Design, Implementation, and Performance of CREAM Data Acquisition Software

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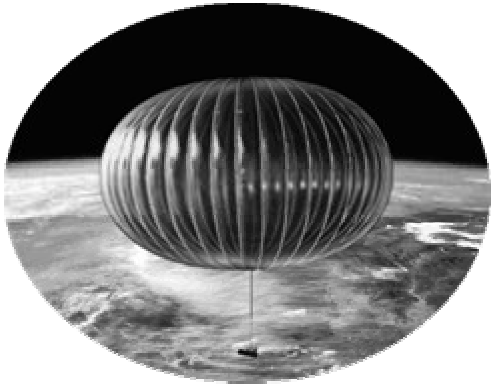
CREAM Project

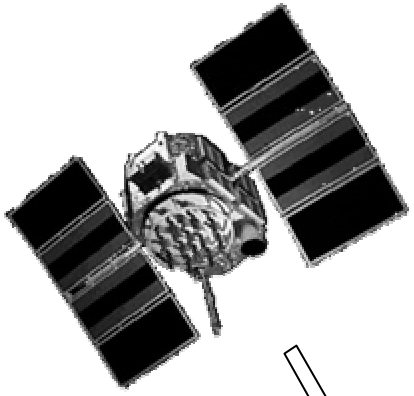
- CREAM stands for ‘Cosmic Ray Energetics And Mass.’

- Science objective is to measure:
  - Energy spectra: 1 to 1000 TeV.
  - Elemental abundances: proton to iron nucleus.

- Balloon-borne experiment
  - Launch in Antartica, December 2004.
  - Ultra Long Duration Balloon (ULDB): 100 days.



Flight Operation



TDRSS/Iridium

CREAM Payload

Science flight computer

NASA flight computers

Operations Control Center

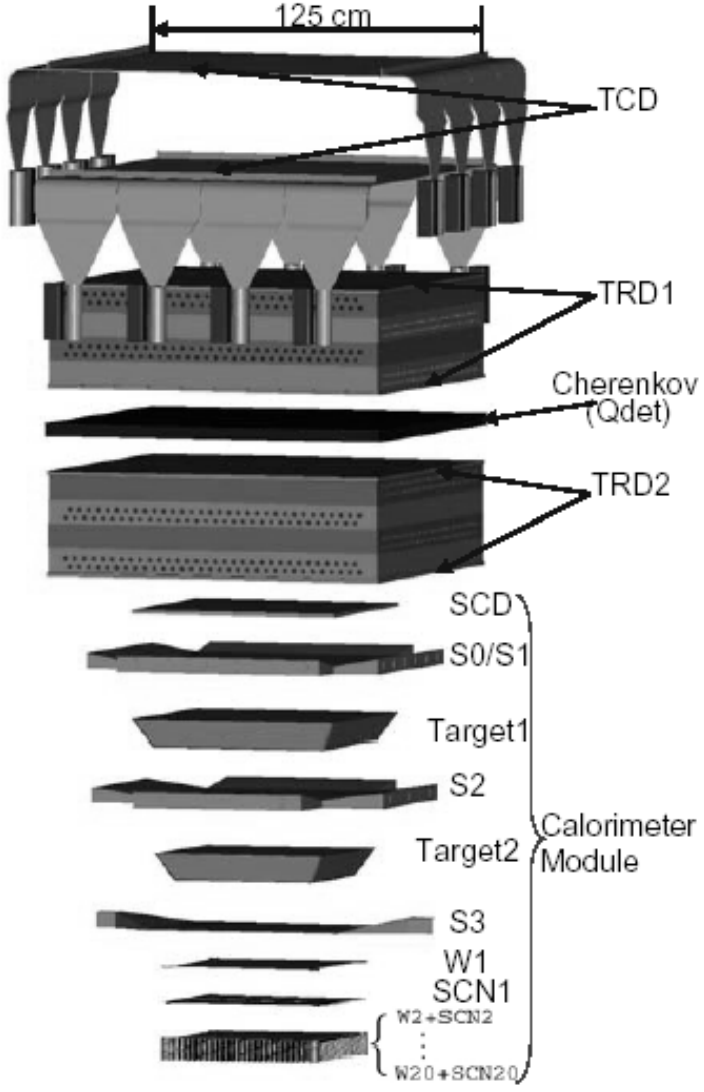
(Palestine, TX)

