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

To be performed by David A. Smith[1*], in collaboration with Denis Dumora[1] and Eric Grove[2].

Presented by Neil Johnson[2].

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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

THE ASTROPHYSICAL JOURNAL, 566:1039–1044, 2002 February 20

- LAT measures time stamp precision relative to an external time stamp.

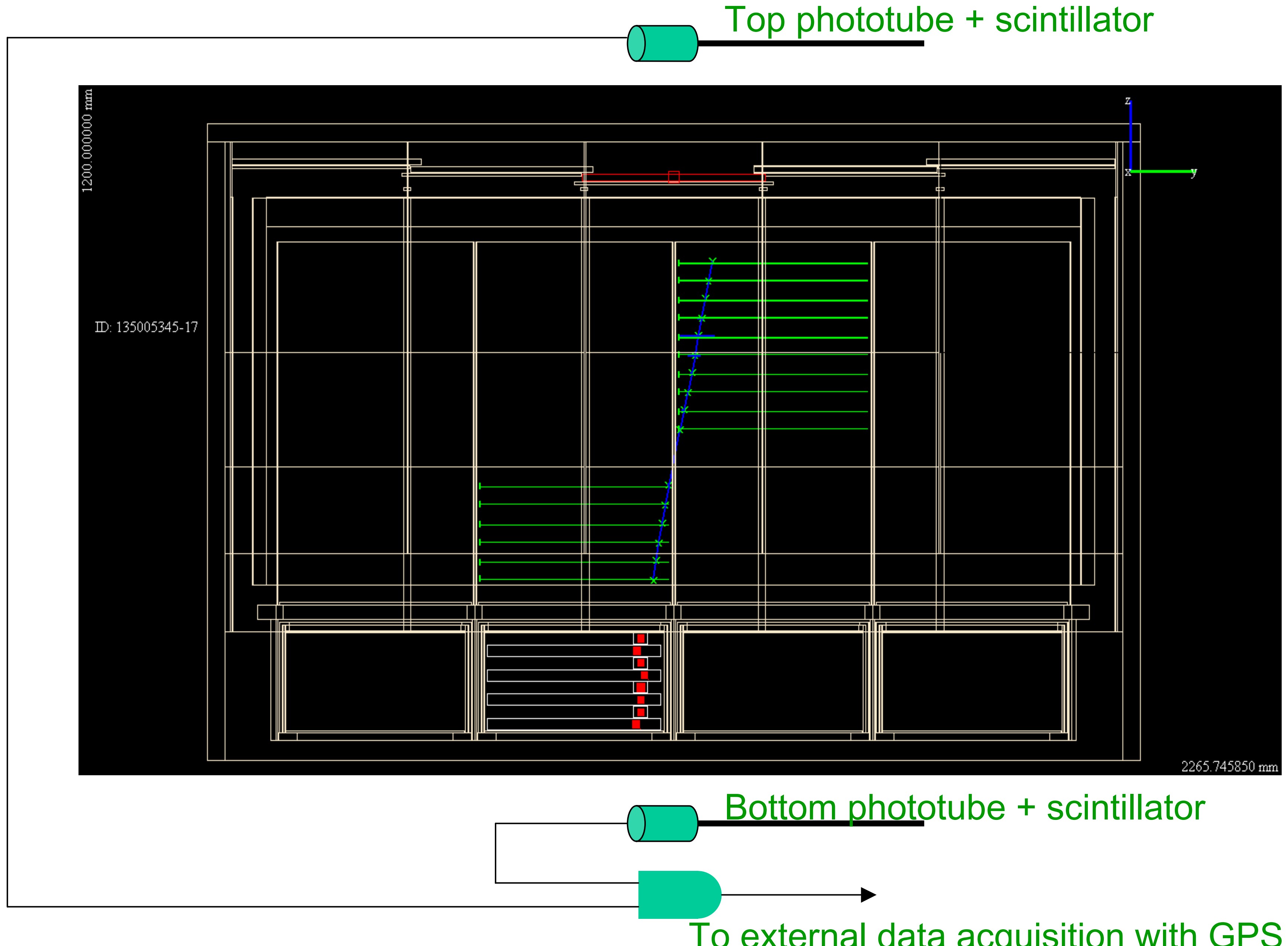
  The LAT 13x tests to meet Level 3 req't 5.2.11 are described in LAT-MD-02730.
- 1 PPS signal precision ("pulse per second") is a spacecraft requirement.
- The complete hardware plus software chain is long & complex.

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
- Risk?

