CALCOM Calibration Challenge Report

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Abstract

This report details the organization and outcomes of the CLAS12 Calibration Challenge organized by the CALCOM group in the period from Dec. 12 to 19, 2016 to test the calibration procedures and the calibration suites developed by the CLAS12 subsystem groups.

Contents

1 Calibration Challenge Overview

Over the past two years the individual CLAS12 detector subsystem groups for both the baseline and ancillary equipment have been developing software suites necessary to calibrate the response of these systems. The software suites have been developed based on the CLAS12 Java common tools software. The suites use either raw or reconstructed data as input and are designed to determine the constants to optimally calibrate the subsystem energy and timing response parameters that are then passed to the CLAS12 calibration database CCDB. The data formats employed are either the native CODA EVIO format or the HIPO format that was developed specifically for CLAS12.

The CLAS12 Calibration and Commissioning (CALCOM) group organized a Calibration Challenge that took place in the period from Dec. 12 to 19, 2016. This challenge was organized as a dress rehearsal of our calibration suites and our procedures, as well as for the training of our calibration teams before the start of the commissioning runs for CLAS12 that will take place in 2017, starting with the February Key Performance Parameter (KPP) commissioning run and then followed by the Oct./Nov. CLAS12 Engineering Run.

The **goals of the Calibration Challenge** were:

1. to test the functionality of the subsystem calibration suites;
2. to test the overall CLAS12 system calibration procedures, including the sequence and inter-dependencies of the calibration steps;
3. to test the work team organization;
4. to train the subsystem calibration teams;
5. to identify any remaining issues with the procedures and the software.

The Calibration Challenge amounted to preparing a Monte Carlo data sample where the detector subsystem response was smeared to reflect what could be expected for data from an uncalibrated CLAS12 data run. The calibration teams were then provided with the simulation data and charged with completing a full calibration for their systems within the one-week duration of the Calibration Challenge.

The end goal was to compare the extracted calibration constants for each CLAS12 subsystem channel-by-channel to those used to generated the uncalibrated/smeared Monte Carlo data set to check the level of convergence and to identify pathologies or systematics that prevented the accurate determination of the calibration parameters.

The **metrics for success of the Calibration Challenge** were as follows:

1. subsystem calibration teams were able to follow the devised calibration procedures and determine a complete set of calibration constants that were then inserted into the calibration database;
2. training of the calibration teams to be able to use the calibration suites with realistic data under the pressures expected during the CLAS12 commissioning runs when semi-online subsystem calibrations are necessary;

3. accurate determination (≈5% - 10%) of the calibration constants used to generate the smeared Monte Carlo data.

A number of important caveats for the Calibration Challenge must be noted:

1. the CLAS12 subsystem geometries were assumed to be ideal with no offsets or rotations included;
2. a small fraction (∼1%) of the channels in the system were flagged in the database as non-functioning as a test of the different calibration suites;
3. the gains of the CLAS12 PMT-based subsystems (EC/PCAL, FTOF, LTCC, HTCC, CTOF, CND) were not smeared as part of the Calibration Challenge as these calibrations are not performed with beam data. Instead the gain calibrations are performed using cosmic ray data and were assumed to be fully gain matched for this test.

2 Calibration Challenge Subsystems

The participants in the Calibration Challenge, including the Analysis Coordinators, database support team, simulation and reconstruction support team, and the subsystem calibrators are listed in Table 1. The CLAS12 subsystems that were involved in the challenge included the FTOF, FT (Cal, Hodo), CTOF, and CND. The specific elements of the subsystem calibrations tested during the challenge were:

- FTOF:
  - Counter status,
  - Left-right timing offset,
  - Effective velocity,
  - Attenuation length,
  - Time walk
- FT:
  - Counter status for FT-Cal and FT-Hodo,
  - Timing offset for FT-Cal,
  - Charge-to-energy conversion for FT-Hodo

- CTOF:
  - Counter status,
  - Upstream-downstream timing offset,
  - Effective velocity,
  - Attenuation length
- CND:
  - Counter status,
  - Coupled-counter timing offsets,
  - Layer timing offsets,
  - Effective velocity

In addition, the challenge data set was used by the DC detector group to further develop the DC calibration suite and to test the underlying algorithms. This work was specifically focused onto the determination of the time to distance function from the analysis of the track fitting residuals.

The Monte Carlo data set included calibrated responses for the EC/PCAL, LTCC, HTCC, and SVT. The forward and barrel MM were not part of the detector response that was modeled. The Central Vertex Tracker consisted solely of the 4 layers of the SVT.

3 Pseudo-Data Generation

The event generator used for the Calibration Challenge to model $e-p$ interactions was Pythia 6.4. The beam energy was set at 11 GeV and the target was a 5-cm-long liquid-hydrogen cell surrounded by a foam scattering chamber. The Pythia events were merged with background events generated by GEANT-4 at a beam-target luminosity of 1×10^{34} cm^{-2}s^{-1}. GEMC and COATJAVA tagged versions 3a.0.2 were employed for the GEANT-4 simulation and the event reconstruction.

The event generator LUND data files contained 10M events and were skimmed to retain only particles in the acceptance of the CLAS12 Forward Detector, Central Detector, and Forward Tagger as most of the generated PYTHIA events actually involved very small scattering angle electrons that went down the beam pipe. The gcard file employed for GEMC running is given in the Appendix.

For the Calibration Challenge two sets of constants were prepared for the data generation:

1. Run 11 - nominal, unsmeared detector calibration constants;
2. Run 17 - smeared detector calibration constants.

For the smeared calibration constants, the detector subsystem groups defined the functional for smearing the parameters and the smearing limits. The chef then used this information to fill the Run 17 database entries into an SQLite copy of the main database. In addition

Calibration Role	Personnel	Institution
Analysis Coordinator	Raffaella De Vita	INFN Genova
	Daniel S. Carman	JLab
Database:		
Manager	Maurizio Ungaro	JLab
Table Creation/Filling	Nathan Harrison	JLab
Simulations:		
GEMC	Maurizio Ungaro	JLab
Event Generator	Harut Avakian	JLab
Data Generation	Nathan Harrison	JLab
Chef	Nathan Harrison	JLab
Reconstruction Code	Veronique Ziegler	JLab
Common Tools Support	Gagik Gavalian	JLab
Subsystem Calibrators:		
EC/PCAL	Cole Smith	UVa/JLab
FTOF	Louise Clark	U. Glasgow
CTOF	Louise Clark	U. Glasgow
LTCC	Maurizio Ungaro	JLab
DC	Krishna Adhikari	U. Miss.
	Michael Kunkel	Juelich
HTCC	Nick Markov	U. Conn
FT-Cal	Erica Fanchini	INFN Genova
FT-Hodo	Gary Smith	U. Edinburgh
SVT	Yuri Gotra	JLab
CND	Gavin Murdoch	U. Glasgow

Table 1: Participants in the Dec. 2016 CALCOM Calibration Challenge.

to smearing of the constants, hits for 1% of the detector components were removed using the *Status* constant to mimic the effect of dead sensors or electronic readout channels. Both distorted constants and the component statuses were not known to the calibrators before the start of the challenge period. Only after the calibration teams completed their determination of the constants were the smeared calibration constants unblinded for the calibrators.

As the subsystem calibration teams completed their calibration steps, the determined calibration parameters were then inserted into the main CCDB. Before the final calibration constants were loaded into CCDB, the subsystem calibration teams used temporary system SQLite databases or text files during their iterative calibration steps.

4 Calibration Suites

The Java-based calibration suites for the CLAS12 detector subsystems are based on the common tool applications developed by the Hall B Software Group. These tools allow for streamlined development of applications that are used across the different subsystem suites. Figs. 1 and 2 show screen captures of the different calibration suites.