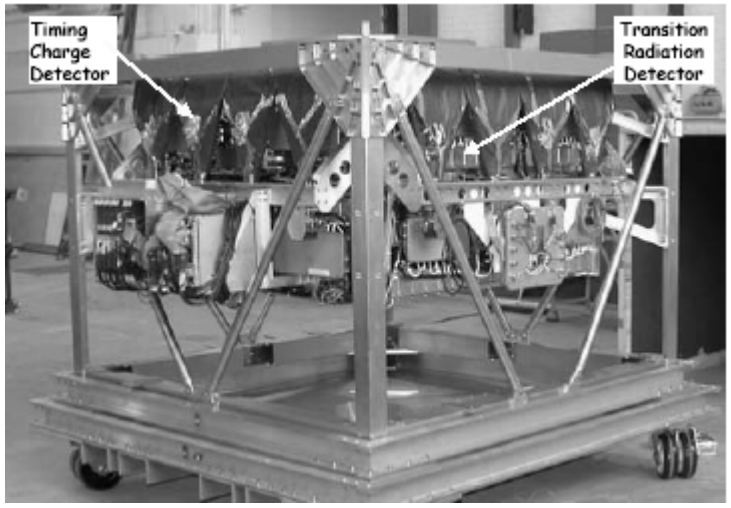
Engineering Support Center

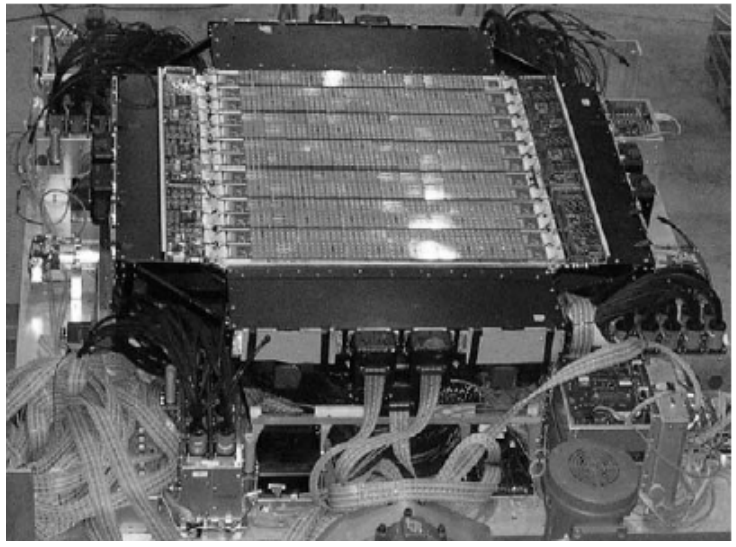
(Wallops, VA)

