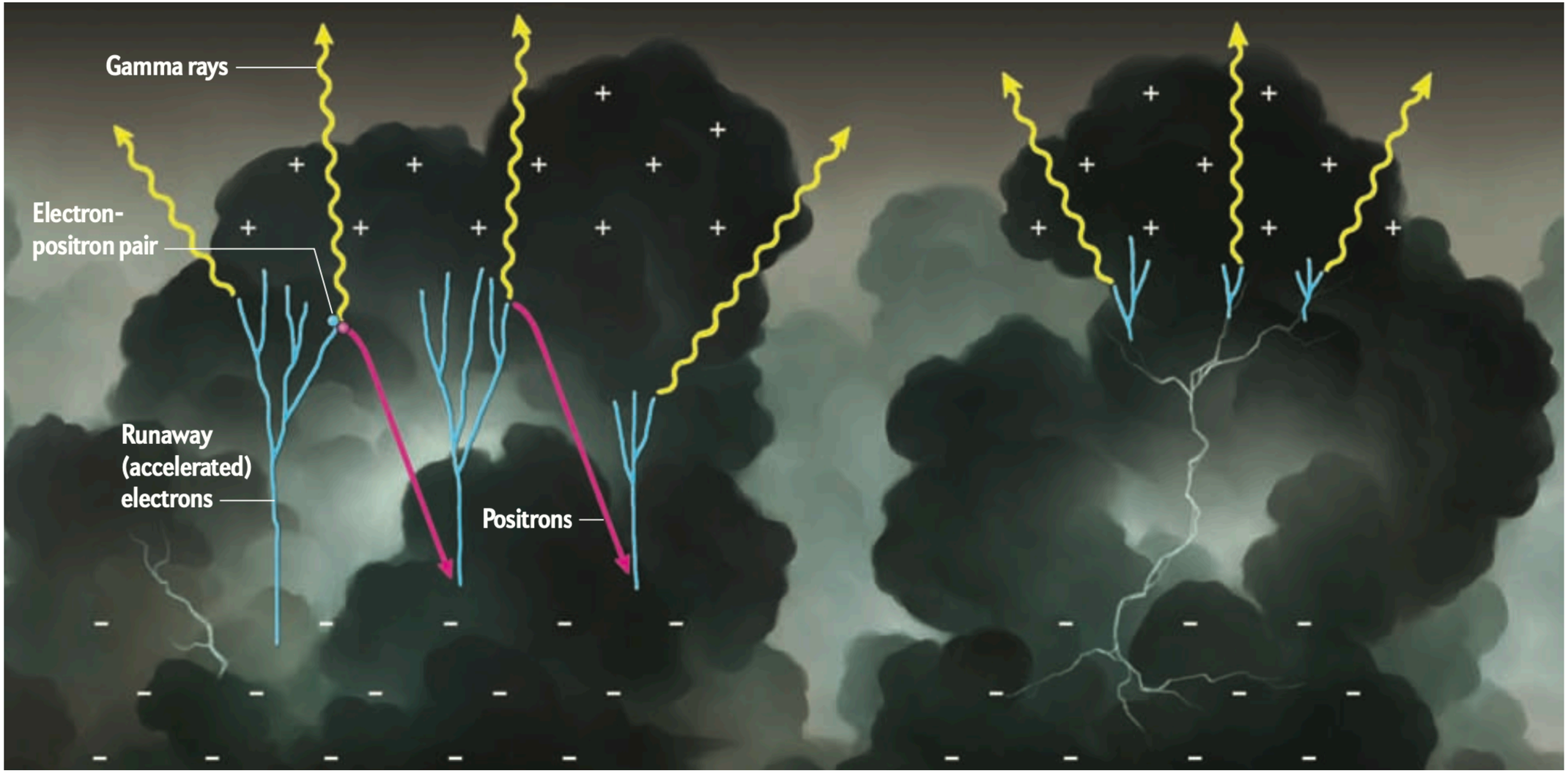
Caractérisation du rayonnement de haute énergie dans les orages

Sebastien CELESTIN[1] & Mélody PALLU[1,2,3]

[1]LPC2E, University of Orleans, CNRS, CNES, France
[2]Institute of Radiation Protection and Nuclear Safety (IRSN), Fontenay-aux-Roses, France
[3]Occupational Health Services, Air France, Roissy CDG, France

