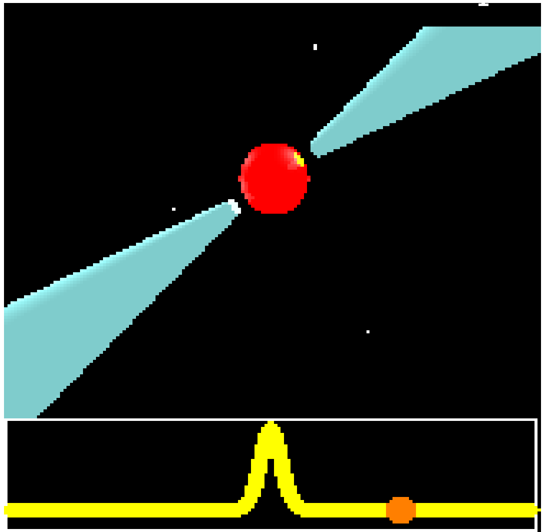
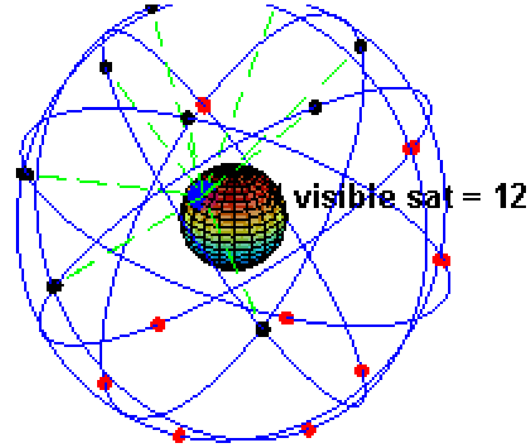
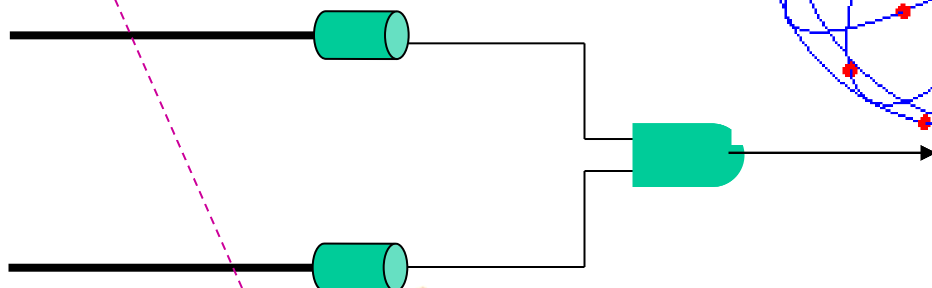
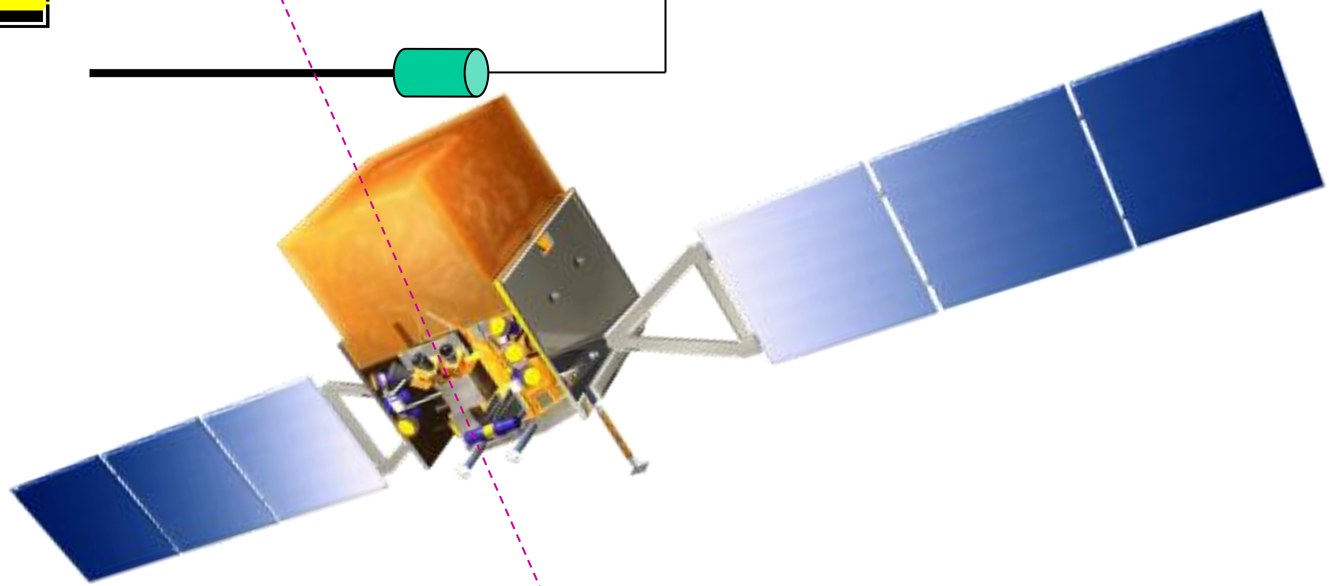
Pulsar Timing for a Balloon-borne TPC









David A. Smith, CEN de Bordeaux-Gradignan
14 avril 2017

an atmospheric muon

Conclusions

- Recording accurate event times and instrument positions isn't as easy as you may think.
- Many major missions goofed.
- Studying gamma polarization as a function of pulsar rotational phase requires forethought and testing.

This talk:

- Required time (and position) accuracy
- Problems on previous missions.
- *Fermi* LAT end-to-end test: bug found & fixed.
- A glimpse at GPS receivers.

