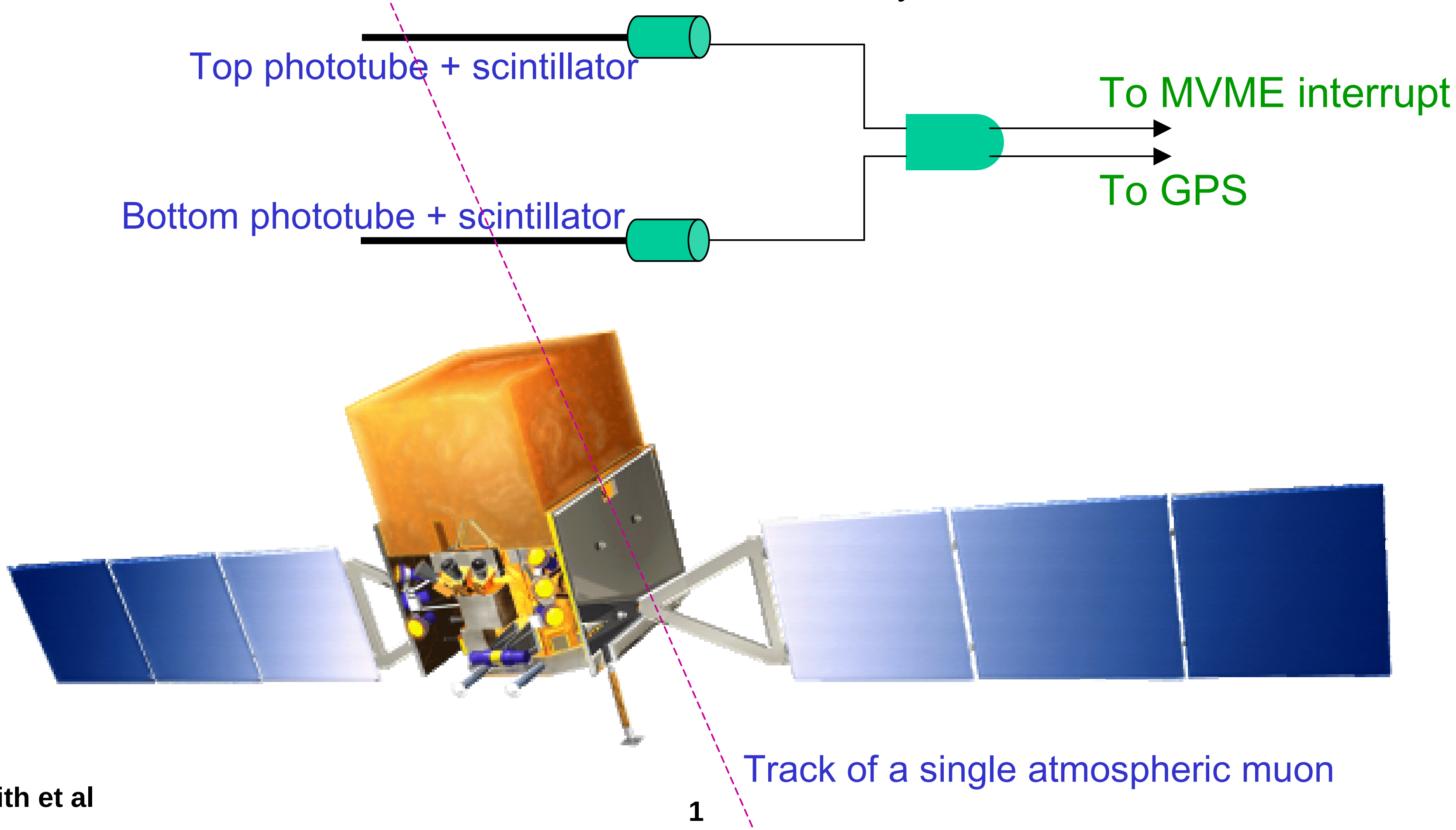
Update of GLAST LAT absolute timestamp end-to-end test

David Smith, Eric Grove, Denis Dumora, Patty Sandora, Eric Siskind
with invaluable support from Anders Borgland and Gregg Thayer.

Calibration & Analysis Face-to-Face, 26 March 2007



Reminder: why, and what

- Accurate measurement of gamma ray arrival times is *essential* for pulsar science.
- Example: PSR J0218+4232 has a rotation period of 2.3 ms.
- Time-stamping is non-trivial: significant problems on major missions.

- Muons allow a simple LAT end-to-end test.
- Bordeaux had the CELESTE VME GPS in the basement…
- …and NRL had a muon telescope from CAL integration.

- Details & trivia at my "blog" https://confluence.slac.stanford.edu/display/CAL/Event+Timestamps

November proof-of-principle (1 of 4)

Written up in LAT-TD-08777-03

- Week of November 16, 2006: Eric, Patty, and I at General Dynamics.
- LAT separate from Spacecraft.
- Use Virtual SpaceCraft (VSC), but without GPS antenna.

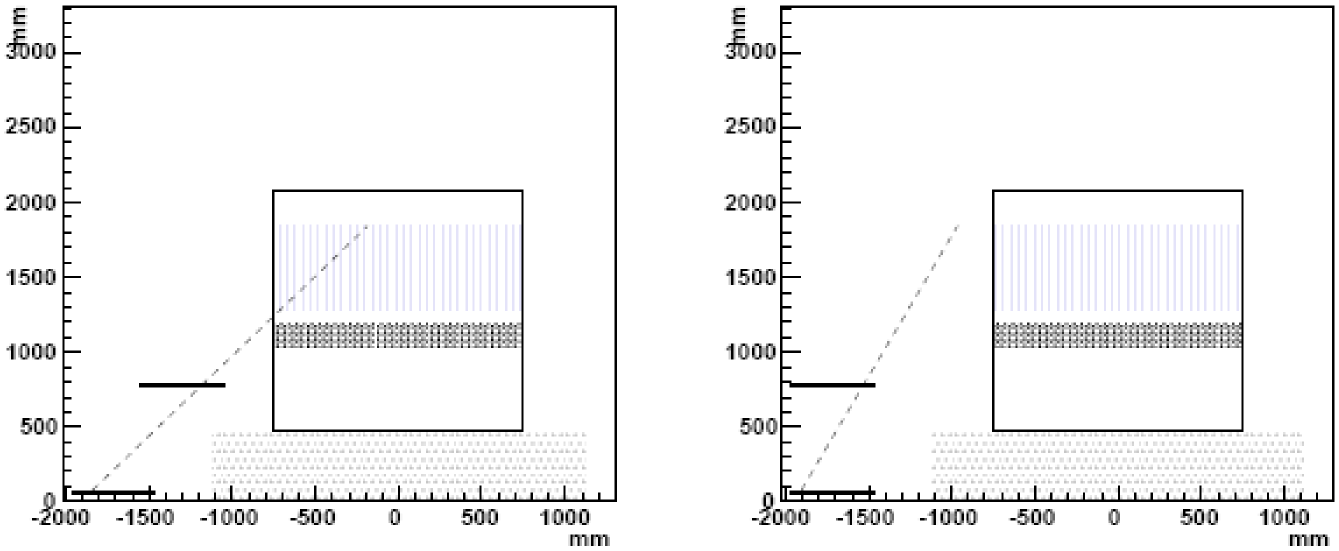


Figure 1: Muon telescope placement. Left: for run 77013003, with the top scintillator unbolted from the stand. Right: for runs '947, '948, '970. No coincidences were observed in data taken in this configuration.