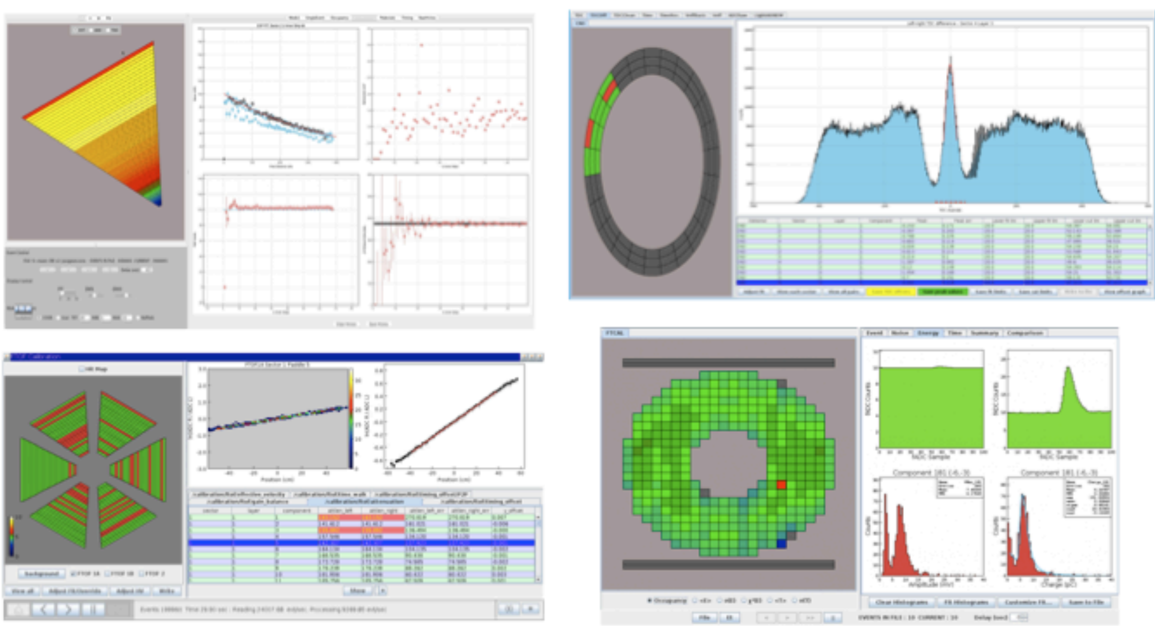

Figure 1: Subsystem calibration code suites for (UL) EC/PCAL, (UR) CND, (LL) FTOF, (LR) FT-Cal.

The suites read in the raw or reconstructed simulation data, display the various calibration quantities, fit the histograms to determine the calibration constants, and then output the parameters into the appropriate database tables.

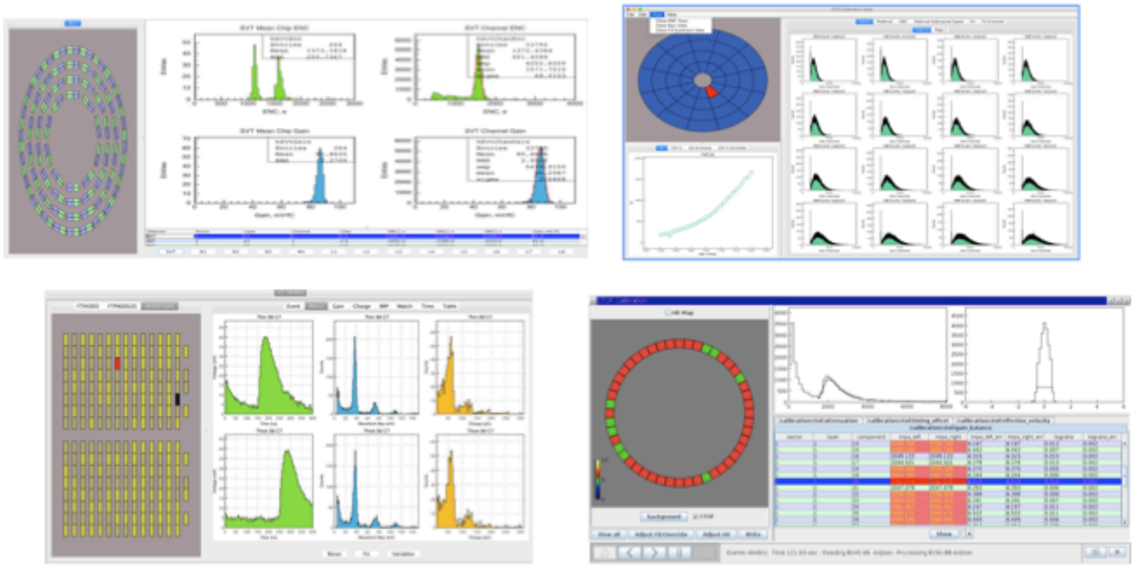

Figure 2: Subsystem calibration code suites for (UL) SVT, (UR) HTCC, (LL) FT-Hodo, (LR) CTOF.

5 Calibration Challenge Planning

The Calibration Challenge took place from Dec. 12 to 19, 2016. The challenge timeline was set as follows:

- First data sample generated by the end of Nov. 2016 to check GEMC files and reconstruction codes.
- Second data sample generated with constants from Run 11 provided to calibrators for final testing on Dec. 5, 2016.
- Day #1 (Dec. 12, 2016): Data (raw and reconstructed) made available to calibrators.
- Day #2: First iteration of calibration. Detector component status checks for all subsystems, energy/gain calibrations for FTOF, CTOF, FT-Cal, FT-Hodo, CND. DC hit-based tracking and SVT tracking verified. DC time-based tracking calibration started.
- Day #3: Second iteration of calibration. Refinement of energy/gain calibrations, timing calibrations from FTOF and CTOF and refinement of DC time-based tracking calibrations.
- Day #4: Third iteration of calibration. Begin preparation of reconstruction plots.
- Day #5: Fourth (and final) iteration of calibration. Continue preparation of reconstruction plots.

- Day #6: Unblind calibration constants from Run 17 to calibration teams. Prepare plots comparing calibration constants for Run 17 from original SQLite file and main CCDB.
- Day #7: Complete calibration constant comparisons and preparation of reconstruction plots.

Daily meetings of the full calibration team took place each morning at 9:00 a.m. (JLab time) to track work progress and to address issues that arose.

6 Calibration Challenge Results

The calibration constant values extracted from the detector calibrators were compared to the original smeared values to evaluate the quality of the results. Figs. 3-6 show the comparison for FTOF, FT, CTOF, and CND, respectively.

In the case of the FTOF detectors, the agreement between the two sets of values is quite good for all the three parameters displayed in Fig. 3, i.e. attenuation length, effective velocity and left-right timing offsets. The observed discrepancies are of the order of few % and in general below the 5-10% limit that was chosen as the metric for success in this first challenge. A systematic offset of about -1.5% for both attenuation length and effective velocity is evident from the distributions and will have to be investigated. The comparison for time-walk constants is not shown since the calibration algorithm converged only for a limited number of counters as discussed in the next sections.

Fig. 4 show the same comparisons for the FT-Cal timing offsets and FT-Hodo charge-to-energy conversion factors. For both sets of parameters, the calibration procedure converged very well after the first iteration. In the case of the FT-Cal, the only three components for which no timing offset was extracted correspond to the "dead" channels, while for the remaining components, the agreement between original and extracted constants is excellent. In the case of the FT-Hodo, the procedure converged for all detector components except for the ones that were not hit by scattered particles, being shielded by the Möller cone. For the other components, the agreement between the original and extracted constants is very good with only a systematic shift of $\sim 3\%$ that is being investigated.

The comparison of the original and extracted constants for the CTOF detector shows again a good agreement even if with a larger spread than for the forward detectors. This is partially due to the lower statistics available for the calibration of this detector since most of the particles in the pseudo-dataset were forward-going.

Finally, good agreement is also found for the CND timing offsets and effective velocities at the level of $\leq$1.5%.

The effectiveness of the calibration procedures was also evaluated comparing the results of the event reconstruction before and after the calibration procedure was applied. For this purpose a set of relevant plots for the detectors involved in the challenge was defined based on reconstructed particle information. Such plots were made from running reconstruction on the pseudo-data with ideal constants, i.e. before the calibration results were available, and with the extracted constants. The most relevant plots are shown in Figs. 7-9.