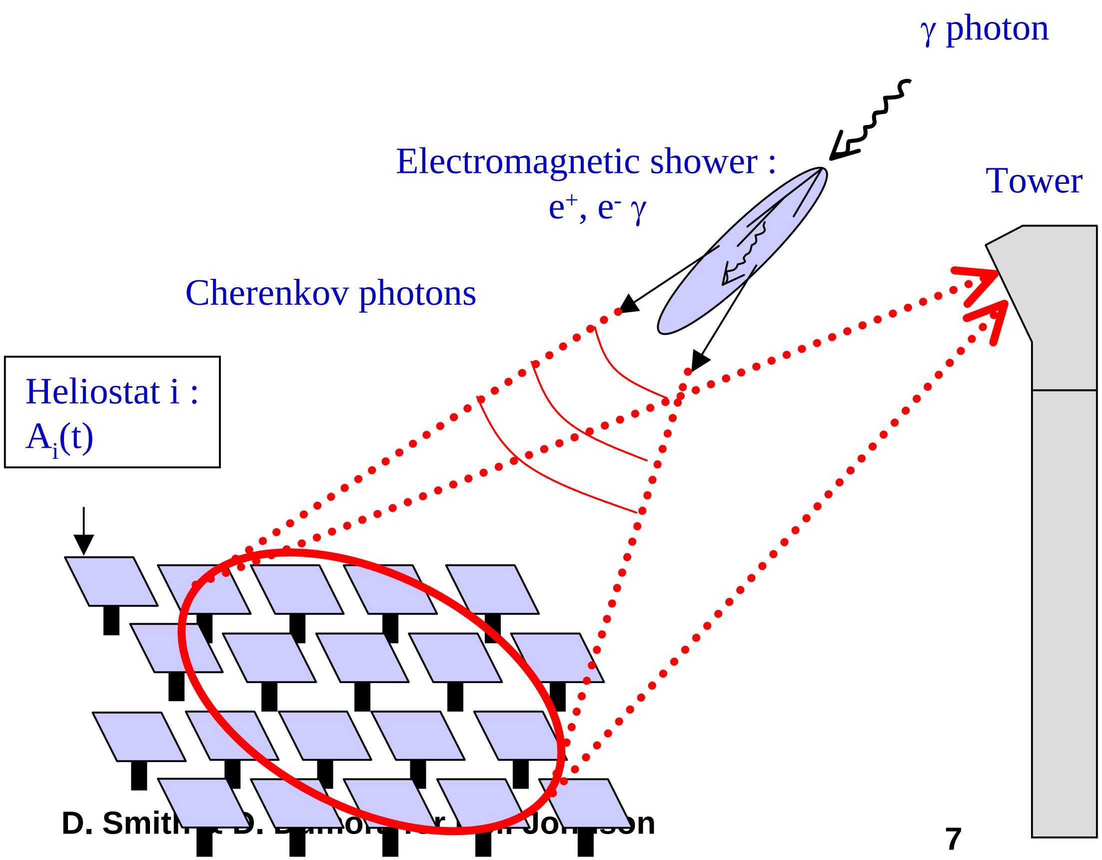
Data acquisition system

- 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.
- 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.



An independent, external muon timestamp

- D. Dumora and D. Smith used the VME GPS to see the Crab optical pulsar with CELESTE.
- An integral part of CELESTE – minor re-cabling, minor software modifications for this study (a validation of the CELESTE gamma ray time stamping).

