AGILE as particle monitor

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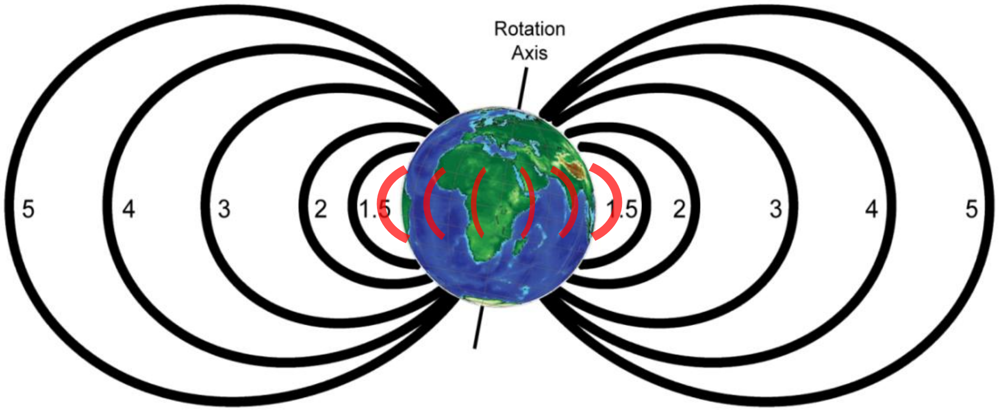
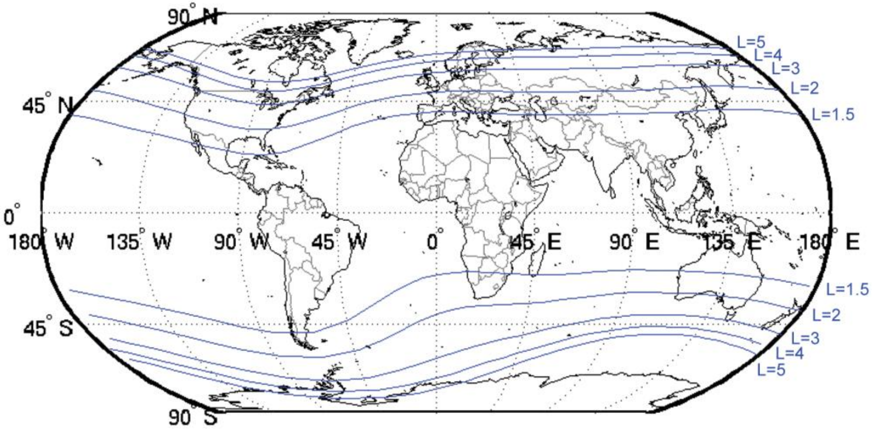
13th AGILE Workshop

"AGILE: 8 and counting"

The AGILE orbit

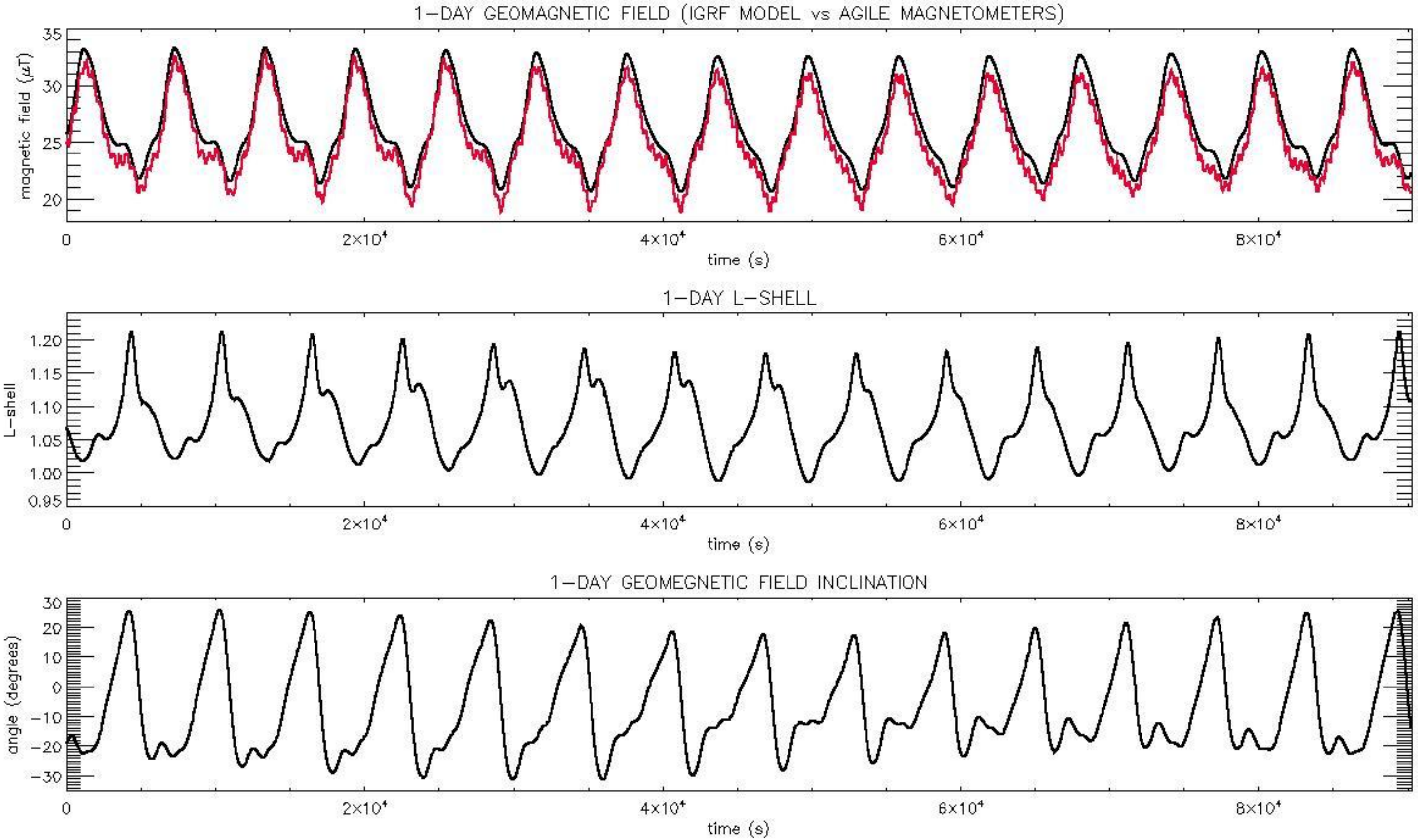
- Quasi-circular orbit with an average altitude of 500 km
- Small inclination → i = 2.7°
- Low particle background → optimal configuration for γ-ray astronomy
- Inner Earth magnetosphere (1.0 ≤ L ≤ 1.2)