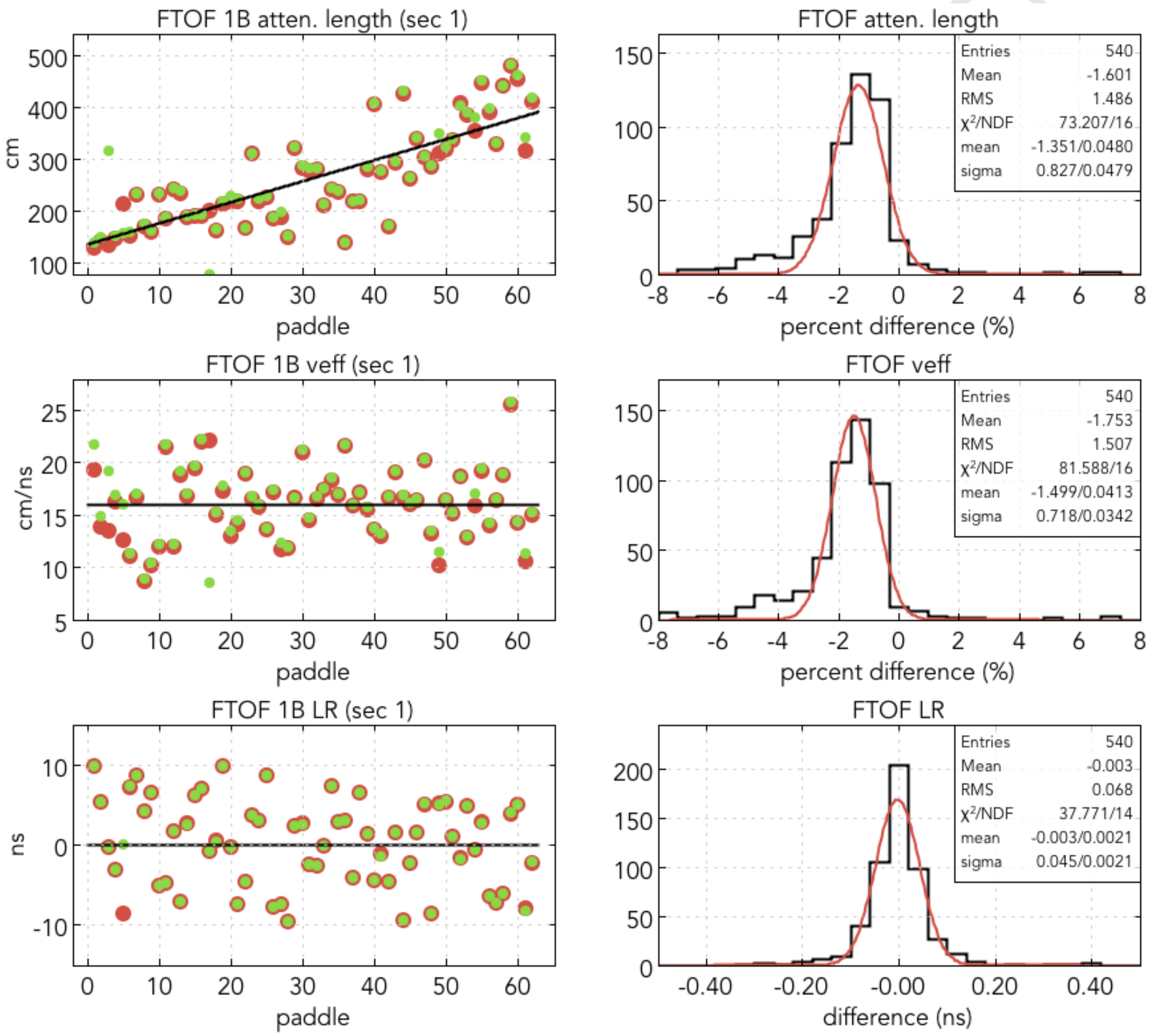

Figure 3: Comparison of the extracted and original constant values for the FTOF detectors. The graphs on the left show the comparison for attenuation length (top), effective velocity (middle), and left-right timing offsets (bottom) as a function of the paddle number for Sector 1, Panel-1b counters. The red and green dots correspond to the original and extracted values, respectively, while the lines show the ideal values. The histograms on the right show the discrepancy between the original and extracted values for the same parameters integrated over all sectors and panels.

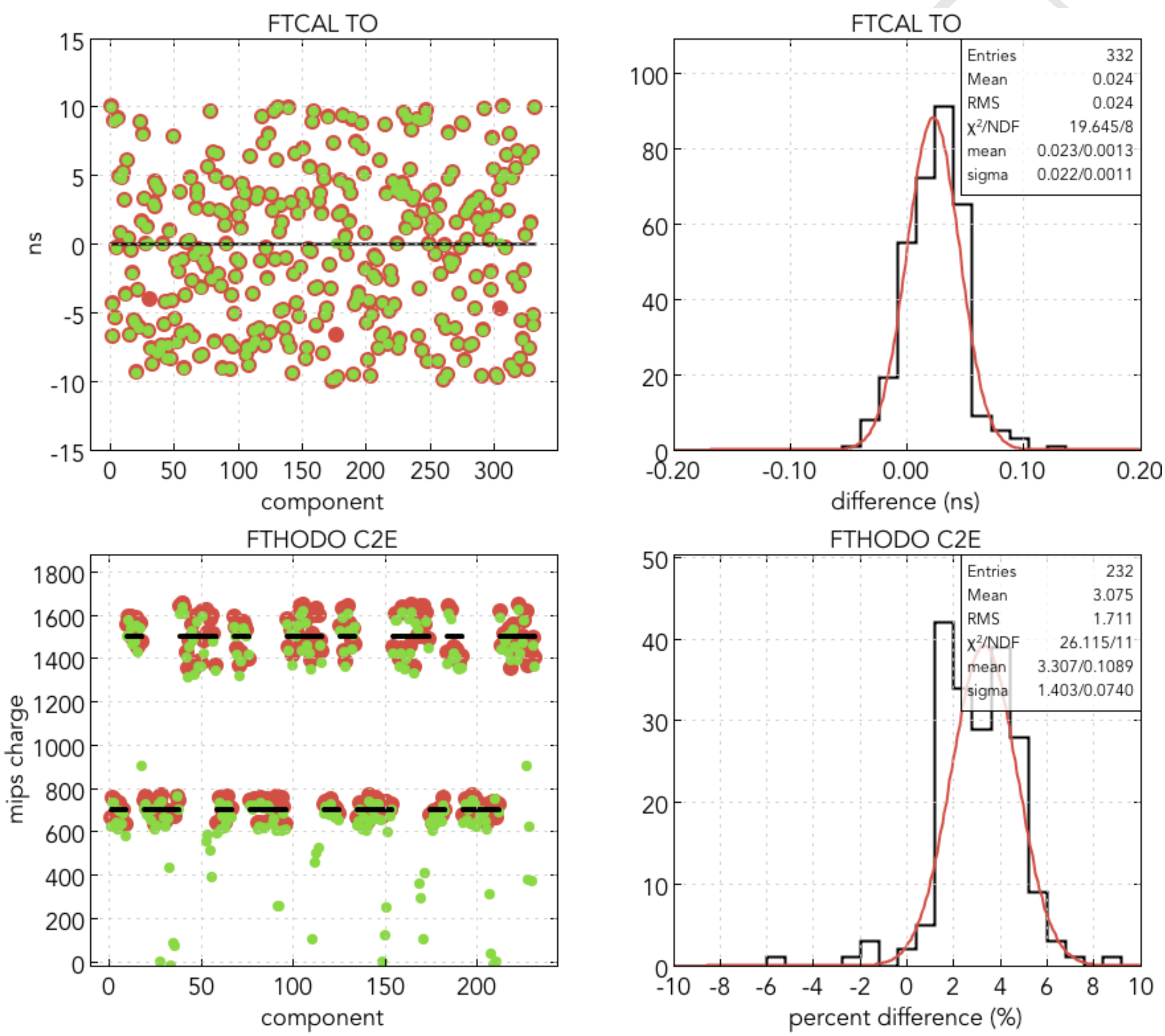

Figure 4: Comparison of the extracted and original constant values for the Forward Tagger calorimeter and hodoscope. The graphs on the left show the comparison for FT-Cal timing offsets (top) and FT-Hodo charge-to-energy conversion factor as a function of the detector component. The red and green dots correspond to the original and extracted values, respectively, while the lines show the ideal values. The histograms on the right show the discrepancy between the original and extracted values for the same parameters.