November proof-of-principle (2 of 4)

- Aerial view of LAT and μ telescope.
- Extrapolate TKR tracks to scintillator heights:

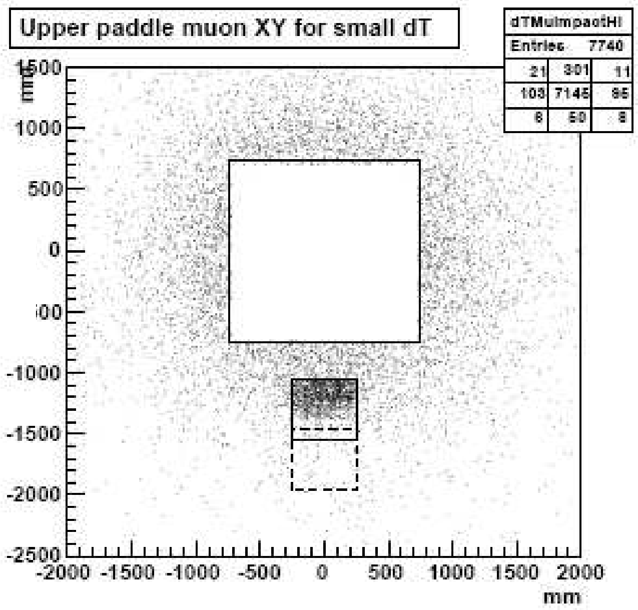
```
XhitHi = Tkr1EndPos[0] + (-Tkr1EndPos[2]+ZPaddleHi)*Tkr1EndDir[0]/Tkr1EndDir[2]
YhitHi = Tkr1EndPos[1] + (-Tkr1EndPos[2]+ZPaddleHi)*Tkr1EndDir[1]/Tkr1EndDir[2]
```

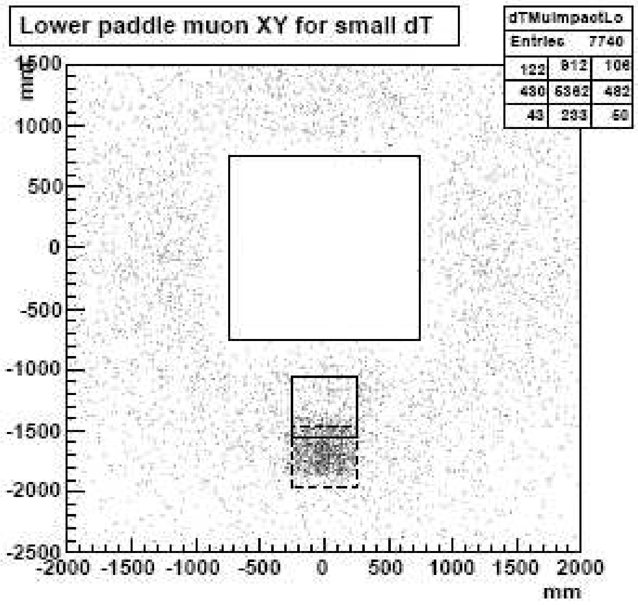
- dT is time difference:

Then, to calculate dT, the time difference between the LAT and standalone GPS times, we

```
Double_t dT =
(double)(SecsBdx[iBdx]-TTCTSecs[iLAT]) + FracBdx[iBdx]-fraction[iLAT] ;
```

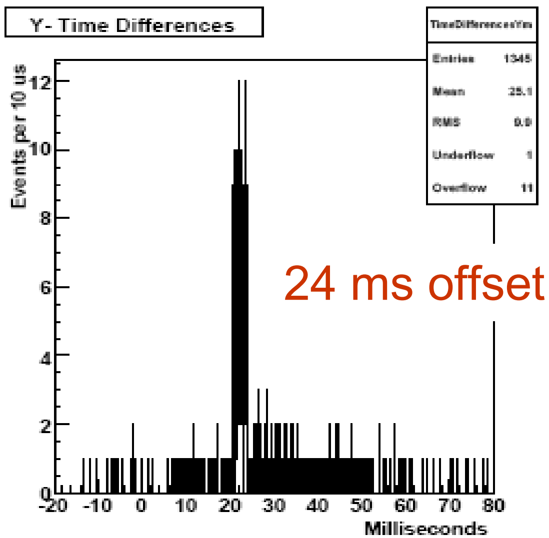
- Look for peak in dT distribution when you select tracks passing through Hi and Lo scintillators (next page).
- Here: Spatial coincidences when selecting small dT's. (a backup slide describes "fraction" calculation)





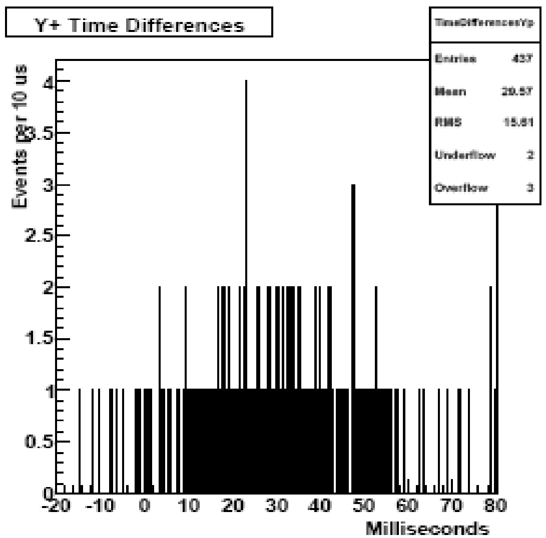
November proof-of-principle (3 of 4)

Side with telescope: signal!