COMET ENV - Ballons & environnement atmosphérique, 18 mai 2022, Toulouse, France

Gamma ray glows and Terrestrial Gamma ray Flashes (TGFs)

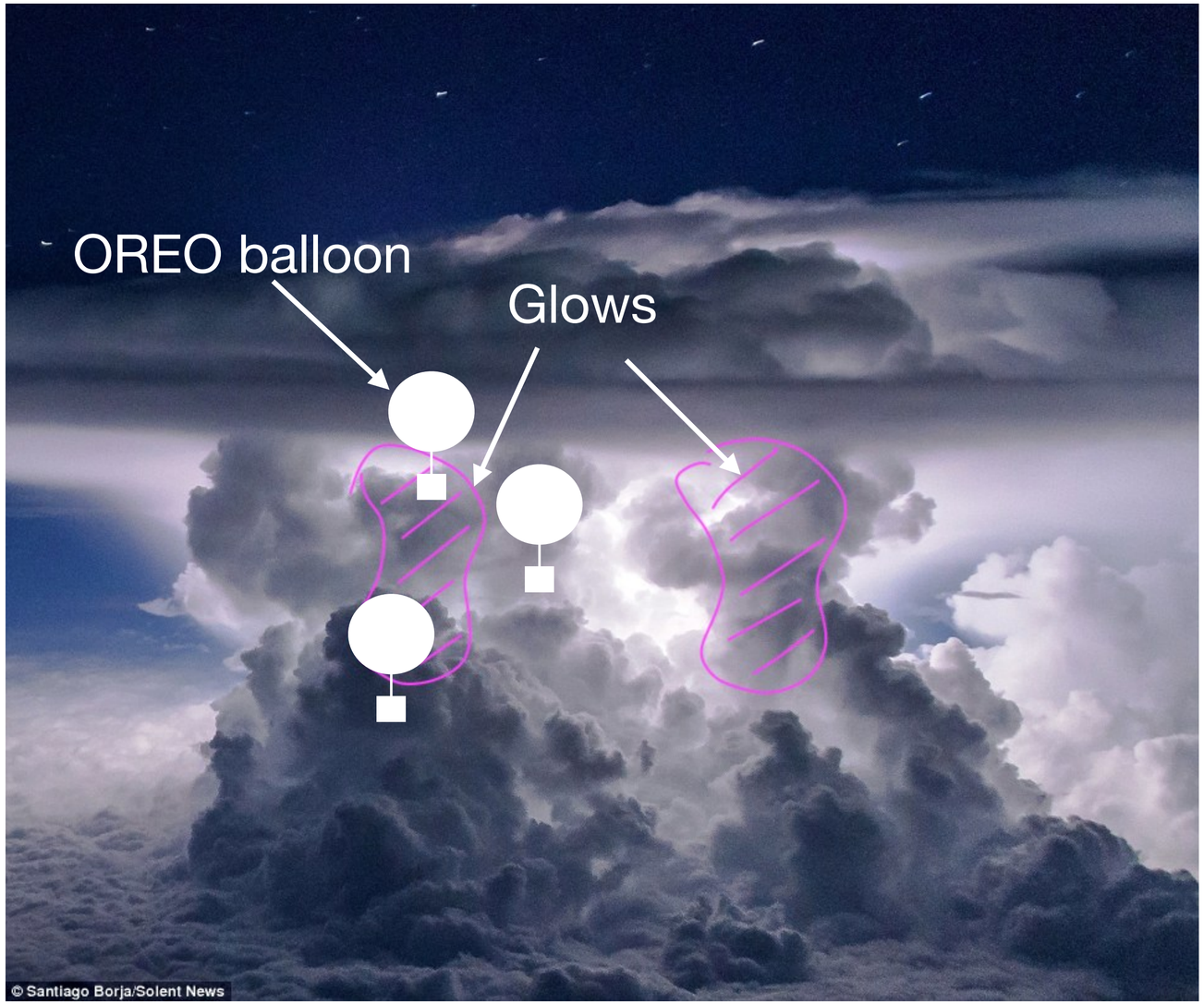


Reproduced from [Dwyer & Smith, Sci. Am., p. 55, August 2012]