Univ. of Maryland

CREAM Instrument







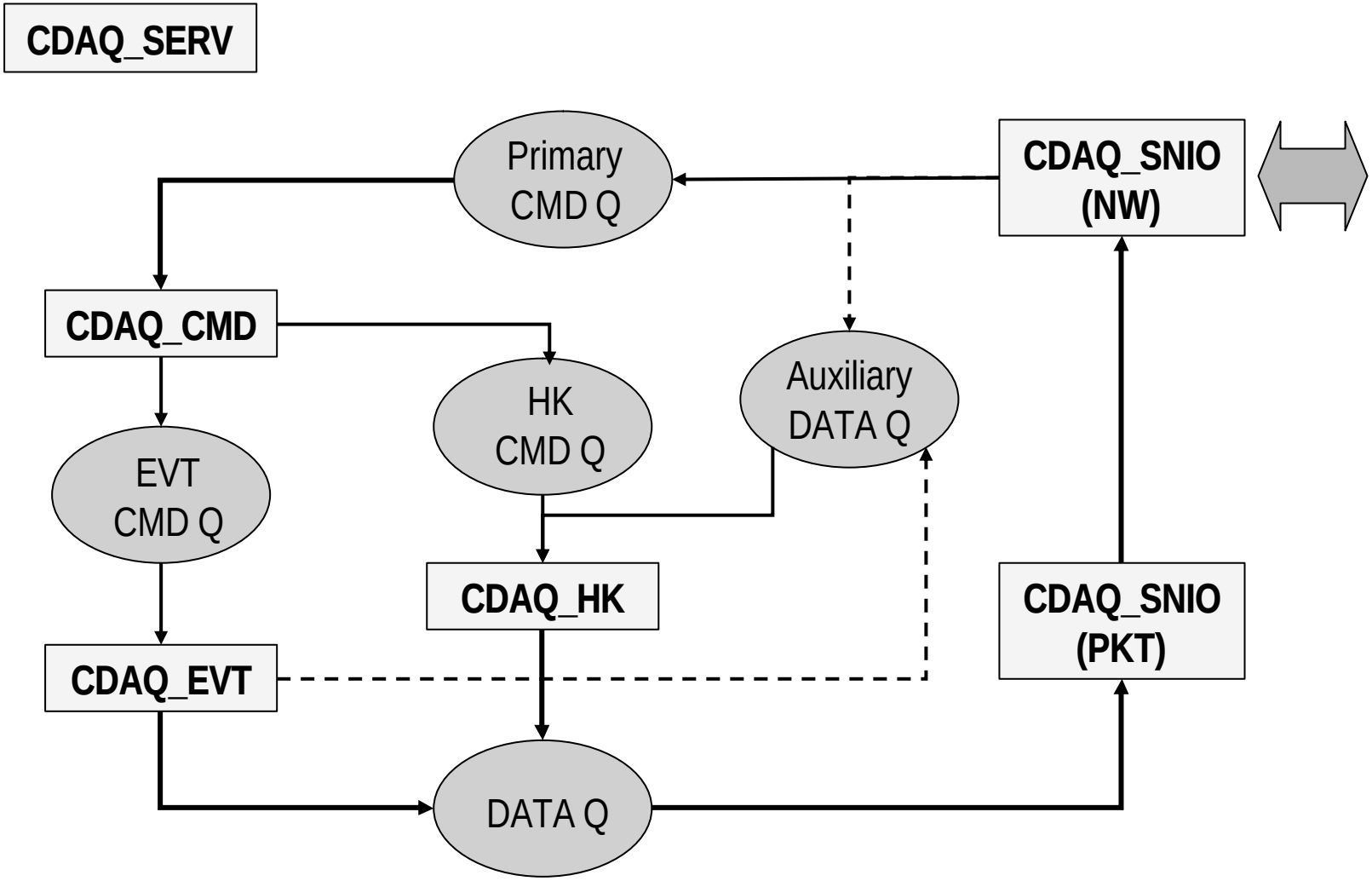
Instrument I/O interfaces

- Timing-based charge detector (TCD) – TCP/IP
- Transition radiation detector (TRD) – FPGA board, Digital I/O board
- Calorimeter (CAL) – PC/104 bus
  - 2560 channels.
- Silicon charge detector (SCD) – PC/104 bus
  - 2944 channels.
- Hodoscope (HDS) – PC/104 bus
  - 2304 channels.
- Master trigger – Digital I/O board
  - Coordinates triggers
  - Distributes event number for synchronization
- Housekeeping board – serial port
  - Housekeeping data: 386 channels.
  - Timers for live and total times.
  - Frequency counter output for calibrations.
- Command box board – serial port

