051	constant_veff_23016_23051_updated.txt
	23052-23065	constant_veff_23052_23065_updated.txt

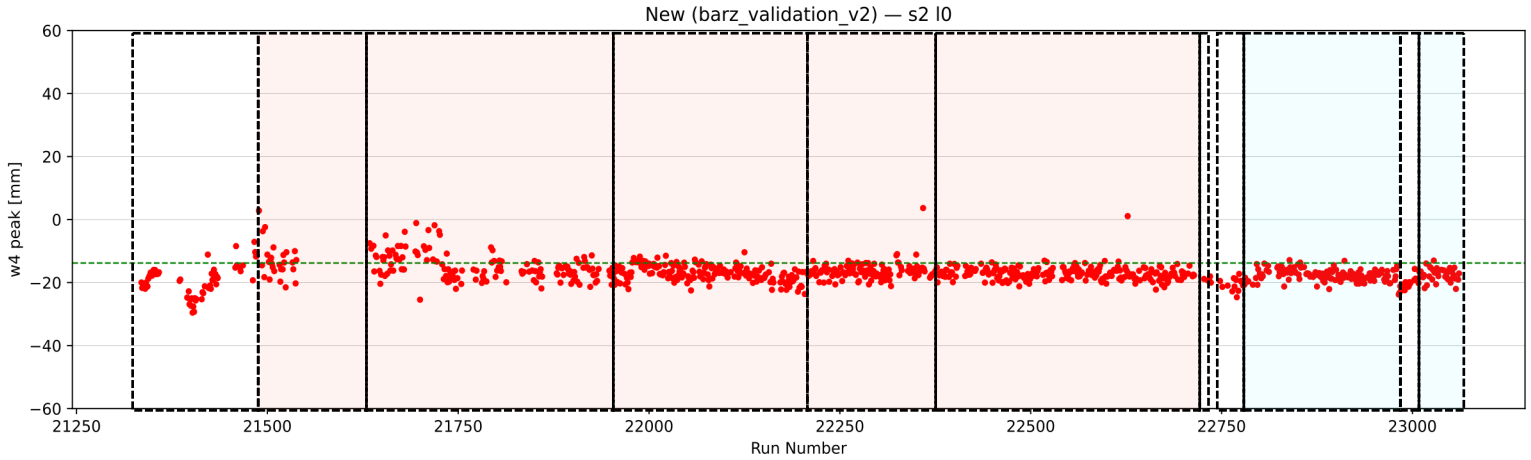
Original



Before

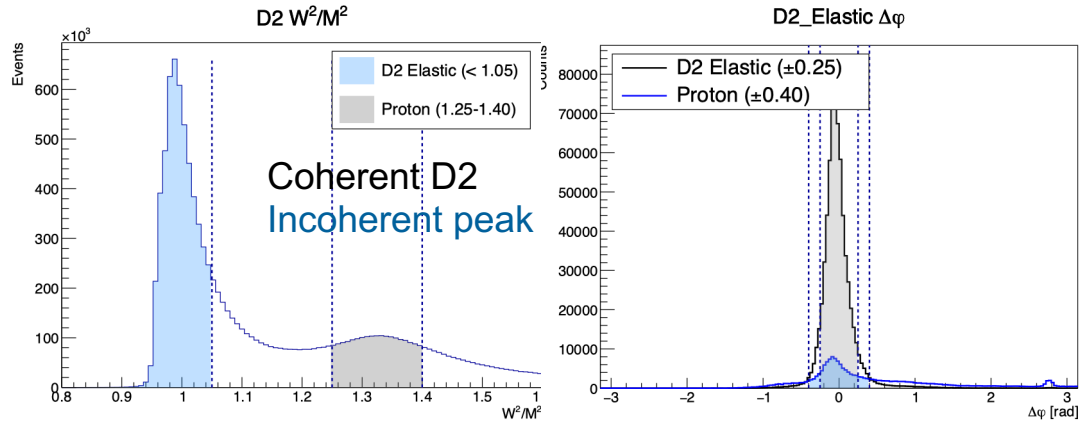


After

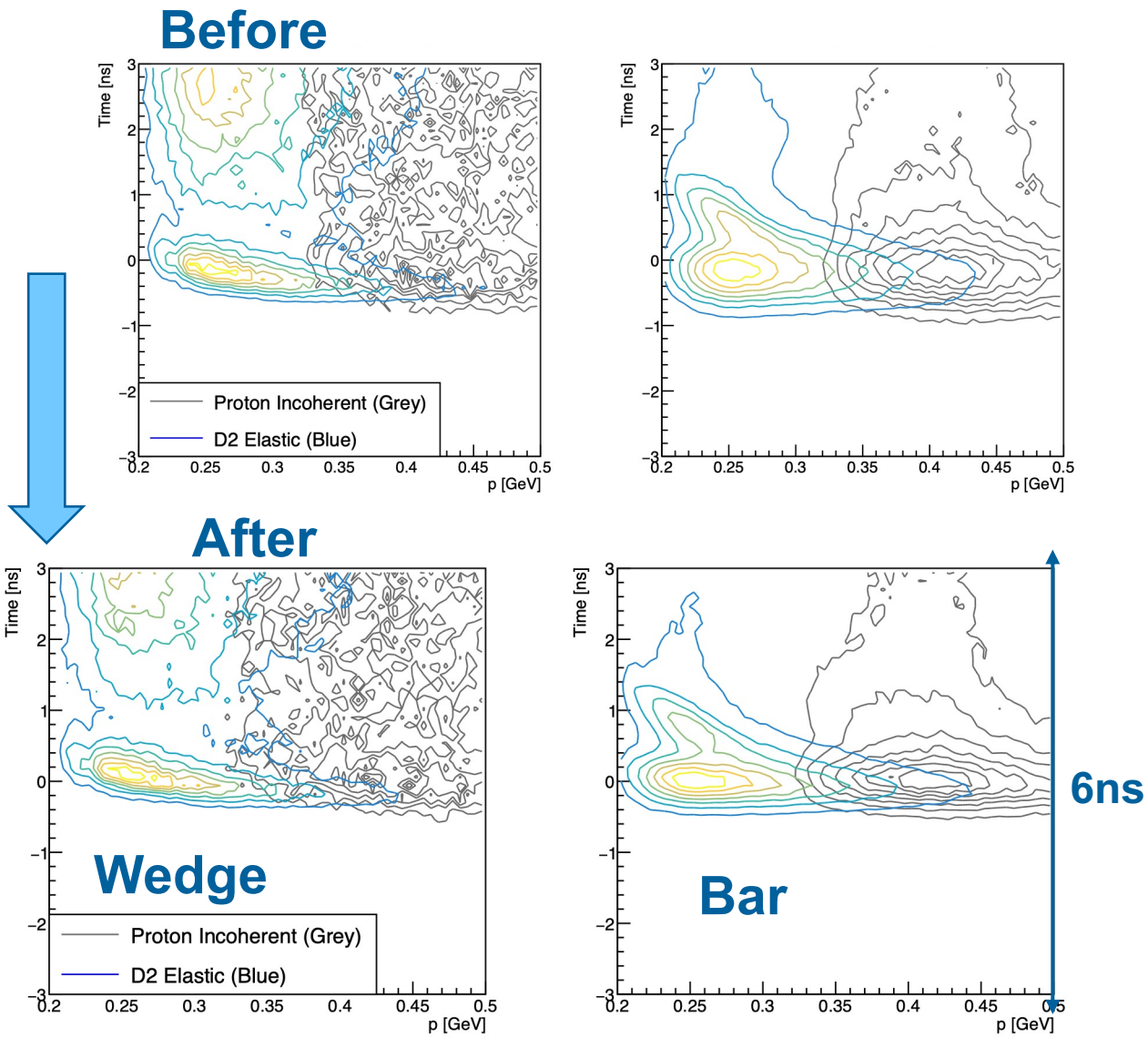


ATOF Calibration

Timeline calibration: PID at D2 2.2 GeV (3 period)



- Show the bar and wedge 5 (at central of ATOF) time distribution.
- **Before**: 1st CCDB constants
- **After**: 2nd iteration of CCDB constants, better time distribution.



Conclusion

- Produced the second iteration of ATOF CCDB calibration constants, updating both time offsets and effective velocity tables.
- Developed an offline framework for ATOF time and bar-(z) timeline calibrations.
- Identified run sub-periods, problematic channels, and bad runs associated with detector conditions, DAQ issues, and target changes.

Outlook

- Extend the calibration framework to energy-related calibration. Refine the current constants.

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THANK YOU