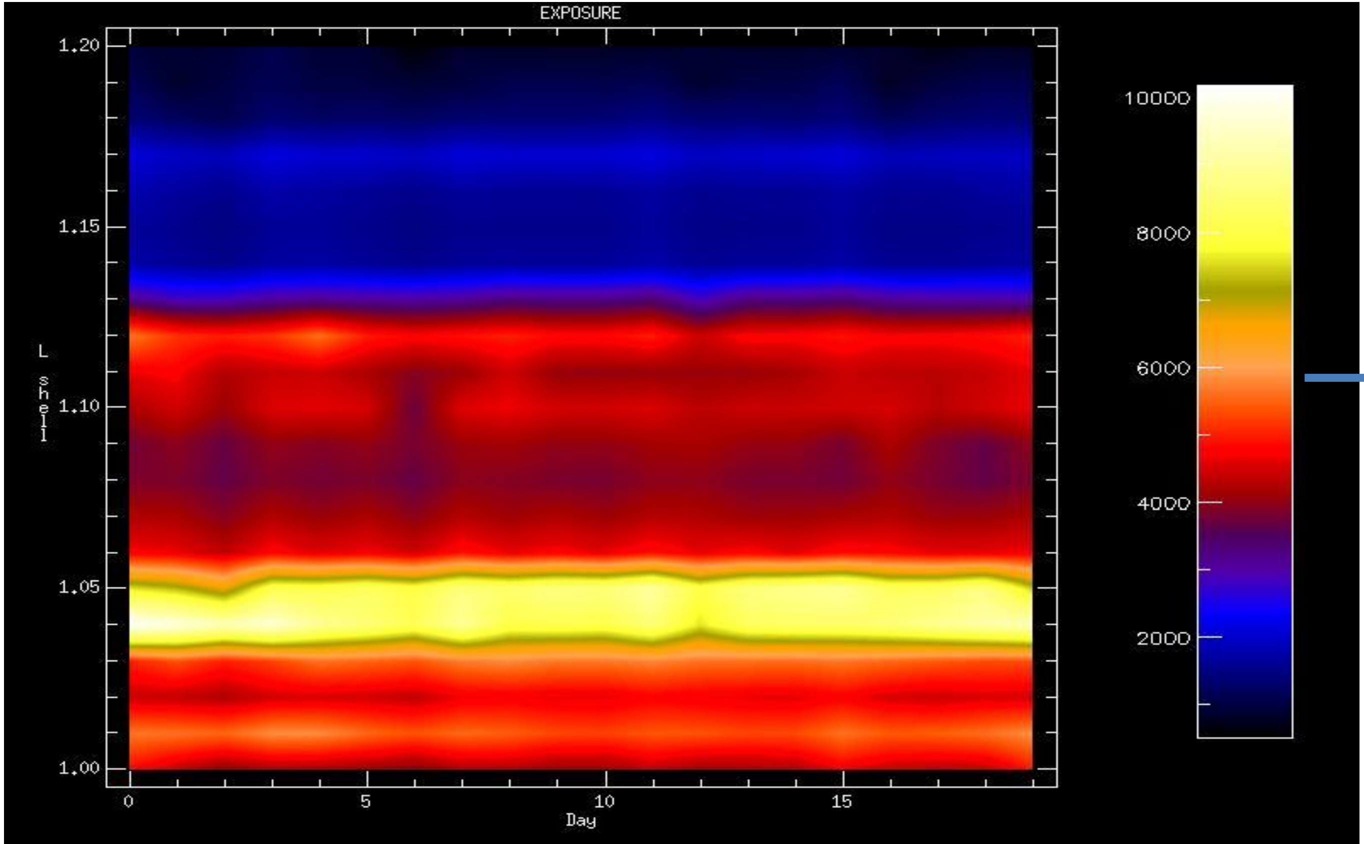
L-shell → set of magnetic field lines (shell) crossing the magnetic equator at L Earth radii (McIllwain, 1961)

Geomagnetic characteristics of the AGILE orbit



AGILE L-shell exposure-time map

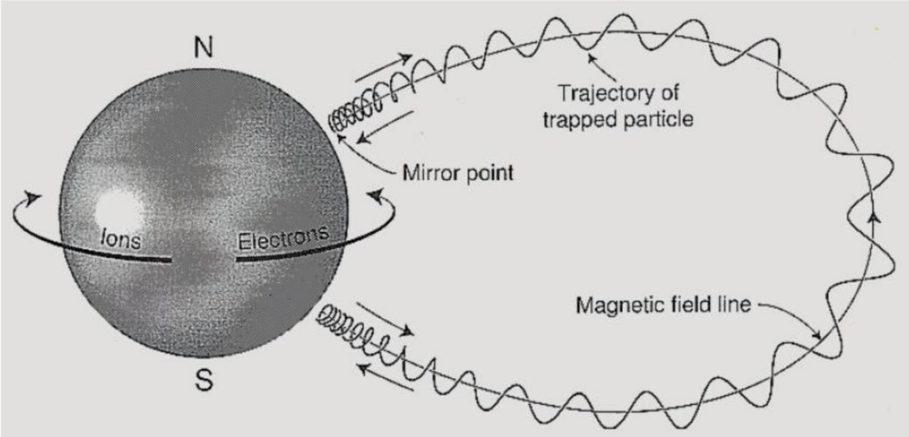
April 14 – May 5 2015



time (s) during which the AGILE satellite was in a given L-shell

Trapped particles in magnetosphere

- Gyromagnetic revolution around magnetic field lines
- Bouncing motion between mirror points
- Longitudinal drift of the guiding center (ions drift westwards, electrons eastwards)



L-parameter → invariant

Trapped particles keep moving into a given magnetic L-shell

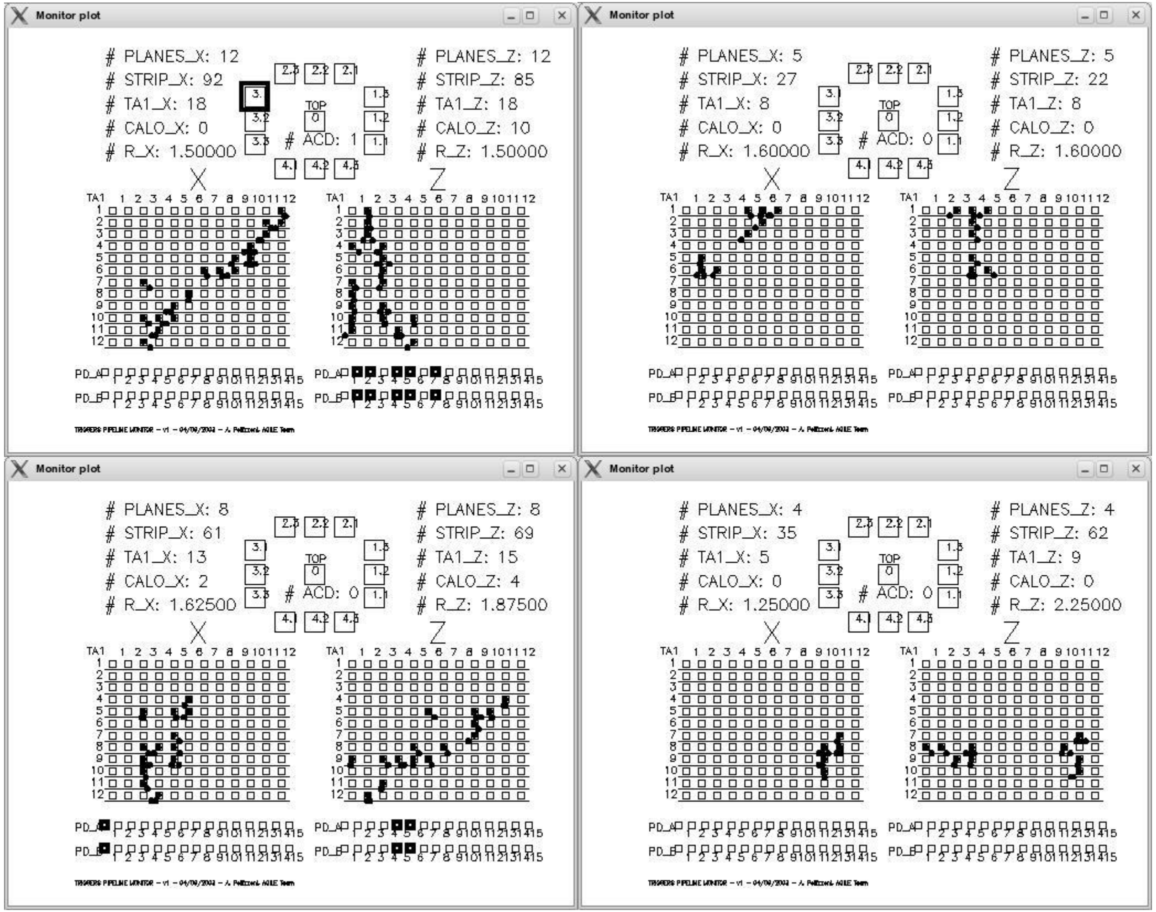
The AGILE tracker as a charged-particle detector