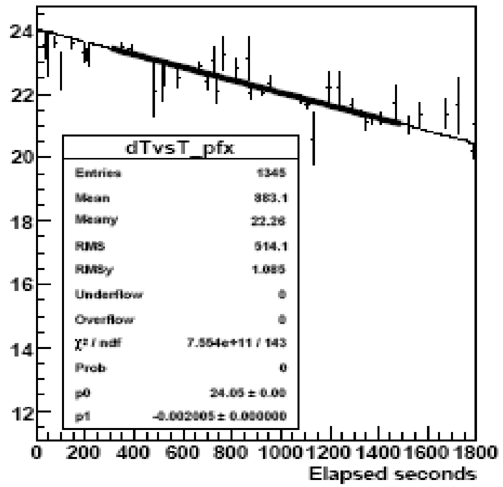


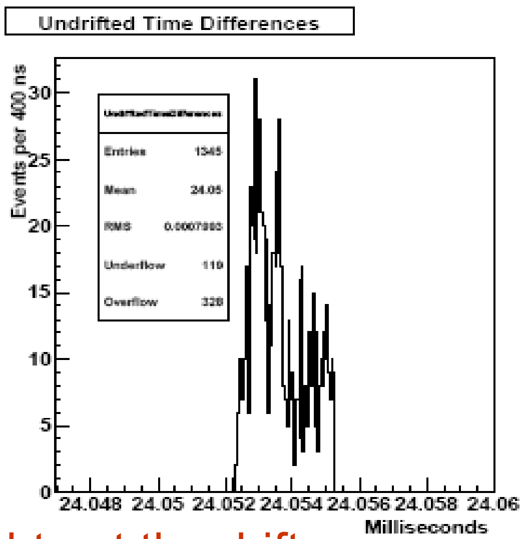
24 ms offset

Other side : accidentals

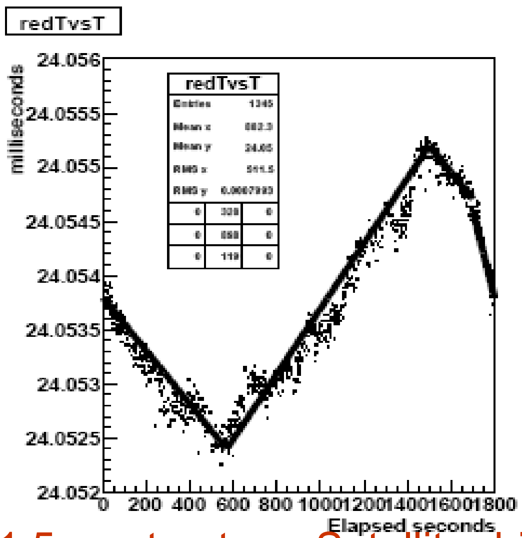


Signal vs time shows drift, 2.009 μs/s

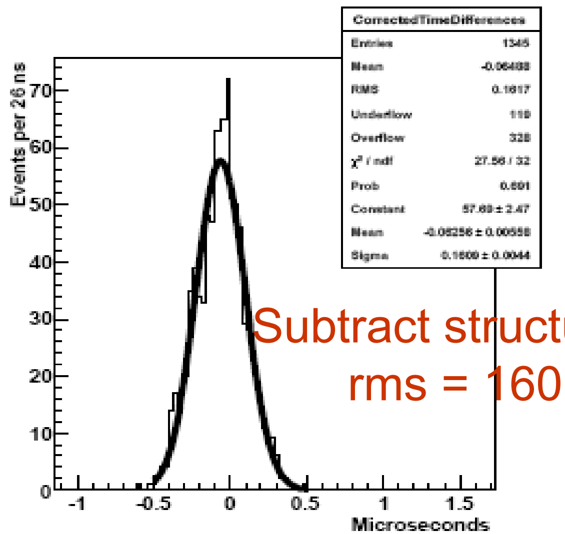




Subtract the drift.



±1.5 μs structure. Satellite drift?



Subtract structure,
rms = 160 ns.

November proof-of-principle (4 of 4)

Written up in LAT-TD-08777-03

- Test scheme works – muons passing through both the LAT and the telescope provide sub-microsecond sensitivity.
- Observed drift and offset consistent with expectations for VSC without GPS satellite lock.
- 6 February 2006: project office at GSFC gives green light for "real" tests.

A First Look at GLAST LAT Absolute Times

Writeup on "blog" page, End2EndFeb07.pdf

- December: LAT integrated with observatory
- mid-February: Flight IEM installed, as well as GPS in C&DH package.

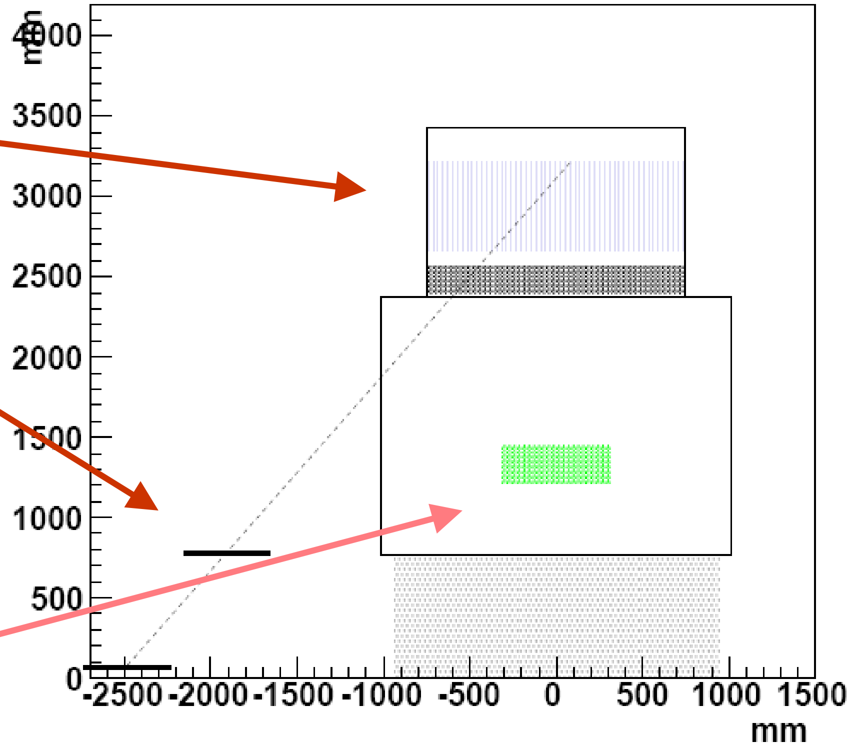
(C&DH = Control & Data Handling)

- Feb 22, 23: Eric & Patty take data in Arizona, Dave analyses in Bordeaux.

LAT on spacecraft, higher off the floor.