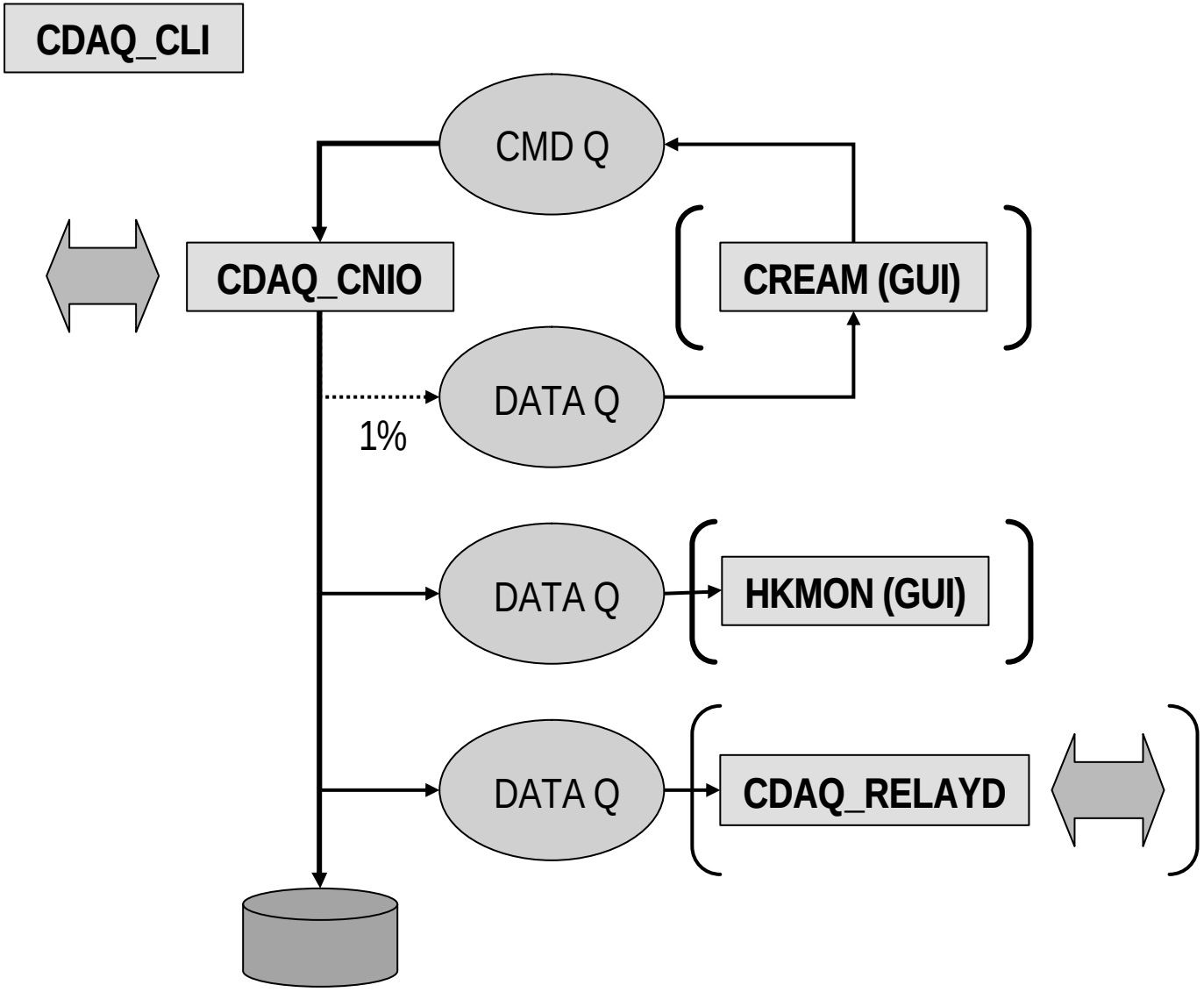
Design Guidelines

- Target O/S: Linux.
- Simple – minimal number of processes.
- Speed – minimum 100 events/sec.
- Robust – due to telemetric nature of operation.
  - No memory leak ✍ avoid dynamic memory allocation as much as possible.
- Easy-to-use: GUI built by using ROOT libraries.
- Object-oriented programming via C++ language.
- Source code management using CVS.
- Usable for flight, beam tests, and lab tests.

