CLAS12 Calibration

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Ready for Science Review
September 25 2017
Outline

• CalCom group organization
• Calibration software and suites
• Calibration Constants Database
• Calibration strategy:
  – Non-beam calibrations (light sources, cosmic ray data, …)
  – KPP data
  – Simulations
• Calibration challenges
• Calibration Status
• Calibration team for CLAS12 Engineering Run
• Summary
CLAS12 CalCom Group

- Calibration and Commissioning Group established in 2011
  - Supervision of commissioning and calibration activities for CLAS12 baseline and non-baseline detectors
  - Liaison between detector groups and CLAS12 hardware and software experts
  - 5 permanent members including software and detector experts acting as advisors
  - Representatives of detector groups and calibration developers
  - Regular weekly meetings and dedicated sessions at Collaboration meetings
Calibration Software

Development of calibration and monitoring applications in an advanced stage for both baseline and ancillary CLAS12 subsystems:

- Calibration software based on CLAS12 Common Tools (COATJAVA):
  - Full integration with CLAS12 software tools and reconstruction packages
  - Optimization of resources, high uniformity and maintainability

- Algorithm development supervised by the CLAS12 calibration & commissioning group (CALCOM)

- Implementation supervised by the software group

- Tests on both cosmic ray, KPP and simulated data
Calibration Suites

Detector Visualization
- callback on clicks
- coloring by occupancy

Data Canvas
- callback for detector
- callback for table

Database Table
- component callback
- constraint coloring
- comparison utils

Detector Visualization Layers

Event Processing Panel
- event by event, or whole
- opens: File, ET ring, EVIO or HIPO

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Calibration Constants DB

- Based on CCDB
- Entries organized according to:
  - Variation
  - Run range
  - Time stamp
  - ID
- Used to store:
  - Calibration parameters
  - Geometry parameters
  - DAQ parameters
- Tables:
  - Organized in “detector” folders
  - Common indexing convention by sector, layer, component
- Accessible via Common Tools
- Used by both simulations and reconstruction software
- Presently, all tables for detector calibrations created and filled


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CLAS12 Calibration
Calibration strategy

Development and validation of calibration algorithms and tools based on:

• **Non beam data:**
  – Light sources (LED or Laser systems for Cerenkov Counters, FT-Cal LMS, …)
  – Noise, pedestals, …(SVT and MM trackers, Cerenkov Counters gain calibration via SPE measurements, …)
  – Cosmic ray data

• **KPP data:**
  – Energy and time calibration of forward detectors (DC, HTCC, FTOF, ECAL)

• **Simulated data:**
  – Use of realistic simulations (GEMC) to exercise calibration procedures
Calibration without beam

Calibration with cosmic ray, light sources, “noise” (SPE, …):

- In progress since detector assembly completion or installation
- Main means of calibration for Cerenkov detectors, SVT, and MicroMegas detectors
- Provide initial calibrations for energy loss and HV/gain calibrations for several detectors:
  - **CND**: full calibration before installation
  - **CTOF**: full calibration before installation
  - **ECAL**: gain and attenuation length
  - **FT**: gain and energy calibrations for calorimeter and hodoscope
  - **FTOF**: full calibration before installation; gain, attenuation length and left-right time offsets after installation
  - **HTCC** and **LTCC**: gain calibrations
  - **MM**: noise and pedestals measurement
  - **SVT**: noise and pedestals measurement
- Crucial for the success of the KPP run
SVT calibration suite

Suite developed to monitor detector parameters (gain, ENC) from global level down to individual channels

- Regular calibration scans
- Calibration data in elog
  https://logbooks.jlab.org/book/hbsvt
- Documentation & tutorial at
FT-Cal cosmic ray calibration

- Energy calibration based on response to cosmic rays
- Calibration performed using:
  - external trigger scintillators during initial test in EEL building
  - self-triggering based on fADC (majority of pulses over threshold in a board above selectable value)

- Routinely done after installation to monitor detector stability vs. time:
  - Charge-to-energy conversion factor
  - Light Yield vs. Temperature
  - Noise levels
  - Component status
Calibration of KPP Data

• First opportunity to perform full detector calibrations based on real data:
  – ECAL cosmic gain calibration cross checked with pions, timing calibration started
  – Full calibration of FTOF done, improvements to reach ultimate resolution in progress
  – DC calibration step sequence developed and implemented
  – HTCC calibration extended to include timing