FERMI-LAT OBSERVATIONS OF THE CRAB PULSAR AND NEBULA

THE ASTROPHYSICAL JOURNAL, 708:1254–1267, 2010 January 10

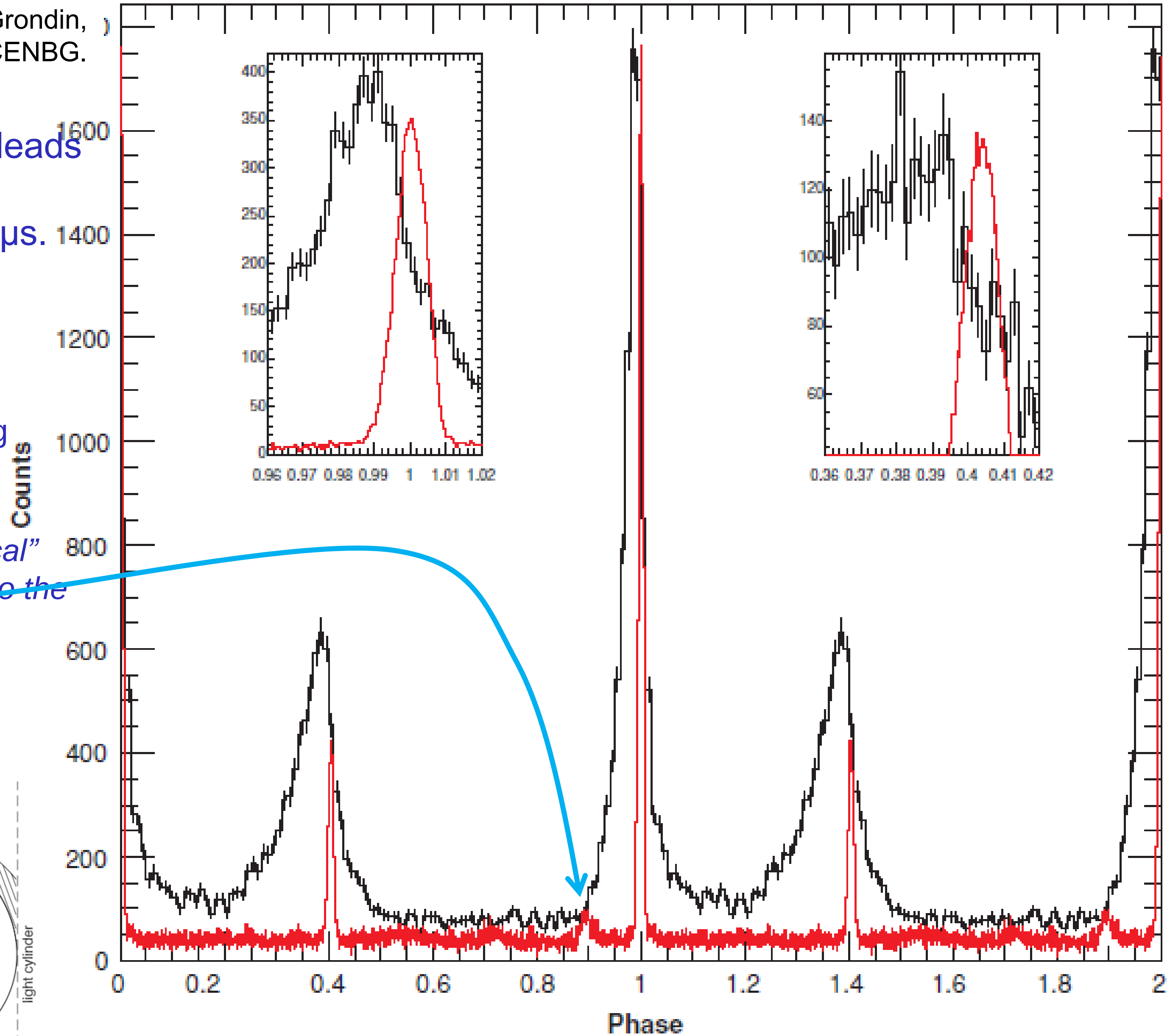
M. Lemoine-Goumard, M-H Grondin,
CENBG.

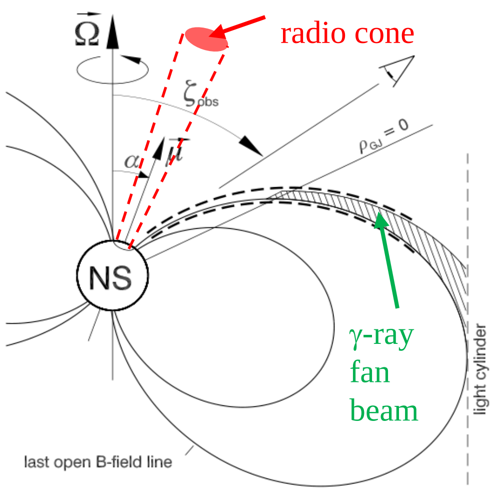
The main gamma peak leads the main radio pulse by
δ = ~~280~~ 138* ± 12 ± 12 μs.

$\delta/P0$ = 0.138 ms/33 ms
= 0.0044 in phase.

0.1 < δ < 0.3 for most young pulsars.

(The little blip is the "classical" radio peak, corresponding to the magnetic axis.)





* Erratum posted at http://fermi.gsfc.nasa.gov/ssc/data/access/lat/ephems/

THE ASTROPHYSICAL JOURNAL, 744:33 (13pp), 2012 January 1 L. Guillemot, ex-CENBG, now Nançay.

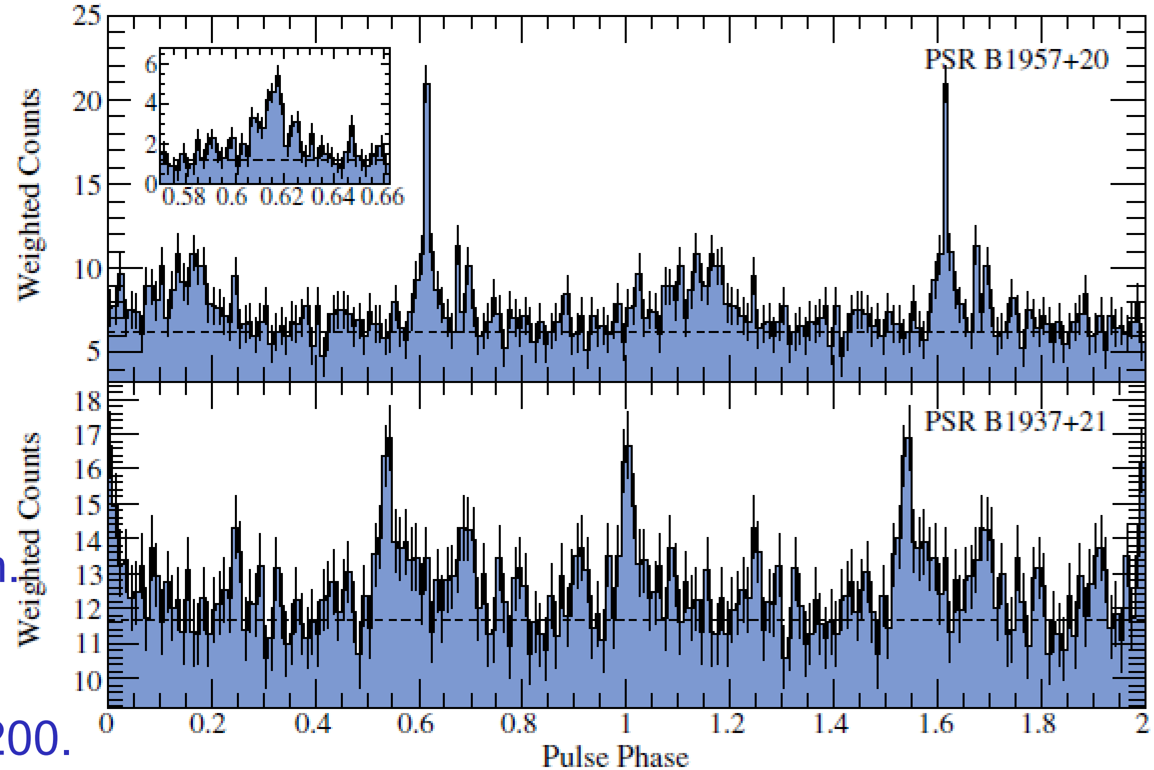
B1957 (= J1959+2048):
First known "black widow" MSP.