Research questions

- Acceleration and amplification processes (RREA, presence of relativistic feedback, etc.)
- Source geometries (altitude, size, etc.)
- Gamma ray spectrum dependence on the local electric field [Cramer et al., JGR, 122, 4763, 2017]
- Impact of/on the T-storm electrodynamic system [Kelley et al., 2015]
- Quantify the radionuclide and neutron production
- Overall radiation risk assessment in T-storms (collaborations IRSN & Air France)

OREO mission concept



- Sending 3-4 balloons at the same time to evaluate the extent in space and time of high-field regions and glows

OREO: CNES-project of lightweight ballons

Two-instrument payload:

- Gamma ray spectrometer (counts time-tagging, fast, and high timing accuracy <1 μs UTC, batteries included, ~1 kg)
- Lightweight field mills (<2 kg) to measure strong electrostatic fields

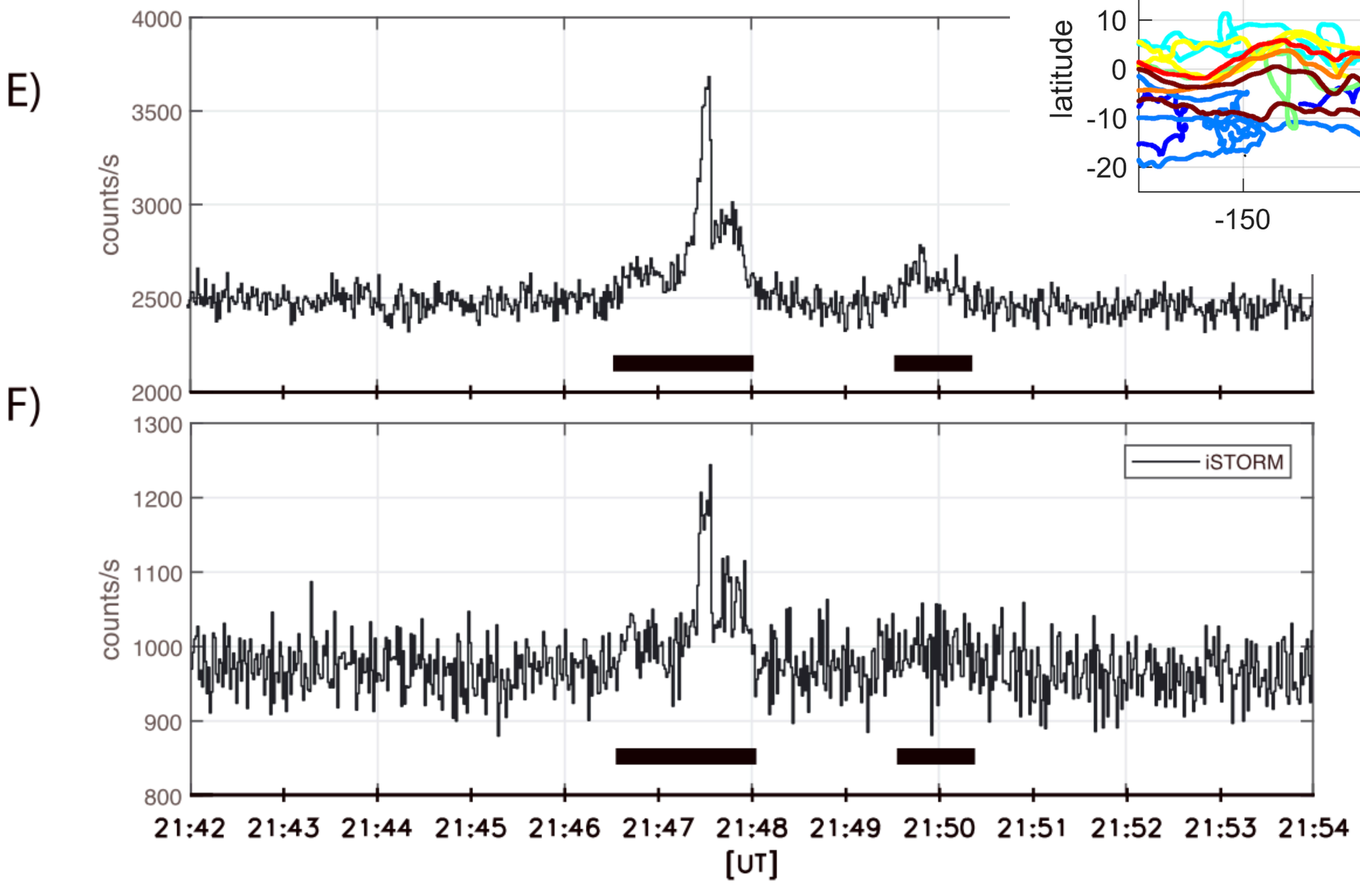
- Need to minimize mass, power, and costs