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ECAL energy calibration

Crucial system for CLAS12 electron trigger:
- Initial energy calibration based on cosmic ray data
- Calibration cross checked with pions in KPP: more uniform six-sector coverage
- Calibration results validated via analysis of \( \pi^0 \) mass spectrum from two-photon events

\[
M^2_{\pi^0} = 2 E_1^\gamma E_2^\gamma \left(1 - \cos \vartheta_{12}\right)
\]

\[
\frac{\Delta M}{M} = \frac{1}{2} \left( \frac{\Delta E_1}{E_1} + \frac{\Delta E_2}{E_2} \right)
\]
FTOF calibration

<table>
<thead>
<tr>
<th>HV/Gain Calibration</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Step #</td>
<td>Action</td>
</tr>
<tr>
<td>✓ 1</td>
<td>Gain Calibration</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Timing Calibration</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>✓ 1</td>
<td>PMT Timing Diff.</td>
</tr>
<tr>
<td>✓ 2</td>
<td>Attenuation Length</td>
</tr>
<tr>
<td>✓ 3</td>
<td>Effective Velocity</td>
</tr>
<tr>
<td>✓ 4</td>
<td>Time-Walk</td>
</tr>
<tr>
<td>✓ 5</td>
<td>P2P</td>
</tr>
<tr>
<td>✓ 6</td>
<td>RF Offset</td>
</tr>
</tbody>
</table>

While the KPP data is limited (low statistics, S2 only), it has allowed for important developments and verifications related to the FTOF calibrations
DC calibration

- GUI driven complete calibration suite for DC
- Tested with both MC and KPP data for convergence, stability and improved resolution

(a) Residual distribution

(b) Residual vs trkDoca

KPP data:
- Sector 2
- Superlayer 5

Typical fit for time-to-distance function
Calibration Challenge

Test of the full calibration procedure:

- Generate pseudo-data with “wrong” calibration constants
- Run calibrations for different systems in appropriate sequence
- Extract calibration constants and save them to DB
- Evaluate calibration quality by:
  - looking at monitoring plots
  - comparing reconstruction output with extracted and original constants

- First challenge in December 2016, second challenge in August 2017 involving all detectors

Who:
- Analysis Coordinator
- Calibrator team
- DB manager
- “Chef” for data processing

When:
- December 12-19 2016
- August 28 – September 8 2017
  (1 week -10 days)

How:
- Generate pseudo-data with Pythia and $10^{34}$ luminosity background
- 1 shift (8 h) worth of data
- Daily meetings and milestones for coordination and progress tracking
Calibration Challenge

Calibration challenge goals, strategy, organization and results documented in CLAS12-Note 2017-010

<table>
<thead>
<tr>
<th>System</th>
<th>Calibration</th>
<th>Calibrator(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CND</td>
<td>Energy &amp; Time</td>
<td>G. Murdoch (Glasgow)</td>
</tr>
<tr>
<td>CTOF</td>
<td>Full</td>
<td>D. Carman (JLab), L. Clark (Glasgow)</td>
</tr>
<tr>
<td>DC</td>
<td>Time</td>
<td>L. Kabir (Mississippi)</td>
</tr>
<tr>
<td>ECAL</td>
<td>Time</td>
<td>J.A. Tan (KNU)</td>
</tr>
<tr>
<td>FTCal</td>
<td>Time</td>
<td>R. De Vita (INFN)</td>
</tr>
<tr>
<td>FTHodo</td>
<td>Energy</td>
<td>N. Zachariou (Edinburgh), S. Hughes (Edinburgh)</td>
</tr>
<tr>
<td>FTOF</td>
<td>Energy &amp; Time</td>
<td>D. Carman (JLab), L. Clark (Glasgow)</td>
</tr>
<tr>
<td>HTCC</td>
<td>Time</td>
<td>N. Markov (UCONN)</td>
</tr>
<tr>
<td>LTCC</td>
<td>Time</td>
<td>B. Duran (Temple), M. Ungaro (JLab)</td>
</tr>
</tbody>
</table>

Day #1: Pass-0 data made available
- FTOF calibrations completed

Day #2: First iteration of calibrations completed
- Detector component status for all subsystems
- Energy/gain calibrations for FT and CND
- DC time-based tracking calibration started
- Pass-1 data made available to calibrators
- CTOF calibrations completed

Day #3: Second iteration of calibrations
- Time calibrations for CND, FT, HTCC, LTCC, ECAL
- Refinement of DC time-based tracking calibrations
- Pass-2 data made available to calibrators
- Unblind calibration constants to calibration teams

Day #4: Third iteration of calibrations
- Recooked data sample with DC reconstruction and calibration fixes made available
- Refinement of ECAL and HTCC timing calibrations