- AGILE has been conceived to detect γ-rays from astrophysical sources:
  - charged particles (trapped in the magnetosphere) represent the strongest background
  - p/γ ratio ≈ 10^4

- Most of the charged particles are rejected onboard:
  - Anticoincidence (AC) system + veto logic

- But…
- Many residuals particles are detected and tracked anyway:
  - No AC panels at the bottom side
  - Lateral AC panels have a less restrictive veto logic

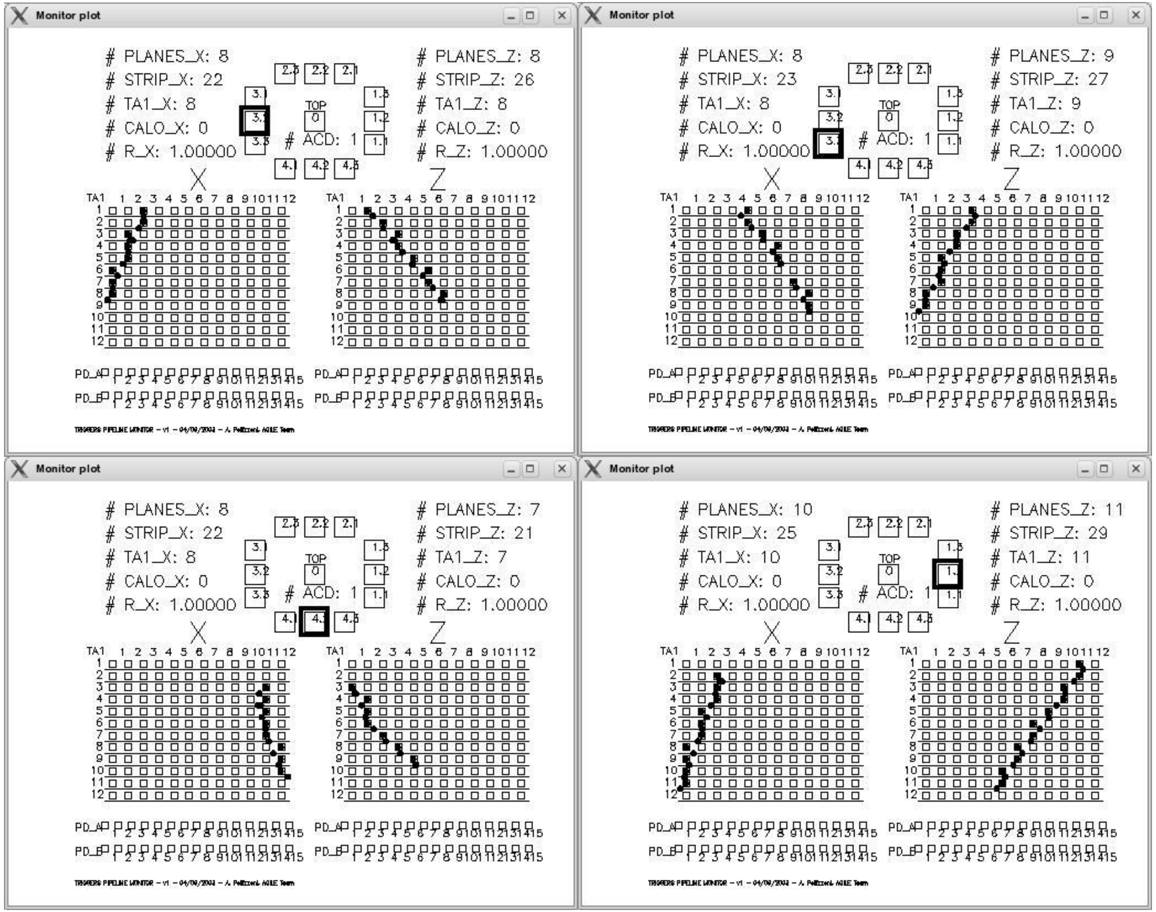
“Particle” events



- All events flagged as “P” by our ground pipeline
- Complex topology
- Most of them come from the bottom of the GRID (no AC panels)
- Standard Kalman filter reconstructs the track from top to bottom ($0° \leq \theta \leq 90°$)

→ **difficult reconstruction of the incoming direction**

“Gold” events



If:

- ✓ “good” single tracks (Rx and Rz ≤ 1.3)
- ✓ signal in 1 lateral AC panel
- ✓ no signal in the last tracker plane
- ✓ no signal in the mini-CAL

- Discrimination between “top-down” and “bottom-up” tracks
- Bottom-up events have bottom-up track reconstruction (inverted Kalman)
- 0° ≤ θ ≤ 180° distribution
- “Gold”/“Particle” event ratio ≈ 1%

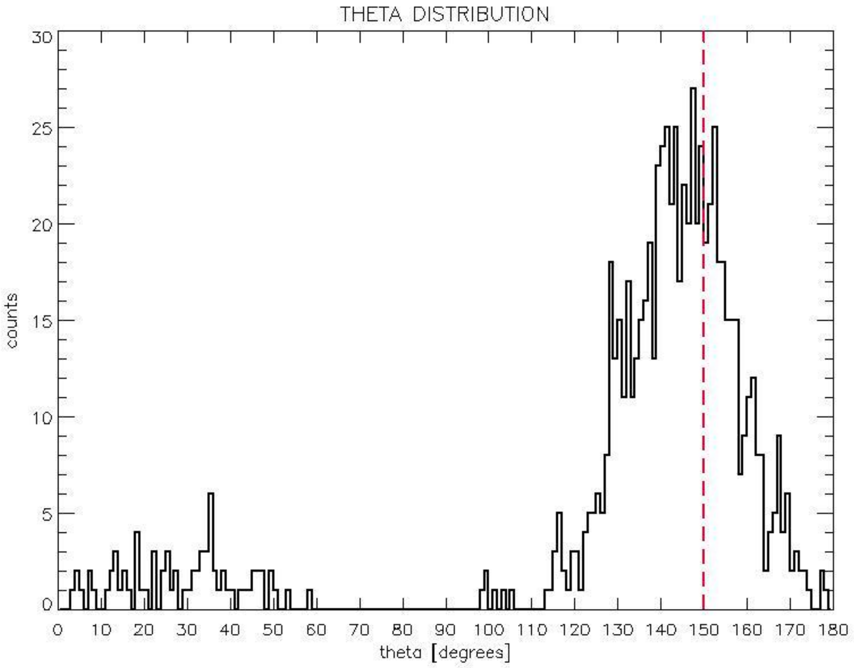
→ **reconstruction of the incoming direction**

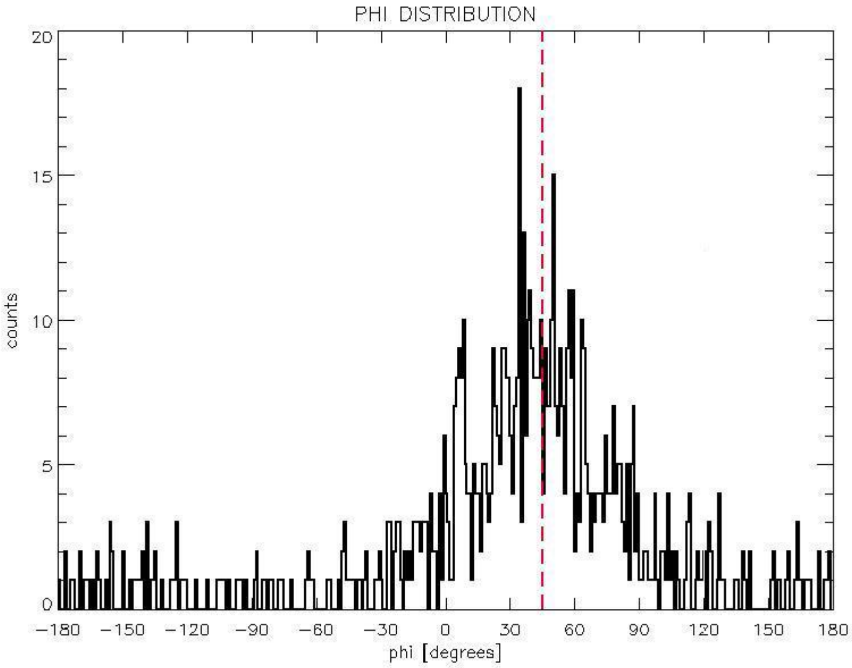
Testing the AGILE reconstruction strategy for "Gold" events

