Proposal for an end-to-end test of GLAST LAT absolute event times

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Motivation

- Gamma ray pulsar research is a primary GLAST LAT science goal.
- Pulsar studies require event *absolute* time stamps to within 10 µS.
- A difficult measurement – major missions have had serious issues.
- Example: CHANDRA HRC-I, see

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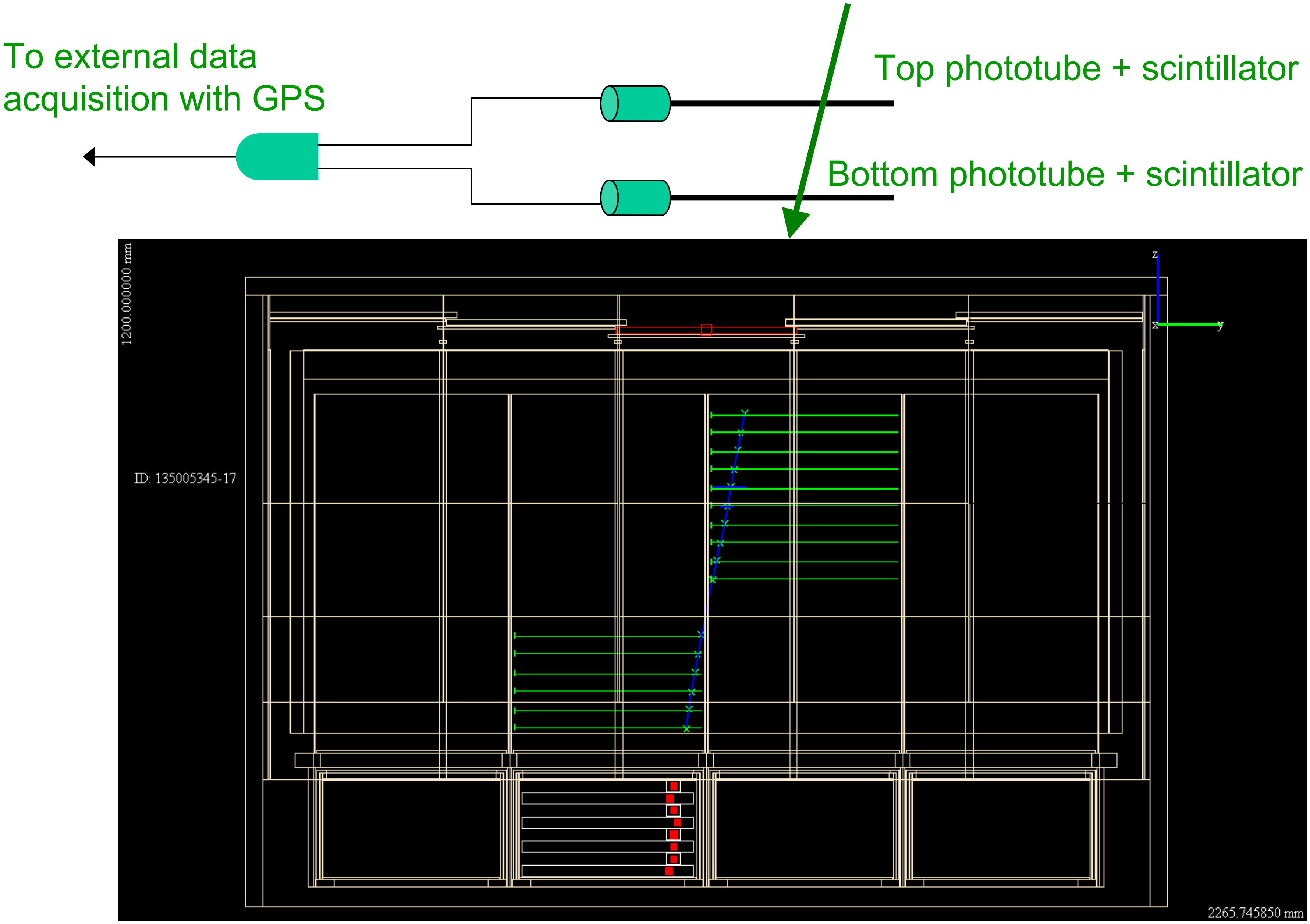
- LAT measures time stamp precision relative to an external time stamp. The LAT 13x tests to meet Level 3 req't 5.2.11 are described in LAT-MD-02730.
- 1 PPS signal precision ("pulse per second") is a spacecraft requirement.
- The complete hardware plus software chain is long & complex.
- This proposal: *cross-check the LAT timestamps using an external, independent, validated system.*