Day #5: Fourth (and final) iteration of calibrations

Days #6 - #12: Complete calibration constant comparisons and preparation of reconstruction plots
Calibration Challenge

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<td>B. Duran (Temple), M. Ungaro (JLab)</td>
</tr>
</tbody>
</table>

Calibration challenge goals, strategy, organization and results documented in CLAS12-Note 2017-010
## Overall Calibration Status

<table>
<thead>
<tr>
<th>System</th>
<th>Calibration algorithm</th>
<th>Calibration Suite</th>
<th>Monitoring Suite</th>
<th>Documentation &amp; Tutorials</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC</td>
<td>Done</td>
<td>Optimization in progress (10/31/2017)</td>
<td>Done</td>
<td>Suite documentation (10/31/2017)</td>
</tr>
<tr>
<td>ECAL</td>
<td>Done</td>
<td>Timing (10/31/2017)</td>
<td>Done</td>
<td>In progress (11/15/2017)</td>
</tr>
<tr>
<td>FTOF</td>
<td>Done</td>
<td>Done</td>
<td>Done</td>
<td>Done</td>
</tr>
<tr>
<td>HTCC</td>
<td>Done</td>
<td>Merging of gain and time (10/31/2017)</td>
<td>Done</td>
<td>In progress (10/31/2017)</td>
</tr>
<tr>
<td>LTCC</td>
<td>Done</td>
<td>Merging of gain and time (10/31/2017)</td>
<td>Done</td>
<td>To be started (11/15/2017)</td>
</tr>
<tr>
<td>FT</td>
<td>Done</td>
<td>Upgrade to Coatjava 4.0 (10/15/2017)</td>
<td>Tracker implementation (10/31/2017)</td>
<td>In progress (11/15/2017)</td>
</tr>
<tr>
<td>SVT</td>
<td>Done</td>
<td>Done</td>
<td>Done</td>
<td>Done</td>
</tr>
<tr>
<td>MVT</td>
<td>Lorentz angle correction (10/31/2017)</td>
<td>Done</td>
<td>Done</td>
<td>In progress (10/31/2017)</td>
</tr>
<tr>
<td>CTOF</td>
<td>Done</td>
<td>Done</td>
<td>Done</td>
<td>Done</td>
</tr>
<tr>
<td>CND</td>
<td>Attenuation length (10/15/2017)</td>
<td>Done</td>
<td>In progress (10/31/2017)</td>
<td>To be started (11/15/2017)</td>
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<tr>
<td>RICH</td>
<td>Global timing (11/15/2017)</td>
<td>In progress (10/31/2017)</td>
<td>In progress (10/31/2017)</td>
<td>Software documentation (11/31/2017)</td>
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Calibration Team
for CLAS12 Engineering Run

<table>
<thead>
<tr>
<th>Task</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analysis Coordinator</td>
<td>N. Baltzell (JLab), R. De Vita (INFN)</td>
</tr>
<tr>
<td>Data Chef(s)</td>
<td>F.X. Girod (JLab), N. Harrison (North Georgia)</td>
</tr>
<tr>
<td>DB manager</td>
<td>H. Avakian (JLab)</td>
</tr>
<tr>
<td>Calibrators</td>
<td></td>
</tr>
<tr>
<td>CND</td>
<td>G. Murdoch (Glasgow), S. Niccolai (IPN)</td>
</tr>
<tr>
<td>CTOF</td>
<td>D. Carman (JLab), L. Clark (Glasgow)</td>
</tr>
<tr>
<td>DC</td>
<td>L. Kabir (Mississippi)</td>
</tr>
<tr>
<td>ECAL</td>
<td>C. Smith (JLab), J.A. Tan (KNU)</td>
</tr>
<tr>
<td>FT</td>
<td>A. Celentano (INFN), L. Lanza (Roma TV), N. Zachariou (Edinburgh)</td>
</tr>
<tr>
<td>FTOF</td>
<td>D. Carman (JLab), L. Clark (Glasgow)</td>
</tr>
<tr>
<td>HTCC</td>
<td>N. Markov (UCONN)</td>
</tr>
<tr>
<td>LTCC</td>
<td>B. Duran (Temple), M. Ungaro (JLab)</td>
</tr>
<tr>
<td>MVT</td>
<td>G. Christiaens (CEA), M. Defurne (CEA)</td>
</tr>
<tr>
<td>RICH</td>
<td>A. Kim (UCONN), M. Turisini (JLab/INFN)</td>
</tr>
<tr>
<td>SVT</td>
<td>Y. Gotra (JLab)</td>
</tr>
</tbody>
</table>
Summary

