

# **HPS** Software

Presentation for DOE Review at SLAC

January 18, 2019

### Overview

#### Introduction

- History
- System Overview
- Software Organization Overview
  - Software Cycle and Releases
- Software Group
- Codes:
  - Generators, MC code
  - Reconstruction, Tracking,
  - Calibration, Monitoring.
- Outstanding Task List
- System resource utilization
- Historic and projected manpower
- Conclusions

### Introduction - history

- Early decision by collaboration to leverage the existing expertise in the SLAC group with the Linear Collider Simulation, LCSim software framework.
  - JLab (CLAS12) software was too immature, and would not suffice for expected 6-GeV era run.
  - Not enough time and manpower to start from scratch.

Result:

- Development of "hps-java" code, which utilizes the "lcsim" framework.
  - ✤ +/- Main code development is in Java.
  - + Robust framework to develop on.
  - + Existing tracking component: seed tracker.
  - No overlap with JLab code.
- Main data storage model: LCIO.
  - + Read / write capabilities from Java and C++.
  - Less flexibility in contents.

### Introduction - System Overview: MC



A' events, Background events

SLIC or hps-sim : Main GEANT4 based simulation.

Readout: Simulates electronics and trigger.

hps-java: Analysis framework: SVT, ECAL, Tracking, Hodoscope

dst-maker or hpstr - reads slcio files and produces data summary files.

Part of org.lcsim that computes geometries.

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### Introduction - System Overview: Data



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### Introduction - System Overview: Online



DAQ uses the EVIO format internally and for data storage of raw data. Event transport distributes and transports events. Monitoring clients use EVIO or the EVIO  $\rightarrow$  LCIO translation layer.

### Introduction - System Overview

### Calibrations codes:

- SVT online calibration code timing in, pedestals, gains.
  - Existing code that runs during commissioning to time in and check SVT.
- ECal calibration Cosmic ray calibration, Full Energy Electron calibration.
  - Existing code to calibrate ECal pedestals, gains and timing.
- Hodoscope calibration.
  - Code needs to be written, but can borrow from ECal code.
- Detector Alignment Millipede II
  - Complicated procedure for getting a good alignment.
  - High on Tracking Group priority list to simplify and improve this procedure.

### Physics Analysis Code:

- Runs after data reconstruction.
- Was in the domain of individual analyzers, but is now becoming more centralized.
- See presentation by Nathan Baltzell.

### Introduction - Software Organization

### Code repository - GitHub

- Tracks code, allows development on branches
- Merging only through "pull requests", which must be approved.

### Issue Tracking - GitHub

Couples code issues with branches.

- Code Documentation Confluence Wiki + Java Doc
- Build System Maven
- Testing Maven integration tests.
- Continuous integration testing Jenkins / Hudson
- Code profilesJProfiler
  - Output to web pages at: <u>http://nuclear.unh.edu/HPS/Profiles</u>
- Releases: Github + Maven + Nexus.
  - Release is tagged on GitHub.
  - Resulting JAR file is available for download from Nexus.

### Software Cycle and Releases



- We make extensive use of the "git" code management system, with GitHub as the repository site.
  - Jefferson lab is an established organization on GitHub.
- Development cycle:
  - "Clone" master branch of repository.
    - This gives the latest official version of the code. A "snapshot" release.
  - Create an issue on GitHub and a corresponding branch of the master code.
  - Develop on your branch. The master branch is not affected.
  - When ready, run integration tests to make sure nothing is now broken.
  - Create "Pull request", with some documentation.
  - Pull request is reviewed. If approved, branch is merged with master.

### Software Cycle and Releases



- Either after a milestone in the development, or before a set of data is processed, we create a new formal release of the software.
  - Current state of the software is tagged in git with a new release number.
  - The build system is updated to increase snapshot number.
  - \* The resulting jar file for the release is put on Nexus for distribution.
- Development continues. The master branch now produces the next snapshot version of the code.

### Introduction - Software Group

- Bi- Weekly meetings with online presentations.
- Software group mailing list
- SLACK for more immediate communication.