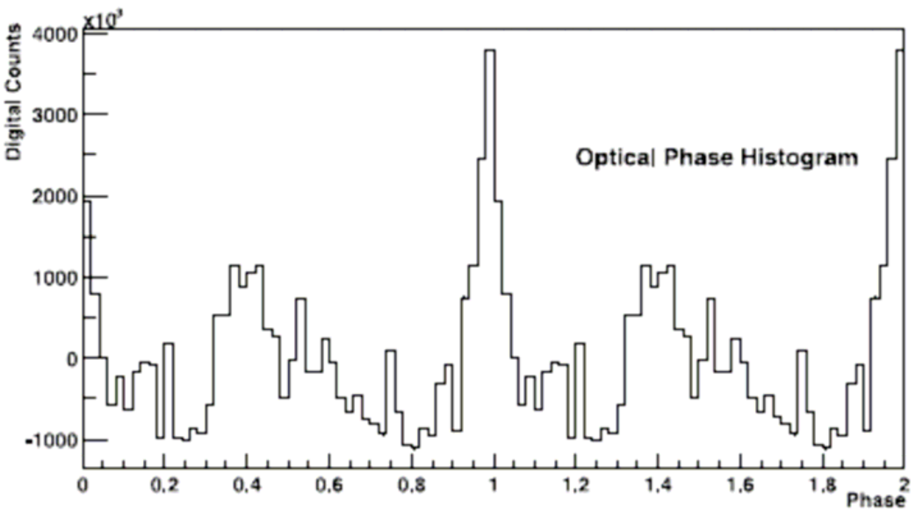


FIG. 16.—Phase histogram for the optical Crab data

THE ASTROPHYSICAL JOURNAL, 566:343–357, 2002 February 10

MEASUREMENT OF THE CRAB FLUX ABOVE 60 GeV WITH THE CELESTE CERENKOV TELESCOPE

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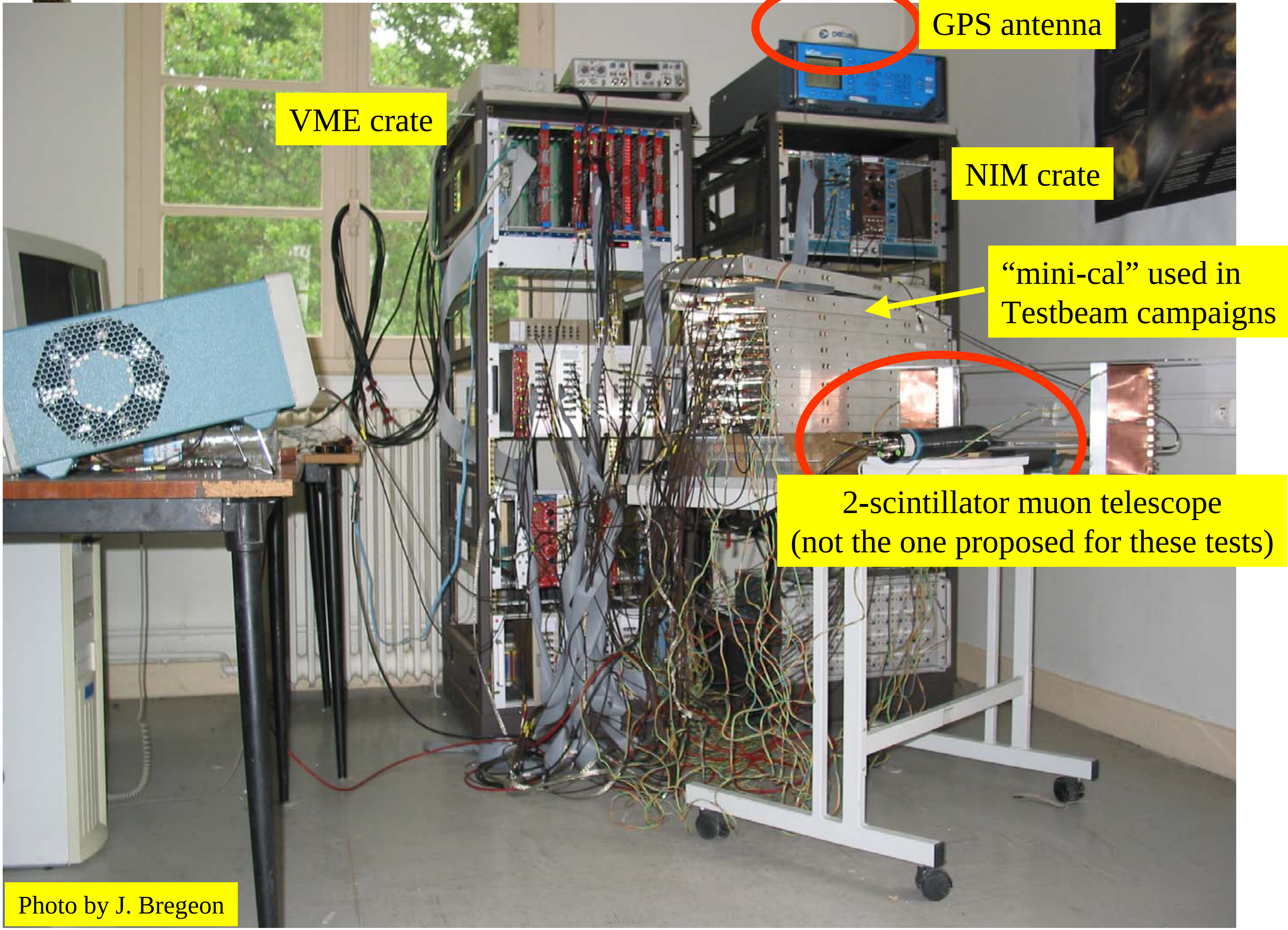
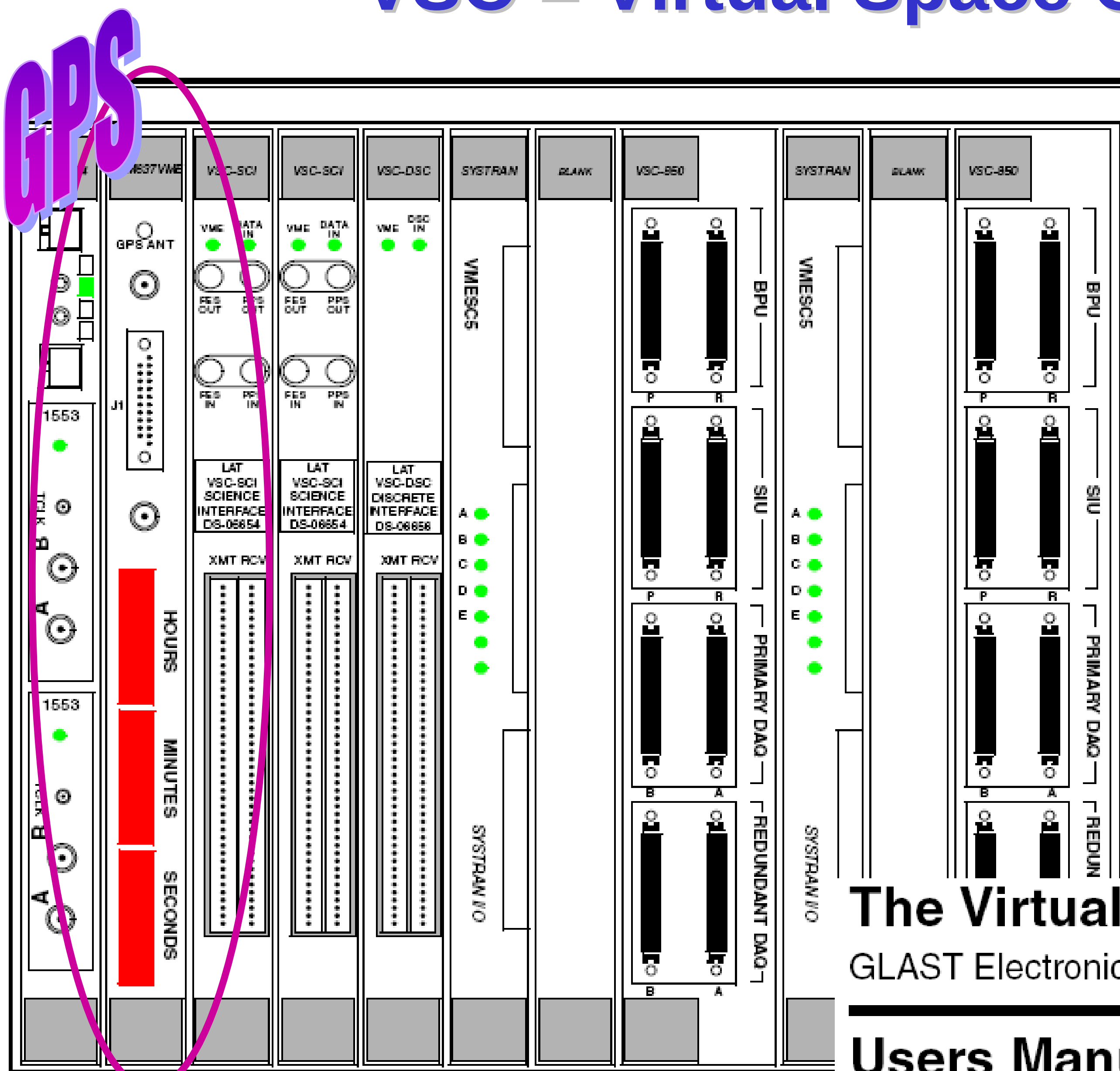

GPS antenna
VME crate
NIM crate
“mini-cal” used in Testbeam campaigns
2-scintillator muon telescope (not the one proposed for these tests)
Photo by J. Bregeon

VSC = Virtual Space Craft



VSC is a VME crate with some ordinary and some special modules.