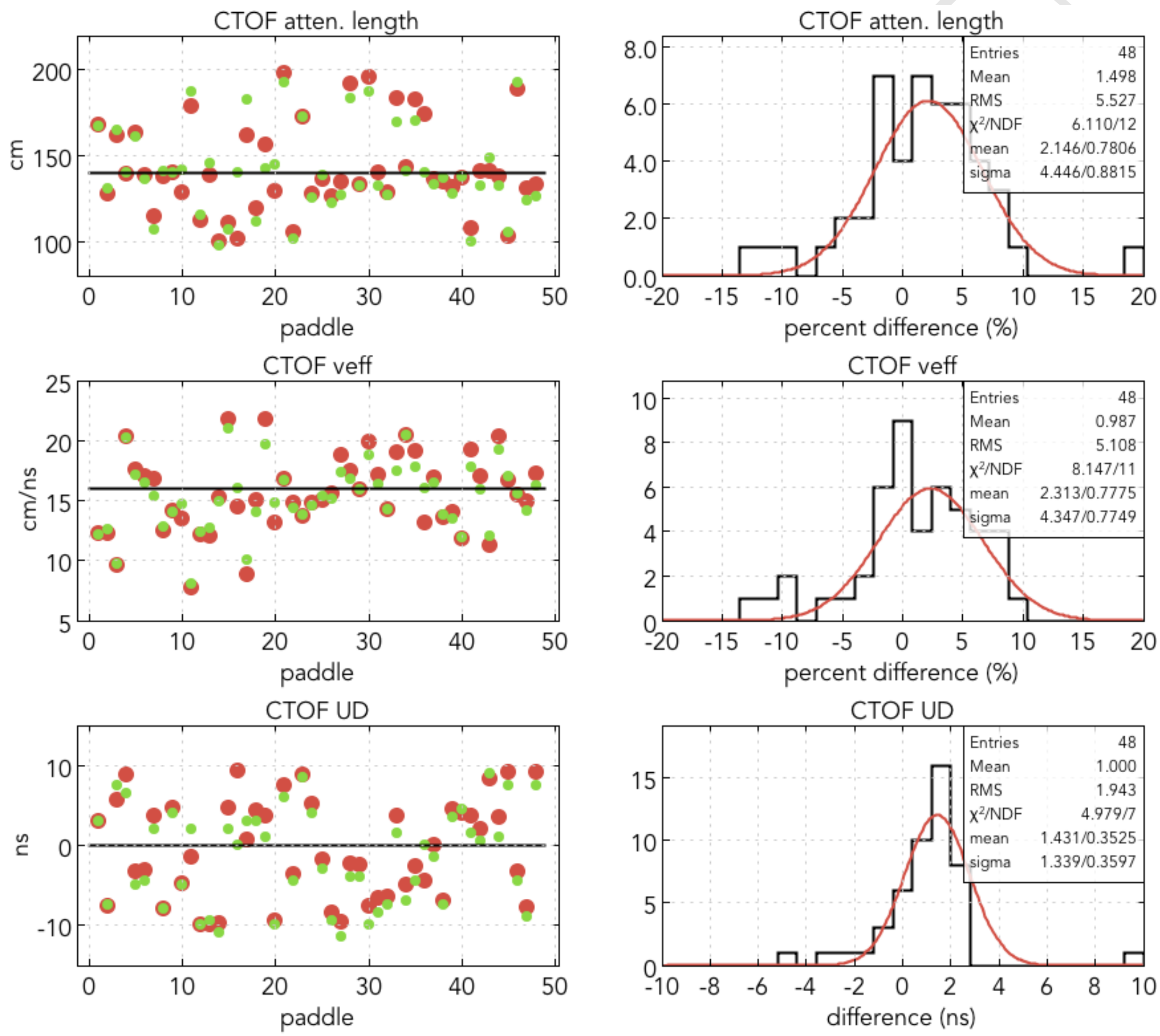

Figure 5: Comparison of the extracted and original constant values for the CTOF detector. The graphs on the left show the comparison for attenuation length (top), effective velocity (middle), and upstream-downstream timing offsets (bottom) as a function of the paddle number. The red and green dots correspond to the original and extracted values, respectively, while the lines show the ideal values. The histograms on the right show the discrepancy between the original and extracted values for the same parameters.

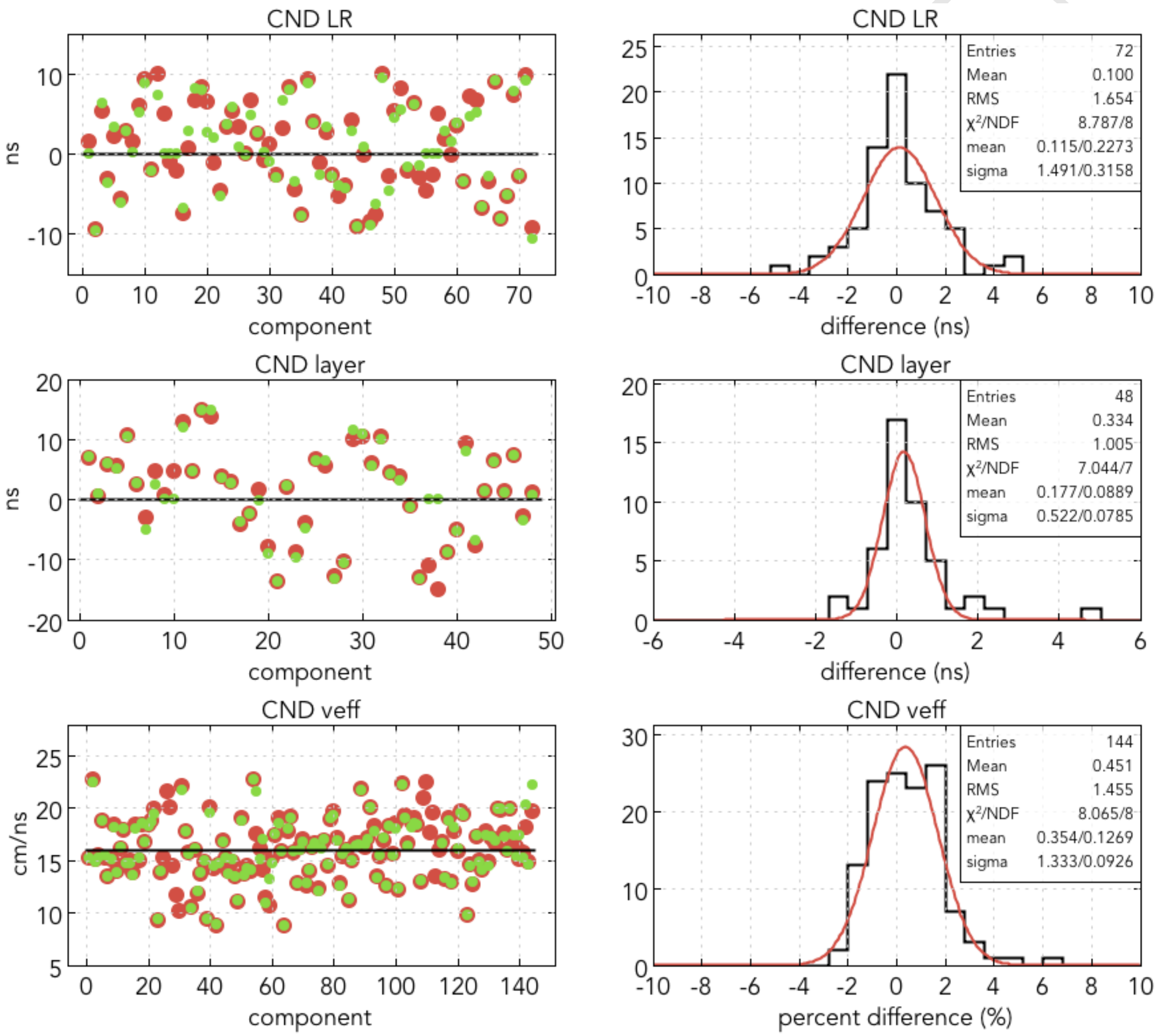

Figure 6: Comparison of the extracted and original constant values for the CND. The graphs on the left show the comparison for left-right timing offsets (top), layer timing offsets (middle), and effective velocity (bottom) as a function of the detector element. The red and green dots correspond to the original and extracted values, respectively, while the lines show the ideal values. The histograms on the right show the discrepancy between original and extracted values for the same parameters.