#### \* People:

- Lead: Maurik Holtrop
- Tracking lead: Norman Graf
- MC Generators: Takashi Maruyama
  - MC data production: Bradley Yale
- Trigger: Valeri Kubarovsky
  - Trigger code: Kyle McCarty
- Data Processing: Rafayel Paremuzyan
- Analysis software: Matt Graham, Nathan Baltzell
- Specific codes:
  - DST code: Omar Moreno
  - MC Simulation code, conditions system: Jeremy McCormick



### Monte Carlo Generators

- The MC physics generators simulate the beam interaction with the target. HPS Expert: Takashi Maruyama.
  - HPS is sensitive to the tails of some distributions which are not fully represented in the GEANT4 simulation, so other tools are required:
    - EGS5 Electro-Magnetic (EM) interactions.
    - GEANT4 EM, hadronic and neutron production.
    - MadGraph/MadEvent Trident (background) production and A' (signal) production, Wide Angle Bremsstrahlung (WAB) production.
  - The output of these various generators are combined according to cross section.
    - This creates a time realistic pulse train of "2 ns events", which represent a small period of real-time. These "2 ns events" are then run through the detector simulation.
    - Many of these "2 ns events" are empty!
  - Detector readout computes triggers, similar to the hardware trigger.
  - Events for which a trigger is found are further analyzed.
  - Generated events can be biased so that the probability of finding a trigger is much larger than a random actual beam time period.

### Monte Carlo Detector Model



- The detector is accurately simulated using the GEANT4 framework.
- All active components are accurately rendered.
- Most of the inactive components that could interact with particles are accurately rendered.
- Two version of the code:
  - SLIC current production version. Inherited from Linear Collider software.
  - hps-sim rewrite. Uses same geometry, but has modernized features to allow more control over the events.

# Tracking: Hit building

- First steps:
  - Sensor Hit Reconstruction
    - Build a 1-D hit from the signals on the strips.
  - Stereo Hit Reconstruction.
    - Combine two adjacent 1-D hits into a 3-D hit.







# Tracking: Seed Tracker

- Second Step: Seed Tracker
  - Largely inherited from Linear Collider.
  - Start with 3-hit track seed.
  - Add hit from confirm layer.
  - Add hit(s) from extend layer.
  - Algorithm allows for different layer combinations to create a seed track.
  - We use 4 combinations. (Seed345Conf2Ext16, Seed456Conf3Extd21, Seed123Conf4Extd56, Seed123Conf5Extd46).
    - Algorithms removes tracks that are found more than once.
  - Resulting tracking efficiency is high.



Tracking efficiency for electrons. Left data, center MC, right ratio of data/MC. from HPS Note: trackEfficiency.pdf by Matt Graham

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# Tracking: GBL fit

GBL-

- Final Step: Generalized Broken Line fit.
  - Seed Tracker tracks are refit with the GBL to improve resolution.
  - Resolution improves 20-30%
  - Fit also provides full covariant matrix of all track parameters.
- Resolution:  $\frac{\sigma_p}{p} = 7.1\% \pm 0.04\%$
- Inv. Mass resolution for Møller events is 1.4 MeV at 33.2 MeV, for the 2015 data (1.05 GeV beam energy)







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# Alignment



- Initial alignment of detector is from surveys.
- Next, alignment is improved using track based alignment.
- \* We used Millipede-II, which works well with the GBL package.
  - Performs least square fit of local (track) and global (alignment) parameters on a track by track basis.
  - Large minimization problem with a lot of parameters.
  - Difficult, because not all the alignment parameters are well constrained, our data does not cover all tracking layers with tracks.
  - Experts: Alessandra Filippi and Norman Graf.
- This has been a fairly time consuming process.
  - Better understanding of the problem and improved procedures have made the alignment a lot better and faster.
  - Some further improvements could make it easier to perform.

# Monitoring Application

- Monitoring application written in JAVA
- Provides flexible platform to display live updating histograms
- Reads data from ET in EVIO format, converts internally to LCIO (data analysis framework file format)
- \* Can run multiple copies, i.e. separate ones for different sub-systems.
- Histograms can be saved at end of run.
- \* Reasonable data rate: ~ 100 Hz (for complicated ECAL monitor)
- Full reconstruction framework available to app to make high level plots.



### Monitoring Application

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# Monitoring: ECAL Event Display

- \* Shows the hits in the ECAL, color coding indicates energy of hit.
- Red box (not shown) indicates a found cluster.
- Text box below shows values of cell that was hovered over.
- Similar display can be added for hodoscope.



### Single channel histograms.



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### Resource use, CPU

CPU requirements for main data processing step.

