GLAST LAT Absolute Time Tests Using Cosmic Ray Muons

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Abstract

We exploit the quasi-simultaneity of cosmic ray muons traversing both the GLAST LAT and an independent charged particle detector to validate the absolute times recorded with the LAT, essential to measure accurate neutron star rotation phases for gamma rays arriving from pulsars. This note describes the PASS/FAIL critieria used in these tests.

1 Background information

1.1 Requirements

Absolute timestamp accuracy requirements at the mission, spacecraft, and instrument levels are described in documents [1, 2, 3]. A distinction is made between periods when the spacecraft GPS receivers have a fix on enough GPS satellites to obtain good timing and position information (*"GPS lock"*), and periods when the fix is lost (*"GPS unlock"*). The redundant circuits in the spacecraft (sides A and B) and in the LAT (configurations 1 and 2) must be tested independently. Table 1 lists the configurations that need to be tested, as well as the PASS/FAIL criteria.

We summarize as follows:

1. **"GPS lock"** *(Absolute time correlation test)* : Section 3.2.5.4 of [2] states that the spacecraft PPS shall be accurate to $\pm 0.5\,\mu$s. Section 5.2.11 of [3] states that for the LAT, "the time accuracy of event time measurements shall be $< 10\,\mu$s relative to spacecraft time [and] the goal is to achieve accuracy better than $2\,\mu$s".

2. **"GPS unlock"** *(Clock drift test)* : Section 3.2.5.7 of [2] further states that if the GPS signals are lost, that the PPS's shall drift no more than $\pm 0.01\,\mu$s per second.

1.2 The basic idea, and previous results

The LAT ("Large Are Telescope") is intended to record GeV gamma rays from scores to hundreds of rotating neutron stars ("pulsars"). Pulsation studies require accurate gamma ray arrival times. The mission requirement is 10 μs relative to an *absolute* time reference such as UTC (Coordinated Universal Time) (see section 2.6 of [1]).

GPS receivers on GLAST acquire absolute times. These times are processed by spacecraft hardware (the Uplink-Downlink board = UDL in the Instrument Electronics Module = IEM) as well as spacecraft flight software, as part of the C&DH subsystem ("Control & Data Handling"). The times are then transmitted to the science instruments (LAT and GBM). The path is complex, and previous missions have had problems, making ground time tests particularly important.

Atmospheric muons ($\mu^{\pm}$ particles) cause some ionization along their path but otherwise don't interact, and in particular buildings or other overburden generally don't stop them. The LAT measures muon track direction vectors for each individual particle (see Figure 1). The direction tells which LAT tracks will also traverse the muon telescope of the ground test equipment ("coincidence events"). The muon telescope triggers readout of a GPS clock in a VME data acquisition system independent of the LAT, to be compared with that obtained from the LAT and GLAST telemetry. The muons travel at nearly the speed of light, hence the delay time between the LAT and the muon telescope is negligeable ($<$ 10 ns).

Proof-of-principle tests performed in November 2006, before the LAT was integrated with the observatory, are described in LAT-TD-08777-03. Tests run in February 2007, after integration of the relevant GLAST LAT elements, revealed some problems, described in `ftp://www.cenbg.in2p3.fr/astropart/Smith/Pulsars/SASS/End2EndFeb07.pdf`. A subset of the (unacceptable) results from the February test is reproduced in Figures 2 and 3.

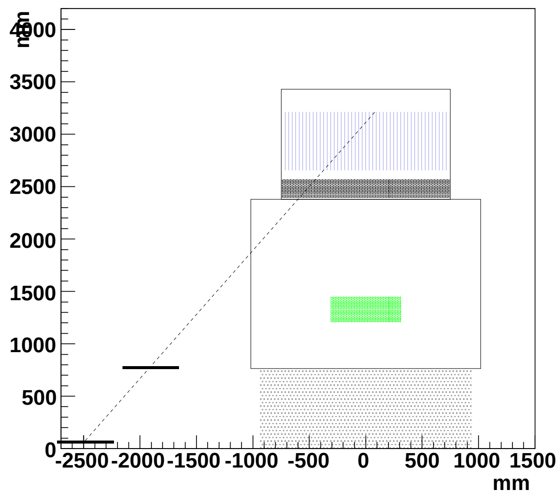

Figure 1: Sketch illustrating the test set-up. The LAT is perched on top of the spacecraft (top-most rectangle), with the silicon tracker (larger, lightly shaded area) and the calorimeter (thinner, darker zone). To the left, the "muon telescope" is drawn as two dark horizontal lines, offset vertically, representing the scintillator paddles, each with two photomultiplier tubes (not shown). The diagonal line is a path that a cosmic ray muon could follow, causing a time stamp to be recorded by both the LAT and the test equipment. A positive test result is a difference of less than a few microseconds between the two times, for roughly 1000 muons per half-hour data run.

2 Running the tests

2.1 Data Acquisition

The muon telescope and VME acquisition system need to be installed near the LAT, following the procedure specified in LAT-PS-08815. To date this has been done by the authors of this memo.