Simulation: monocromatic electrons from a given direction (θ_s, φ_s)

- 200000 simulated events inside the tracker
- E = 100 MeV
- $(\theta_s, \varphi_s) = (150°, 45°)$ → bottom-up events
- Reconstruction strategy for "Gold" events applied to the simulated electrons

Simulations

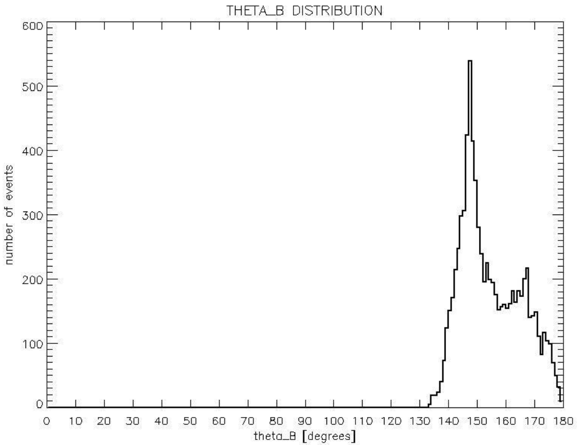


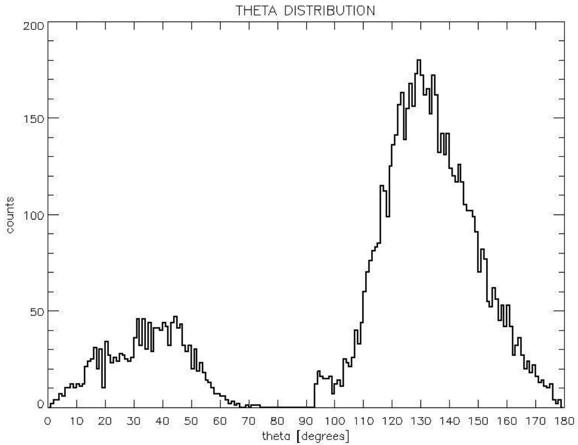


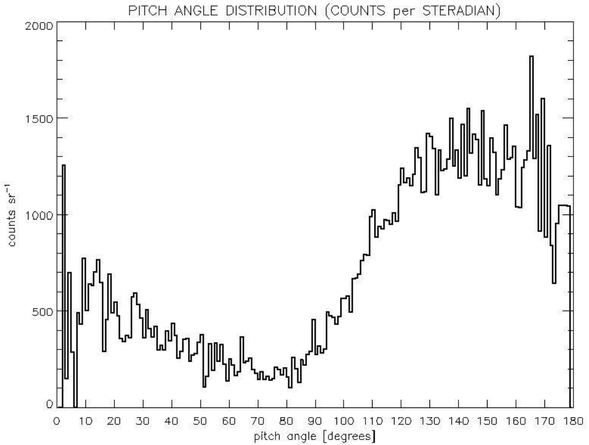
785 events have been reconstructed as “gold” events → ~0.4% of the simulated events are reconstructed as “gold”

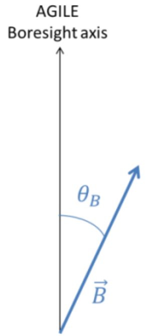
712 events have been reconstructed as bottom-up “gold” events → 91% of the reconstructed “gold” events

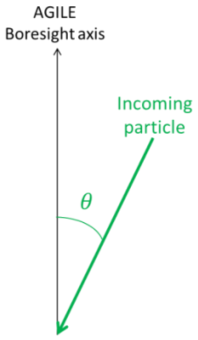
“Gold” events
1 week - Pointing (1585-1683)
E < 100 MeV

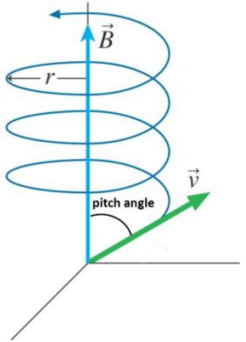




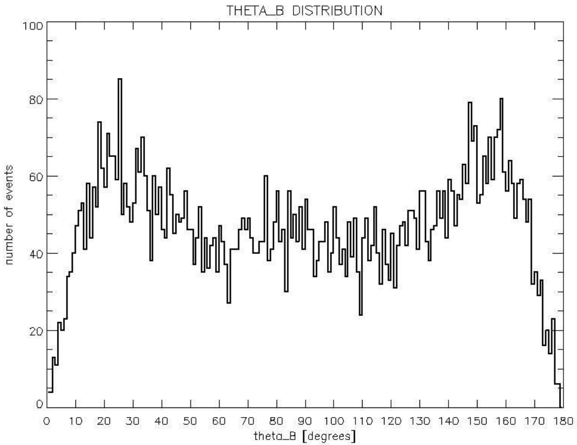


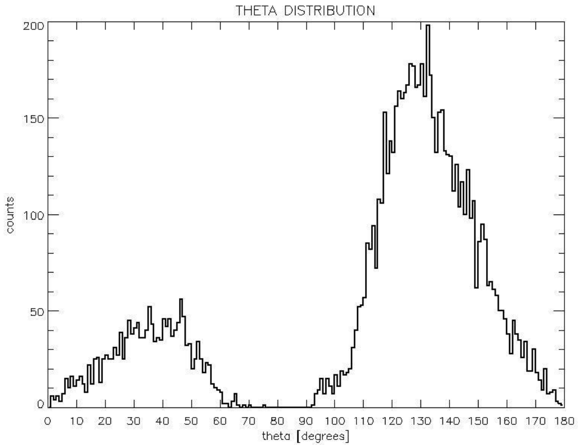


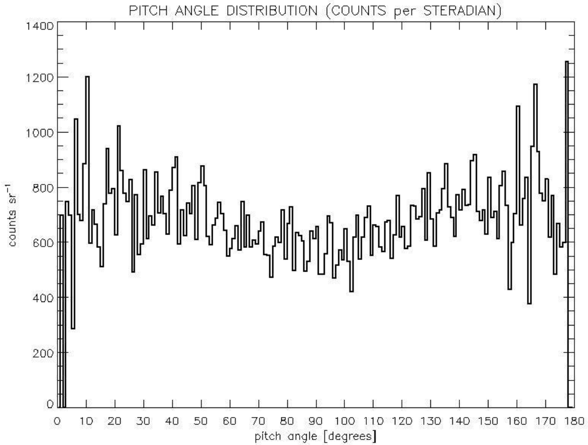


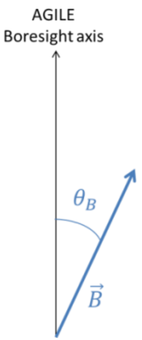


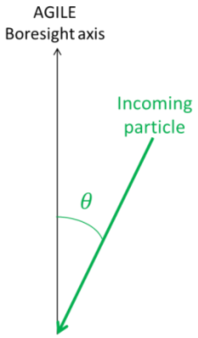
“Gold” events
1 week - Spinning (15000-15098)
E < 100 MeV