- 2017 May 165 ms/event/core
- \* 2018 Nov 70 ms/event/core  $\Rightarrow$ 
  - \* 500 simultaneous job slots  $\approx$  7 KHz data analysis (2 3x slower than data taking)

#### ⇒ About 13 weeks to process 2019 data.

Actual time will depend on number of job slots.

Profile: http://nuclear.unh.edu/HPS/Profiles/Call Tree doProcess 2018 12 11.xml

Tree: Call Tree

Calls: 4827, local time:NaN, total time: 1,663,533.008 ms , 50.30 % -- org.hps.recon.tracking.TrackerReconDriver.process calls: 4827, local time:NaN, total time: 1,663,406.703 ms , 50.30 % -- org.lcsim.util.Driver.process calls: 4827, local time:NaN, total time: 1,663,402.222 ms , 50.30 % -- org.lcsim.util.Driver.processChildren calls: 4827, local time:NaN, total time: 1,663,391.957 ms , 50.30 % -- org.lcsim.util.Driver.doProcess Calls: 4827, local time:NaN, total time: 1,663,382.259 ms , 50.30 % -- org.hps.recon.tracking.SeedTracker.process calls: 9653, local time:NaN, total time: 2.511 ms , .00 % -- java.lang.System.nanoTime calls: 9653, local time:NaN, total time: 1.784 ms , .00 % -- java.util.Iterator.hasNext calls: 4827, local time: NaN, total time: .789 ms , .00 % -- java.util.List.iterator calls: 4827, local time:NaN, total time: .708 ms , .00 % -- java.util.Iterator.next ۵ calls: 21254, local time:NaN, total time: 38.275 ms , .00 % -- hep.physics.vec.VecOp.sub ۵ calls: 9652, local time: NaN, total time: 10.848 ms , .00 % -- org.lcsim.event.base.BaseLCSimEvent.get ۵ calls: 4826, local time: NaN, total time: 10.659 ms , .00 % -- org.hps.recon.tracking.TrackerReconDriver.setTrackType ۵ calls: 21254, local time: NaN, total time: 6.257 ms , .00 % -- hep.physics.vec.BasicHep3Vector.magnitude 0 calls: 33688, local time: NaN, total time: 3.698 ms , .00 % -- java.util.Iterator.hasNext 0 calls: 25058, local time:NaN, total time: 2.749 ms, .00 % -- java.util.Iterator.next 0 calls: 21254, local time: NaN, total time: 2.389 ms , .00 % -- hep.physics.vec.BasicHep3Vector.<init> 0 calls: 21254, local time:NaN, total time: 1.971 ms , .00 % -- org.lcsim.fit.helicaltrack.HelicalTrackHit.getCorrectedPosition 0 calls: 21254, local time: NaN, total time: 1.921 ms , .00 % -- org.lcsim.fit.helicaltrack.HelicalTrackHit.getPosition 0 calls: 21254, local time: NaN, total time: 1.891 ms , .00 % -- org.lcsim.fit.helicaltrack.HelicalTrackHit.chisq 0 calls: 8630, local time: NaN, total time: 1.333 ms, .00 % -- java.util.List.iterator 0 calls: 4826, local time:NaN, total time: .887 ms , .00 % -- java.util.List.size 0 calls: 3804, local time: NaN, total time: .432 ms , .00 % -- org.lcsim.event.base.BaseTrack.getTrackerHits calls: 1207, local time:NaN, total time: 692,632.061 ms , 21.00 % -- org.hps.recon.ecal.EcalRawConverter2Driver.process calls: 1207, local time:NaN, total time: 483,325.585 ms , 14.60 % -- org.hps.recon.tracking.RawTrackerHitFitterDriver.process calls: 1206, local time:NaN, total time: 259,630.054 ms , 7.90 % -- org.hps.recon.tracking.gbl.GBLRefitterDriver.process Calls: 1207, local time:NaN, total time: 87,474.758 ms , 2.60 % -- org.hps.recon.tracking.DataTrackerHitDriver.process I calls: 1207, local time:NaN, total time: 36,481.321 ms , 1.10 % -- org.hps.recon.tracking.HelicalTrackHitDriver.process

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### Resource use, CPU - Monte Carlo

- Throughput for MC production is much harder to assess due to the many different steps involved.
- The A' "signal" MC events are quick to produce.
- Most expensive is full background simulation: Wide Angle Bremsstrahlung + Trident + Beam background.
  - A useful input event sample, 100M events, requires:
    - 100M Trident events from MadGraph ≈ 10k core-hours
    - Proportional amount of WAB, MadGraph ≈ 10k core-hours
    - ✤ Beam background generation ≈ 10k core-hours
  - Detector simulation ≈ 7 ms/event, 1 hour per file, 10k files ≈ 10k core-hours for full run.
  - Reconstruction of simulated data ≈
  - ✤ Total CPU for 100M event run is  $\approx$  45 k core-hours  $\Rightarrow$  500 jobs for 4 days.
- Will want to run 10-20 times more events.
- Monte Carlo jobs will also run on off-site farms: SLAC & UNH.
- Investigating the use of Open Science Grid.

