GRETA
Gamma Ray Energy Tracking Array

Auxiliary Detector Requirements

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1 REVISION HISTORY

Rev.	CM Number	Description of Change
A	--	First release.
B	--	Updates to all content with final design information; reorganization of document structure.
C	--	Includes additions (primarily in sections 7, 8-10) after feedback from FRIB groups.

2 ABBREVIATIONS AND ACRONYMS

BNC	Bayonet Neill-Concelman (miniature quick-connect/disconnect connector)
CS	Computing Systems
DAQ	Data AcQuisition
DCC	LBNL Document Control Center
DOE	U.S. Department of Energy
DS	Detector Systems
ES	Electronics Systems
GRETA	Gamma-Ray Energy Tracking Array
HPGe	High Purity Germanium
HTTP	HyperText Transfer Protocol
LBNL	Lawrence Berkeley National Laboratory
MS	Mechanical Systems
NIM	Nuclear Instrumentation Module
REST	REpresentational State Transfer
SMA	SubMiniature version A
TDC	Time to Digital Converter

3 PURPOSE/OVERVIEW

This document defines the requirements and constraints on auxiliary detector systems or devices to interface with GRETA. This includes but is not limited to mechanical space/mounting considerations, trigger and timing communication links and data acquisition system communications.

4 AUTHORITY

The GRETA Project Engineer, Project Manager or Project Director authorize approval of this document for release and for subsequent changes.

5 MAGNETIC FIELD ENVIRONMENT

In the event that an auxiliary detector system employs magnetic fields, stray fields at the locations of the Quad Detector Module crystals (radially 18-27 cm from the target location) and the locations of the electronics digitizer modules (radially ~1 m from the target location) should be below **600G**.

6 ELECTRICAL ISOLATION (GROUND)

The GRETA system(s) will be grounded together to a facility clean safety ground. Other facility systems may also use this common ground, assuming that these systems DO NOT add machinery or equipment with large current and current switching, which may create noise.

7 ELECTRONICS: TRIGGER AND CLOCKS

7.1 Clock/Timing Signal Input(s) to GRETA

7.1.1 Clock Inputs

The GRETA electronics timing subsystem provides the capability to accept clocks into the data stream from outside systems. This may include timing signals from clocks associated with auxiliary detector systems. GRETA will be able to accept and process up to three auxiliary detector clock signals that meet the specifications below.

- Inputs: single ended or differential
- Input Level:
    - Single Ended Mode = 0 to 3V maximum
    - Differential Mode = LVDS standard, common mode voltage not to exceed 2V
- Connectors: User and application selectable, SMA, BNC or LEMO options will be provided
- Frequency: <= 1 GHz
- Duty cycle: 50% nominal
- Termination:
    - Single Ended = 50 Ω
    - Differential = 100 Ω nominal

If a non-standard connector type is required by an auxiliary detector, this would need to be provided by the group responsible for the auxiliary system.

7.1.2 TDC Inputs

TDC inputs to the GRETA timing system are 'stop' signals, with the TDC measurement started by the GRETA master clock, to provide sub-clock-tick timing information. The TDC inputs should be a minimum of 10ns wide, with a minimum of 20 ns between successive pulses on any specific input.

The TDC timing capability is expected to have a resolution better than 100 ps. The achievable timing resolution will vary depending upon the characteristics of the signal provided (e.g. level, rise/fall time, single-ended vs. differential), but should be ≤ 100 ps.

7.2 Clock/Timing Output(s) from GRETA

7.2.1 Clock Outputs

The GRETA electronics timing system will provide an clock output(s) derived from the GRETA system clock for transmission to external/auxiliary DAQ systems clock(s). Outputs are available in the frequency range from 100 Hz to 1 GHz, derived by division/multiplication of the native 50 MHz GRETA master clock. The clock-generator chip (LMK03328) output is controlled by a sigma-delta divider with 12 bits of integer value and 16 bits of fractional value, resulting in millions of potential output frequencies. The output can be fully optimized to the requirements of the external/auxiliary DAQ system. Software from the manufacturer (Texas Instruments) is available at https://www.ti.com/tool/TICSPRO-SW to estimate exact clock output frequencies and jitter for given chip parameters.