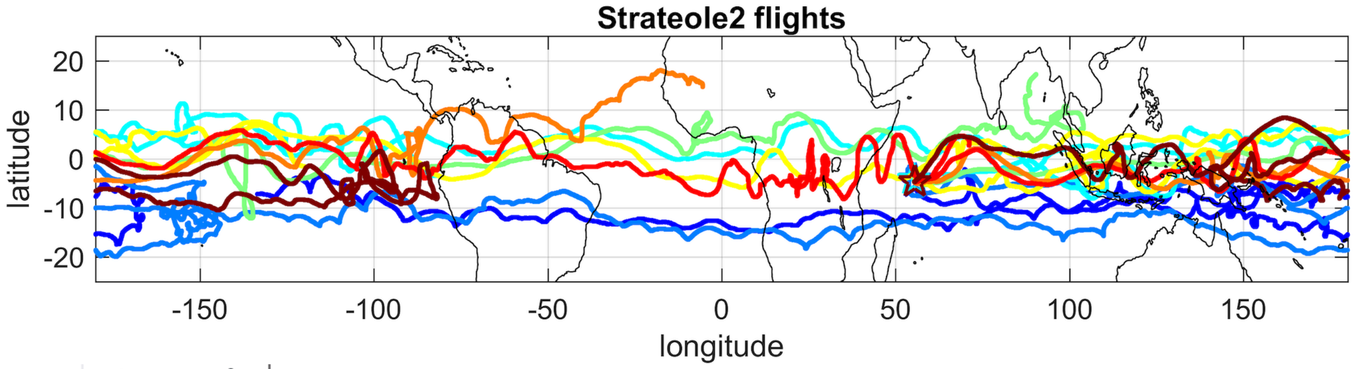
+ “Subprojects”: OREO-Japan, New Mexico Tech, STRATELEC

STRATELEC (XStorm) on Stratéole-2

~20 km altitude for ~3 months above the equator (campaigns in 2021 and 2024)

- Observation of **gamma ray glows** and TGFs





Stratéole-2 flight trajectories 2019-2020.

Observation on board ER-2 at 20 km altitude in Colorado. (e) UiB-BGO (>300 keV) (f) Two plastic scintillators (~100 keV à 8 MeV).

[Ostgaard et al., J. Geophys. Res., 124, 7236, 2019]