- CalCom group has supervised the developments of calibration procedures and software since 2011
- Calibration suites have been developed based on the CLAS12 Common Tools (COATJAVA) to ensure resource optimization and maintainability
- CCDB has been adopted as calibration constants database and is being used by simulation and reconstruction software
- Detector calibrations have been developed and performed based on:
  - Non-beam data (light sources, cosmic ray data, …)
  - KPP data
  - Simulations
- Two calibration challenges were performed in December 2016 and August 2017 to exercise the whole calibration procedure, the work and team organization
- Calibration algorithms, software and documentation are on track for full completion before the engineering run
- The calibration team for the CLAS12 Engineering Run has been formed including calibration developers and detector experts
Backup
Computing requirements

Values used in estimate calculations:

- event rate 10 kHz
- 24-hr duty cycle 60%
- core efficiency 90%

**data**
- reconstruction processing time per event per core 120 ms*
- number of reconstruction passes 2
- ratio of simulated to data events 6

**MC**
- simulation time per event per core 500 ms*
- number of MC passes 1.5

**calibration**
- fraction of data for calibration 5%
- calibration processing time per event per core 50 ms
- number of calibration passes 5

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### Core Requirements

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Number of Cores Days for Data Cooking</td>
<td>1600</td>
</tr>
<tr>
<td>Number of Cores Days for Simulation</td>
<td>7500</td>
</tr>
<tr>
<td>Number of Cores Days for MC Cooking</td>
<td>1800</td>
</tr>
<tr>
<td>Number of Cores Days for Calibration</td>
<td>83</td>
</tr>
<tr>
<td><strong>Total for 1 day</strong></td>
<td><strong>10983</strong></td>
</tr>
</tbody>
</table>

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### Storage Requirements

[in TB per day of running]

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>DAQ data volume</td>
<td>41</td>
</tr>
<tr>
<td>Raw data volume</td>
<td>4</td>
</tr>
<tr>
<td>Cooked data volume</td>
<td>17</td>
</tr>
<tr>
<td>Simulated evio data volume</td>
<td>16</td>
</tr>
<tr>
<td>Simulated hipo data volume</td>
<td>4</td>
</tr>
<tr>
<td>Cooked Simulated data volume</td>
<td>16</td>
</tr>
<tr>
<td>Calibrated data volume</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total data volume in TB for 1 day</strong></td>
<td><strong>97</strong></td>
</tr>
</tbody>
</table>

* un-optimized values (depends on B-field swimming step size, nb of tracks and Bkg.)
Alignment of the SVT

- Track-based alignment of SVT requires fitting many parameters: \(N_{\text{sectors}} \times N_{\text{layers}} \times N_{\text{trans}} \times N_{\text{rot}} = 66 \times 2 \times 3 \times 2 = 792\)

- Program millepede does linear least squares with many parameters.
  - Uses matrix form of least squares method and divide the elements into two classes.
    - Global parameters – the geometry misalignments. Same in all events.
    - Local – individual track fit parameters. Change event-to-event.
  - Calculate first partial derivatives of the fit residuals with respect to the local (i.e. fit) parameters and global parameters (geometry misalignments).
  - Manipulate the linear least squares matrix to isolate the global parameters (geometry) and invert the results to obtain the solution.

- Apply to a ‘simple’ example – Type 1 tracks.
  - Simulated cosmics for validation.
  - Shift layers 1-2 (Region 1) by 20 microns in \(x\).
  - millepede reproduces shifts in the range 2-500 \(\mu m\).

- Apply to Type-1 cosmic ray sample from SVT.
  - 5.9M events; fixed layer 4 to SVT residual.
  - Millepede misalignments added to reconstruction, residuals \(\sim 25 \mu m\).
  - Resolution in sectors 70-80 \(\mu m\).

- Code for more complex events now being tested.
Alignment of the SVT

• Ideal Geometry Validation and Testing
  • Calculate ideal fiducial location on each module.
  • Observed significant difference with engineering drawings - up to 100 µm.
  • Worked with engineers to correct differences.
  • Ideal geometry now well defined with parameters from engineering drawings.

• Geometry package
  • Common Java utility to access geometry for gemc simulation and reconstruction.
  • Generate shifts from ideal geometry to measured fiducial results.
  • Processing fiducial survey data in alignment shifts – validating with simulated tracks.
  • Putting full inventory of material in SVT gemc simulation.