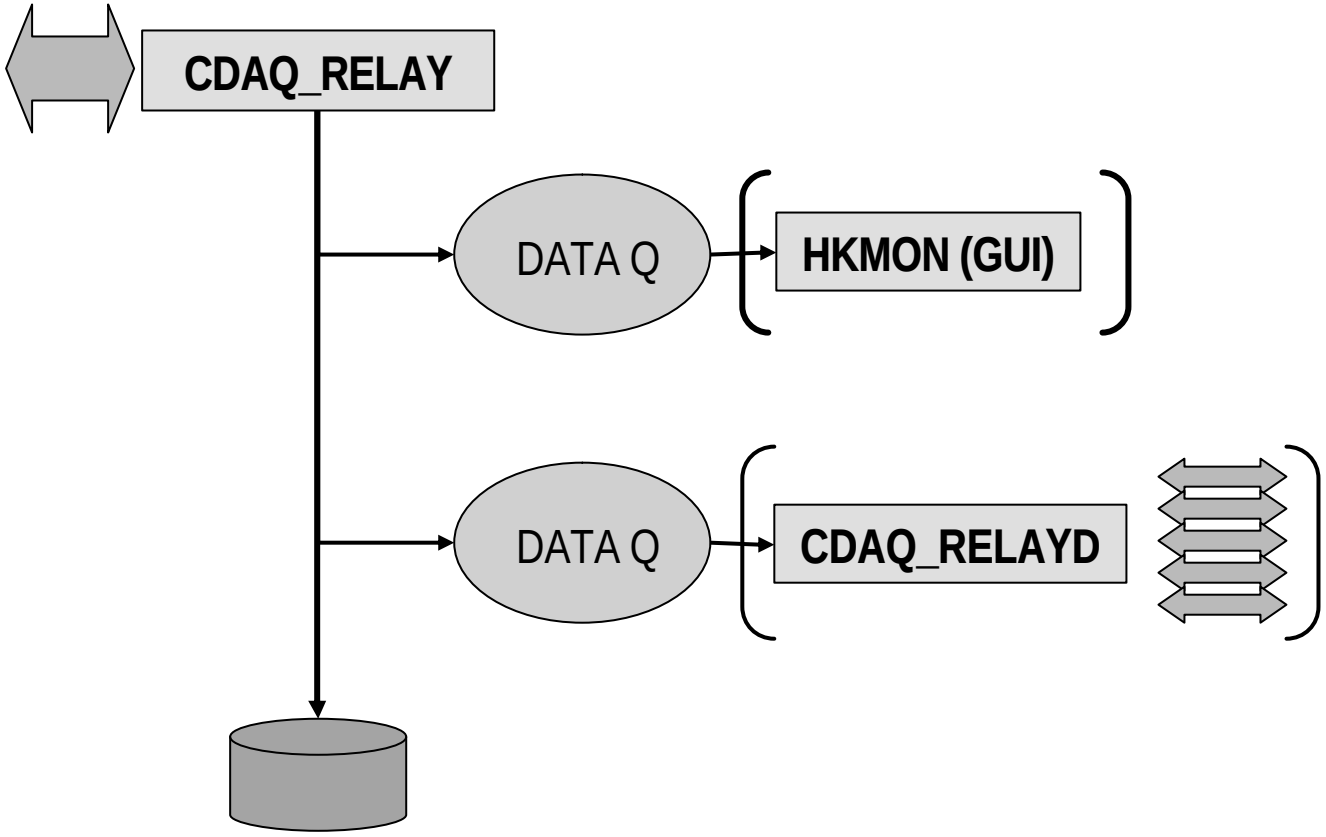
Design of CDAQ: Server-side



Design of CDAQ: Client-side



Data Backup and Relay



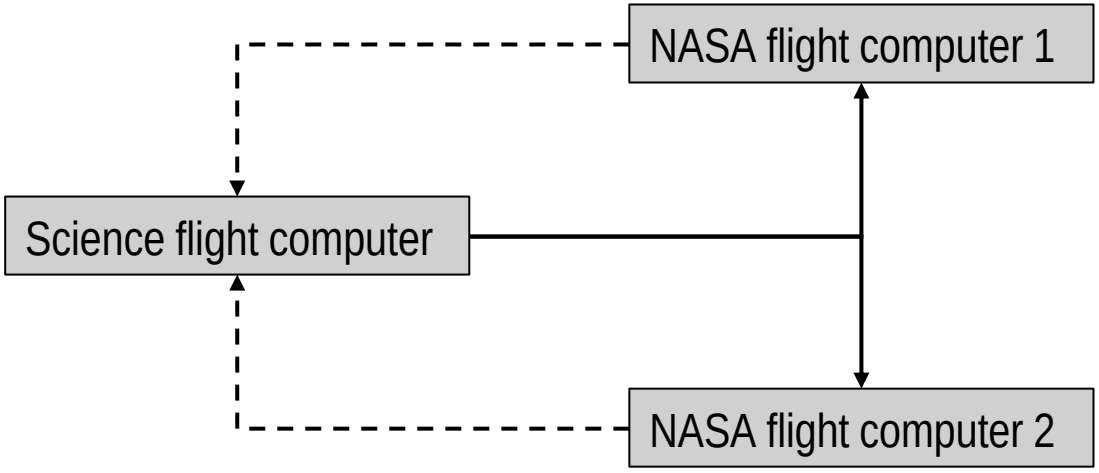
Network Communications

- Between server and primary client: UDP
  - UDP is connectionless.
  - Custom protocol for maintaining connection and for delivering packets.
  - Packets: fixed-length
    - Event data packet (263 bytes)
    - Housekeeping data packet (263 bytes)
    - Command packet (16 bytes or 1058 bytes)

    } Packet counter and CRC

    - Acknowledgment packet (4 bytes): low half-word of packet counter
    - Connection status packet (2 bytes)
  - Fragmentation and reassembly are required.
    - Each packet contains 4 bytes of reassembly information.
    - A packet can contain multiple events.
    - Fault tolerant.
  - Packet timeout.
- Between data relaying programs: TCP
  - Connection-oriented.
  - Data length + data.