CELESTE VME GPS is very similar.

The Virtual Spacecraft (VSC)

GLAST Electronics group

Users Manual

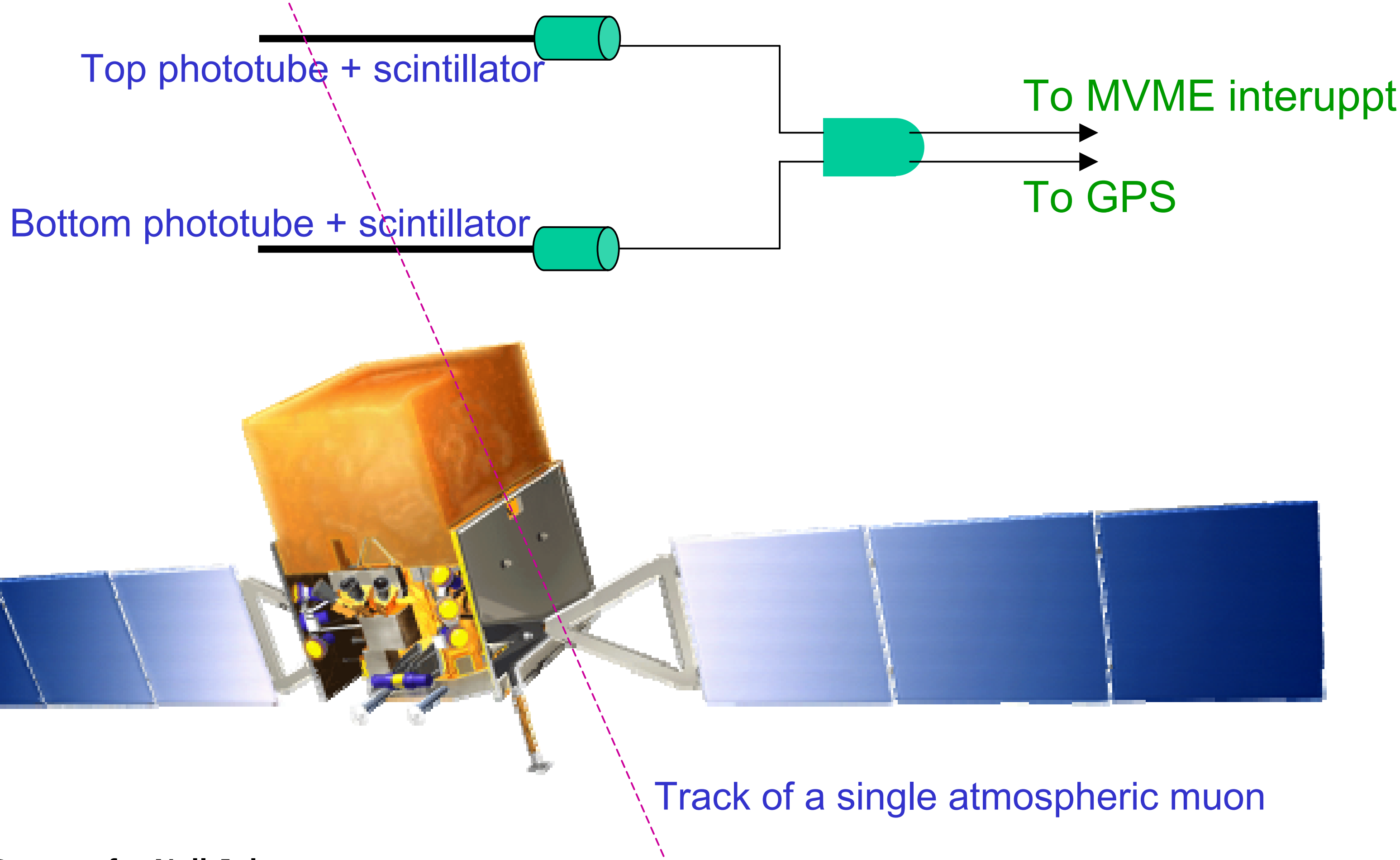
10

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.

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 PMTs on a "diving board" that can be rolled into place, placing the telescope above GLAST. Minimum of 1 meter vertical separation of the 2 scintillators. 2 meters would make muon identification easier.
- On a table, in or out of the clean room, out of people's way, we will have:
  1. A VME crate, with external hard disk.
  2. A NIM crate, with the PMT HV supply.
  3. A computer monitor and keyboard (perhaps a laptop computer).

(picture of SLAC "diving board" next slide)

"Diving boards" at SLAC…

The scintillators for the muon telescope used during LAT I&T at SLAC were placed on these platforms.

NRL has a structure they used to support their muon telescope during CAL integration. Suitable for this test?

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.

$R \approx (15\ Hz)/d^2$ (d in meters)

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

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

- CELESTE dismantled in June 2004. In Bordeaux, bring system back up using the small scintillators shown in slide 9.
- If time permits, bring VME system to NRL before LAT shipment to exercise test procedure.
- Final tests at General Dynamics after integration of LAT with spacecraft. Tests run in parallel with LAT cosmic ray acquisition.
  - Post-integration checkout?
  - GBM calibration?
- Need to know position of LAT relative to muon telescope, to within a few inches.
- Tests to be performed by (a) US citizen(s).
- No GLAST schedule or cost impact.

Risk?