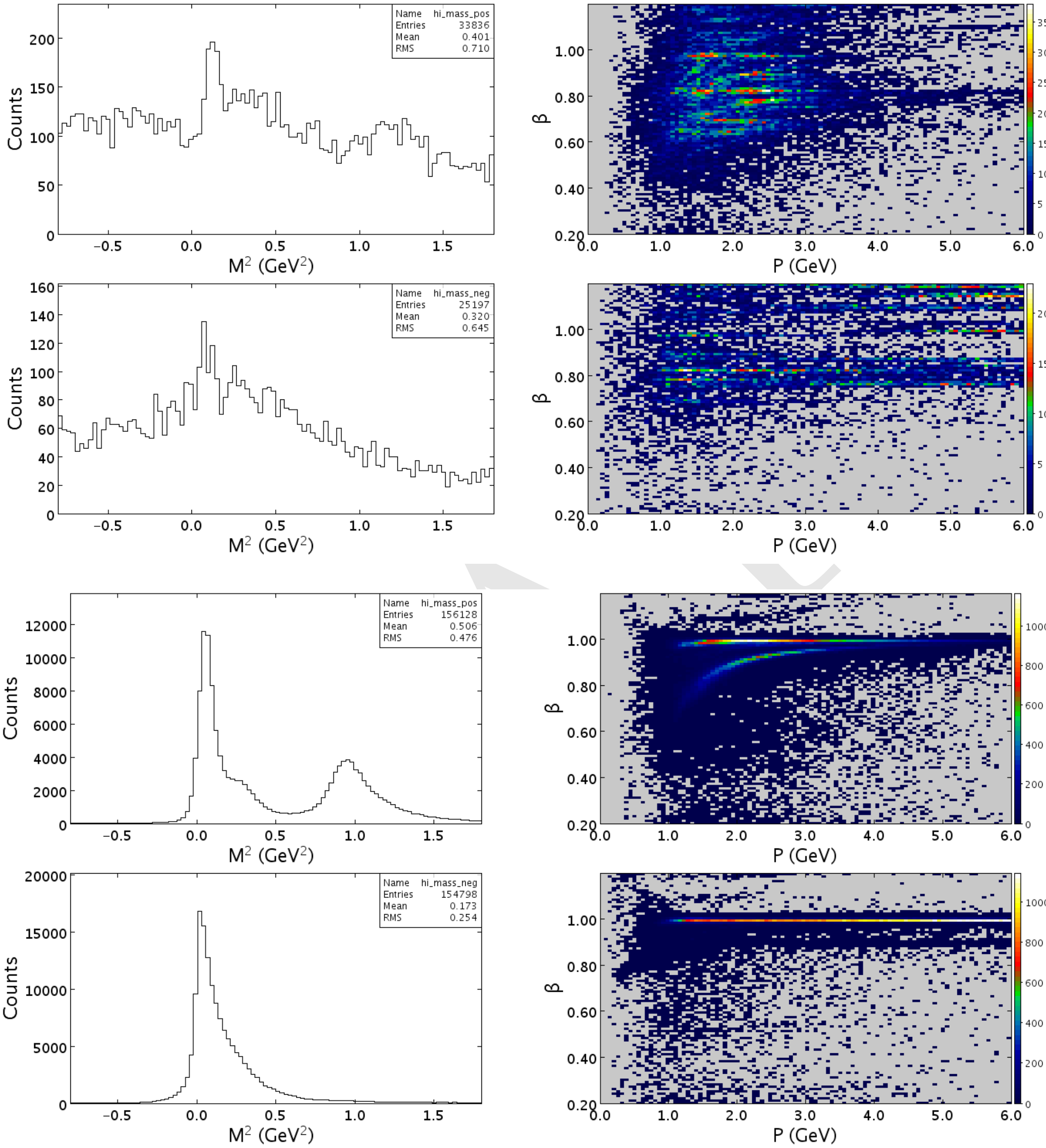

Figure 7: Comparison of the FTOF reconstructed mass and β vs. momentum before (top four plots) and after (bottom four plots) calibrations. The two sets of four plots show the reconstructed mass squared and the β vs. momentum distributions for positively (first row) and negatively (second row) charged particles.

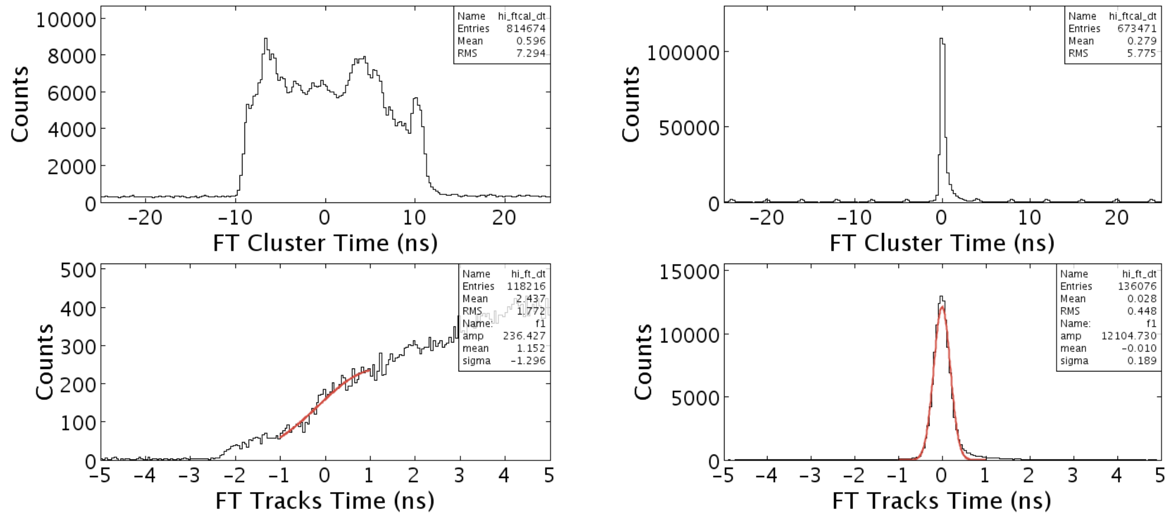

Figure 8: Comparison of the FT-Cal reconstructed time before (left) and after (right) calibrations. The plots show the difference between the reconstructed time for all clusters (top) and for clusters with more than 200 MeV and a multiplicity of 3 (bottom). The resulting timing resolution is consistent with the spread introduced in the detector simulation.

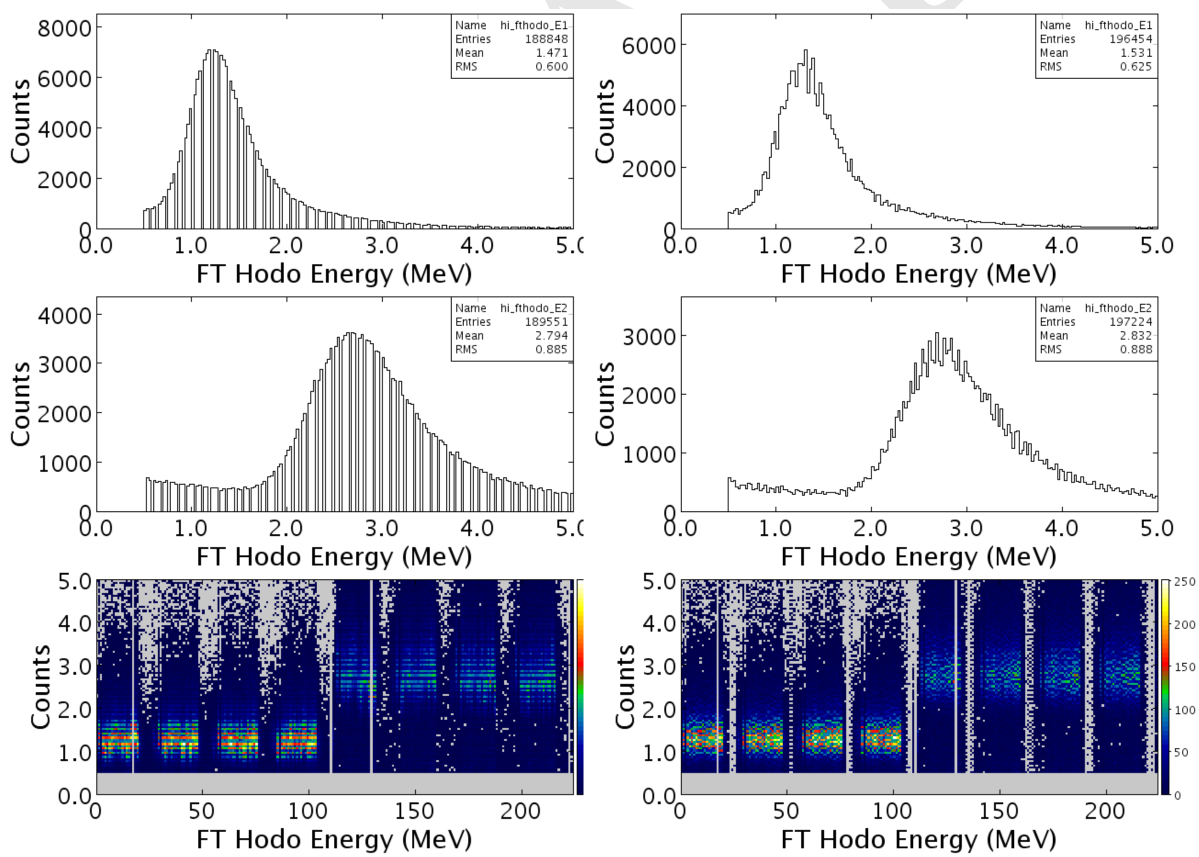

Figure 9: Comparison of the FT-Hodo reconstructed energy before (left) and after (right) calibrations. The plots show the energy deposition in the thin (top) and thick (middle) layers, as well as a function of the tile ID.