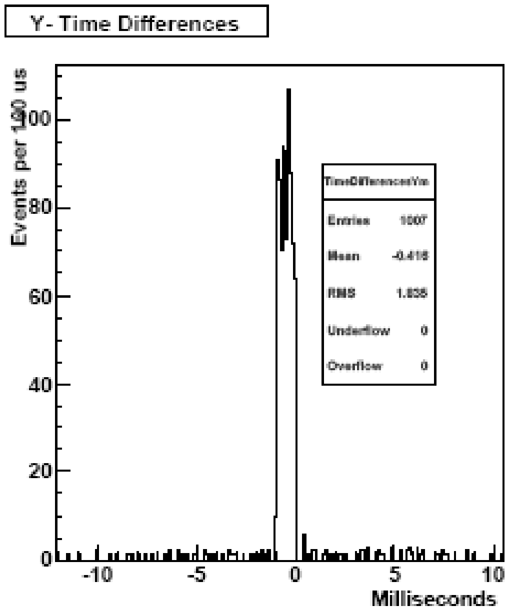
Top paddle cantilevered farther out.

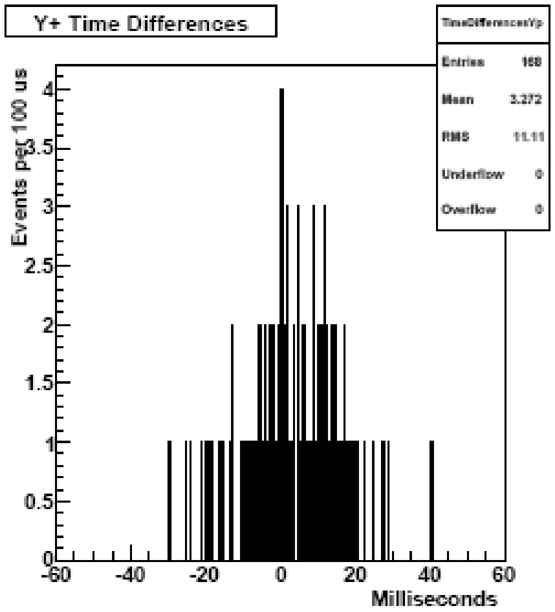
Add GBM geometry, for future use.

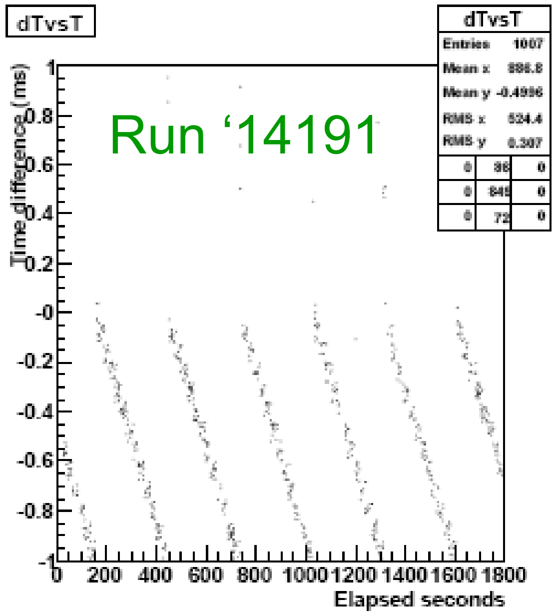


Something is wrong…

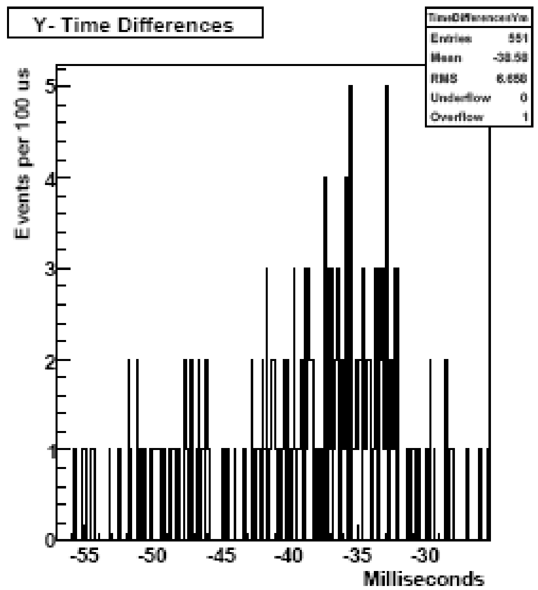
- 8 half-hour muon runs:
  - 4 for satellite side A, LAT config 1, and 4 for side/config B/2.
  - 4 with GPS lock, to test <10 μs absolute time requirement
  - 4 without GPS, to test <0.01 μs/s drift requirement.
- 0>dT>-1 ms sawtooth with ~290 s period during GPS lock runs.
- Need to add 1 second to Bordeaux times to match LAT