Clock outputs can be single-ended or differential. In differential mode the single output is AC-coupled to the output of an LVDS driver with no termination. In single-end mode, the two outputs are DC coupled and directly connected (no series terminations) to two LVCMOS/LVTTL drivers.

7.2.2 Clock Reset

The clock reset signal is available as NIM, ECL or RS-485 levels, and is a minimum of 100ns wide.

7.3 Trigger System Input(s) to GRETA

The GRETA trigger system provides capabilities to include fast trigger primitives from auxiliary detector systems to be incorporated into the overall trigger decision. For example, a fast particle trigger from an auxiliary device may be input into the GRETA trigger system to be combined with a fast γ-ray OR within GRETA to produce a coincidence master trigger. GRETA can accept and process auxiliary trigger signals that meet the specifications below.

- Signal types:
  - NIM
  - RS-485
  - ECL
- Connectors types:
  - NIM: LEMO 00 connectors
  - RS-485: AMPMODU IV crimped on twisted pairs
  - ECL: AMPMODU IV crimped on twisted pairs

The latency from the input of an auxiliary trigger signal to issuance of a master trigger based solely on that auxiliary signal is less than 1 μs. The latency from input of an auxiliary trigger to its inclusion in coincidence logic is less than 100 ns.

7.4 Trigger System Output(s) from GRETA

The GRETA trigger system will output fast trigger decisions for transmission to external/auxiliary DAQ systems. A total of twelve outputs are available, as NIM, RS-485 or ECL levels. The NIM outputs are presented on LEMO 00 connectors for use with coax, whereas the RS-485 and ECL outputs are presented on triple-row headers (ground/plus/minus) for use with twisted pairs.

Fast triggers for GRETA will include gamma-ray singles and multiplicity triggers, as well as down-scaled gamma-ray triggers. In addition, external inputs can be incorporated to form fast coincidence triggers. The time jitter for a given trigger will depend on the properties of the constituent components; for gamma-ray only triggers, the jitter will be dominated by the 'walk' associated with timing of low-energy transitions, which in GRETINA has been observed to be on the order of 500 ns, but depends strongly on the trigger threshold.

8 DAQ/COMPUTING: RUN CONTROL

Run control with auxiliary detector DAQ systems is mediated by the GRETA Conductor component, which maintains the run state for the GRETA data pipeline. This is done through the exchange of HTTP/REST message between the conductor and the auxiliary detector DAQ systems. These control messages are sent over the same network interface as data is sent, using standard Ethernet. The computer supporting the auxiliary detector DAQ must be able to support dual-homing, with one network interface assigned an IP address in the GRETA network address space.

The minimum message set supported must include start and stop runs messages. The source of start and stop directives (GRETA, auxiliary DAQ, both) is a policy decision and could vary between experiments. Flow-control directives produced within the GRETA system can be sent to the auxiliary detector DAQ if desired/required.

9 DAQ/COMPUTING: INTERFACE FOR AUXILIARY DATA INTO THE GRETA EVENT BUILDER

The GRETA global event builder can incorporate time-stamped auxiliary detector data into a common data stream with the native GRETA data, up to a maximum (GRETA HPGe + all auxiliary systems) bandwidth limit of 500 MB/s. Events from auxiliary DAQ systems will be combined with GRETA's HPGe data in time order, based on a (GRETA) global timestamp contained in the routing header (see below). The global event builder has a maximum message rate of 480 kHz, including both GRETA HPGe and data from auxiliary detectors[†].