- No schedule impact – tests in parallel with existing program.
- No cost impact, beyond minimal time by General Dynamics personnel to position the muon telescope, and to accommodate D. Smith.
- D. Smith is paid by the French CNRS – no NASA, DOE, or other US funding.

- Should a >10µS disagreement arise between GLAST LAT timestamps and external timestamps, an investigation by LAT and spacecraft personnel will ensue.

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…

An idea…

- While at Nançay recently, Ismael had us listen to a sound recording of the Vela pulsar. It sounds like a boogie locomotive jammin' through the jungle.
- If we had time, we could haul our VME crate up to Nançay, trigger on their 1 jansky signal, bary center, and show that our timing is still good even after dismantling => resurrection.
- Perhaps wiser to not suggest to anyone that it might not be.

How to build MET from raw data

Slide 9 of Anders Borgland's talk,

http://www-glast.slac.stanford.edu/IntegrationTest/SVAC/Instrument_Analysis/Meetings/05262006/SVAC.pdf

Time Tones

- We receive a time tone from the GPS every second: 1-PPS
- Can be used to make an event time stamp!
- For every event:
  - Information about the current and previous time tone
  - Can correct for drift in the system clock i.e. The Tiem Tone is our absolute time!
- Example:
  - Event time stamp in seconds:

Number of seconds since Epoch start 01.01.2001 of last 1-PPS

TimeStamp = ContextLsfTimeTimeToneCurrentSeconds

+ [ContextLsfTimeTimeTicks / (ContextLsfTimeTimeToneCurrentGemTimeTicks - ContextLsfTimeTimeTonePreviousGemTimeTicks)]

Number of system clock ticks between last two 1-PPS

Number of system clock ticks (50 ns) since last time tone for this event

All the ContextLsf.... are SVAC ntuple variables!

(What does "plausible" mean?)

- Run 77005390 started at 2006-05-27 18:59:38, according to IA runs database.
- MET (=Mission Elapsed Time is seconds since 2001 January 1) .

<78>smith:borlin57.cenbg.in2p3.fr% /bin/date -u --date="1 Jan 01 00:00" '+%s' ➔ 978307200

<79>smith:borlin57.cenbg.in2p3.fr% /bin/date -u --date="27 May 06 18:59:38" '+%s' ➔ 1148756378

Difference is 170,449,178 (MET of begin run).

SVAC recipe shows 170,449,260 82 second difference "plausible"

EvtID	TTCTSecs	TTCTTicks	TTCGemTTix	TTPGemTTix	diff	TTicks/diff
3695052	170449260	21287574	2918647	16473104	19999975	1.064380
3696052	170449263	32400049	29364140	9364165	19999975	1.620004
3697052	170449265	9014258	2255226	15809683	19999975	0.450713

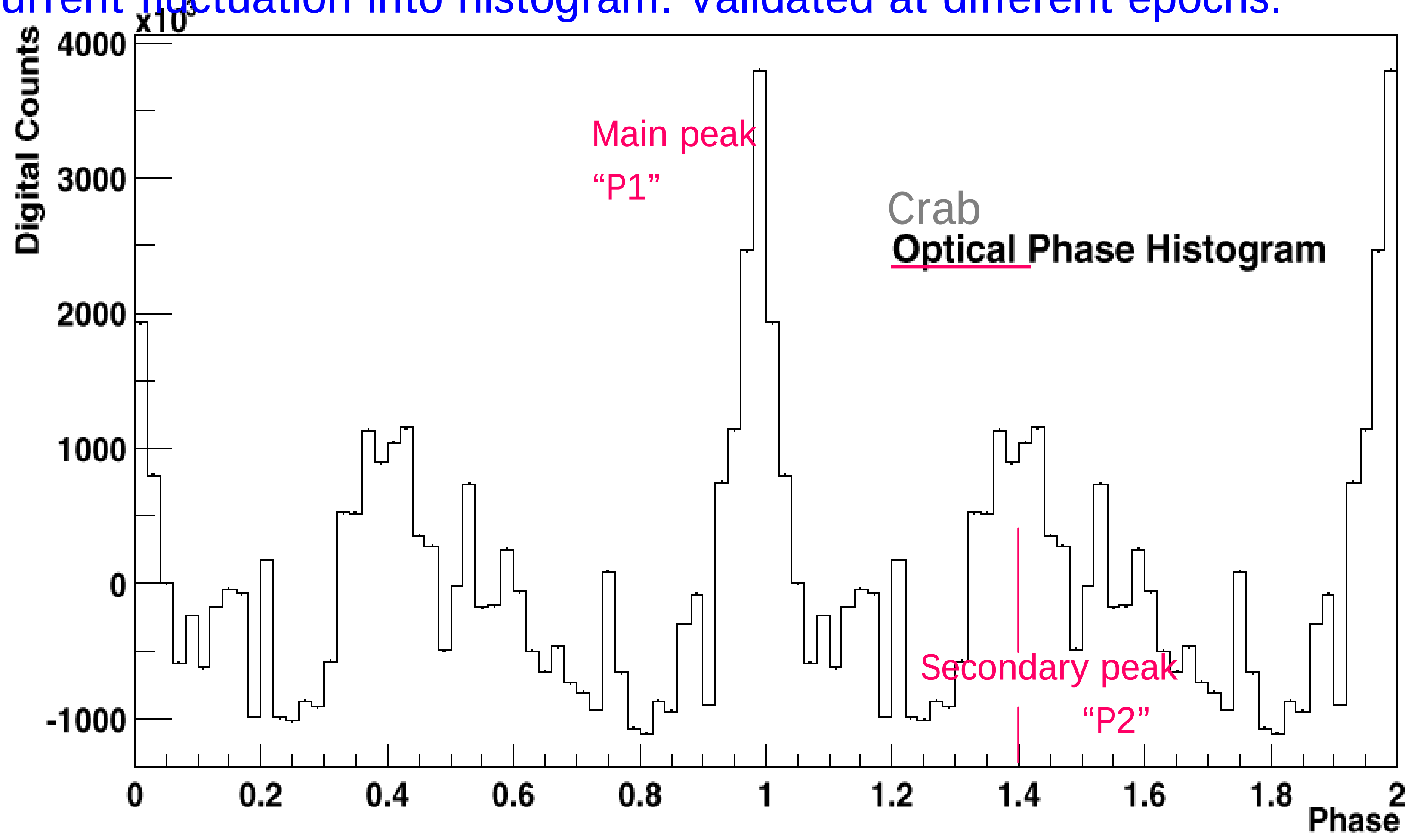
The 20 MHz scaler counts 19999975 times per second instead of counting 20000000. Fine.