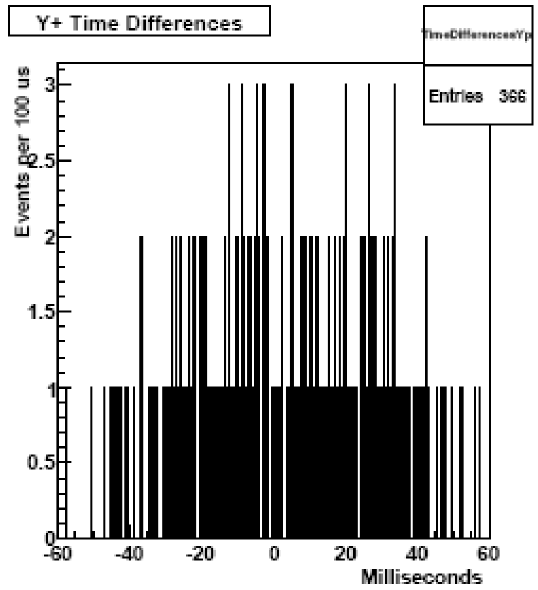


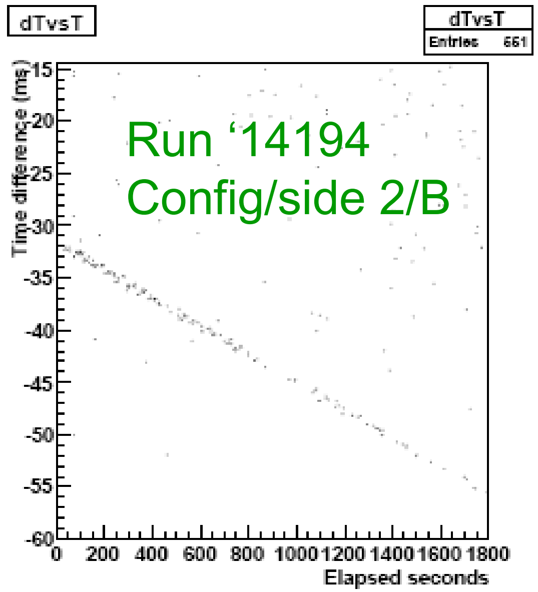


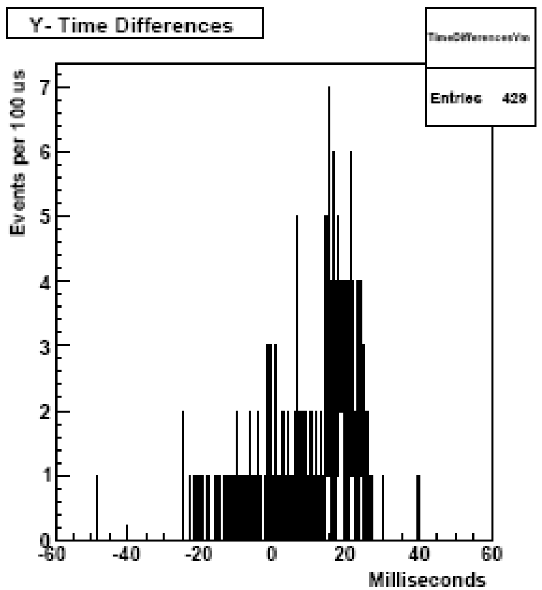


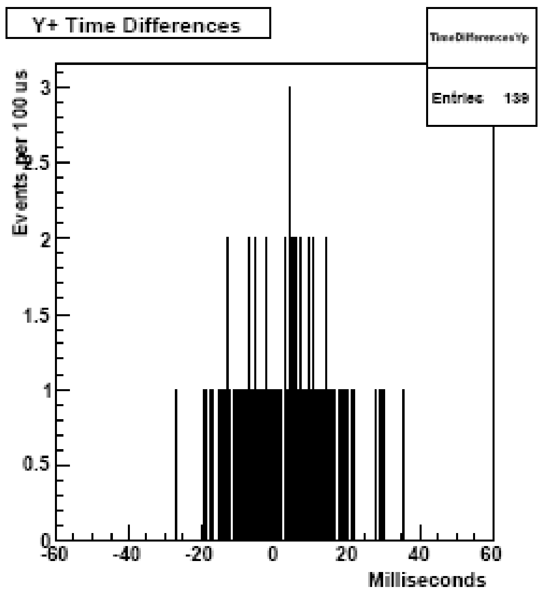
GPS unlock runs : no wrap-around

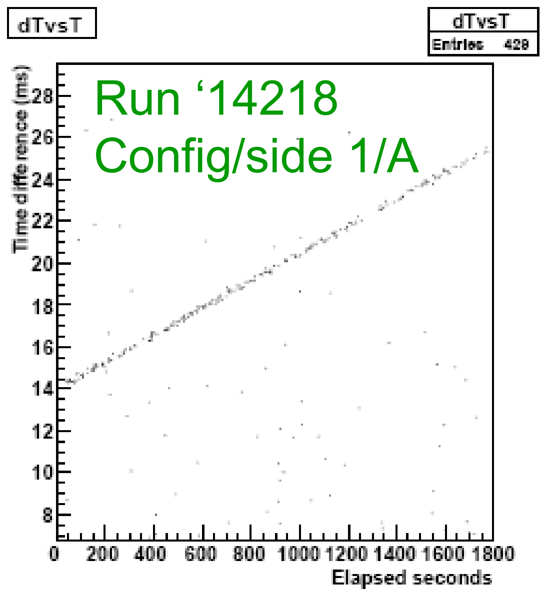












Details…

LAT run	GPS lock?	Config/Side	Diff. from 20 MHz (~ 50 ns ticks)	Observed dT drift	Wraparound?
77014191	Yes	2/B	110	$-3.4\ \mu s/s$	Yes
77014192	Yes	2/B	110	$-3.4\ \mu s/s$	Yes
77014193	No	2/B	306	$-13\ \mu s/s$	No
77014194	No	2/B	306	$-13\ \mu s/s$?	No
77014215	Yes	1/A		$-3.4\ \mu s/s$	Yes
77014216	Yes	1/A	115 to 125	$-3.4\ \mu s/s$	Yes
77014217	No	1/A	-70 to -60	$+7\ \mu s/s$	No
77014218	No	1/A	-60 to -50	$+7\ \mu s/s$	No

Table 1: The 8 data sets acquired February 22 and 23, 2007.

TicksPerSecond = scaler ticks between two successive PPS signals.

dTicks = 20,000,000 – TicksPerSecond

More details…

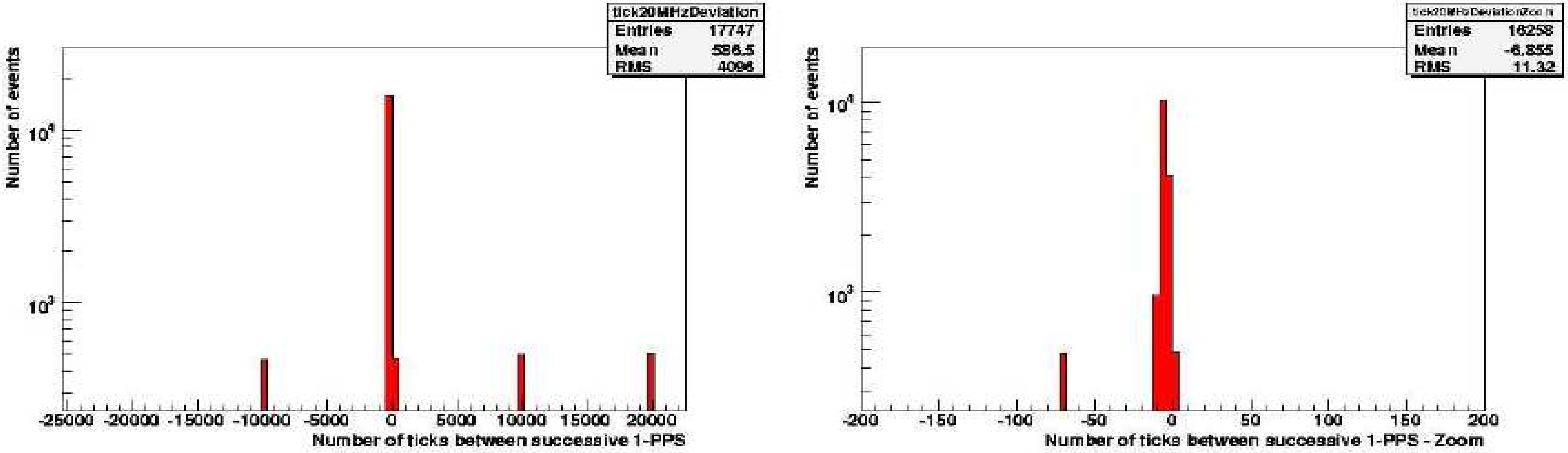


Figure 14: Run 77014210 (same S/C and LAT configuration as 14214, that is, GPS locked. `dTicks`, as in previous figure and text, plotted differently. Left: all events. Right: Zoom on central region. *Credit: A. Borgland*

- At wrap-around during GPS lock runs, dTicks acquires values of +/-10k and +20k ticks, i.e., +/-0.5 ms and +1 ms deviations from PPS.
- The wrap-around process lasts about 3 seconds.