The LAT operators acquire muon data. Here follows an extract from the swing shift summary for 2007 February 21, when runs 77014191 through 77014218 were taken (see Figures 2 and 3). This example is for illustration only.

```
2) Perform 1196 ET-I74927-000 Para 6.4.2 SC B-side Turn On
*** Set the observatory clock and verify that GPS lock is achieved

3) Perform 1196 ET-I74927-000 Para 6.4.3.1 LAT Config 2 Power On
(select lower banks at Boot Selection popups)

    ( ... )

8) Perform 1196 ET-I74927 LAT Functional Test Para 6.4.3.5 L-OBS-222 - LAT
Config 2 Science Ops Demo Repeat 6.4.3.5, using the following test pairs.
NOTE: these runs may total more than the available time. Do not start a new run after 5am.
In that case proceed to the loadshed section and mark the unused runs in the procedure as n/a.

8.1 The following two runs will be used to do the Absolute time correlation test:
When LAT triggers are observed (i.e. when the GEM Trigger Sent rate becomes non-zero),
start data acquisition with the muon telescope:
From the /home/glast/gps2006 Lynx directory on the telescope DAQ PC, type
a.out > mutelNNNN.txt?, where NNNN is the LAT run ID for the LAT-22x acquisition.

(a) intMOOSeApp.py; e2e_LAT-22x; (0.5 hr) Perform memory dumps...
(b) intMOOSeApp.py; e2e_LAT-22x; (0.5 hr) Perform memory dumps...

*** Force GPS to lose lock and verify that GPS lock has been lost
```

Config/Side	GPS lock?	Time criteria	Drift criteria
1/A	Yes	$\lvert\overline{dT}\rvert < 10\,\mu$s	
1/A	No	$\lvert\overline{dT} - \overline{dT_0}\rvert < 0.01 \times T\,\mu$s	$< \pm 0.01\,\mu$s/s
2/B	Yes	$\lvert\overline{dT}\rvert < 10\,\mu$s	
2/B	No	$\lvert\overline{dT} - \overline{dT_0}\rvert < 0.01 \times T\,\mu$s	$< \pm 0.01\,\mu$s/s

Table 1: The four test configurations. See text for details.

```
8.2 The following two runs will be used for the Clock drift test:
When LAT triggers are observed (i.e. when the GEM Trigger Sent rate becomes non-zero),
start data acquisition with the muon telescope:    ( ... )
```

Table 1 summarizes the 4 different test configurations. At least one half-hour data run in each configuration is needed. If time allows, two half-hour runs are preferable. The order of execution does not matter.

2.2 Analysis, and success criteria

The LAT data are automatically copied to SLAC computers (California) where the muon track directions are derived from the raw silicon tracker data. One of the authors (to date: das) performs the analysis described in the previous test reports. Transfer, reconstruction, and analysis generally take less than two days. Figures 2 and 3 illustrate the analysis results, using data acquired on 2007 February 22 and 23. Note that tests prior to April 2007 have failed and the figures do *not* show what we aim for.

The top-left plots show the distribution of time differences $dT = T_{EGSE} - T_{LAT}$, where T_{EGSE} is the muon arrival time recorded by the test equipment, and T_{LAT} that from the LAT. The spike should be within $10\,\mu$s of zero when the GPS is locked, and will most likely still be within $10\,\mu$s of zero even with GPS unlocked. In Table 1, $\overline{dT}$ is the average of dT for at least 500 muon coincidence events, while $\overline{dT_0}$ is the average for the first 10 muon coincidence events at the beginning of a data run, and T is the elapsed time since GPS lock was lost.

(The distribution is contaminated by spurious events ("accidental coincidences") which are an artifact of the analysis method. The top-middle figure requires the LAT muon track to traverse a "virtual" telescope position on the opposite side of the spacecraft, and provides an estimate of the rate of these spurious events.)

The top-right plot of the figures shows how dT evolves with time, during the 1800 seconds of these acquisitions. In a successful test, the diagonal lines shown would be nearly horizontal (the slope would be $< 0.01\,\mu$s per second), at a value within $\pm 10\,\mu$s.

To summarize: For the absolute time correlation test (GPS lock runs), the criterium is that the spike in the top left hand plot be centered. For the clock drift test (GPS unlock runs), that spike should still be nearly centered, *and* the diagonal line in the top-right plot should be nearly horizontal.

References

[1] "Science Requirements Document",
`http://glast.gsfc.nasa.gov/science/433-SRD-0001_CH-03.pdf`

[2] "LAT Instrument-Spacecraft Interface Requirements Document",
`http://giants.stanford.edu/ioc/docs/433-IRD-0001.pdf`

[3] LAT-SS-00010 "LAT Level II(B) Performance Specification". See also LAT 13x tests described in section 6.7.2.10 of the "Performance and Operation Test Plan" LAT-MD-02730-04.