TTicks/diff would, naively, never be more than 1 but apparently some PPS's get lost, which is also fine.

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.

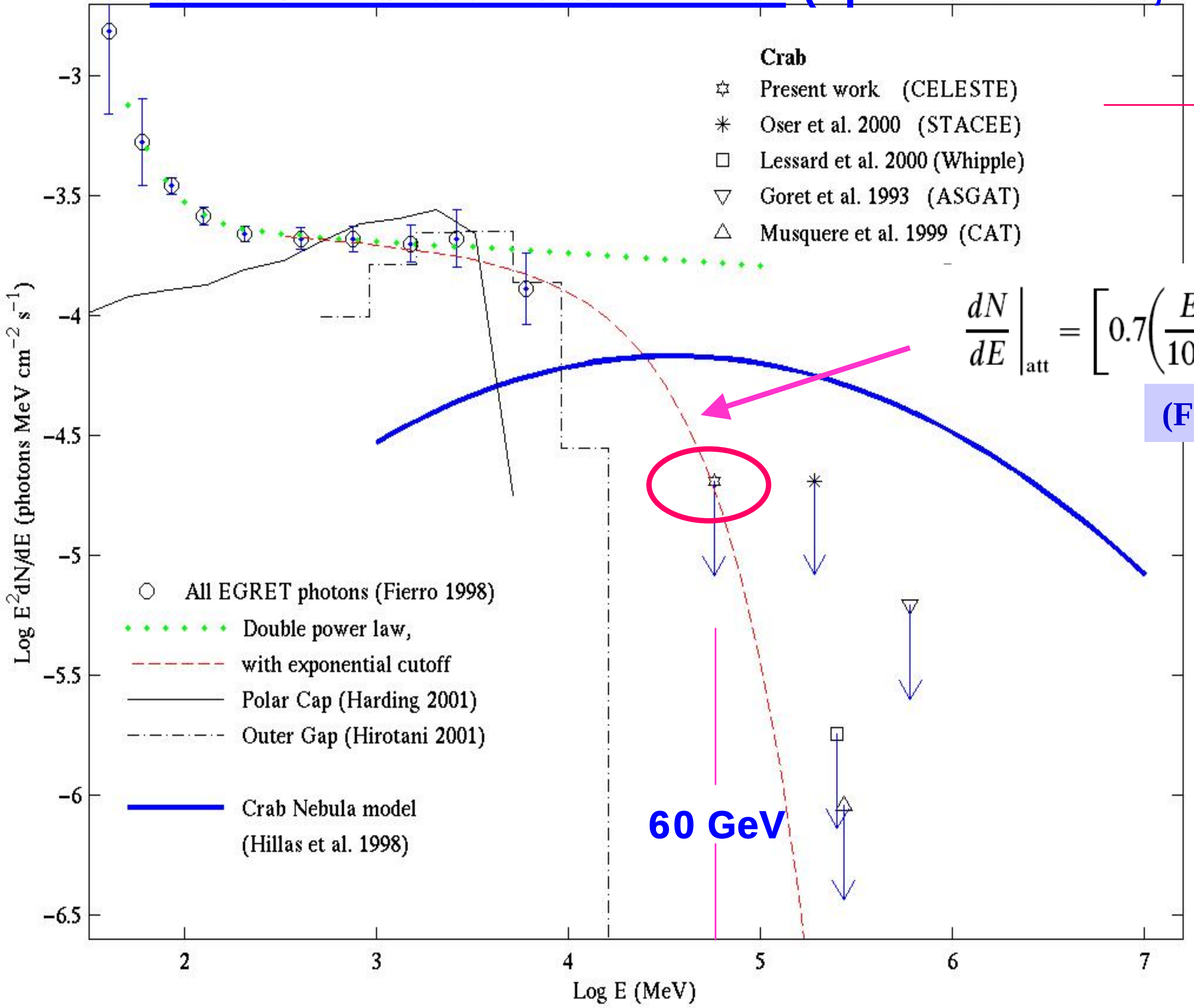


1 period = 33 milliseconds. *Nota bene*, **TWO** rotations shown.

(By D. Dumora)

La meilleure contrainte sur le spectre du Crabe est *"Made in CENBG"*

CELESTE Crab Pulsar Limit (ApJ 566:343-357, 2002)



$$\left.\frac{dN}{dE}\right|_{att} = \left[0.7\left(\frac{E}{100}\right)^{-4.89} + 2.3\left(\frac{E}{100}\right)^{-2.05}\right]e^{-E/E_0}$$

(Fierro et al)

CELESTE: Eo<26 GeV

<0.5 γ /minute

Example of “real life” timing problem

THE ASTROPHYSICAL JOURNAL, 568:226–231, 2002 March 20

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

THE ASTROPHYSICAL JOURNAL, 566:1039–1044, 2002 February 20

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

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Received 2001 June 28; accepted 2001 October 22