- Anders added the above plots to the pipeline digi report.

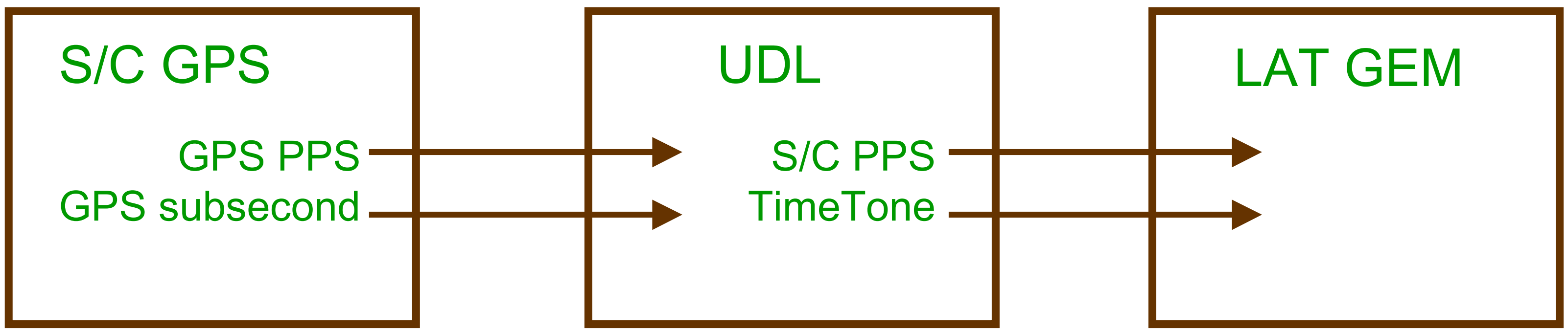
- We have several arguments to say that it is not the Bordeaux GPS system.

Diagnosis (revised)

- Once we trusted our result, we dumped it on E. Siskind, who best knows LAT/GEM/Spacecraft circuitry (circuit diagrams hard to come by…)
- Hypothesis to 'easily' explain the observations: *polarity inversion of the PPS signal between the spacecraft GPS and the UDL board?*

(UDL = Uplink DownLink, pronounced "oodle", as in "oodles of noodles".)

- He's half-right: trouble *is* at GPS⇔UDL level, but more complex than just one signal's polarity.



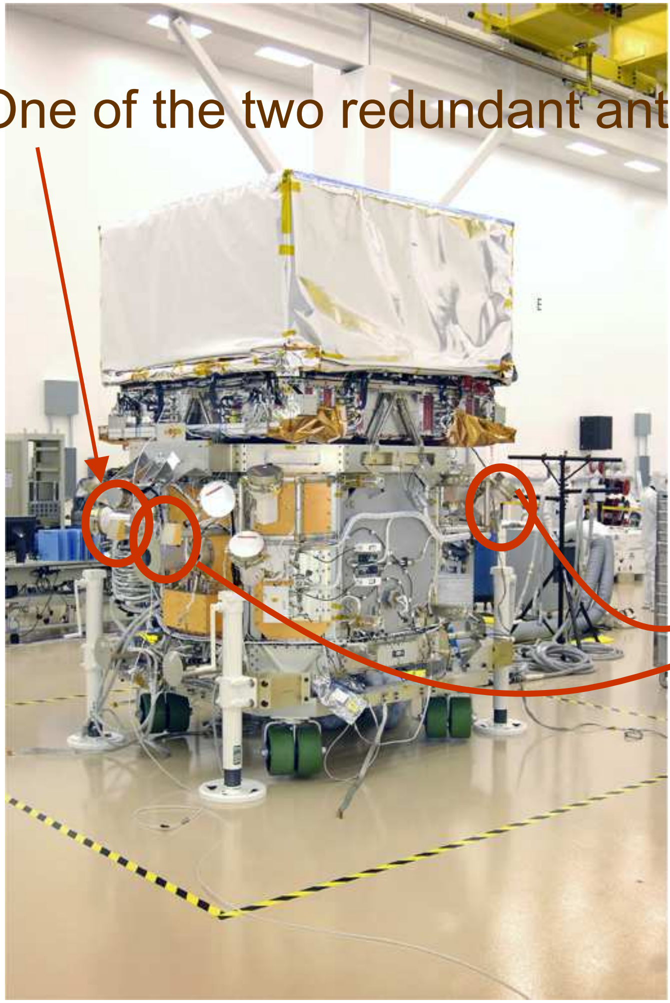
The UDL provides a reliable PPS to LAT & GBM even without GPS lock is lost, by "remembering" the "right" frequency from the previous 100 seconds.

Viceroy™ GPS Spaceborne Receiver

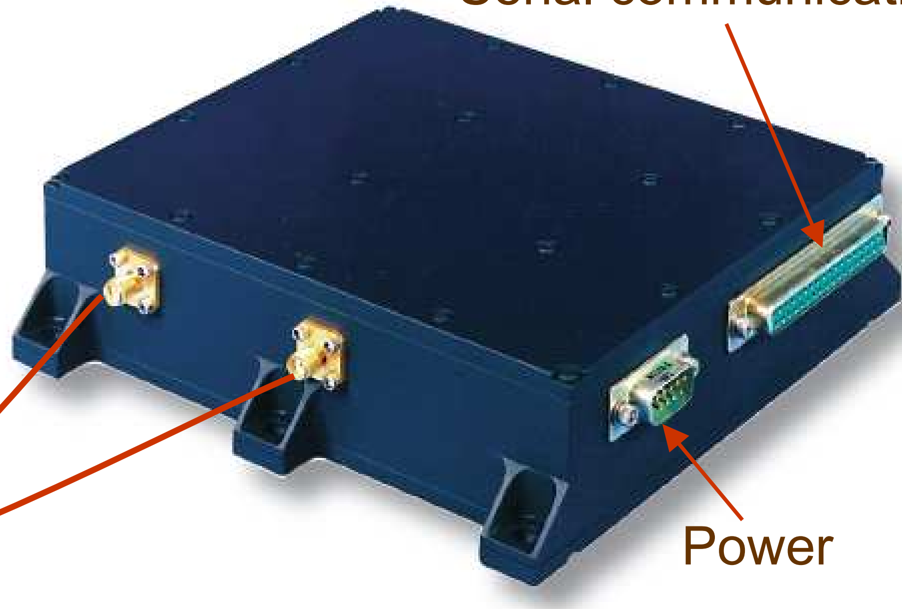
(Two of these on spacecraft.)

standard positioning service in space

One of the two redundant antennae.