Overview

- Cosmic ray muons traverse the LAT and are routinely used to test LAT performance.
- Some of these muons can be intercepted by a “telescope” of two scintillators, to trigger an external data acquisition system that includes a GPS time stamp.
- LAT track reconstruction will be used to identify individual muons that crossed the scintillators.
- The external GPS timestamp will be compared with the LAT timestamp.

  – *Measurements to be made in parallel with planned tests, by external personnel, with existing equipment – no schedule or cost impact.*



Event display by Riccardo Giannitrapani, INFN Udine
Animated "Movie" by Anders Borgland, SLAC

Outline

- About the data acquisition system
- About the scintillators (the “muon telescope”)
  - Placement
  - Data rates
- Preparation, planning, and personnel

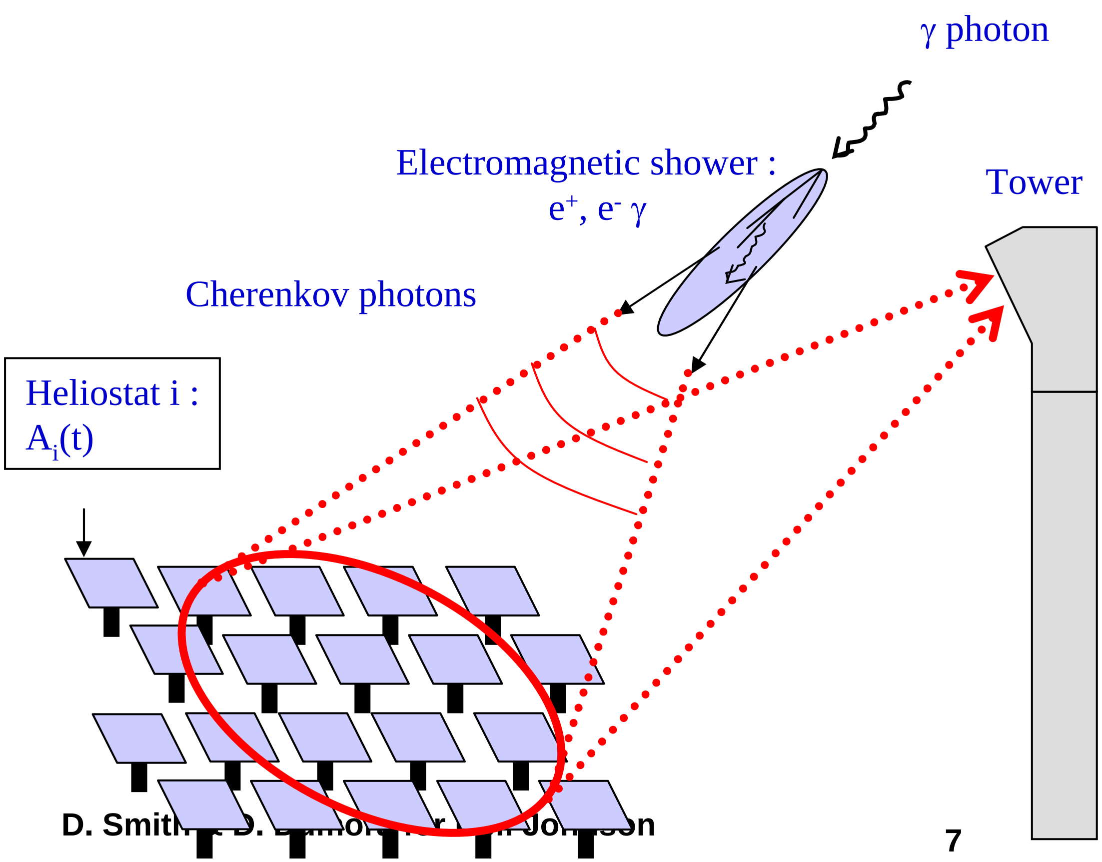
Data acquisition system

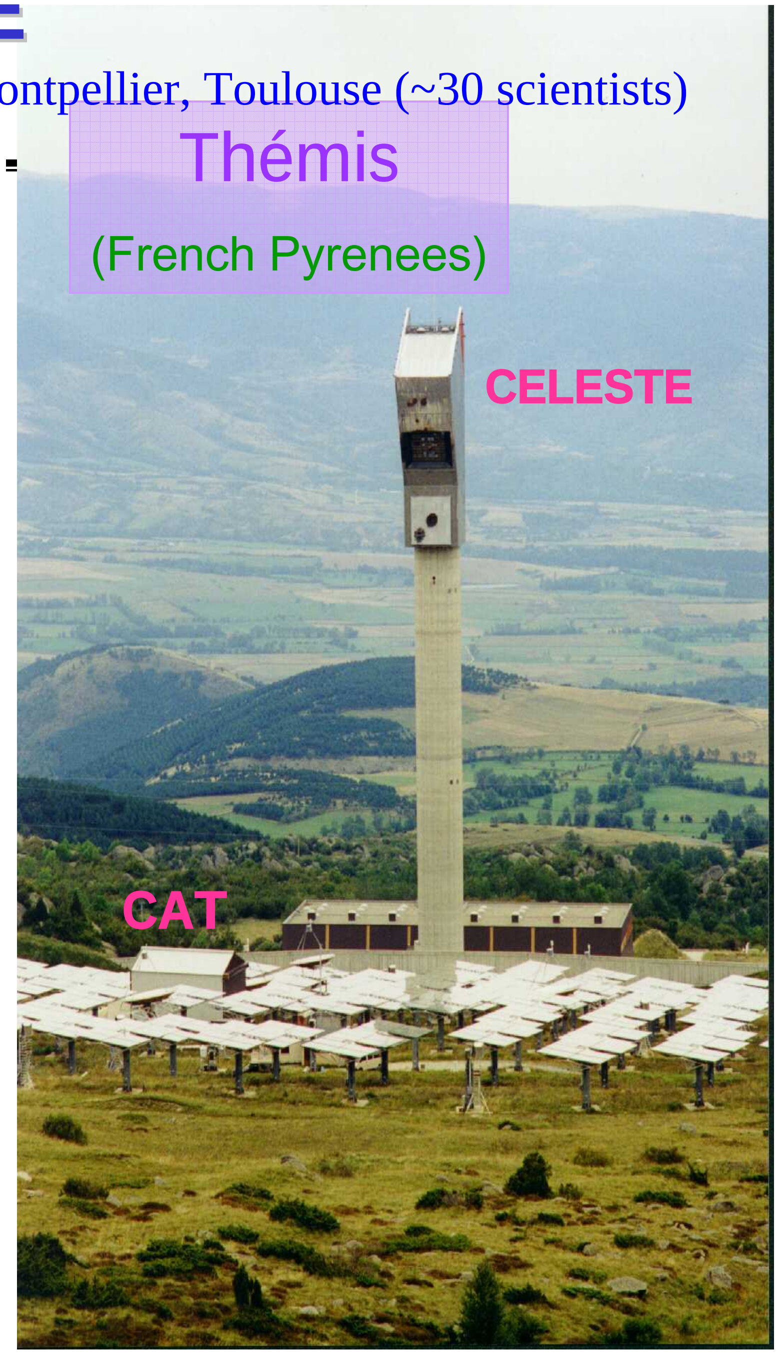
- Used by “CELESTE”, a ground-based gamma ray telescope.
- Also used for GLAST LAT calorimeter testbeam studies (without GPS).
- The GPS is in a VME crate controlled by a Motorola 68040 running the Lynux OS. *(Datum bc635 VME)*
- Standard NIM electronics will be used to trigger on the coincidence of the phototube signals that occurs when the scintillators are traversed by a muon.