### Resource use, disk

- Estimated disk space usage:
  - For 2016 engineering run raw data were 2 GB
    - File contains  $\approx$  407k events, takes 20s to 30s to write.
    - Processed reconstruction file has 396k events.
    - Space for reconstructed event file + all DSTs = 7 GB
- Estimated Space for 2019 run
  - ✤ 9 Weeks, at 50% efficiency = 756h = 2.7 M sec.
  - \* At 20 kHz, we expect  $\approx$  **54B events**.
  - Raw data storage expected: 260 TB.
  - Processed data storage expected: 910 TB
    - The full DST only would take 65 TB.
    - The V0 DST, pre-selected trident events, takes 3.3 TB fits on single hard disk!
- \* MC, 100M events simulation output  $\approx 8$  TB most of this is intermediate files.
  - Reconstruction of simulated output is only about 1% if input, because of acceptance and background rejection ≈ 81 GB, but we probably want to simulate 10 to 20x more.

#### One run file:

	Size [Mb]	# of events		
Raw data	2048	407500		
recon	6100	395930		
dst	521	395930		
v0_dst	26	10852		
pulser_dst	6.8	14036		
Moeller_d	14	6396		
nt_tri	26	10962		
nt_Moeller	9.1	4350		
v0	219	10852		
pulser	159	14036		
Moeller	124	6396		
Total	7205			

### Software Task List

Mostly, our software is in reasonably good shape, but many improvement are desirable: directly related to 2019 running, smoothing operations, speeding up processing.

#### Very Important (critical) Tasks for 2019 run:

- Complete Hodoscope simulation and new trigger optimization analysis.
  - Extensive task which is already well underway. See Rafayel Paremuzyan's talk.
- Add FADC bit-packed data decoder to hps-java.
  - Already exists for CLAS12, so not expected to be too complicated or time consuming.
- Update monitoring histograms.
  - Needs hodoscope and L0 histograms added.
  - Cleaning up, revisit, existing histograms.
- Improve/update data quality monitoring.
  - Update for hodoscope and L0.

### Software Task List

#### \* Important Tasks, highly desirable:

- Improve the alignment procedures.
  - We need the detector alignment to be easier so results can be obtained more quickly.
  - Procedures have already improved tremendously, now to make it easier to use.

#### Other Important Tasks:

- Revisit all other calibrations and see where updates are needed.
  - It has been a little while since we last needed a full calibration.
- Improve processing speed of the code. Not essential, but makes us good citizens of JLab farm.
  - Further improve the speed of the tracking code.
  - Complete the investigation of alternate tracking: Kalman filter and different seed finder.
  - Possibly: preprocess the FADC and SVT pulse fits.
- Learn to use the Open Science Grid for simulation.

Lots of minor issues, code maintenance, and code improvements.

### People: Software contributions



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### People: Software contributions



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### People: Software contributions



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### Software contributions

#### New people joining software team:

- Cameron Bravo (SLAC), once SVT L0 work is finished.
- New Postdoc (UNH), advertisement is out.
- New Postdoc (SLAC)
- New students
- Total number of software tasks, and amount of effort required, is now lower than 4 years ago, just before the 2015 engineering run.
- Fewer tasks are critical.
- With the new people, there is enough manpower to continue a strong software group.

### Conclusions

#### \* The HPS software is fully functioning.

- Data analysis of 2015 engineering run is complete and published.
- Data analysis of 2016 engineering run is well under way.
- A lot was learned by the collaboration to get there.
- Some updates are needed for the new detector.
  - No show stoppers.
  - Amount of work to be performed is manageable with new people coming on board.
- Procedures are becoming standardized and more streamlined.
  - Data processing will be faster, requiring far fewer iterations.
  - Analysis path is now clear and becoming standardized. (See Nathan's talk)

\* HPS is (nearly) ready to process the 2019 data.