Serial communications



Power

One antenna on each side of spacecraft,
to see whole sky, i.e., as many GPS satellites at a time as possible.
Receiver handles them both together.

‘Viceroy’ purchased from Motorola by GD (I was told…)

Prognosis

- GSFC project office very supportive. Telecons with GD engineers (GNC FSW, where GNC = Guidance and Navigation Control).

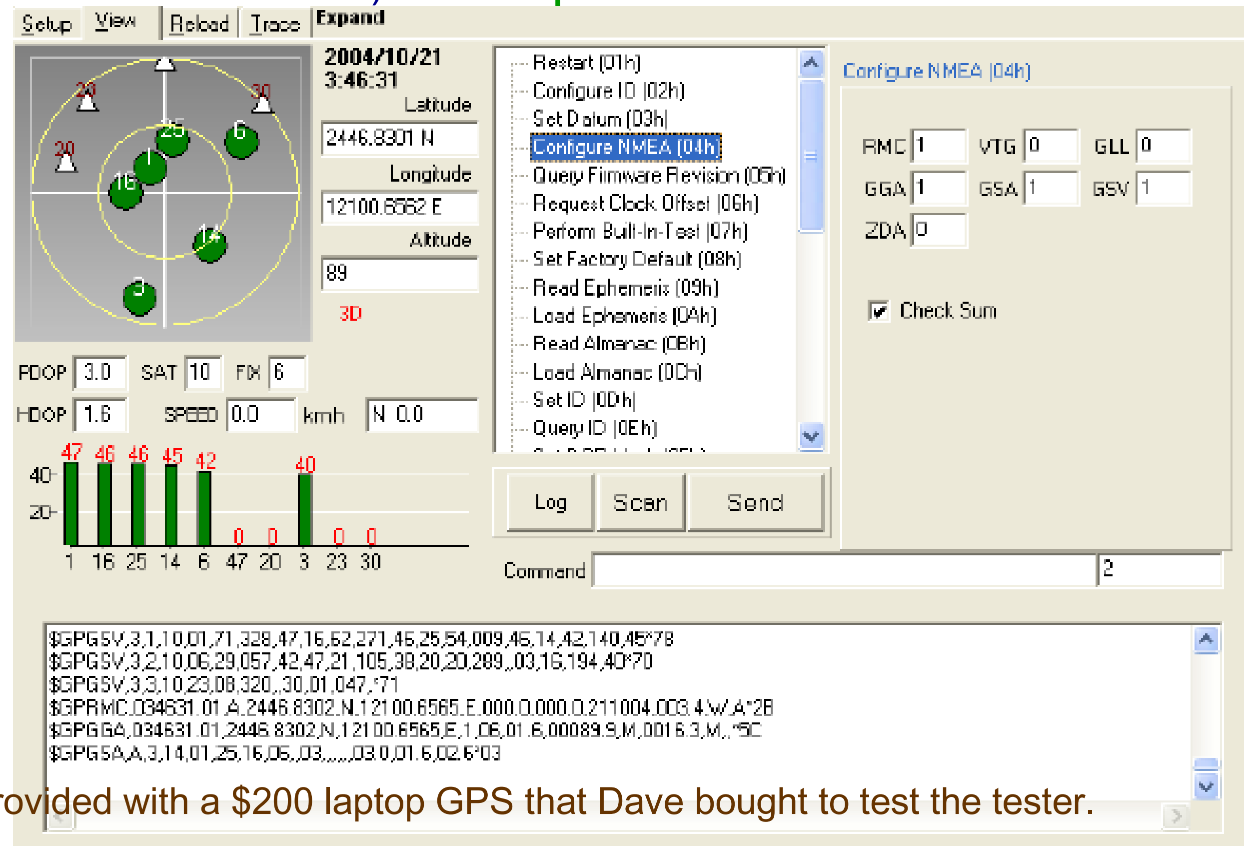
1. Sawtooth with GPS lock: "subseconds" output (a 32-bit integer) from S/C GPS shows the 1ms sawtooth. If set to zero in S/C FSW then "should work". GD-Spectrum asking GD-Viceroy about init/config.
2. Ramp without wrap-around when no GPS lock: UDL FSW averages PPS's over preceding 100 seconds, to give good PPS when GPS fix lost. Lock problem thus propagated to un-lock mode.
3. 1 second offset from UTC: Spacecraft epoch ("MET") is set to ground PC NTP server time, not to GPS UTC. Estimate of time-to-set can be off by an integer step. Looking into a CCSDC compliant method change.

- S/C GNC mentioned new tests & verifications at their end (I don't know what they are yet).
- They will request us to repeat the measurements. And again, after the last S/C FSW build.

Monitoring?

- We're thinking about what, if any, additional info we want in the data streams to diagnose on-orbit timing, should the need arise.
- GPS standard output includes theoretical precision for a given satellite configuration ("HDOP"=Horizontal Geometric Dilution of Precision) (Figure shows a 6-satellite fix, for 10 satellites above the horizon). Perhaps don't want all that…
- Presently exploring:

1. Exact flag meanings
2. Datagram contents



Software provided with a $200 laptop GPS that Dave bought to test the tester.

an example of why to trust Bordeaux times

- RF solutions LS-40EVALR1, 168 euros.
- Use PPS output to trigger VME GPS “time capture”
- 50ks run (overnight)
- ± 0.5 µs dispersion.
- 500 ns offset due to cable run of one antenna.
- Lost satellite fix during 4% of the run.