B1937 (= J1939+2134) :
First MSP discovered.

Both remain among the fastest:
P0 ≈1.6 ms.

0.014 * 1.6 ms = 22 μs peak width.

Photon fluxes >100 MeV ≈ Crab/200.



Parameter	PSR B1937+21	PSR B1957+20
First peak position, Φ_1	0.004 ± 0.009	0.146 ± 0.026
First peak full width at half-maximum, $FWHM_1$	0.030 ± 0.029	0.137 ± 0.074
First peak radio-to-gamma-ray lag, δ_1	-0.010 ± 0.009	-0.016 ± 0.026
Second peak position, Φ_2	0.543 ± 0.013	0.616 ± 0.002
Second peak full width at half-maximum, $FWHM_2$	0.041 ± 0.041	0.014 ± 0.007
Second peak radio-to-gamma-ray lag, δ_2	0.006 ± 0.013	0.012 ± 0.002

Fermi LAT timing precision

- NASA requirement: δt_i <10 μs absolute time accuracy per event.
- LAT collaboration goal: < 2 μs.
- We achieved <1 μs (and possibly <100 ns).
- 100 us would probably be fine for the TPC's balloon flights…

- Position localization accuracy: Simply $c\delta t_i$ *(but in 3-D)*.

Example: 3e8 * 1e-6 = 300 m.

Timing failures on 6 missions (1 of 2)

USA (X-rays): The GPS often froze on orbit and had to be reset a few times a day. The satellite would go through GPS beams intense enough to confuse the receivers. Also, the speed of the satellite relative to GPS's was far from the design-regime for ground-based GPS's.

XMM: Two years elapsed before absolute phases were reliable, after a series of 5 different kinds of electronics problems. Proc. SPIE 5165, 85-95 (2004).

INTEGRAL: Orbital inaccuracies due to ground software caused 300 us problems.

CHANDRA: For the HRC, the time stamp of a given event was that of the previous event. On-board filters remove events, so obtaining the right date for a given event was impossible. The solution is to trigger only on the central CCD chip, to reduce the event rate, to allow sending all events to the ground (“timing mode”).

S. Murray et al, ApJ 568:226-231 (2002) and references therein.

Timing failures on 6 missions (2 of 2)

Compton GRO: In the days before GPS. Events were assembled into packets on board, and the packets were grouped into a "major packet", to which a time stamp was afixed. These packets were sent to the ground. But the time stamp was from the preceding packet! And the time was off by over a second.

ROSAT: Excerpt from http://www.mporzio.astro.it/~gianluca/phdthesis/node28.html :
"A problem was…found…timing individual events, due to…software (Briel *et al.* 1994). The origin…was the spacecraft clock reset which followed the spacecraft tumbling incident of 1991 Jan. 25. All PSPC data after that time are affected. The problem leads to relative shift of 1s between adjacent PSPC events."

Never quite the same problem twice…
GPS issues seem *easily avoidable today, not the others…*
The above problems were either large (100's and 1000's of μs) or fatal.

I spent 2004-2005 at Stanford working on LAT "I&T"*, mostly watching muons go through the calorimeter (="CAL").

I realized there was no plan to test timing, and that the system is complex.