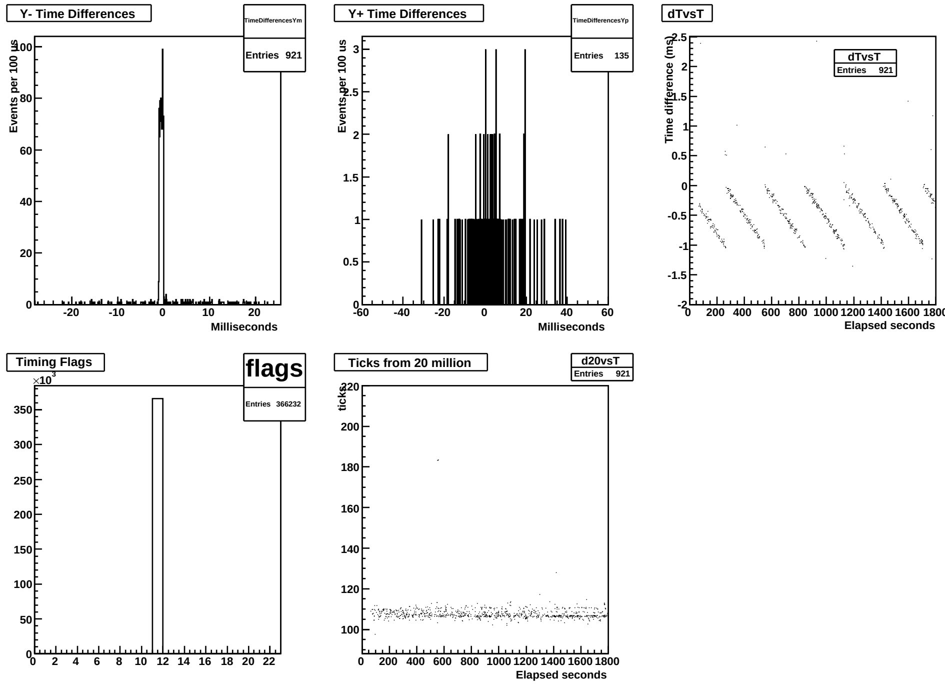

Figure 2: Run 77014192, absolute time test: GPS locked, spacecraft side B, LAT configuration 2. Top-left shows dT, the difference between muon arrival times as recorded by the LAT and by the test equipment, for muon tracks traversing both. The other plots provide diagnostic information described in the previous test reports. In a successful test, the spike in the top-left plot would be centered at $dT < \pm 10\,\mu$s, with a narrower width than shown here.

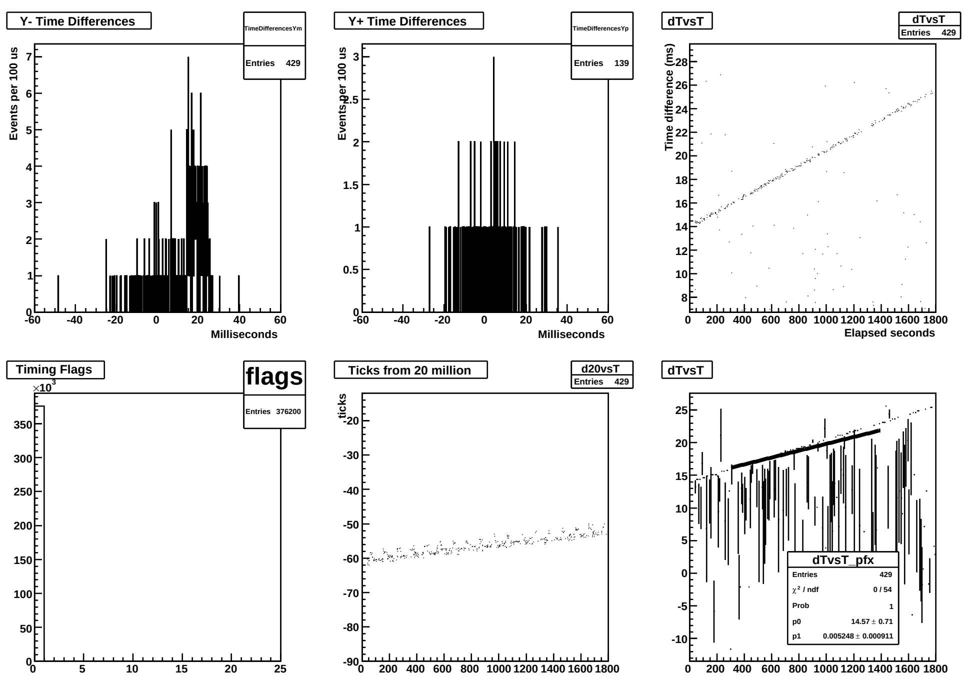

Figure 3: Run 77014218, clock drift test: GPS unlocked, spacecraft side A, LAT configuration 1. The plots are as in the preceding figure. In a successful test, the spike in the top-left plot would be near the average value of the preceding figure, possibly offset by $\pm 0.01 \times T\,\mu$s, where T is the time (in seconds) since GPS lock was lost. The top-right plot shows dT versus the elapsed time of the half-hour data run. For a successful test, the diagonal line would be nearly horizontal, that is, its slope would be less than the $0.01\,\mu$s per second requirement