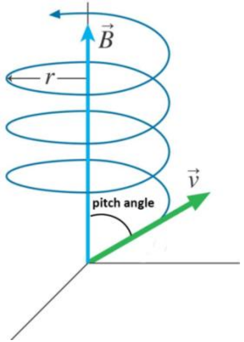










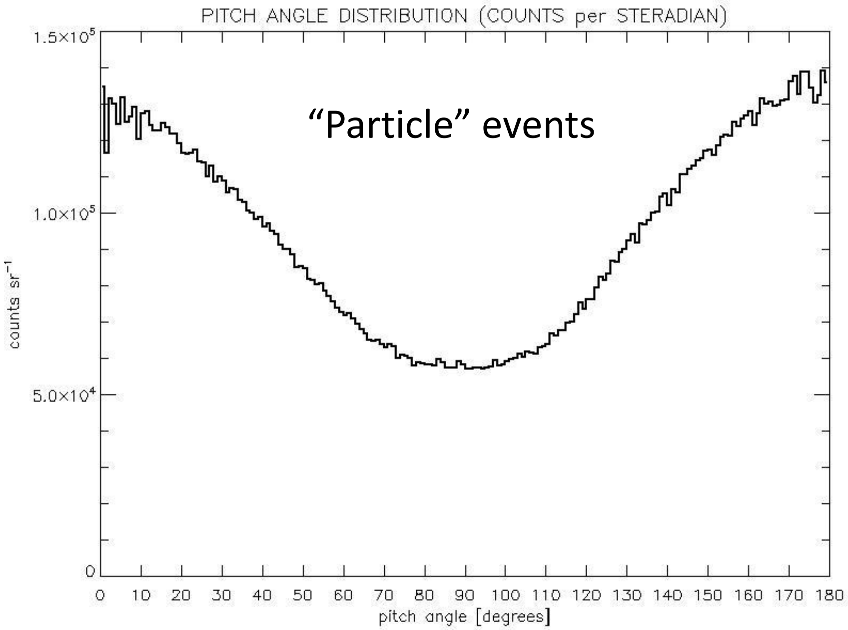


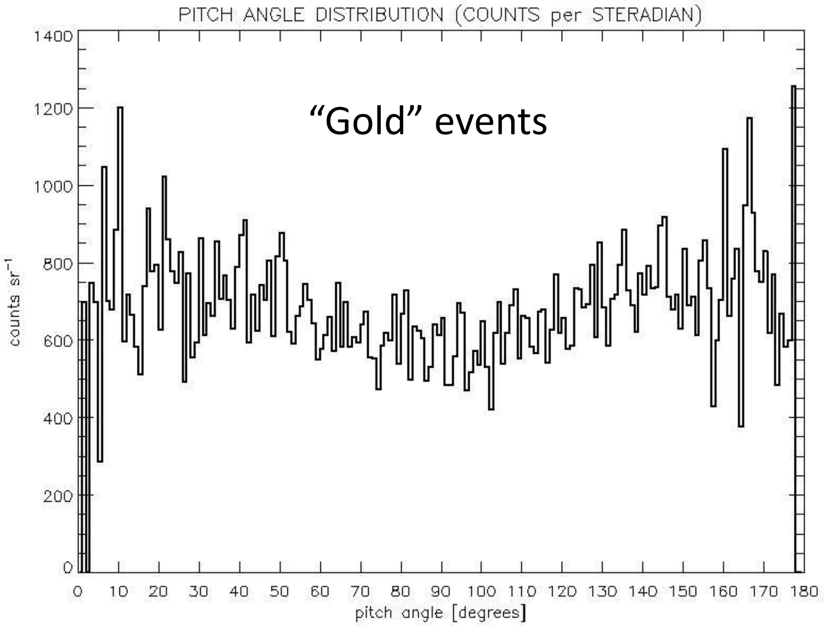
Pitch-angle distribution

“Particle” and “Gold” events

1 week - Spinning (15000-15098)

E < 100 MeV



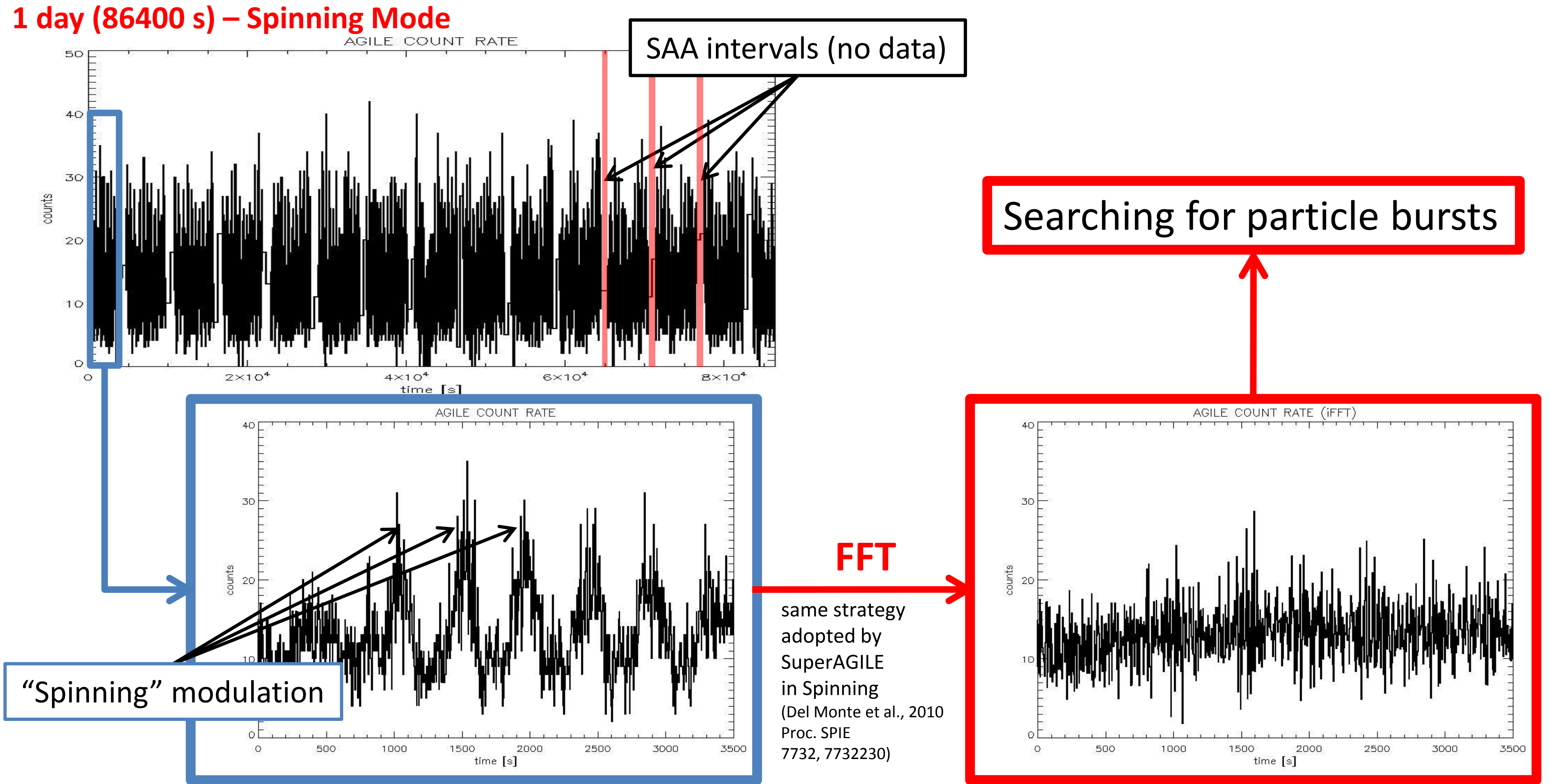


- Large statistics → Pitch angle distribution for “Particle” events is similar to “Gold” events
- Quasi-symmetrical distribution → “dumbbell”