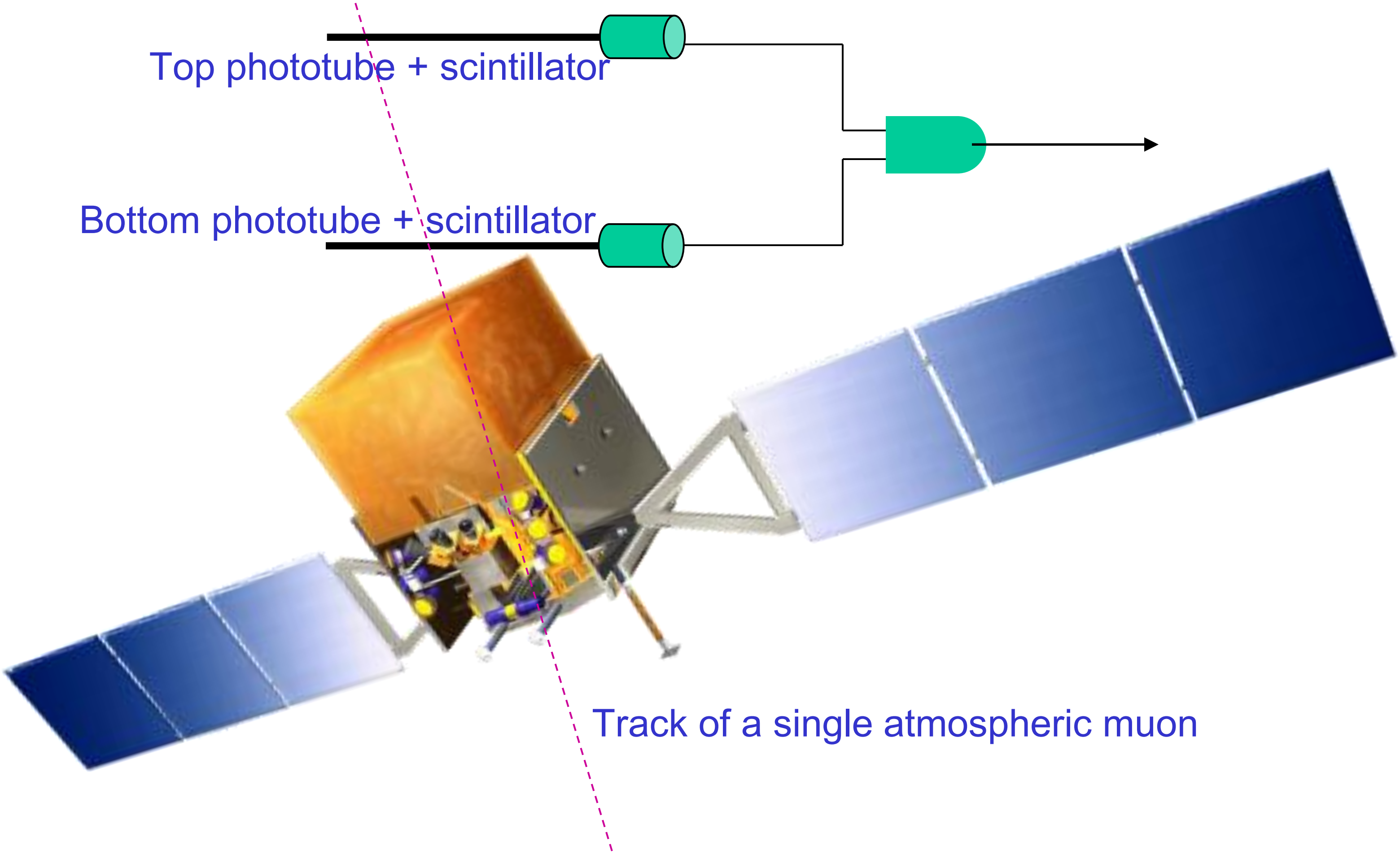
I learned about the previous mission failures.

I proposed a simple test.

* "I&T" = Integration & Test.

GLAST LAT absolute timestamp end-to-end test

David Smith, Eric Grove, Denis Dumora,
with invaluable support from Neil Johnson & Dave Thompson.

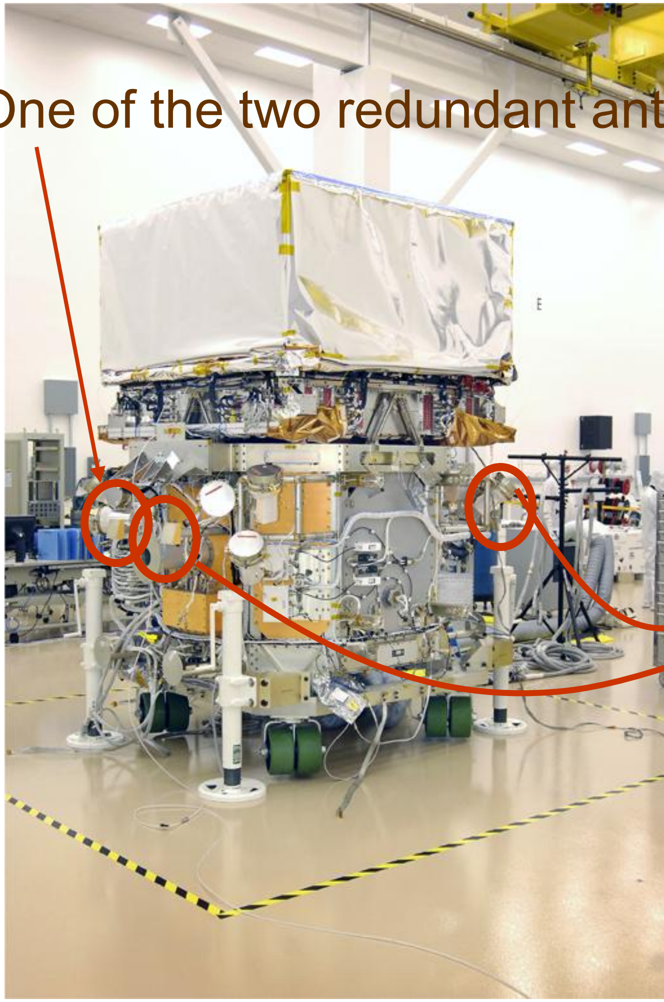


Viceroy™ GPS Spaceborne Receiver

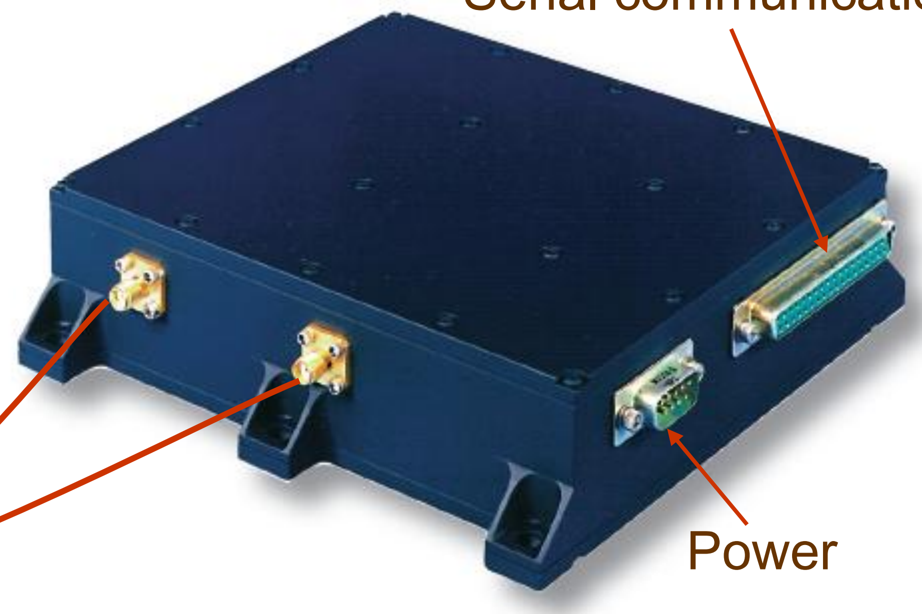
(Two GPS units on spacecraft, here at GD's "*Factory of the Future*" in Arizona.)

standard positioning service in space

One of the two redundant antennae.