STRATELEC / XStorm

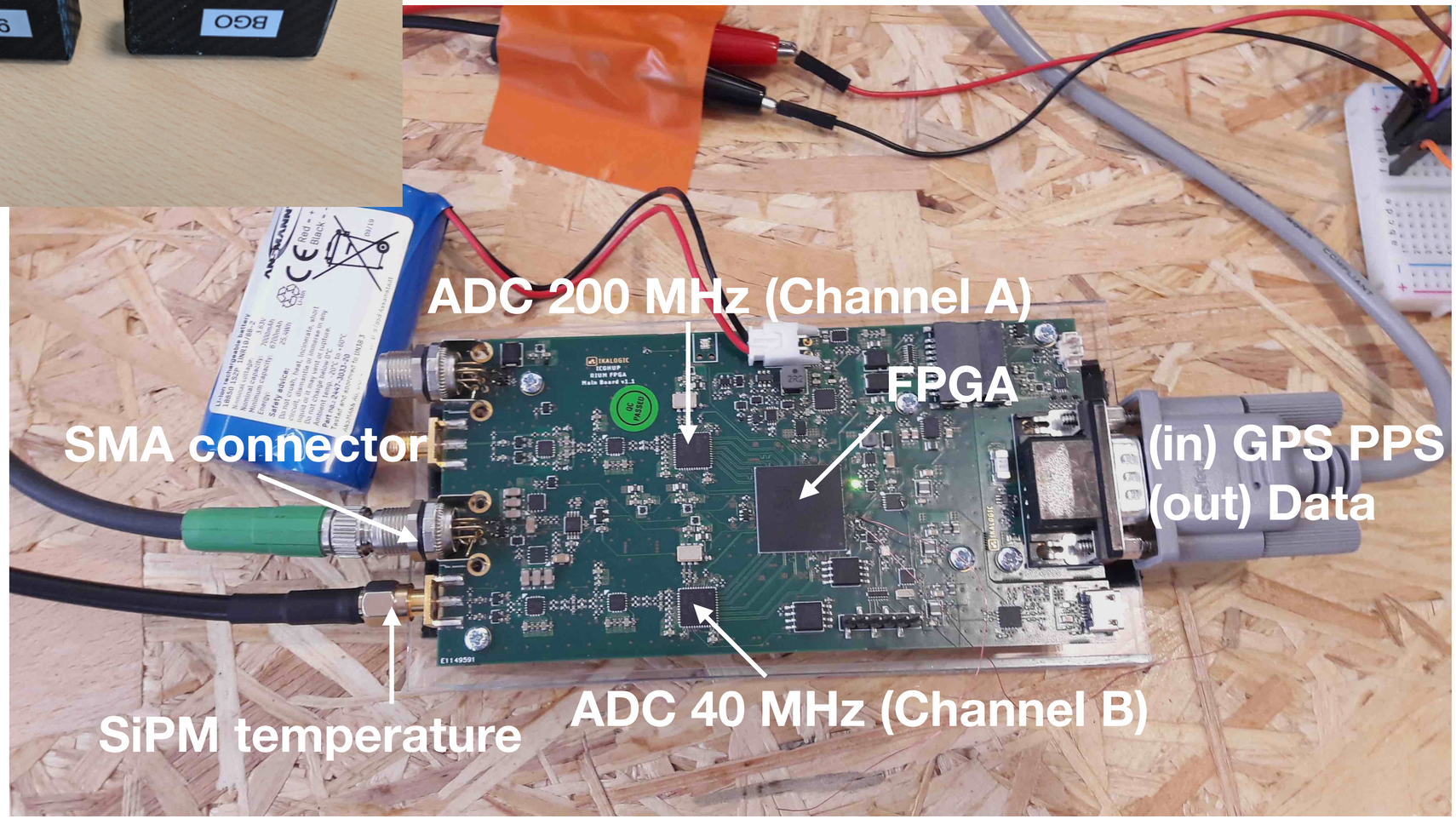
Objectives and challenges

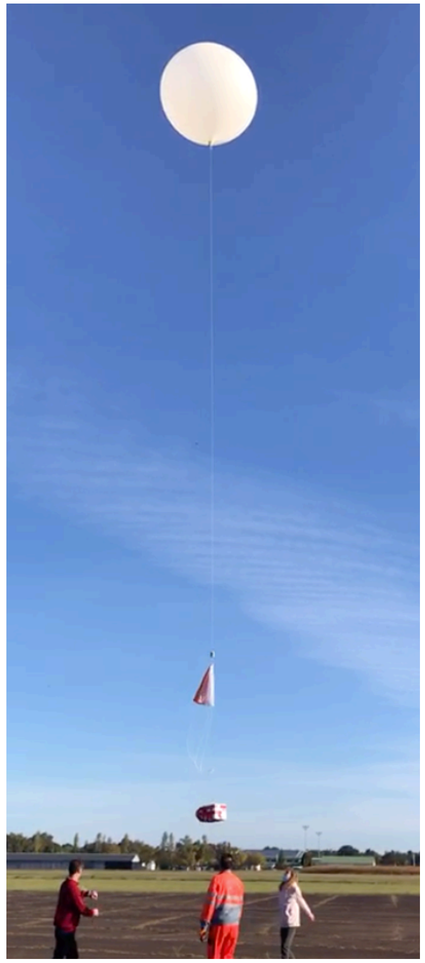
- Opportunity to detect TGFs and high-altitude gamma ray glows [Ostgaard et al., 124, 7236, 2019]
- No recovery: Need to adapt interfaces to ST-2 gondolas (data, telemetry, power)
- Telemetry limited to a few MB/day => event triggers definition

(Accomplished in ~8 months with limited HR)