CELESTE

CENBG, Ecole Polytechnique, Collège de France, Montpellier, Toulouse (~30 scientists)

1998-2004: Only gamma ray telescope in the world sensitive between 30 et 130 GeV.

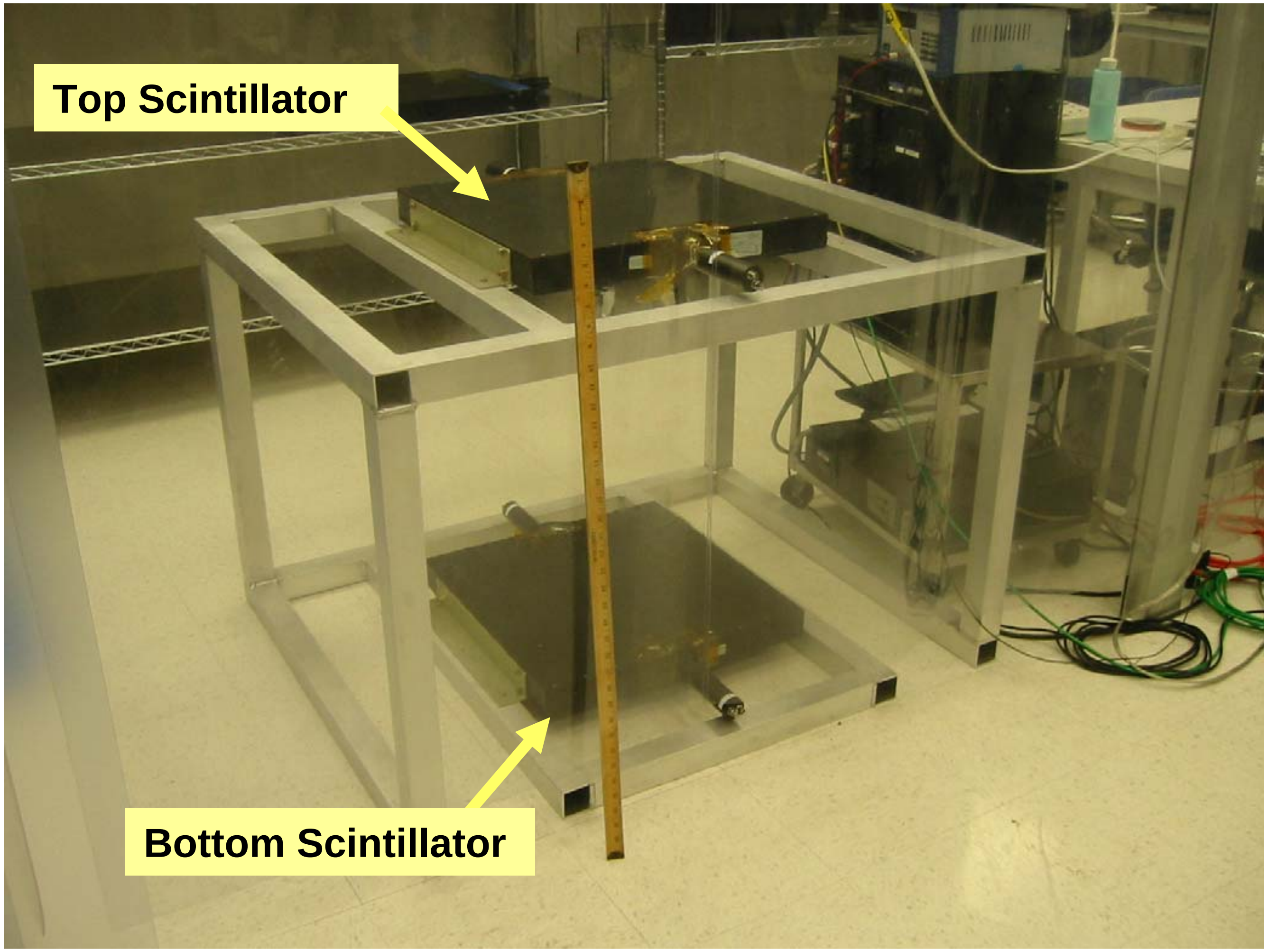




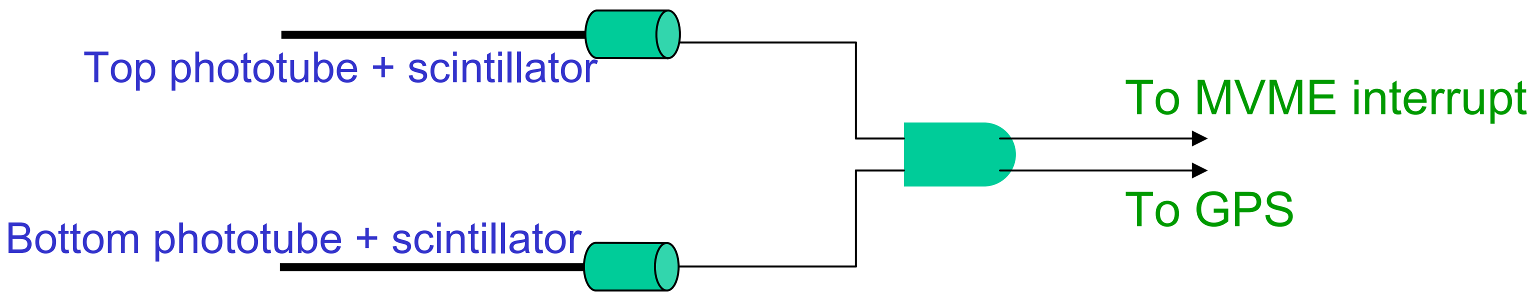
The muon telescope

- During the LAT calorimeter integration, NRL used a muon telescope for module-level CAL testing. We will use these same scintillator + photomultiplier tube assemblies for the GLAST absolute time validations.
- Each scintillator is $(50\ cm)^2$.
- Two photomultiplier tubes per scintillator (total of 4).
- High voltage supplies and settings, and NIM discriminators and settings available from NRL.

LAT Calorimeter's Muon Telescope + Stand



Muon telescope placement



- Ideally, one scintillator above GLAST, and the other below.
- No room below? Then both above

Muon telescope placement, cont'd

- Each scintillator+PMT assembly weighs a few pounds. High voltage plus signal cables (4x2 = 8) add several more pounds.
- We picture the scintillator assemblies mounted in the NRL muon telescope frame (or something similar) on a "diving board" that can be rolled into place, placing the telescope over GLAST.
  - Over GLAST is not strictly necessary. Could be at the side and above GLAST with a reduced event rate.
- On a table, in or out of the clean room, out of people's way, we will have:
  - A VME crate, with external hard disk.
  - A NIM crate, with the PMT HV supply.
  - A computer monitor and keyboard (perhaps a laptop computer).

Muon rates, test duration

Muon rate: $R = I_v^{hard} A \Omega$ where

$I_v^{hard} \approx 80\ /m^2/s/sr$ is the rate for ground muons ("hard component")

$A = r^2 = (50\ cm)^2 = 0.25\ m^2$ is the scintillator area

$\Omega \approx \pi(r/d)^2$ is the telescope solid angle of acceptance, where d is the vertical separation between the scintillator paddles.

$$R \approx (15\ Hz)/d^2 \quad \text{(d in meters)}$$

[Eric says 10 Hz for 1.5 CAL heights, including $(\text{PMT efficiency})^4$]

A few hundred events is more than we need – a few minutes of running.

TOTAL TEST DURATION:

DAY ONE: a few hours to set up. A few runs of a few minutes, in parallel with LAT muon runs.

DAY TWO: Overnight for data analysis. Repeat runs only in case of problems.