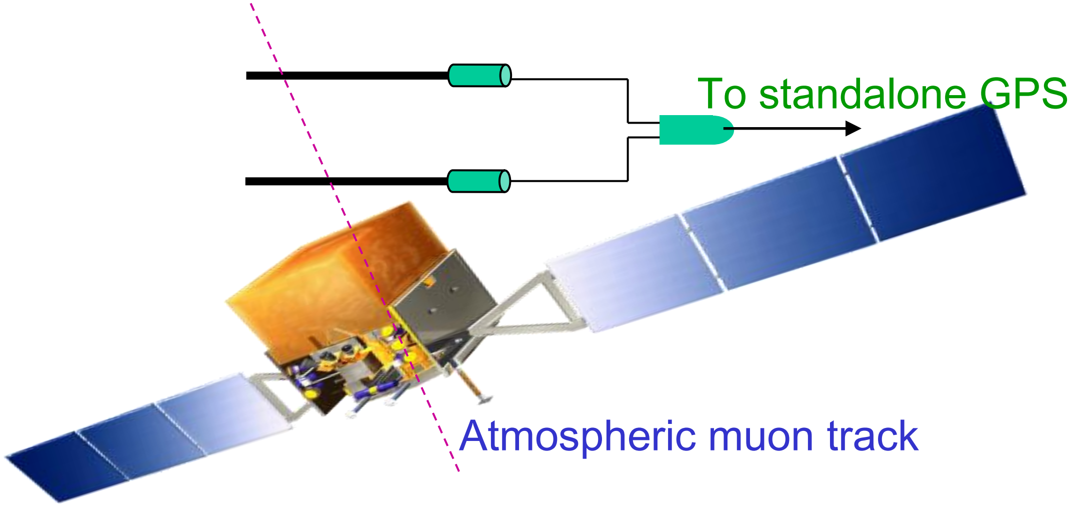
Serial communications



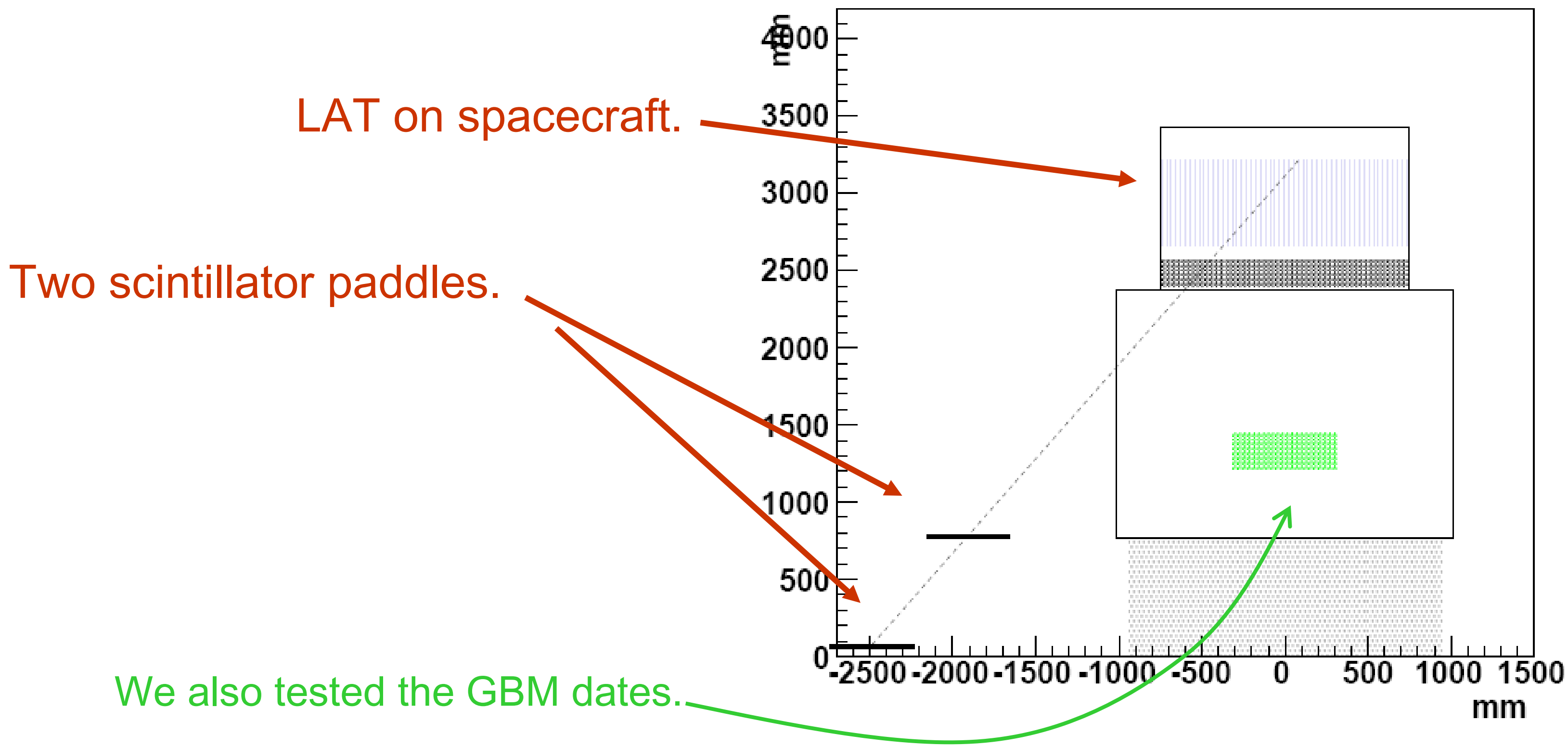
Power

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.