Selection of CDM Flight Computer



- SFC sends connection status (CS) packets to both NFC 1 and 2 every five seconds.
- Only active NFC responds with CS packets (also every five seconds).
- SFC updates the IP address of active NFC upon receiving a CS packet.

- In case of connection loss, SFC pings both NFCs.

Inter-process Communication

- Message queue
  - FIFO.
  - Queue size is 16 KB but can be enlarged.
  - Data length is limited to (8192 – 4) bytes.
  - Data exceeding the limit must be fragmented
    - Reassembly is required.
    - Race condition
      - Solution 1: semaphore lock.
      - Solution 2: sophisticated reassembly algorithm ✍ dyn. mem. alloc.

- Shared memory with semaphore lock.
  - Chunk of memory shared by processes.
  - Limited to 32 MB.
  - No fragmentation and reassembly required.

Comparison of Data Transfer Time

- Pentium 4 with 512 MB RAM.
- Time to transfer data of total 1 GB.

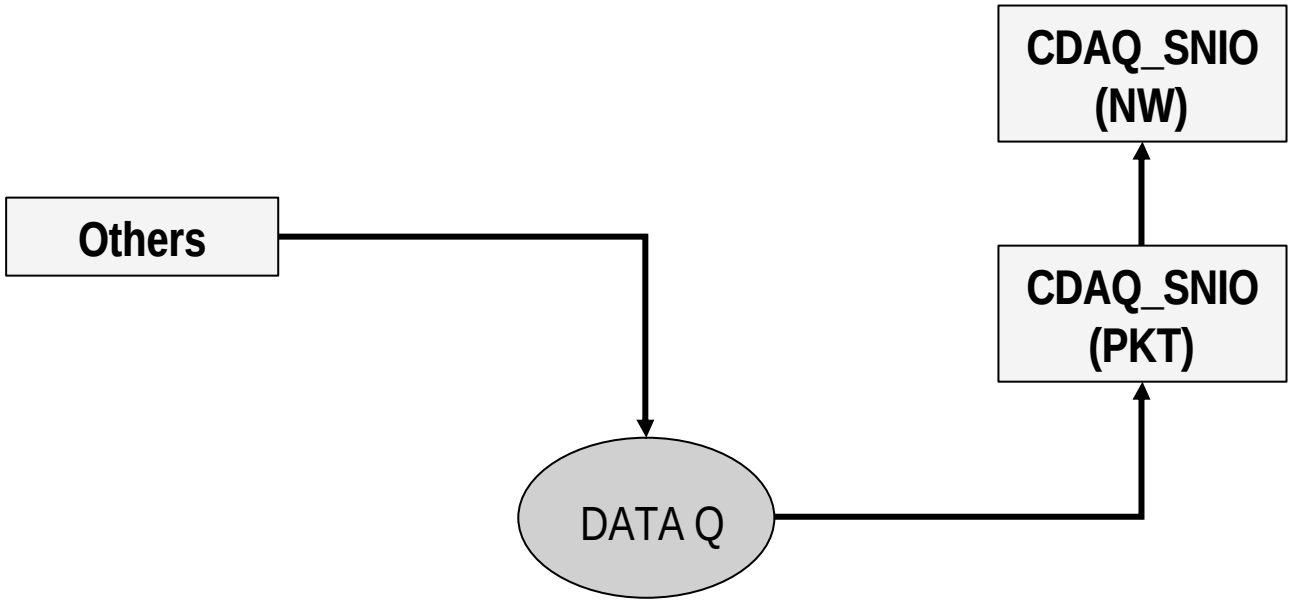
Data size	Message Queue w/o Semaphore	Message Queue with Semaphore	Shared Memory Queue with Semaphore
1 KB	4.50 sec	10.1 sec	9.10 sec
64 KB	1.84 sec	2.07 sec	1.67 sec

Data Types: Server-to-client

- High priority packets:
  - Housekeeping event:
    - Temperatures, gas pressures, voltages, currents, etc.
    - GPS data.
    - Trigger rates.
    - Master trigger timer data.
    - Data transmission rates.
  - Server message.
- Low priority packets:
  - Science event.
  - Calibration event.
  - Sparsification information.
  - Linux command output.
  - Control: server-to-client command (for example, opening/closing files).