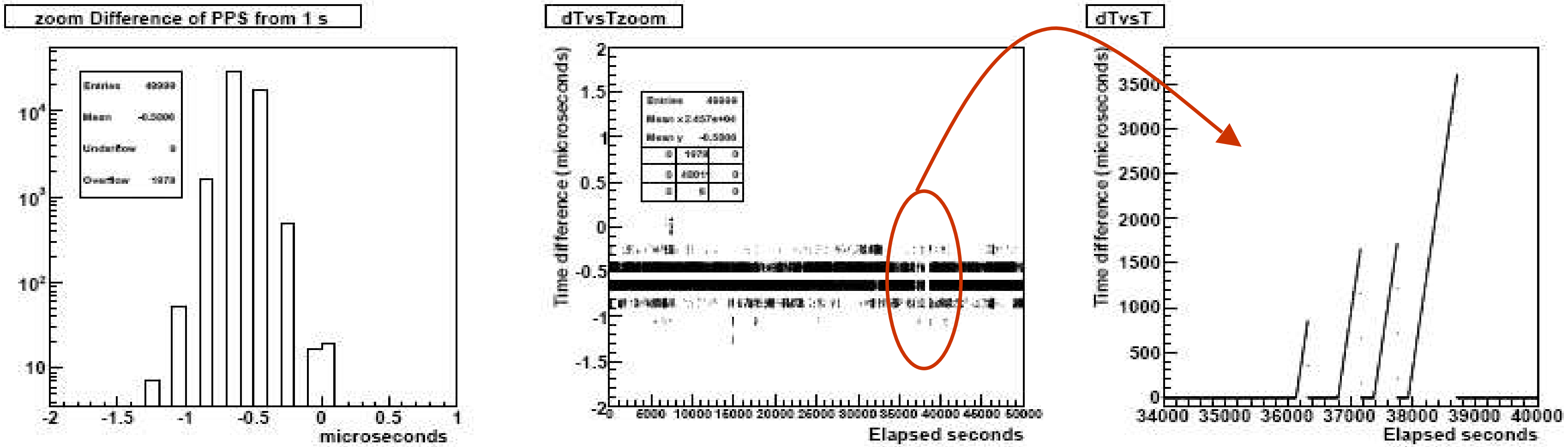


Figure 17: The deviation of the Symmetricom VME GPS times from an integer number of seconds, when the VME “time capture” is triggered by the PPS output of the *RF Solutions* GPS. Left: Histogram of values. The mean of -580 ns is roughly consistent with the cable run of the Trimble antenna used for the Symmetricom. The dispersion is better than the ±1 μs claimed by *RF Solutions*. Middle: Values versus elapsed time. It appears that satellite lock was lost briefly after 12k seconds, and again between 36k and 39k seconds. Right: Zoom on the long GPS-unlock period.

Digression: Merit Tuple & FITS files

- Not-so-long ago, Anders added GEM-based times to the MeritTuple.
- Thierry: MakeFT1 to get FITS file read by Science Tools.
- Sawtooth there – times correct – one step closer to pulsars.

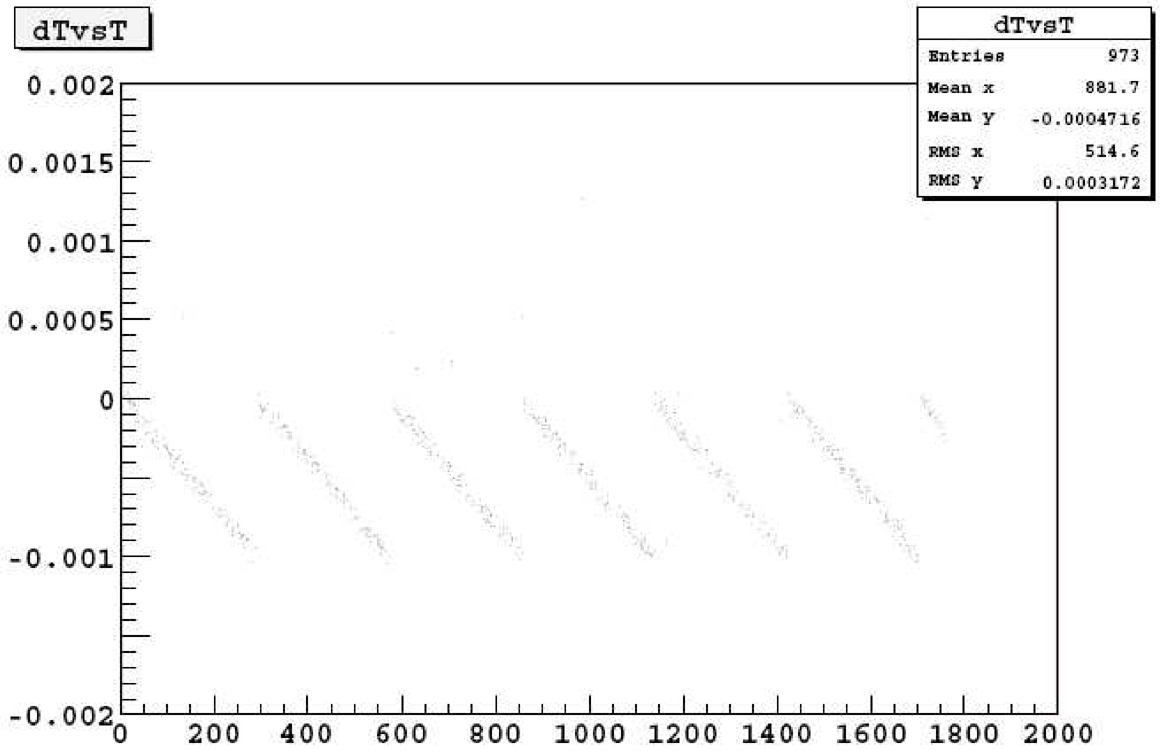


Figure 18: Same sawtooth from run 14215, but made with the dates from the Science Tools FITS file, derived from the MeritTuple root file. Anders Borgland calculates the MeritTuple times, and Thierry Reposeur made this plot.

Conclusions

- Time test method is simple and effective.
- Turned out to be more necessary than anticipated.
- Significant problems being carefully addressed.

What, me worry?

Backup slide

the time calculation

page 4 of End2EndFeb07.pdf

very similar to what Anders put into the MeritTuple

Here follows the algorithm used to convert the LAT variables obtained from the root SvacTuple into MET times. The "Context" (and all other) variables in the SvacTuple are described in Anders' documentation,

ftp://ftp-glast.slac.stanford.edu/glast.u33/u01/svac_workshop/Svac_ntuple_description/new/html/inde

The quite long variable names have been abbreviated. For example, ContextLsfTimeTimeToneCurrentGemTimeTicks becomes TTCGemTimeTicks and, similarly, ContextLsfTimeTimeTonePrevious becomes TTP. The algorithm is then

```
// Rollover offset for the 25 bits GEM counter:
double RollOver = 33554432.0;

TicksPerSecond[iLAT] = TTCGemTimeTicks[iLAT] - TTPGemTimeTicks[iLAT];
if (TTCGemTimeTicks[iLAT] < TTPGemTimeTicks[iLAT])
TicksPerSecond[iLAT] += RollOver;

EvtTicksSincePPS[iLAT] = TimeTicks[iLAT] - TTCGemTimeTicks[iLAT];
if (TimeTicks[iLAT] < TTCGemTimeTicks[iLAT])
EvtTicksSincePPS[iLAT] += RollOver;

fraction[iLAT] =
((double)EvtTicksSincePPS[iLAT]) / ((double) TicksPerSecond[iLAT]) ;
```

Then, to calculate dT, the time difference between the LAT and standalone GPS times, we use

```
Double_t dT =
(double)(SecsBdx[iBdx]-TTCTSecs[iLAT]) + FracBdx[iBdx]-fraction[iLAT] ;
```

where Bdx is short for Bordeaux, the home of the standalone GPS. Time coincidences were