Preparation, planning, & personnel

- In Bordeaux, bring timing system back up using the small scintillators.
- Deliver VME system to NRL for checkout with CAL scintillators before shipment to GD C4.
- Final tests at General Dynamics after integration of LAT with spacecraft. Tests run in parallel with LAT cosmic ray acquisition.
  - Post-integration checkout?
- Need to know position of LAT relative to muon telescope, to within a few inches.
- Tests to be performed by (a) US citizen(s).
- Post test correlation of muon telescope timestamped event list with LAT's filtered muon event list demonstrates timing accuracy (or consistency).
- No GLAST schedule or cost impact.

Summary

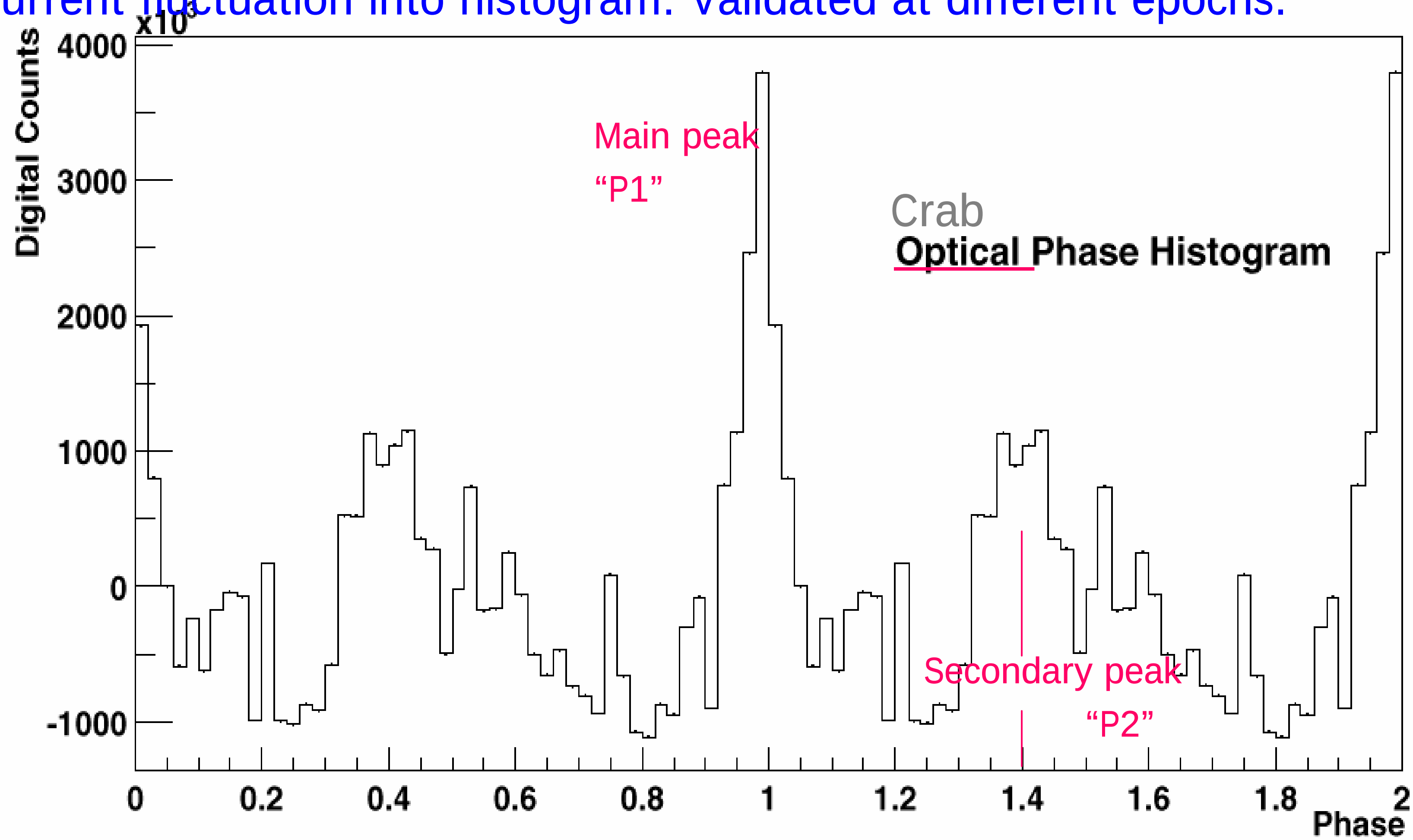
- 10 uS timestamp accuracy of GLAST LAT gamma ray events is absolutely critical to the success of GLAST pulsar research, a primary mission goal.
- The GLAST + LAT hardware & software chain involved in event dating is complex. Previous missions have had problems discovered after launch.
- We propose a simple test for end-to-end validation.
- The test exploits the synchronicity of cosmic ray muons traversing both the LAT and a simple external detector.
- The test would be performed by a US citizen supported by non-US funding, and would take a few hours on a couple of days, with no schedule impact.
- The testers have extensive experience with both pulsar timing and cosmic ray detection.