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…

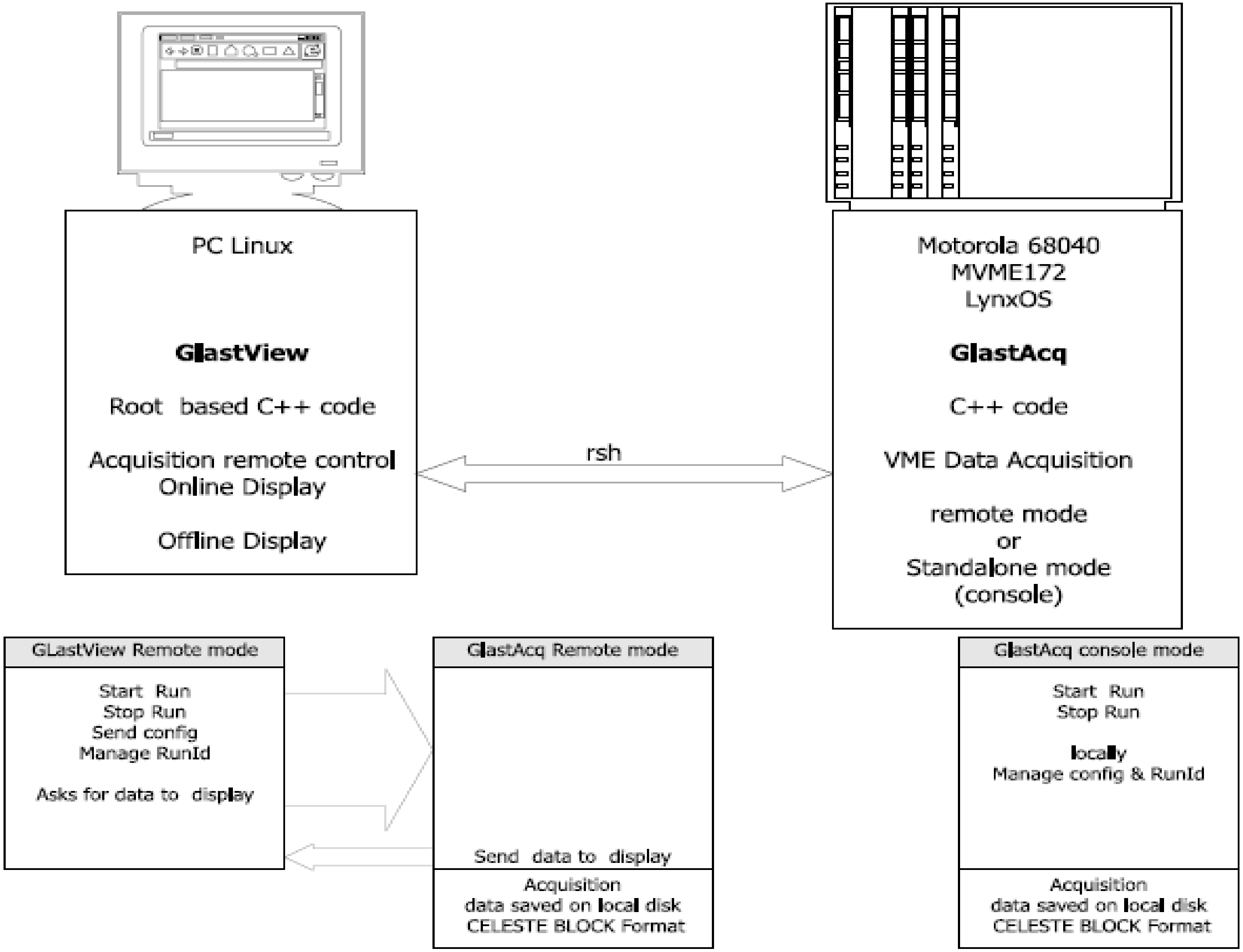


Figure 1: Bordeaux Acquisition system

Trigger interrupts, and data formats

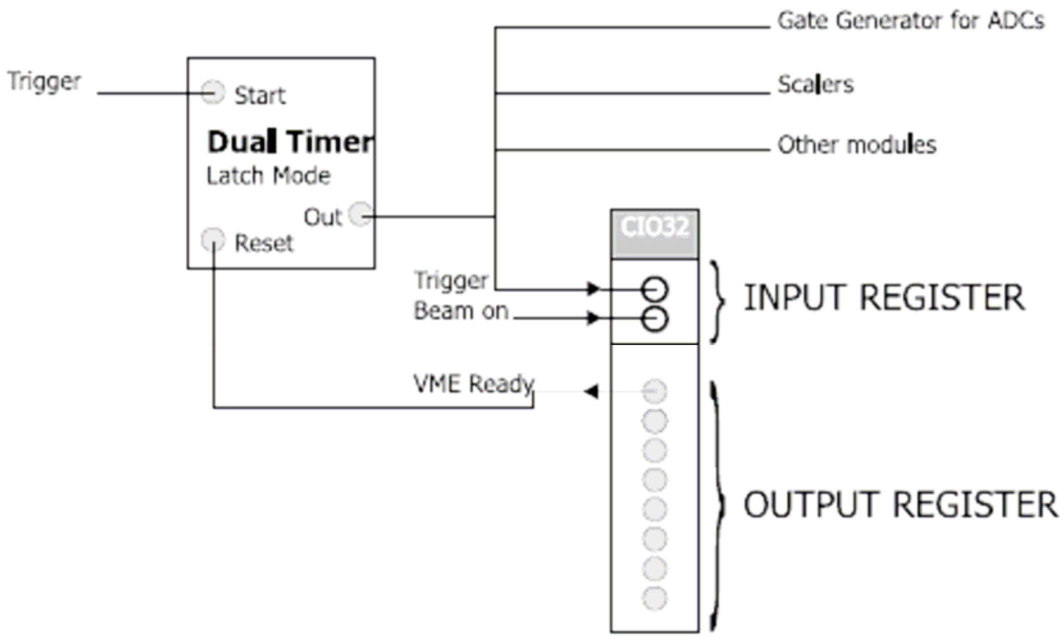


Figure 2: CIO32 as a trigger and disk writing manager

The CIO32 is an “Industry Pack” daughter card.
We have another one for RS-232 serial connections, if you like.