Auxiliary detector data is sent from its local DAQ system to the GRETA computing system using standard Ethernet. The computer supporting the auxiliary detector DAQ must be able to support dual-homing, with one network interface assigned an IP address in the GRETA network address space.

[†] GRETA is designed to run at a maximum of 480k signal decompositions/s – in this limiting case, the full message rate bandwidth would be used for gamma-ray data. It should be noted however that this extreme rate is anticipated for experiments with no external detector to provide a more refined (lower-rate) trigger.

Event from auxiliary detector will be sent as UDP packets, prepended by a GRETA routing header (shown below). The use of UDP in this application limits event sizes from auxiliary detectors to 64 kB (including the routing header)[‡].

```
struct routingHdr {
    uint8_t version;    /* protocol version */
    uint8_t flags;      /* for future use, e.g. debugging */
    uint8_t type;       /* message payload identifier */
    uint8_t subtype;    /* message sub-type, e.g. crystal ID in GRETA */
    uint16_t length;    /* length of payload, in bytes */
    uint16_t seqnum;    /* sequence number */
    int64_t timestamp;  /* GRETA master clock (100 MHz clock) */
    int64_t checksum;   /* integrity checksum */
} hdr;
```

The `type` and `subtype` fields together uniquely identify a stream of data from an auxiliary device. In general, the `type` should be the device type, and the `subtype` should refer to a given detector element or readout board. Types or type ranges are assigned to a given auxiliary detector system and are immutable. This prevents confusion in downstream sorting and analysis packages. Auxiliary detector system owners should contact mcromaz@lbl.gov or hlcrawford@lbl.gov if they wish to be assigned a type number.

The GRETA computing system does not perform a transformation or interpretation on data with a `type` corresponding to an auxiliary detector. Instead, the data is copied verbatim through the GRETA signal processing pipeline in timestamp order.

The `length` field gives the length of the payload in bytes. The `seqnum` field is a counter which is incremented independently (with rollover) for each `type`/`subtype` pair so that the loss of a UDP packet can be identified. The `checksum` field is optional (but recommended) for auxiliary detector systems and is calculated over the full message including the routing header. The checksum algorithm used is Fletcher32.

GRETA employs internally a streaming model and has an end-to-end latency requirement of 10 s. As such, events from the auxiliary DAQ system need to be provided promptly to be included in time-order in the final event stream for storage to disk or online physics monitoring. The GRETA global event builder for GRETA can run in one of two modes: (i) a low-latency mode where events

[‡] The GRETA computing architecture, specifically the use of a forward buffer to interface with auxiliary detector systems, can support additional protocols such as TCP to accommodate larger event sizes if this becomes necessary in the future. In the routing header, the support for future protocols is contained in the '`version`' field. When a protocol change is implemented the version will be updated, at which time the '`length`' field can be updated in addition to other required changes.

should be forwarded within ms of their collection, or (ii) a time-out mode, where ~2 s of latency is allowable for the auxiliary DAQ system.

If the performance of the GRETA event builder system is insufficient to accommodate the message and/or data rate of the combined event data stream from the GRETA detectors and auxiliary detectors, two alternative options are available:

(a) An event builder external to the GRETA network could be used. Such an event builder could use the GRETA Application Protocol (GAP) library to read GRETA interaction point messages directly from the event processing nodes of the GRETA cluster.

(b) Offline merging of the GRETA data with the auxiliary detector data, after it has been exported by the GRETA data transfer node (DTN).

A primary reason that GRETA event builds auxiliary data is to allow online monitoring of an experiment. If auxiliary data rates exceed GRETA requirements it is always an option for the auxiliary detector system to send smaller summary events to the GRETA event builder which are sufficient for online monitoring. This would be followed by offline merging (option (b)) for the complete data set.

10 DAQ/COMPUTING: ONLINE PHYSICS DATA MONITORING

Prompt online analysis on the subset of global (physics) event data can be done either within the GRETA Computing Systems using facility/community supplied online analysis programs or distributed via a network interface for analysis outside the GRETA Computing Systems.