Extra slides…

Testing Celeste pulsar search hardware & software.

Sum of AC-coupled PMT anode currents for three heliostats, tracking the Crab.

Sample at 2 kHz for 20 minutes. For each sample, calculate phase and enter current fluctuation into histogram. Validated at different epochs.



1 period = 33 milliseconds. *Nota bene*, **TWO** rotations shown.

(By D. Dumora)

Example of "real life" timing problem

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- While reading up on PSR J0205+6449 I came across this:

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IS THE COMPACT SOURCE AT THE CENTER OF CASSIOPEIA A PULSED?

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ABSTRACT

A 50 ks observation of the supernova remnant Cas A was taken, using the *Chandra X-Ray Observatory* High-Resolution Camera (HRC) to search for periodic signals from the compact source located near the center. Using the HRC-S in imaging mode, problems with correctly assigning times to events were overcome, allowing the period search to be extended to higher frequencies than possible with previous observations. In an extensive analysis of the HRC data, several possible candidate signals are found

CHANDRA pulsar timing problems, cont'd

1.1. *Problems with HRC-I Timing*

Using the *Chandra X-Ray Observatory* and the HRC, we obtained a 50 ks observation of Cas A specifically to search for pulsations from the compact source detected near the center of the remnant. This observation (OBSID 01505) was taken using the HRC-I on 1999 December 20. It was subsequently found that the HRC has a wiring error that incorrectly assigns event times such that the assigned time is that for the previous event trigger (Murray 2000; Seward 2000).[1] If every event trigger resulted in an event in the telemetry, this error could be easily corrected by simply shifting event times by one event during ground processing. However, because of telemetry limitations (184 events s^{-1}) and onboard event screening, not all event triggers necessarily result in an event entering the telemetry stream. Therefore, determining true event times is not always possible and under normal HRC operating conditions cannot be done for a significant fraction of the events.

In order to evaluate the effect of the HRC timing error on our ability to detect pulsations, we developed a high-fidelity software simulation of the detector and telemetry system. Simulations for this observation (OBSID 01505) show that if no attempt is made to correct the timing error, or if the only correction made is to shift the telemetered time for each event by one event, then a sinusoidal pulse signal with $<20\%$ modulation amplitude or with a period of less than 20 ms will be undetectable (similar to the conclusions of Chakrabarty et al. 2001).

CHANDRA pulsar timing solution

1.2. *Solution using HRC-S in Imaging Mode*

Fortunately, the HRC-S can be operated in a "special" mode where all event triggers result in events that are included in the telemetry. In this mode, only the central microchannel plate segment is able to initiate an event trigger. This restriction reduces the background by about a factor of 3 from the normal HRC-S rate (i.e., total event rate goes from ~250 to ~90 counts s^{-1}) and therefore allows onboard event screening to be turned off. All event triggers are processed as valid events and fitted within the telemetry limit of 184 counts s^{-1}. This mode is designated the HRC-S (Imaging) Mode. It is now available for all observers and was used to reobserve those AO-1 and AO-2 targets requiring the high time resolution of the HRC, including our Cas A observation.

They recovered, but apparently with some loss of pulsed sensitivity…