AGILE as a particle detector: experimental evidences

- Most of the charged particle detected by AGILE are bottom-incoming, due to the onboard trigger logic
  - AGILE → detector for top-incoming photons
  - AGILE → detector for bottom-incoming particles
- AGILE is able to constantly monitor the trapped-particle motion in connection with the local geomagnetic field lines (pitch angle distribution)
  - In Spinning mode AGILE is continuously sampling the pitch-angle range of the particles → complete coverage of the pitch-angle distribution (0°-180°)
- AGILE tracker has an accurate time resolution → burst detector
  - time tagging accuracy ≈ 2 μs
  - dead time (single event acquisition) ≈ 200-300 μs

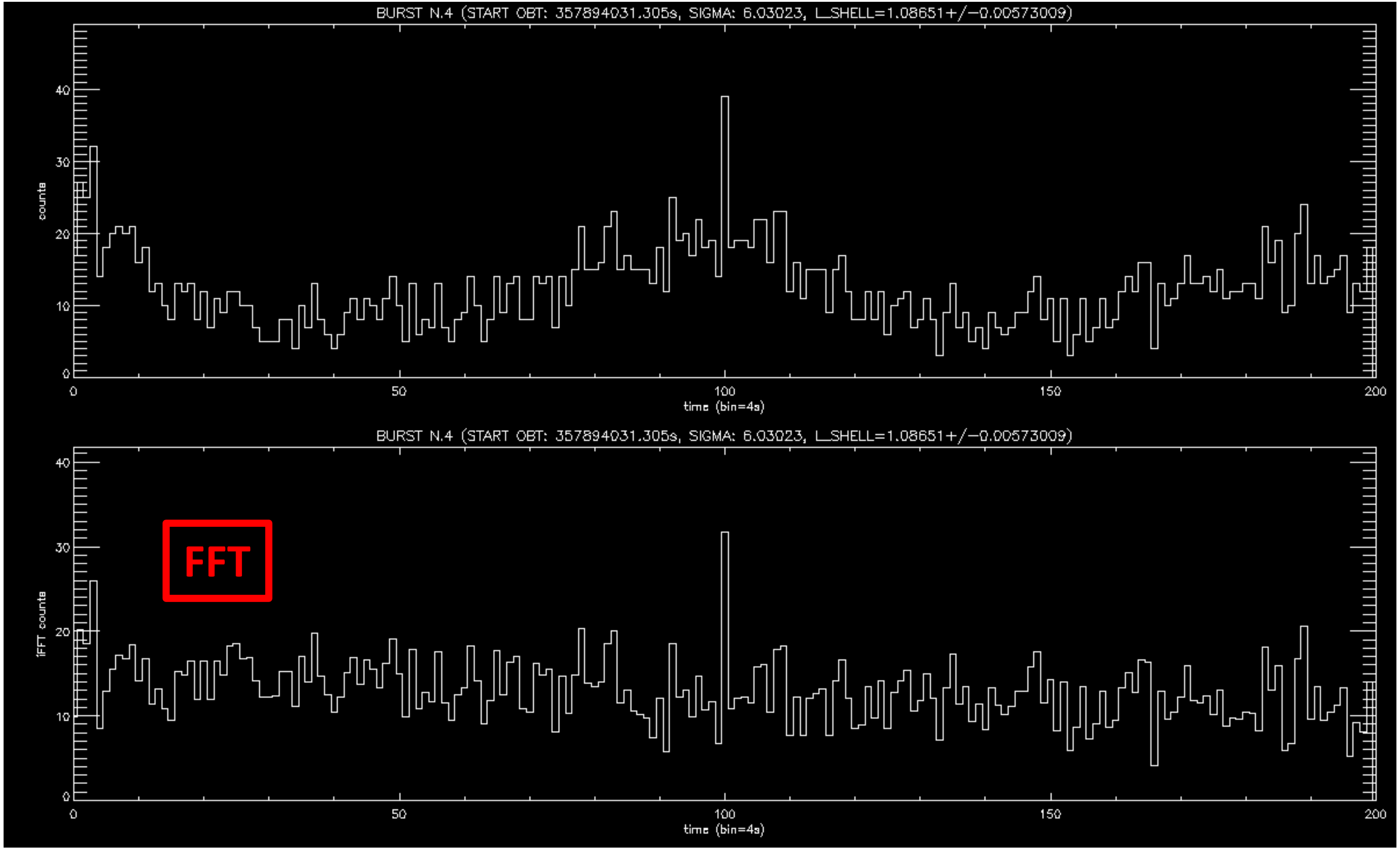
AGILE: looking for particle bursts



Strategy for finding bursts

- Binning time = 4s, 8s, 16s, 32s
- Sampling time = 4s
- Background calculated as the average counts of the previous 10 time bins $\left((bgd)_i = \frac{\sum_{j=i-10}^{i-1} n_j}{10} \right)$
- Poisson statistics assumed → $\sigma_i = \sqrt{(bgd)_i}$
- Burst → if $n_i \geq 5\sigma_i + (bgd)_i$

Particle burst (PB)



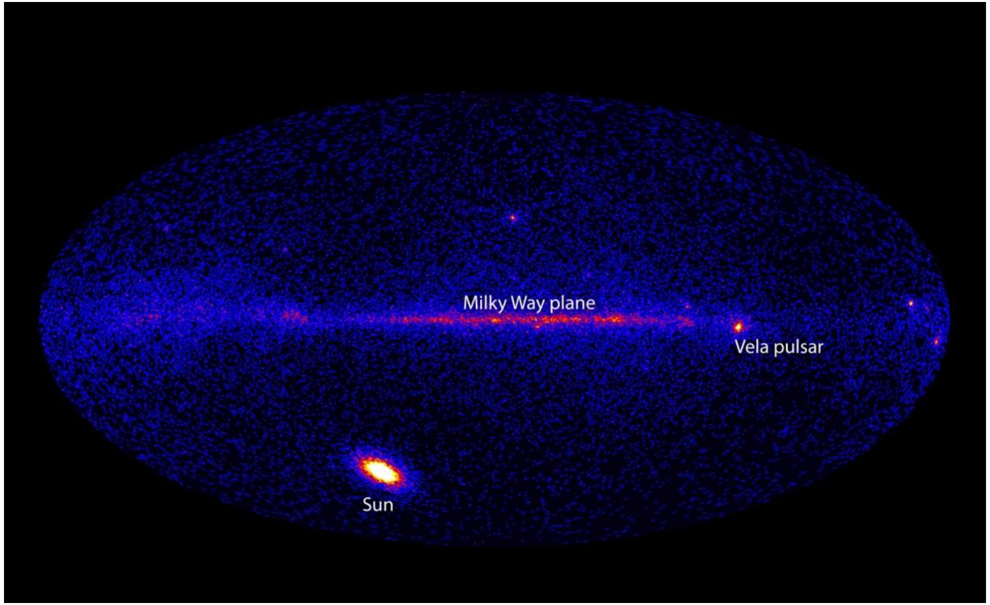
Potential scientific objectives

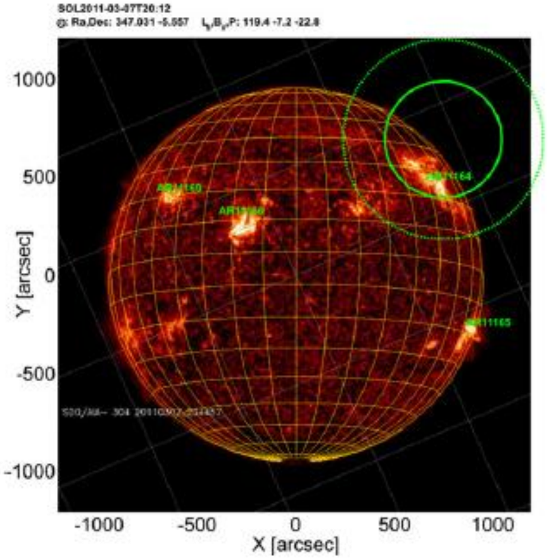
- Monitoring solar activity
  – Solar flare → geomagnetic storm → variation of the particle count rate