Server Message Logging

- All server processes except CDAQ_SNIO enqueue messages to the data queue.
- BUT CDAQ_SNIO drops messages to a file to avoid a deadlock situation.



- Implemented a command that sends the file contents and makes it empty.

Commands

- Total 168 commands: 8-bytes long.
- Calorimeter, hodoscope, SCD commands: 46 commands.
  - Forwarded to the command box.
- TRD commands: 25 commands.
- TCD commands: 12 commands.
- Linux system commands: 12 commands.
  - Monitoring disk spaces, processes, system load, etc.
  - Rebooting the system.
- DAQ software commands: 73 commands.
  - Automated pedestal updating.
  - DAQ start, stop, and reset.
  - Various runs: pedestal, calibration, and normal runs.
  - Setting intervals for automated runs.

Event Building

- Master trigger
  - Triggered by TCD, CAL, Calibration, and External.
  - DAQ flow is branched according to who triggered.
- TCD/TRD
- Calorimeter, Hodoscope, SCD.
- CAMAC beam tracker: beam test only.

- Sparsification:
  - Hardware level: TCD, TRD, CAL, HDS, and SCD.
  - Additional software level: CAL, HDS, and SCD.

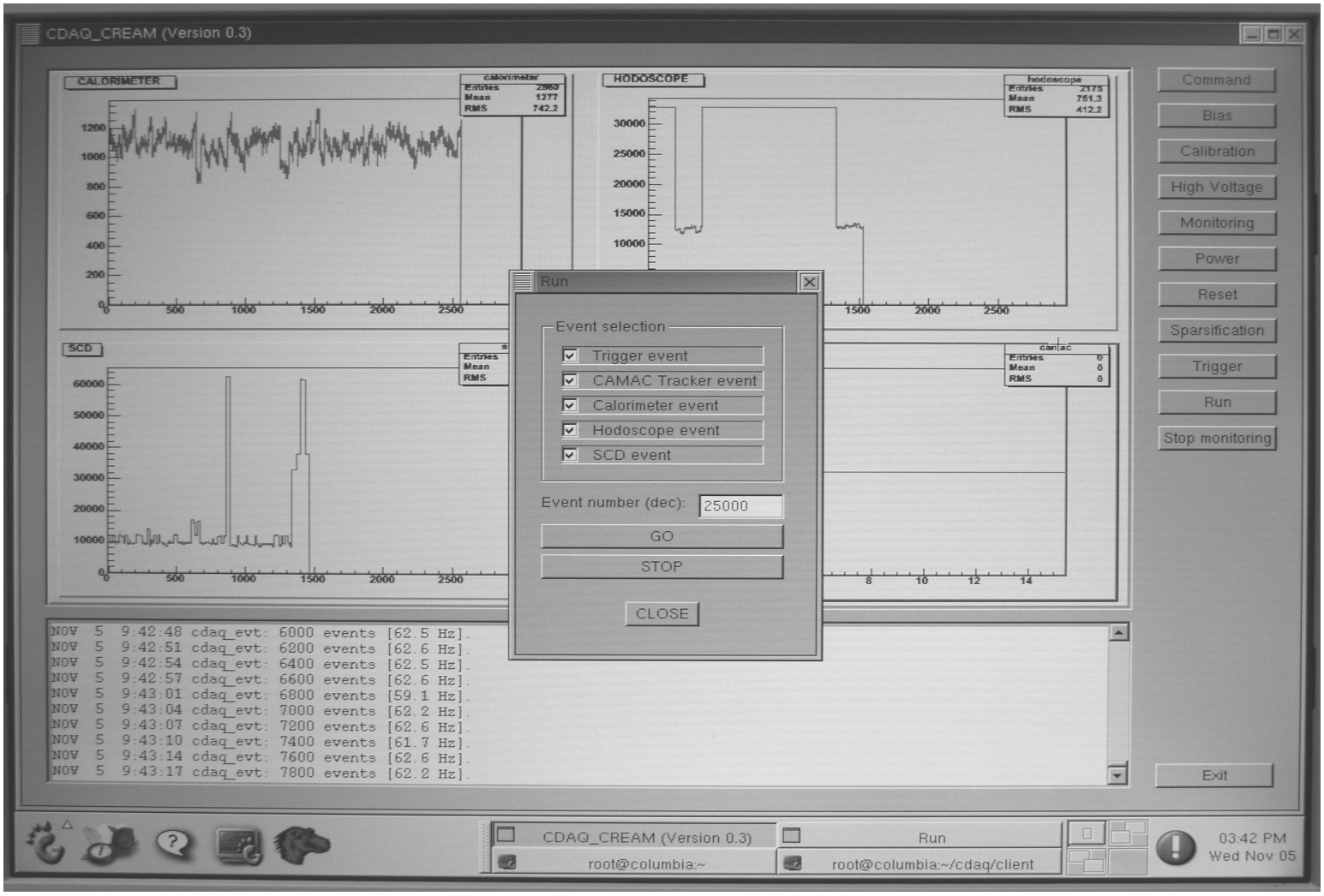
- Event numbers are checked for synchronization.