The user-provided analysis software retrieves events from the GRETA global event builder via an event server using the GRETA Application Protocol (GAP). This event server can be dual-homed with the GRETA network. This TCP-based protocol employs the Nanomsg (https://nanomsg.org/) library to provide a high-bandwidth connection with predictable latency. The library allows groups of events to be retrieved in a single message for efficiency. Language bindings for C/C++ and Go are provided. The complete API for the GAP layer will be available when the fabrication of the GRETA Computing systems is completed.

For user applications that wish to analyze full data files, the following options are available:

(a) (Preferred) Run the analysis package in a software container directly on the GRETA analysis node. Docker containers are currently supported in the GRETA environment.

(b) (Acceptable) Run the analysis package in a VM or directly on the GRETA analysis node (this may cause library dependency challenges for complex analysis packages).

(c) (Not recommended) Run the analysis package on a dual-homed host (one interface on the GRETA network, one interface on the host laboratory network) which mounts the GRETA user file system. This option breaks the GRETA security model which isolates the filesystem from unpatched systems in the data plane. While this approach is currently implemented with GRETINA, it is not considered a good practice going forward. If this option is chosen it should be qualified by the local operations group.

11 ACCESSING EXPERIMENTAL DATA (END OF EXPERIMENT)

The time-ordered data GRETA, and auxiliary detector data (if they have interfaced to the GRETA global event builder) are stored to a large disk cache on the GRETA network. This data can be moved off the disk cache to a user system outside the GRETA network through a local data transfer node (DTN). This DTN will be connected to the host facility via a high-speed network interface. The preferred method for file transfer is using Globus (https://www.globus.org/); systems receiving this data must have an accessible Globus endpoint. Host facilities may also provide options for downloading data to user-provided external hard-drives or other media. This is anticipated to be accomplished via a dedicated machine transferring data from the GRETA storage system via Globus.

12 VOLUME AVAILABLE TO AUXILIARY DETECTORS

Compact auxiliary detector systems can be located within the GRETA detector sphere, surrounding the target position. Due to the translation of the GRETA detectors and the placement of Quad Detector Modules on the midplane (the vertical plane aligned with the beam axis), a radius of < 16.2cm is available in this plane. This is shown schematically in Figure 1, which shows a profile of the available volume, looking along the beam direction.

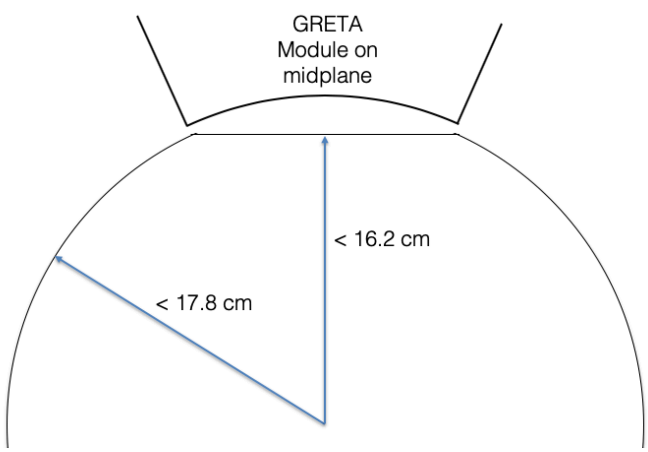

Figure 1: *Cross-section or profile view of the available volume around the target position, viewed along the beam axis.*

For further details of the volume available to auxiliary systems, including options for accessing the volume surrounding the target, the CAD model for the GRETA system is available upon request. The GRETA team is also willing to work with auxiliary detector groups to evaluate details of the mechanical/spatial interfaces.

13 AUXILIARY DETECTOR INFRASTRUCTURE / CABLE ROUTING

The GRETA support structure DOES NOT provide any infrastructure to support auxiliary detector system positioning or required cabling.