- Testing the lithospheric-magnetospheric coupling
  – Resonant interaction between seismo-electromagnetic emission (SEME) and high-energy particles trapped in the magnetosphere

Solar flare: March 7, 2012

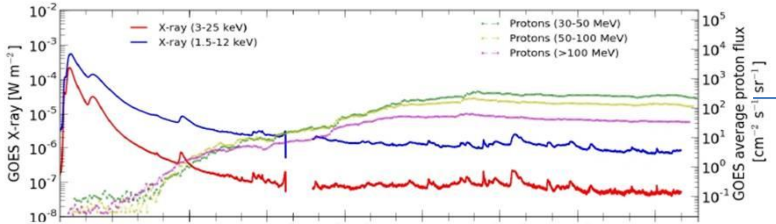
- Observed by Fermi-LAT in γ-rays ($E > 100$ MeV)
- The Sun was ~1000 times brighter than the Vela pulsar
- (The AGILE tracker cannot detect γ-rays from the Sun because of the solar panel constraints)



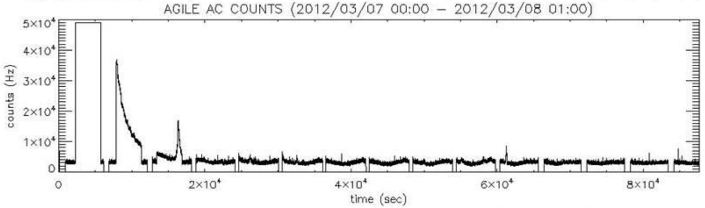


Monitoring solar activity

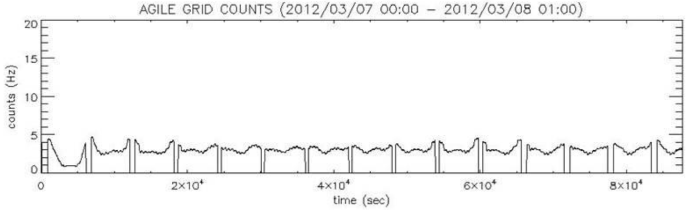
Solar flare: March 7, 2012



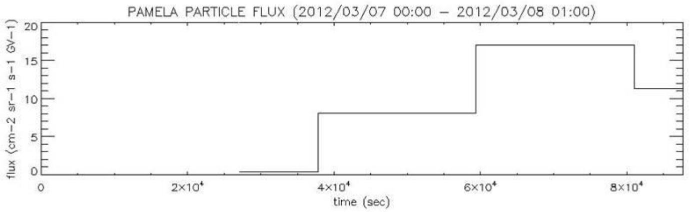
GOES (geostationary orbits→ ~36000 km)
X-ray bump, then enhanced particle rate



AGILE AC count rate
X-rays → Compton scattering

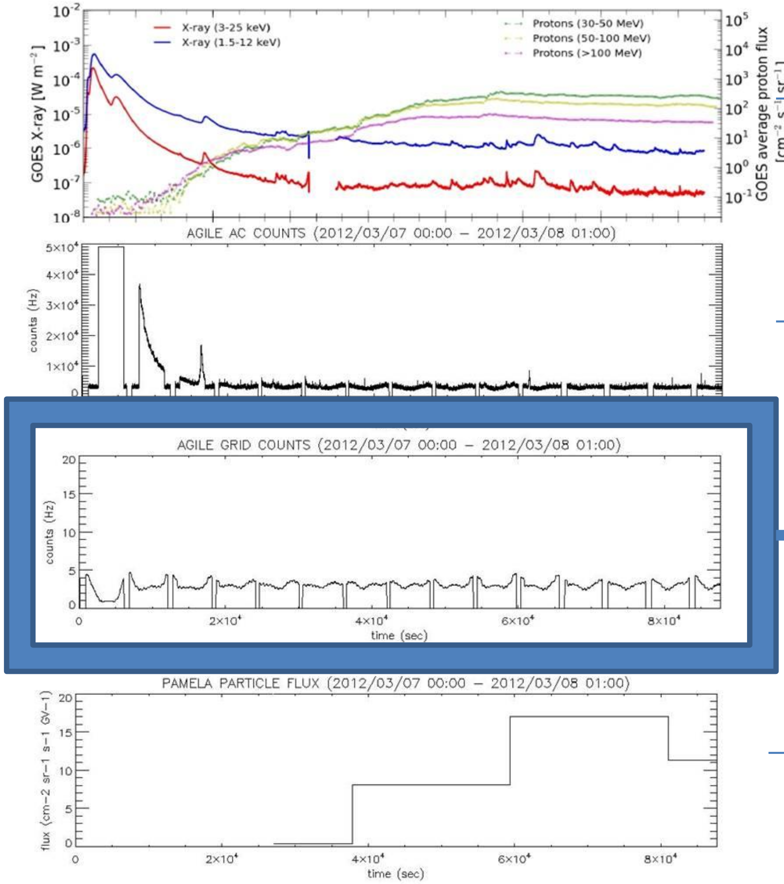


AGILE GRID count rate
NO enhanced particle rate detected



PAMELA (polar orbit, i=70°, height = 350-610 km)
Enhanced particle flux detected

Monitoring solar activity



Solar flare: March 7, 2012

GOES (geostationary orbits → ~36000 km)
X-ray bump, then enhanced particle rate

AGILE AC count rate
X-rays → Compton scattering

AGILE orbit is shielded by the outer magnetosphere
Charged-particle rate is not influenced by solar activity

PAMELA (polar orbit, i=70°, height = 350-610 km)
Enhanced particle flux detected

Potential scientific objectives

- ~~Monitoring solar activity~~
  - ~~Solar flare → geomagnetic storm → variation of the particle count rate~~

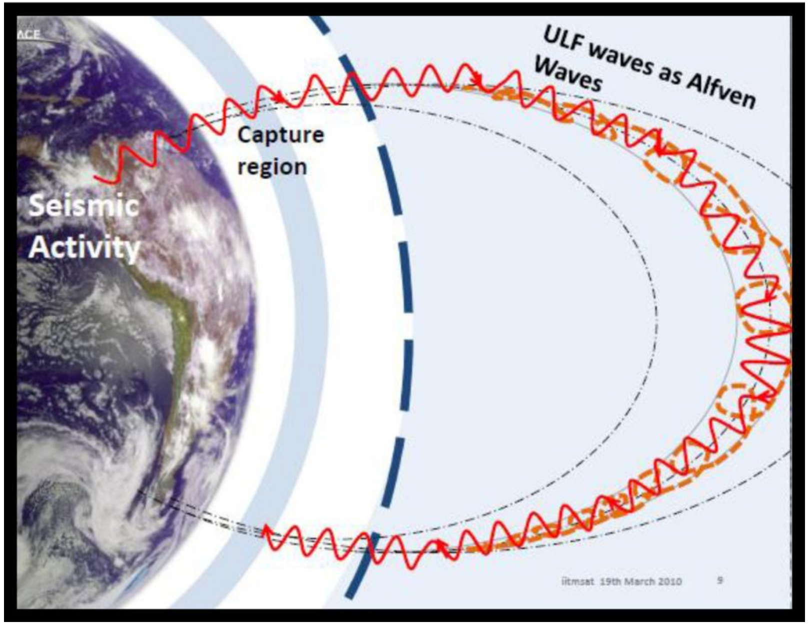
- Testing the lithospheric-magnetospheric coupling
  - Resonant interaction between seismo-electromagnetic emission (SEME) and high-energy particles trapped in the magnetosphere