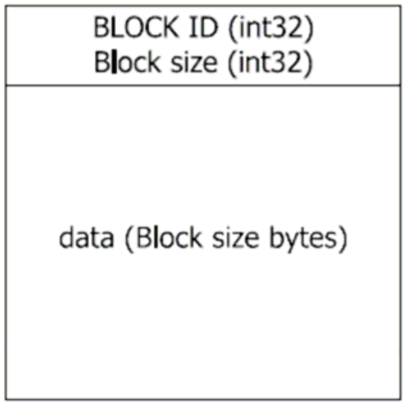


Figure 3: Binary Block Format

Speed

- In CELESTE, we typically read 20 bunches of 128 bytes each from ten VME cards from 3 VME crates in under 10 ms.
- That is, 20*128b/10 ms = 256 kb/s
- Triggering 256 kb events at 20 Hz gave us 20Hz*0.01=20% deadtime.

- At CERN 2003, we had

  ~ 7*32*1.5b*400 Hz = 134 kb/s

  (we could have gone faster…)

2.5 Performance

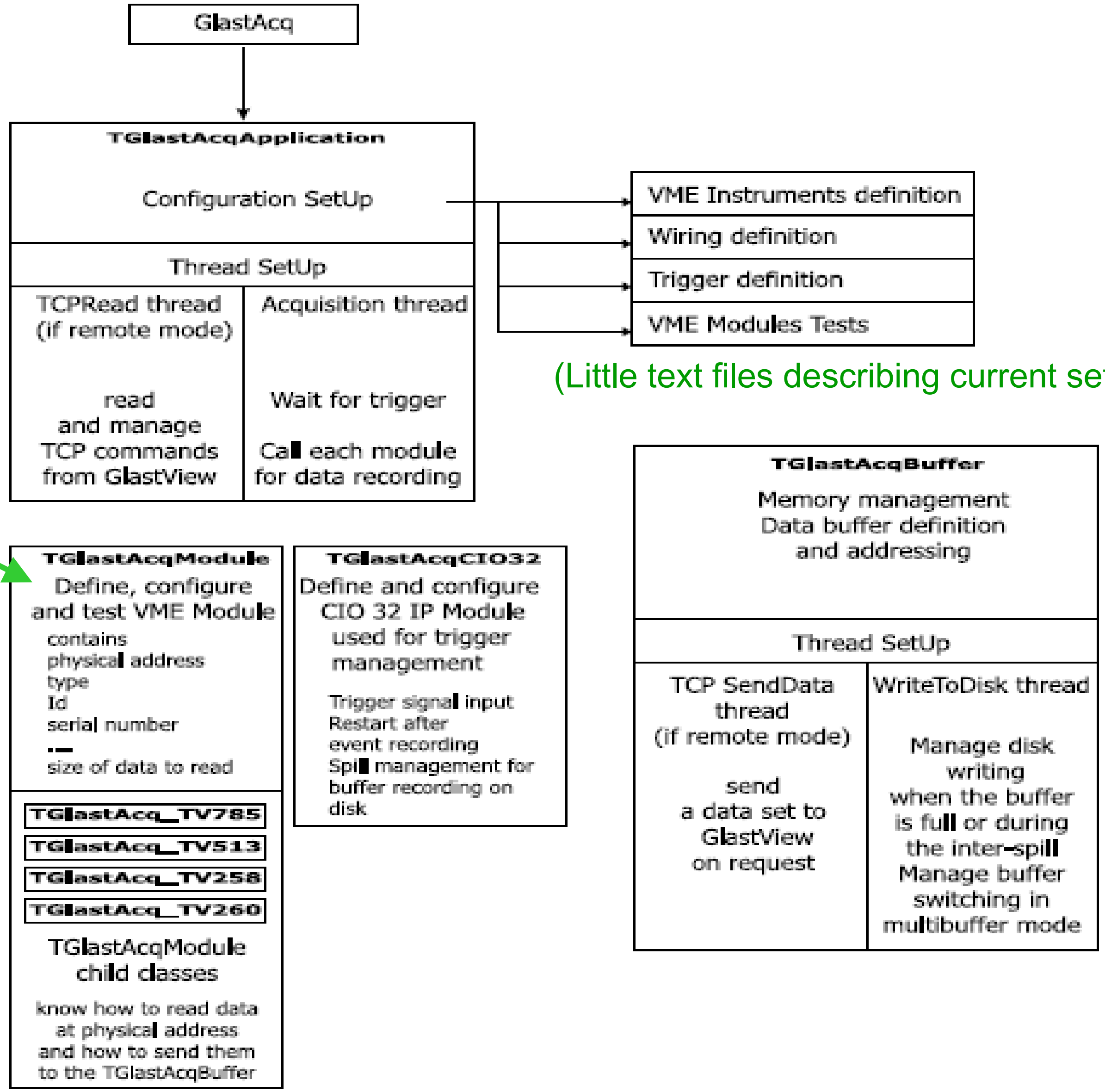
	read out speed
CERN 2003 (7*32 Adc Channels)	Hundreds of Hz
GSI 2003 (4*32 Adc Channels)	better than $\frac{1}{700}\mu sec$

At GSI, CAL EM set the readout cadence, with Bordeaux DAQ following.
Above means “better than 1 per 700 μsec”.

Modular Software architecture

If you add a new VME card to the system, you have to write a new routine *here*

Names of some CAEN VME modules we've used.



(Little text files describing current setup)

Figure 4: GlastAcq Classes