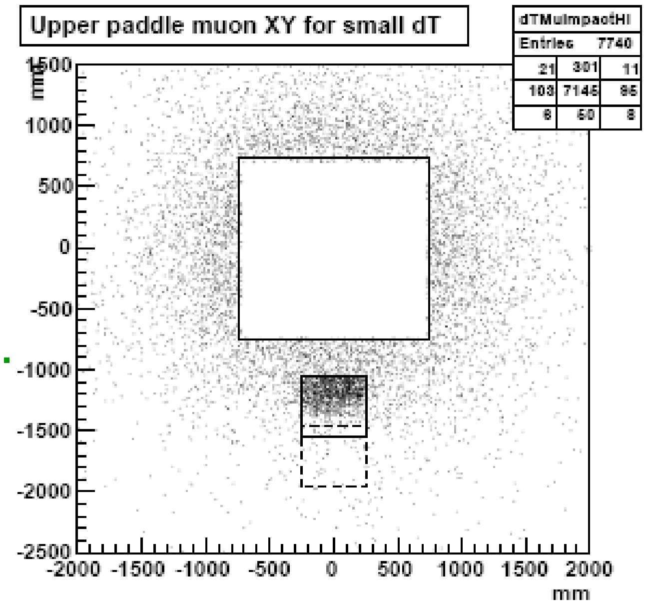
'Viceroy' purchased from Motorola by GD (I was told…)

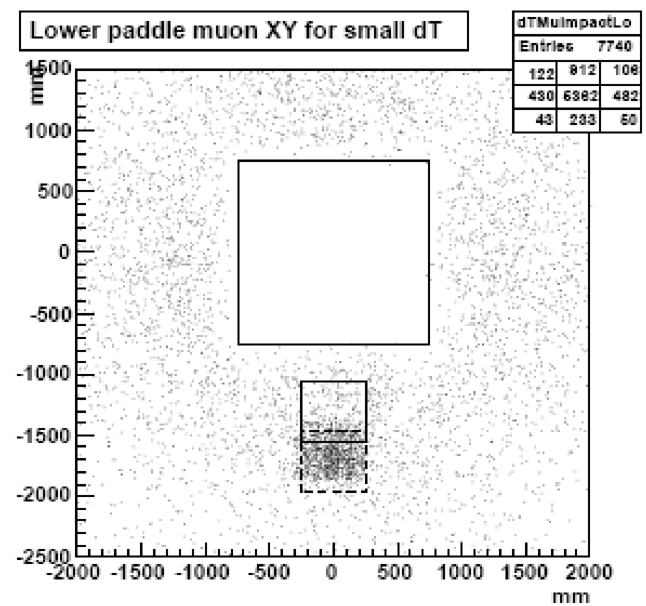


- We went to Arizona.
- We put the scintillators from CAL tests next to GLAST.
- The triggerable GPS module from CAT & CELESTE interrupted the VME readout.
- Muons hit LAT and us within ns's.
- Compared dates offline.



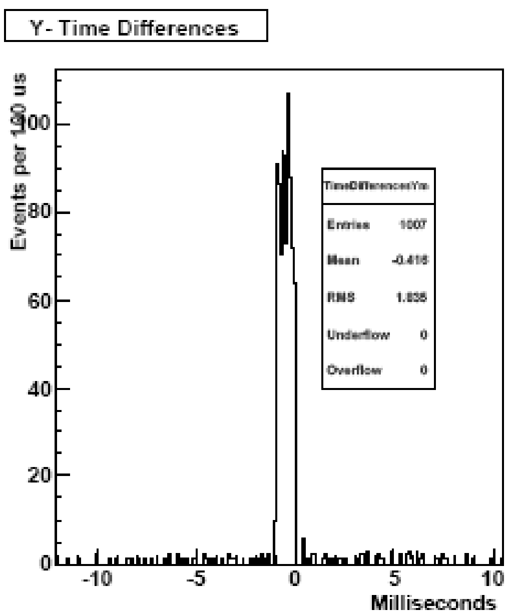
- Aerial view of LAT and μ telescope.
- Extrapolate TKR tracks to scintillator heights.
- For small GPS vs LAT time differences, the paddles appear.