Testing the lithospheric-magnetospheric coupling

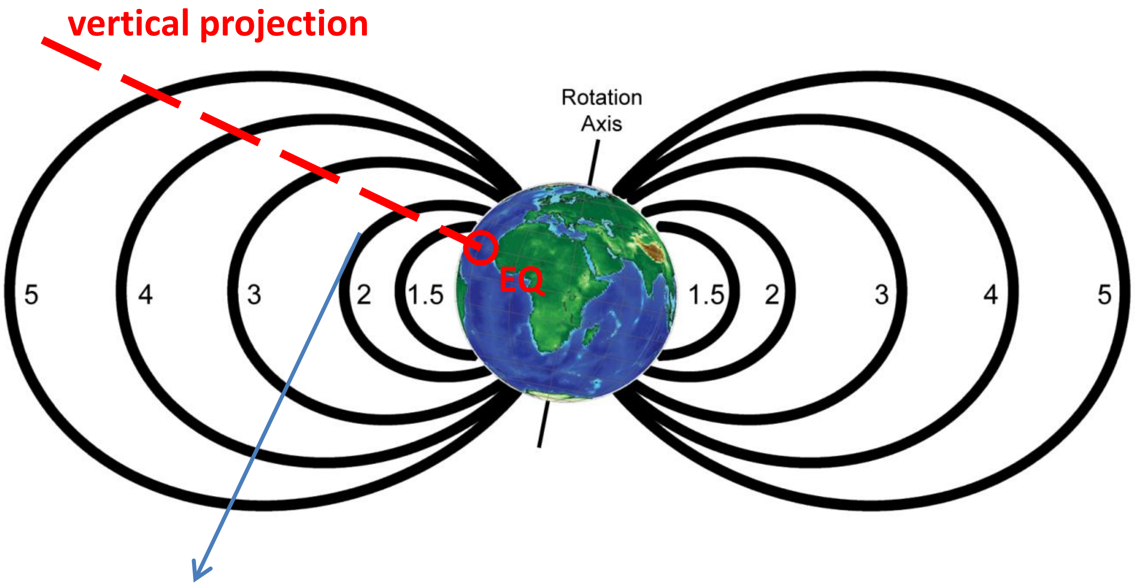
The model

(Galper et al., 1989, 1995; Voronov et al., 1990; Aleshina et al., 1992, Pustovetov et al., 1993; Aleksandrin et al., 2003)

- Seismo-electromagnetic emission (SEME) produced in the lithosperic preparation zone
- Waves are captured in the ionosphere-magnetosphere transition region (300-500 km)
- ULF waves (hundred Hz) propagate as Alfvén waves along the magnetic lines
- Bounce resonance with trapped particles in the magnetosphere
- Pitch angle diffusion → lowering of the bounce-motion mirror points
- Particles precipitate and longitudinally drift
- Particle bursts propagate for minutes/hours along the same geomagnetic L-shell



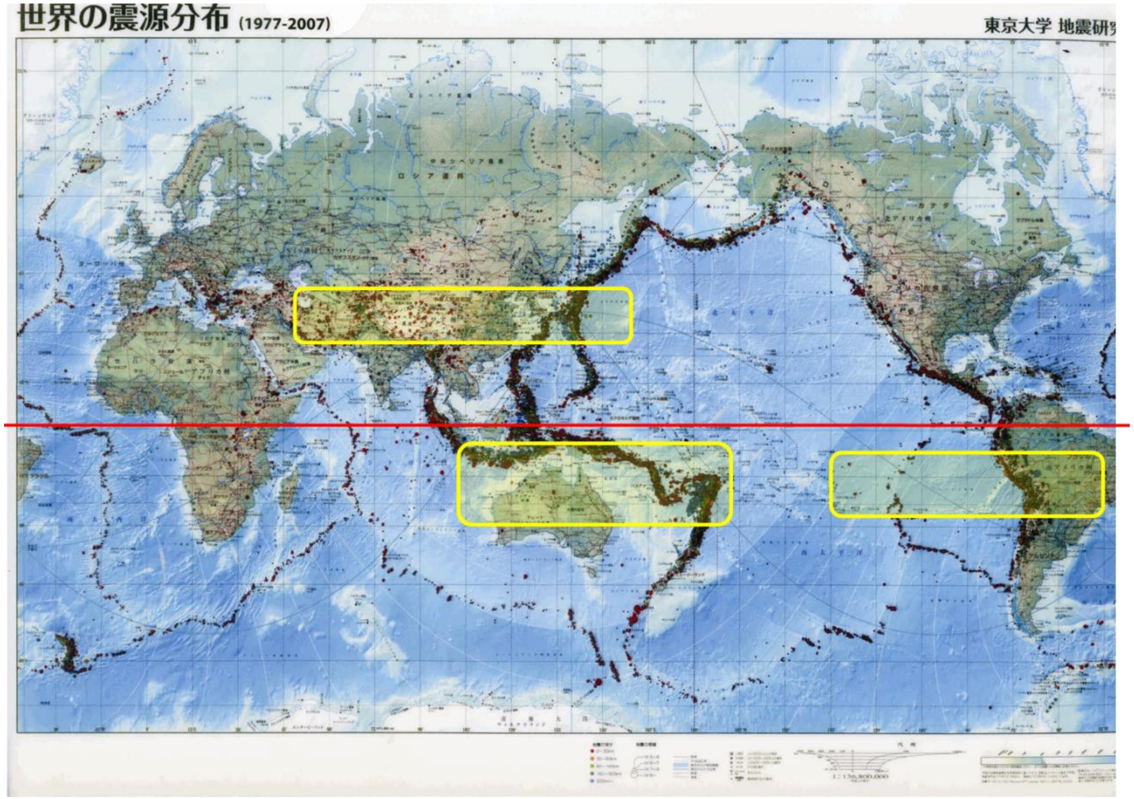
Geomagnetic correlation between PBs and seismic events



EQ L-shell is strongly dependent on the projection altitude

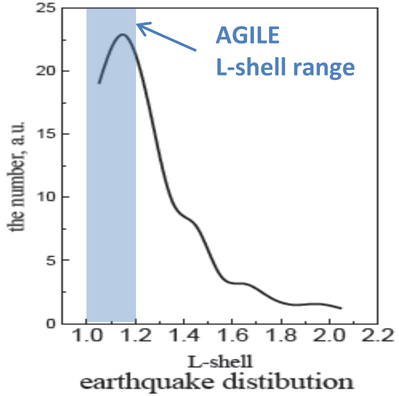
- L-shell of the PB detected by AGILE
  - from the position of the satellite
- L-shell of the earthquake
  - vertical projection of the epicenter at a given altitude
  - the altitude is related to the “capture” of the SEME wave into a geomagnetic field tube (propagation as Alfvén waves)

Seismic regions geomagnetically correlated with AGILE



- Iran
- Pakistan
- Nepal
- China
- Japan
- Indonesia
- California
- Mexico
- Peru
- Chile

L-distribution for earthquakes



A.M.Galper, Erice, Italy, 23 October 2012

Remarks

The instrument

- Innovative approach, event selection and reconstruction strategy for AGILE → charged-particle detector
- Imaging capability + spinning mode observations → complete coverage of the pitch-angle range for trapped particles in the lower magnetosphere
- Accurate time resolution → PB detector

The orbit

- Quasi-equatorial low-Earth orbit → not directly influenced by geomagnetic storms induced by solar flares
- Geomagnetically correlated with very active seismic regions

AGILE: optimal configuration to test the lithospheric-magnetospheric coupling

Perspectives

Testing the lithospheric-magnetospheric coupling

- statistical approach: comparing the geographical and geomagnetical distribution of AGILE PBs and seismic events → time-correlation

- "case study" approach: comparing space-observable parameters from other satellites (total electron content, electron density, ongoing longwave radiation, …) and PBs detected by AGILE, during some large-magnitude seismic events → cross-correlation

Work in progress…

STAY TUNED!