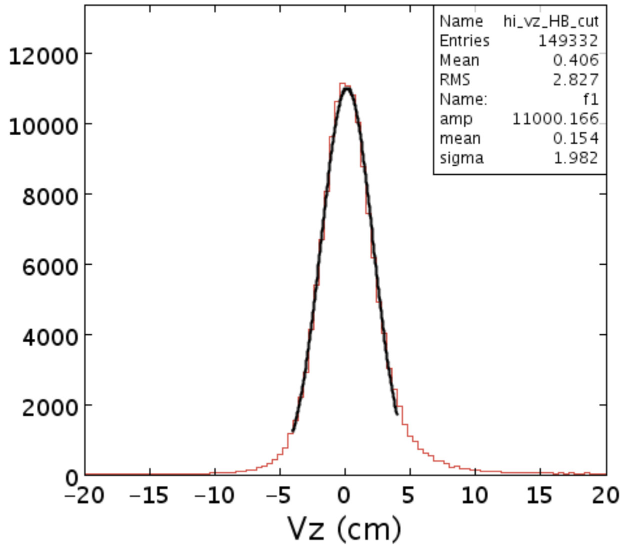

Figure 10: Electron track z-coordinate distribution as reconstructed from hit-based tracking.

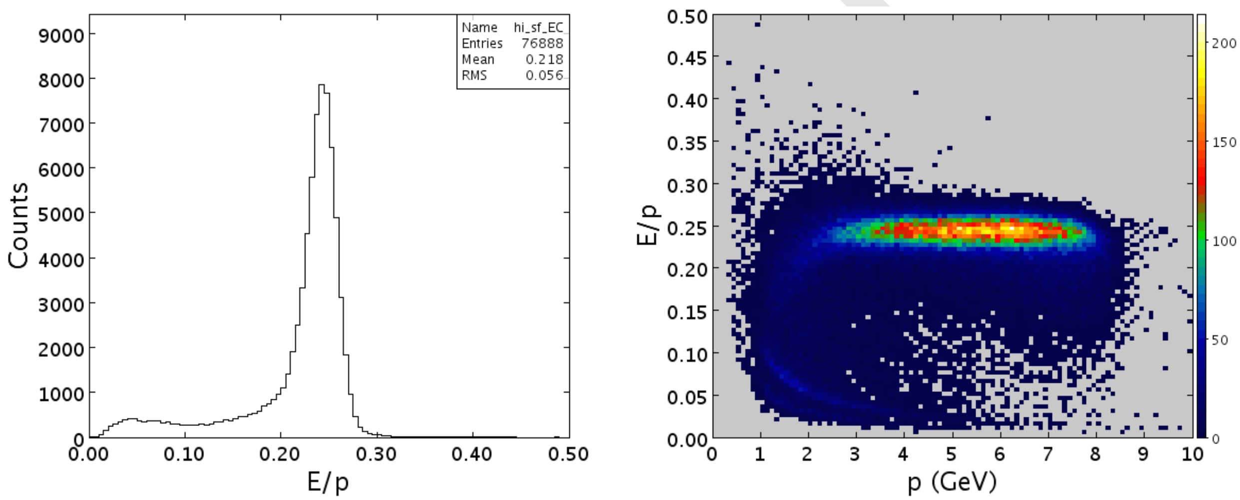

Figure 11: Electromagnetic calorimeter sampling fraction for electrons integrated over all momenta (left) and as a function of momentum (right).

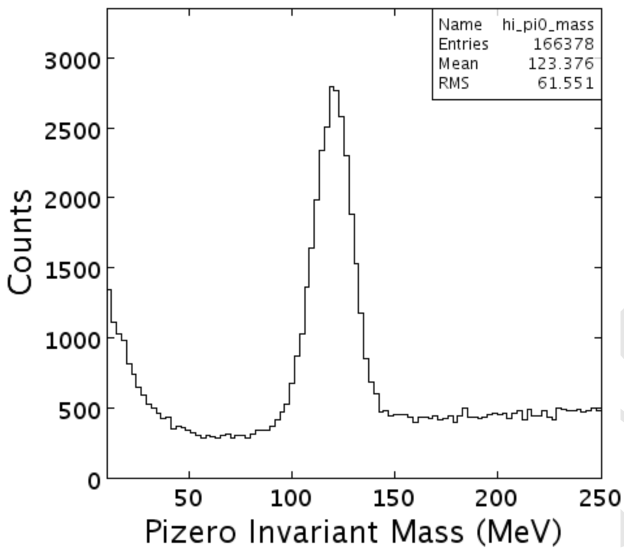

Figure 12: Two photon invariant mass distribution as reconstructed from the electromagnetic calorimeters.

To further assess the quality of the reconstructed information, additional plots showing the reconstructed electron vertex from hit-based tracking and the electromagnetic calorimeter response to electrons and π^0s were made and are shown in Figs. 10-12.

7 Calibration Challenge Findings

7.1 Successes Achieved During the Calibration Challenge

7.1.1 FTOF

- Counter status: all missing PMT anodes and dynodes were identified correctly.
- Left-right timing offset, effective velocity, attenuation length: calibration constants were extracted using 1M events and were in reasonable agreement with the distorted values.
- Time walk: limited success. In some paddles the data were successfully fitted to the functional form and the constants were extracted, but in other paddles the algorithm did not converge. An improved algorithm was suggested during the challenge based on this finding and remains to be tested.
- Overall:
  - The estimated time to complete the calibration is 1 day, allowing for 5 iterations at 1 hour per iteration and 2 hours for manual checks between iterations.
  - The convergence of the calibration results was observed using 1M events, i.e. statistics that in the real case could be accumulated in an hour of data taking.

- It will be possible to perform multiple iterations of the calibration without recooking; this could be automatic in the future, with the option of using starting values for constants from the database, from a text file, or from a previous iteration.

7.1.2 CTOF

- Counter status: all missing PMTs were identified correctly.
- Effective velocity, attenuation length: calibration constants were extracted using 1M events and were in reasonable agreement with the distorted values.
- Upstream-downstream timing offset: values were extracted, but with a systematic shift due to the method used to overcome the forward bias of the timing distribution; more details are included under the issues section.
- Overall:
  - The estimated time to complete the calibration is 1/2 day, allowing for 3 iterations at 1 hour per iteration and 1 hour for manual checks between iterations.
  - The convergence of the calibration results was observed using 1M events, i.e. statistics that in the real case could be accumulated in an hour of data taking.
  - It will be possible to perform multiple iterations of the calibration without recooking; this could be automatic in the future, with the option of using starting values for constants from the database, from a text file, or from a previous iteration.

7.1.3 FT-Cal

The calibration procedure consisted of the analysis of all events with hits in the FT-Cal with no selection criteria applied, except the detection of the electron in the Forward Detector that would provide the event start time. This choice was made to avoid the necessity of using information from other subsystems (as this was the first Calibration Challenge). All hits, including beam background signals, photons or pions, were accepted for both calibration steps performed:

- Channel status check: the status of all channels is based on the number of detected hits and on the energy deposited in the crystal. Since we were reading GEMC output files where a dead channel was defined to have an event with energy released equal to zero, the selection was mainly due to an energy cut. In real life, if a channel is dead, there are no hits recorded. Both selections were implemented, the energy cut was tested during the Calibration Challenge and the event cut was already tested on real data (cosmics). During the challenge, the dead channels were easily identified using a single file (20k events).
- The timing offset calibration was tested in realistic conditions for the first time. For each channel, the algorithm considers the time difference between the FT-Cal time projected to the target in the assumption of a photon-induced shower and the event

start time. As shown in Fig. 8 the resulting distributions show a main peak, due to photons or hadrons hitting the calorimeter, surrounded by spurious peaks from background associated with the nearby beam bucket. The main peak is fitted to a Gaussian function whose mean corresponds to the desired timing offset. The fit range is limited to the central and left regions of the peak to exclude the contribution from pion-induced hits that are in the right tail of the peak (as they are slower than photons). The results obtained with this method were found to agree with the distorted constants using both different subsets of simulated data of about 2M events and using the full statistics.

- The whole calibration procedure took a few hours and did not require iterations.

7.1.4 FT-Hodo

All calibration steps were successful. A modification to the charge distribution fit function was necessary (an exponential was added to model background) as was setting the status of some tiles in the shadow of the Möller cone.