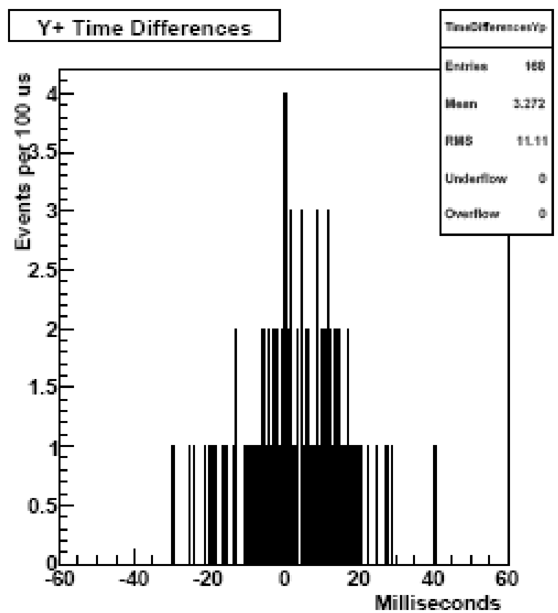


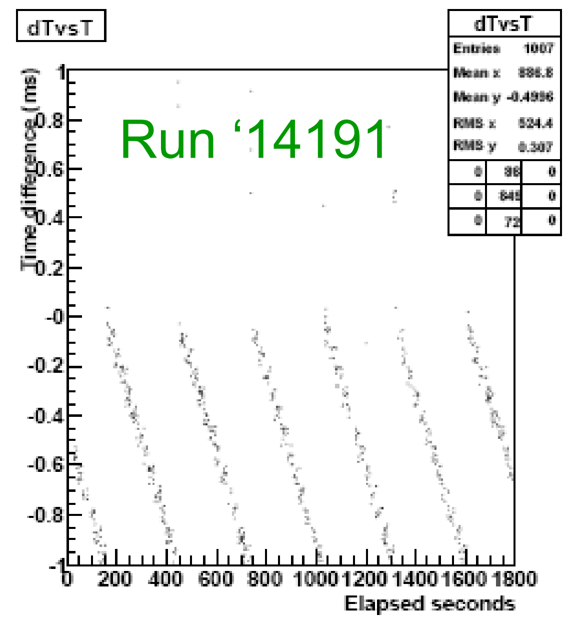


Something is wrong…

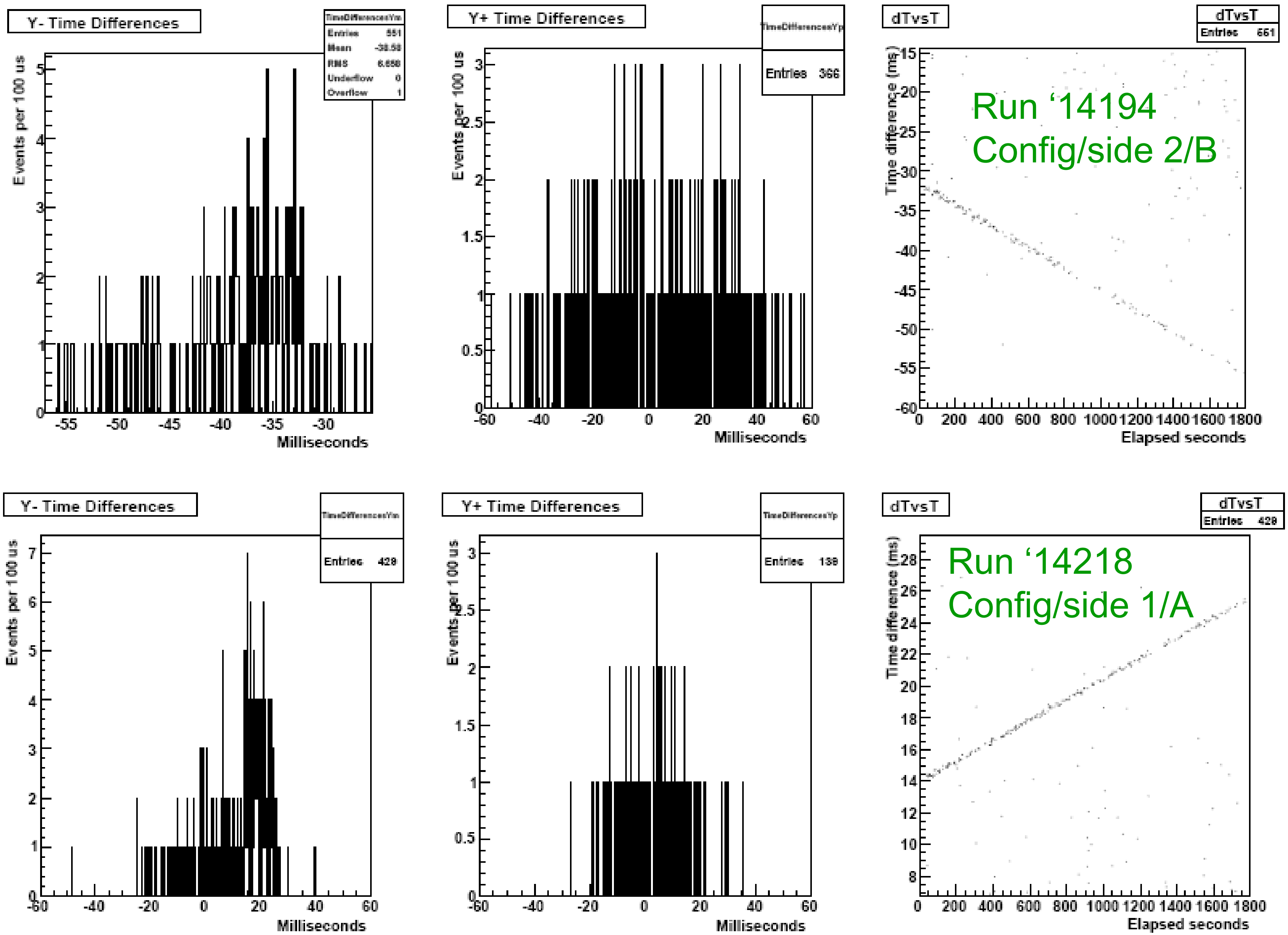
- 8 half-hour muon runs:
  - 4 for satellite side A, LAT config 1, and 4 for side/config B/2.
  - 4 with GPS lock, to test <10 μs absolute time requirement
  - 4 without GPS, to test <0.01 μs/s drift requirement.
- 0>dT>-1 ms sawtooth with ~290 s period during GPS lock runs.
- Need to add 1 second to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







GPS unlock runs : no wrap-around



Prognosis

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

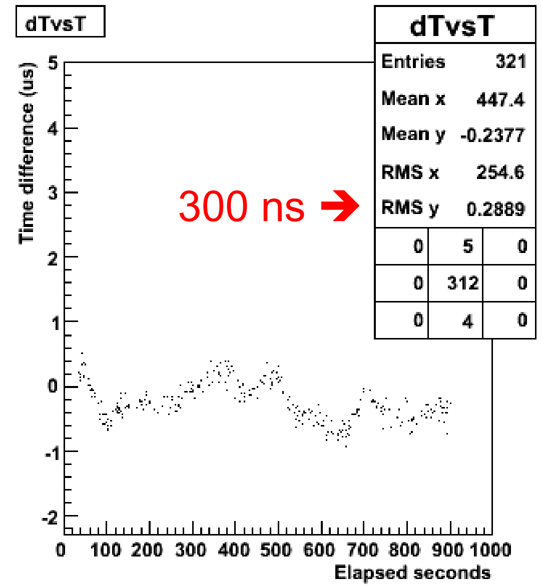
1. Sawtooth with GPS lock: "subseconds" output (a 32-bit integer) from S/C GPS shows the 1ms sawtooth. If set to zero in S/C FSW then "should work". Should *not* have been wired to input.
2. Ramp without wrap-around when no GPS lock: UDL FSW averages PPS's over preceding 100 seconds, to give good PPS 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 had us repeat the measurements once all the fixes were made, which took *months*.

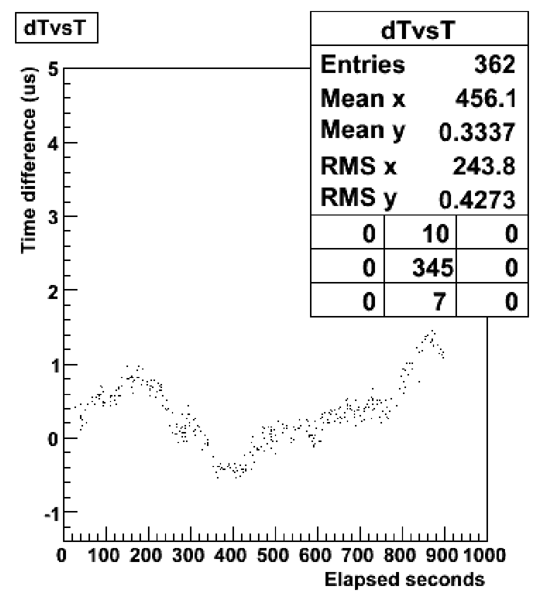
Eric Grove report to Collaboration, 7 months before launch.