- CDAQ_EVT: reads and builds a science event ✍ enqueued to the data queue.
- CDAQ_HK: reads and builds a housekeeping event ✍ enqueued to the data queue.

Operation Mode

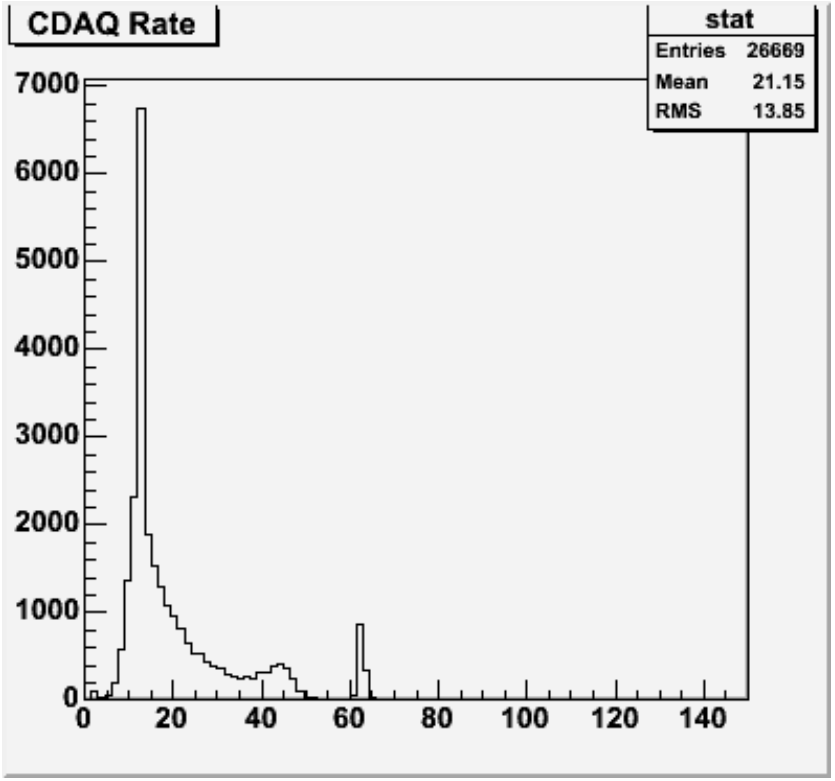
- Flight
  - Continuous data acquisition.
  - Auto-calibrations at specified interval.
  - Executes command.
- Test: for beam and lab. tests.
  - Data acquisition every one second if requested ✍ on-line display.
  - Executes command.
- Standby
  - Executes command

GUI for Commanding and On-line Monitoring



Picture from the beam test at CERN in November 2003

DAQ Performance



- Histogram based on CERN beam test in Nov. 2003.
- Full readout of CAL, HDS, and SCD without sparsification [24.3 KB/event]
- Max rate 125.7 event/sec [or 3 MB/sec].
- No software crash during the period Nov. 1 – 9 ✍ stable.

Conclusions

- CDAQ has been implemented.
  - C/C++ language: over 55,000 lines.
- Tested.
  - Daily in the lab ✍ good for bug fixes.
  - Beam test ✍ stability checked out.
- Speed.
  - Master trigger, CAL, HDS, and SCD: over 100 event/sec w/o sparsification.
  - With additional TCD/TRD readout, likely to meet minimum 100 event/sec.
    - during flight events will be sparsified.
- Easy-to-use.
  - GUI for commanding and on-line monitoring.