The whole calibration procedure took a few hours and did not require iterations.

7.1.5 CND

- Successfully identified dead channels, indicating no issues with the detector numbering scheme or with reading the data.
- Visually showed that the coupled-counter timing offsets were applied correctly to CND-specific GEMC data (after fixing problems with the CND hit-process code), although no quantitative results can be provided at this time.
- A preliminary method for determining the layer timing offsets was used (rather successfully).
- The nominal CND-specific GEMC simulations will be further investigated to fine tune the algorithms, but the preliminary effective velocity values determined were very promising with respect to the expected values.
- Automatic fits seem to work successfully regardless of quality of data. Fit adjustments are easy to implement as necessary. Most functionality works, allowing for intuitive and easy viewing/navigation of data.

7.2 Issues and Problems Encountered

7.2.1 FTOF

- Counter status: no issues.
- Left-right timing offset:

  - Smaller bins were used to obtain an accurate determination of the centroid, requiring larger statistics. 100 ps resolution was achieved with 1M events. It is still to be determined how many events will be required for 50 ps bins.
  - Running with smaller bins meant more variations in the plateau of the time difference distributions. Improvements will be made to the algorithm with this in mind.

- Effective velocity:
  - The extracted values seem to be systematically larger than the distorted values. This needs to be investigated.
  - Events were cut where the hit position from tracking differs from the hit position derived from FTOF timing values by more than 20 cm. This caused an issue when the distorted value of effective velocity was far from the ideal value. It may also mean that there is a correlation between the (ideal distorted) and (extracted distorted) parameters. Re-iterating with newly calculated values for effective velocity may correct for this.
  - The histograms for some paddles did not have data over the full length of the paddle; to be investigated.

- Attenuation length:
  - As for the effective velocity, the extracted values seem to be systematically larger than the distorted values; to be investigated.
  - The histograms for some paddles did not have data over the full length of the paddle; to be investigated.

- Time walk: Time walk constants were not successfully extracted. The corrections did not converge for the majority of paddles. This was traced back to the algorithm, which models the left time walk effect using the corrected values for the right and vice versa. An improved procedure using the existing algorithm has been identified, as well as a new algorithm that decouples the left PMT time walk effects from the right PMT time walk effects, but neither has yet been considered. It is also important to note that good time walk constants are required to complete all steps in the calibration.

- RF calibrations: As the Monte Carlo did not include full modeling of the RF time structure of the beam, the RF calibrations algorithms could not be tested. This will be investigated in more detail in the near future.

- Energy loss calibrations: The energy loss calibration algorithm was not tested. This still needs to be done and should be straightforward to test given the data generated for the challenge.

- Paddle-to-paddle offsets: The paddle-to-paddle timing offset algorithm was not studied as it requires proper modeling of the beam RF structure and particle identification abilities (the algorithm requires electrons and pions from $ep \to e'\pi X$). Some testing of aspects of this algorithm can be tested using the data generated for the challenge but the particle identification algorithm was not ready in time for any studies to be carried out. Studies of this algorithm will be done in the near future.

- Overall:
  - Large uncertainties were returned by the straight line fit to a profile graph, therefore the uncertainties reported for the calibration constants were large, in many cases around 50%. More investigation is required.
  - The "View all" option has a bug whereby missing data for one paddle prevents plots for subsequent paddles from being displayed.
  - The full sequence of steps for the FTOF calibration suite was not exercised. This will be important to test more fully to understand the proper ordering of the steps of the calibration suite and the number of iterations required for each step for the algorithms to converge.
  - The FTOF calibration suite needs to be able to handle the different calibration steps even with hardware/electronics problems that lead to the value of PMT status$\neq$0 as is the case with the FTOF reconstruction code. This has not been considered within the calibration code.

7.2.2 CTOF

- Counter status: no issues.
- Upstream-downstream timing offset:
  - The existing algorithm assumes a uniform distribution of hits along the length of the counter. For beam data, however, this is not the case and the distribution of hits is skewed to the downstream end of the counters. This asymmetric distribution caused us to consider alternative algorithms and approaches:
    1. Use only particles emitted at $90^{\circ} \pm 2^{\circ}$ for the calibration
    2. Use hits in the downstream position range of 35 cm - 40 cm.
    3. Use CTOF cosmic ray data to complete this step in the calibration.
  - Statistics were low for option 1, therefore option 2 was followed. In the future it is likely that option 3 will be employed as it leads to uniform hit population along the counters.
- Effective velocity:
  - Some adjustments to fit ranges were required to account for the low statistics at the upstream end of the paddles.
  - Further investigation into paddles for which there was a difference in extracted vs. distorted is required.
- Attenuation length:

- Further investigation into paddles for which there was a difference in extracted vs. distorted is required.

- RF calibrations: As the Monte Carlo did not include full modeling of the RF time structure of the beam, the RF calibrations algorithms could not be tested. This will be investigated in more detail in the near future.

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  - The "View all" option has a bug whereby missing data for one paddle prevents plots for subsequent paddles from being displayed.
  - The full sequence of steps for the CTOF calibration suite was not exercised. This will be important to test more fully to understand the proper ordering of the steps of the calibration suite and the number of iterations required for each step for the algorithms to converge.
  - The CTOF calibration suite needs to be able to handle the different calibration steps even with hardware/electronics problems that lead to the value of PMT status$\neq$0 as is the case with the CTOF reconstruction code. This has not been considered within the calibration code.

7.2.3 FT-Cal

No specific problems were encountered during the challenge. The only potential issue that was identified applying the chosen calibration algorithm was the optimization of the timing distribution fit parameters that could require manual adjustments.

7.2.4 FT-Hodo

Additional charge and timing conditions were applied to the timing distribution histograms to remove false narrow peaks created by similar distorted constant values for the thin and thick layers. The mean charge values from the fits underestimated the distorted values used systematically by around 30 pC ($< 5\%$ offset); the reason for this is being investigated.

7.2.5 CND

- A separate step in the suite will be introduced for the counter status, allowing for a formal report via text file output.
- The event selection will be changed to analyze the Pythia files, for calibrating on a more realistic data set.
- CND-specific GEMC simulated data required correction to the application of timing offsets to give quantitative measures for calibration steps. This was resolved and tested a few days after the end of the challenge.
- Most suitable automatic fit parameters can be assessed in further analysis of data.
- Strict criteria for selection needs to be loosened.
- A new layer timing offset method will be developed.

7.3 Future Calibration Development Plans

7.3.1 FTOF

- Refinement of the left-right time-offset algorithm,
- Testing of the energy loss calibration algorithm,
- Refinement of the time walk algorithm,
- Testing of the RF calibration algorithm,
- Event selection for the paddle-to-paddle step and testing of the paddle-to-paddle algorithm,
- Testing of the full calibration algorithm to optimize the order of the calibration steps and to study the number of iterations required to converge on optimal calibration parameters,
- Develop and test the calibration suite to handle the full set of hardware failure conditions,
- Documentation and tutorials. A preliminary version of the calibration algorithm steps was completed after the challenge period and will be finalized after the algorithms of the calibration suite are optimized.

7.3.2 CTOF

- Refinement of the upstream-downstream time-offset algorithm,
- Testing of the energy loss calibration algorithm,
- Refinement of the time walk algorithm,
- Testing of the RF calibration algorithm,
- Event selection for the paddle-to-paddle step and testing of the paddle-to-paddle algorithm,
- Testing of the full calibration algorithm to optimize the order of the calibration steps and to study the number of iterations required to converge on optimal calibration parameters,
- Develop and test the calibration suite to handle the full set of hardware failure conditions,
- Documentation and tutorials.

7.3.3 FT-Cal

- Extend the the energy calibration algorithm, presently based on cosmic data, to real data using the π^0 mass distribution.
- Migrate the calibration suite to COATJAVA 3.0 or newer versions.
- Documentation and tutorials.

7.3.4 FT-Hodo

- Complete the timing calibration.
- Migrate the calibration suite to COATJAVA 3.0 or newer versions.
- Documentation and tutorials.

7.3.5 CND

- Finalize the import of the light attenuation step.
- Introduce energy calibration step.
- Uncertainty calculations need to be finalized/checked.
- Migrate to COATJAVA 3.0.
- Documentation and tutorials.

7.4 Common Tools Development

Based on the work performed during the Calibration Challenge, further developments of the COATJAVA package that would be useful for the calibration suites were identified:

- extend the event decoder to provide the same data structure when using real data in Mode 1 or 7, or simulated data;
- add to the event panel the possibility of reading multiple EVIO files;
- fitting to profile graphs;
- extension of the calibration constant table functionalities: possibility of specifying constraints for combination of layer and paddle, cursor up and down in the table to trigger a listener event in the same way as for a mouse click, completion of the comparison to previous calibration run function.