Verification of Absolute Time Accuracy

- **SC PPS meets spec with and without GPS sync**
  - **July/Aug and Oct 07 retest demonstrate that SC FSW bug is fixed**
    - **With GPS sync, SC PPS is in phase with GPS PPS**
      - **See upper panel**
    - **Without GPS sync, SC PPS drift rate ~10x better than spec**
      - **See lower panel**



- **Getting the integer seconds right…**
  - **Our tests amply demonstrate that SC PPS will have correct subseconds**
  - **Integer seconds are set by procedure at SC power-up**
    - **Recall that SC time is seconds since reference epoch**
    - **LAT, GD, and GPO are working together on power-up procedure**



For the record:

L. Guillemot thesis, pages 77-78.

http://adsabs.harvard.edu/abs/2009arXiv0910.4707G

The on-orbit calibration of the Fermi Large Area Telescope

Abdo, A. A. et al. 2009, Astropart. Phys., 32, 193

http://adsabs.harvard.edu/abs/2009APh....32..193A (p.212)

Beyond the scope of this talk (rotation ephemerides, software tests).

Pulsar Timing for the Fermi Large Area Telescope

Smith, D. A. et al. 2008, A&A, 492, 923

http://adsabs.harvard.edu/abs/2008A&A...492..923S

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1	quantity
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$67.46	25+ units
$63.71	100+ units

Eric G now flies gamma detectors in U2 "spy" planes to study thunderstorms.

He says this unit works well.

(U2's have antennas on roof, and connectors inside.)

Trimble is a historical leader in the field…

Works above 40,000 feet.

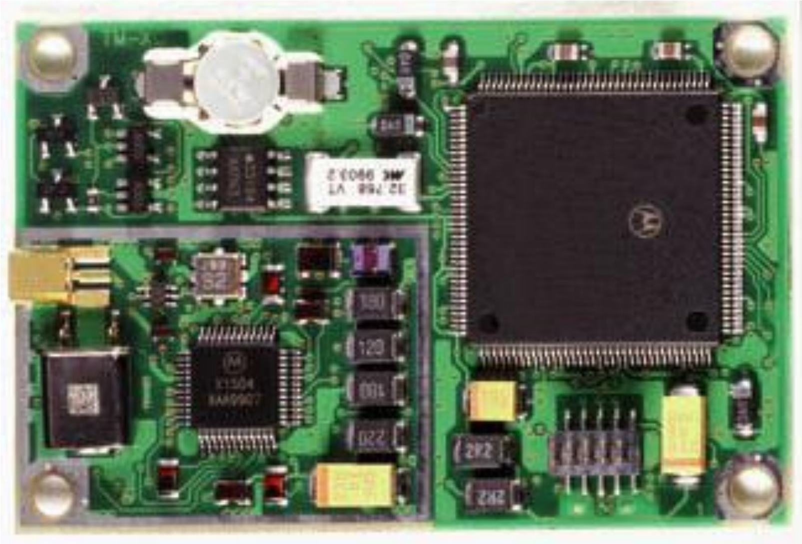
Not triggerable, but we don't care.

"The GPS for the first flight of EUSO-Balloon is the Motorola Oncore M12.

For EUSO-SPB we are using differential GPS." *–Simon Bacholle.*

Oncore M12 ↓ Old! Circa 1999.

Nota bene: some GPS's disabled above ~40,000 feet.



Conclusions

- Recording accurate event times and instrument positions isn't as easy as you may think.
- Many major missions goofed.
- Studying gamma polarization as a function of pulsar rotational phase requires forethought and testing.

What, me worry?

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)
- $\pm$ 0.5 μs dispersion.
- 500 ns offset due to cable run of one antenna.
- Lost satellite fix during 4% of the run.

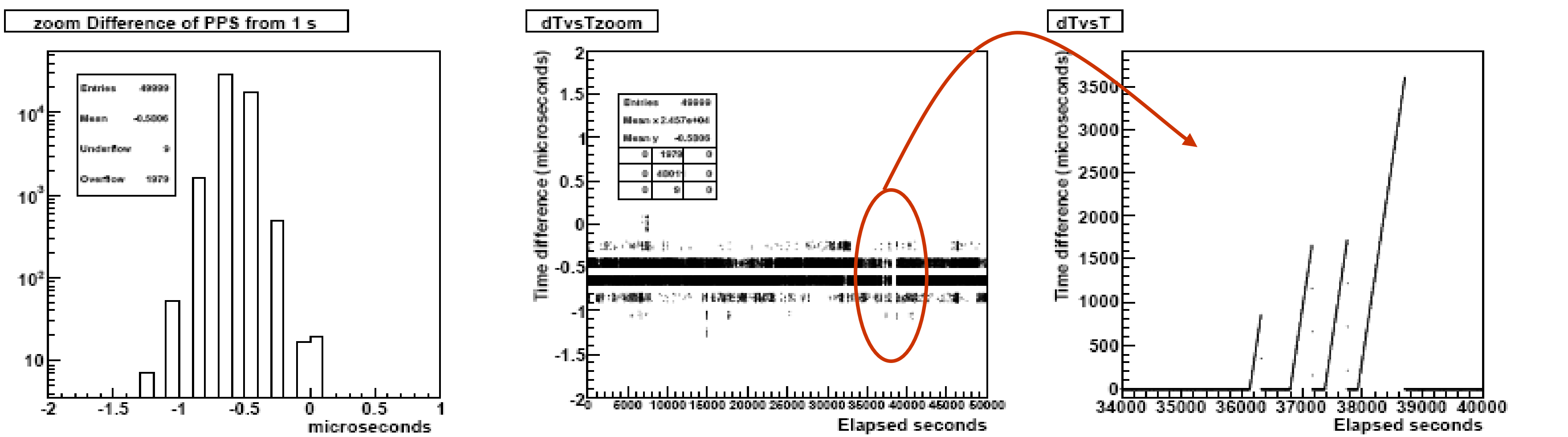


Figure 17: The deviation of the Symmetricom VME GPS times from an integer number of seconds, when the VME “time capture” is triggered by the PPS output of the *RF Solutions* GPS. Left: Histogram of values. The mean of -580 ns is roughly consistent with the cable run of the Trimble antenna used for the Symmetricom. The dispersion is better than the $\pm 1\ \mu s$ 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.