7.5 Plans for Future Calibration Challenges

For each of the detector subsystems the Calibration Challenge exercise revealed a number of issues with the calibration suites that will require attention. The issues ranged from modifications to the algorithms that were employed, to problems with the common tools, to layout of the calibration suite interfaces, to necessary changes to the calibration database parameters, to the organization of the data bank structures. In addition, due to the current state of the simulation, reconstruction, and calibration code sequences, for some subsystems the full set of steps for the calibration sequence could not be completed. The challenge therefore has provided each of the detector subsystems with a list of tasks that will be worked on in the near future. For the FTOF and DC systems, a number of tasks have urgency in order to be fully prepared for the upcoming KPP beam run in early 2017.

Given the work lists for the calibration suites and the timelines to complete this work, the next Calibration Challenge exercise will be not be scheduled until some time after the KPP run. This next challenge will focus on the calibration suites for the full set of CLAS12 subsystems, both baseline and ancillary, that will be necessary to calibration during the fall Engineering beam run and the first physics production running as part of the RG-A run group.

8 Summary and Conclusions

There were five main goals that were identified for this Calibration Challenge exercise (see Section 1). Here we review those goals and provide a brief comment on the realization of these goals after the completion of the week-long challenge exercise.

1. To test the functionality of the subsystem calibration suites:
    - The functionality of the calibration suites for the FTOF, CTOF, FT-Cal, FT-Hodo, and CND subsystems were tested in whole or in part.

2. To test the overall CLAS12 system calibration procedures, including the sequence and inter-dependencies of the calibration steps:

    - The full tests of the inter-dependencies across the subsystems were not checked in this calibration exercise (e.g. DC tracking necessary for the FTOF calibrations, SVT tracking necessary for the CTOF and CND calibrations). However, those calibration suites that required iterative calibration sequences (e.g. FTOF and CTOF) were studied, although additional investigations will be required after further work is completed to update the simulation and the reconstruction codes.

3. To test the work team organization:

    - The level of the work team organization and motivation was high throughout this challenge exercise.

4. To train the subsystem calibration teams:

    - The challenge exercise proved to be a very important training opportunity for the subsystem calibrators.

5. To identify any remaining issues with the procedures and the software:

    - Each subsystem identified a number of areas where work on either the calibration suites or algorithms was necessary as a direct result of the challenge exercise. This was an important opportunity that will lead to improvements in and continued development of the suites across all CLAS12 subsystems.

There were three metrics for success that were identified for this Calibration Challenge exercise (see Section 1). Here we review these metrics and provide a brief assessment on how well these metrics were met in terms of a pass/fail grade after the completion of the week-long challenge exercise.

1. Subsystem calibration teams were able to follow the devised calibration procedures and determine a complete set of calibration constants that were then inserted into the calibration database:

    - The calibration suites were exercised in whole or in part according the planned procedures from reading in the raw or cooked data banks, to filling histograms, to performing the necessary fits, to writing out the determined calibration constants for the database. Even though in some cases not all steps of the calibration sequence were tested during the challenge exercise (e.g. FTOF, CTOF, CND), the tools, for the most part, worked as they were designed.
    - In several cases the algorithms needed improvements and the challenge exercise allowed for the path to these improvements to be identified. Additionally, in several cases due to limitations in the simulation data set or in the reconstruction code, portions of the calibration suites could not be tested. However, the challenge exercise helped to identify what work was needed to test these portions of the calibration suites.

- **Overall, this metric is assigned a passing grade.**

2. Training of the calibration teams to be able to use the calibration suites with realistic data under the pressures expected during the CLAS12 commissioning runs when semi-online subsystem calibrations are necessary:

    - Overall the calibration teams were well prepared to tackle the work and the pressures associated with this challenge exercise. Additionally, the exercise allowed for additional training of the calibration teams that was invaluable.
    - **Overall, this metric is assigned a passing grade.**

3. Accurate determination ($\approx$5% - 10%) of the calibration constants used to generate the smeared Monte Carlo data:

    - Where the subsystem calibration steps could be completed, the agreement between the calibration constants used to smear the data and those determined by the calibration teams had very good agreement. The only issue was the failure of the FTOF time-walk calibration algorithm to converge for all counters. However, the issues seen here led to suggestions for several modifications to the algorithm that are expected to solve the problems that were seen.
    - **Overall, this metric is assigned a passing grade.**

9 Appendix

```
<gcard>
<option name="geometry" value="1400x1200"/>

<!-- target. Notice variation give the target type. Can be: lH2, lD2, ND3 -->
<detector name="experimentsd/clas12/targets/target" factory="TEXT" variation="lH2"/>

<!-- The java variation of various detectors come from the coatjava factories
 The "original" variation is still available if needed -->


<!-- central detectors -->
<detector name="experimentsd/clas12/bst/bst"               factory="TEXT" variation="java"/>
<detector name="experimentsd/clas12/cnd/cnd"               factory="TEXT" variation="original"/>
<!--<detector name="experimentsd/clas12/micromegas/micromegas" factory="TEXT" variation="original"/>-->

<!--ctof, cad volumes -->
<detector name="experimentsd/clas12/ctof/ctof"             factory="TEXT" variation="cad"/>
<detector name="experimentsd/clas12/ctof/cad/"             factory="CAD"/>

<detector name="experimentsd/clas12/htcc/htcc"          factory="TEXT" variation="original"/>

<!-- magnets volumes-->
<detector name="experimentsd/clas12/magnets/solenoid"      factory="TEXT" variation="original"/>
<detector name="experimentsd/clas12/magnets/torus"         factory="TEXT" variation="original"/>

<!-- Beamline configuration: FT is used -->
<detector name="experimentsd/clas12/beamline/beamline" factory="TEXT" variation="FTOn"/>
<detector name="experimentsd/clas12/ft/ft"             factory="TEXT" variation="FTOn"/>


<!-- forward carriage -->
<detector name="experimentsd/clas12/fc/forwardCarriage" factory="TEXT" variation="original"/>
<detector name="experimentsd/clas12/dc/dc"              factory="TEXT" variation="java"/>
<detector name="experimentsd/clas12/ftof/ftof"          factory="TEXT" variation="java"/>
<detector name="experimentsd/clas12/ec/ec"              factory="TEXT" variation="java"/>
<detector name="experimentsd/clas12/pcal/pcal"          factory="TEXT" variation="java"/>
<option name="SCALE_FIELD" value="clas12-torus-big, -1"/>

<!-- hall field  -->
<option name="HALL_FIELD"  value="clas12-solenoid"/>


<!-- fields, precise mode -->
<option name="FIELD_PROPERTIES" value="clas12-torus-big, 2*mm, G4ClassicalRK4, linear"/>
<option name="FIELD_PROPERTIES" value="clas12-solenoid, 0.5*mm, G4HelixSimpleRunge, linear"/>

<!-- beam conditions
<option name="BEAM_P"   value="e-, 4.0*GeV, 20.0*deg, 10*deg"/>
<option name="SPREAD_P" value="0*GeV, 10*deg, 180*deg"/>
-->

<option name="SAVE_ALL_MOTHERS" value="0"/>

<option name="PHYSICS" value="FTFP_BERT + STD + Optical"/>

<option name="OUTPUT"   value="evio, out.ev"/>

<option name="RUNNO"   value="17"/>

<!--  Will print message every 10 events -->
<option name="PRINT_EVENT"    value="10" />


<!--  RF Signal needs event time window defined by LUMI_EVENT.
      If Backround is activated make sure to use LUMI_EVENT below instead.
```

```
<option name="LUMI_EVENT"  value="0, 248.5*ns, 4*ns" />-->
<option name="RFSETUP"     value="0.5, 80, 40" />

<!--  beam background. for 250 ns timewindow we have 124,000 e- on
      a LH2 target at 10^35 luminosity
      I suggest in this case to set SAVE_ALL_MOTHERS to 0
      or the many tracks will slow down the simulation a lot
  For background studies use field in fast mode:
 -->
<option name="LUMI_EVENT"     value="12400, 248.5*ns, 4*ns" />
<option name="LUMI_P"         value="e-, 11*GeV, 0*deg, 0*deg" />
<option name="LUMI_V"         value="(0.,0.,-4.5)cm" />
<option name="LUMI_SPREAD_V"  value="(0.01, 0.01)cm" />


</gcard>
```