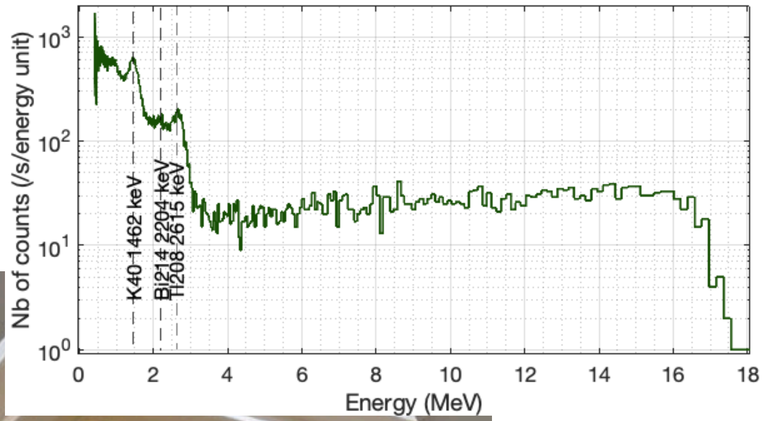
Gamma ray spectrometer

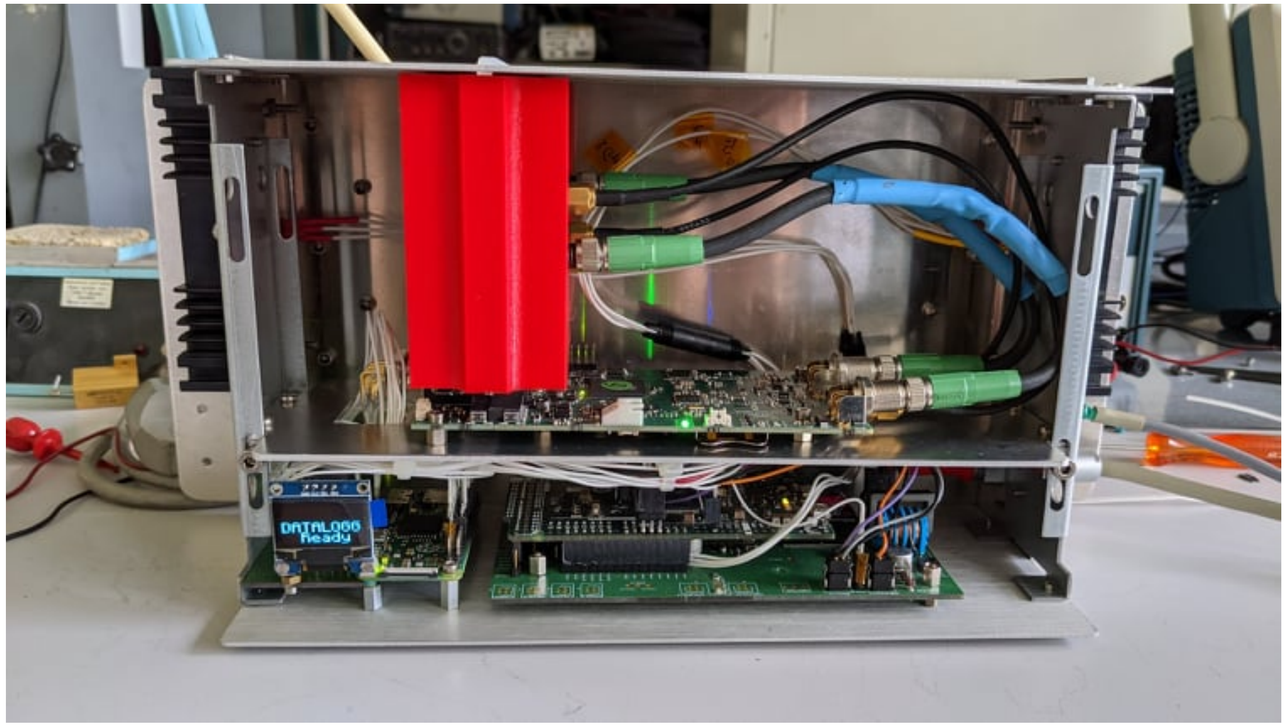
Gamma ray count time-tagging with a 100 ns accuracy on UTC





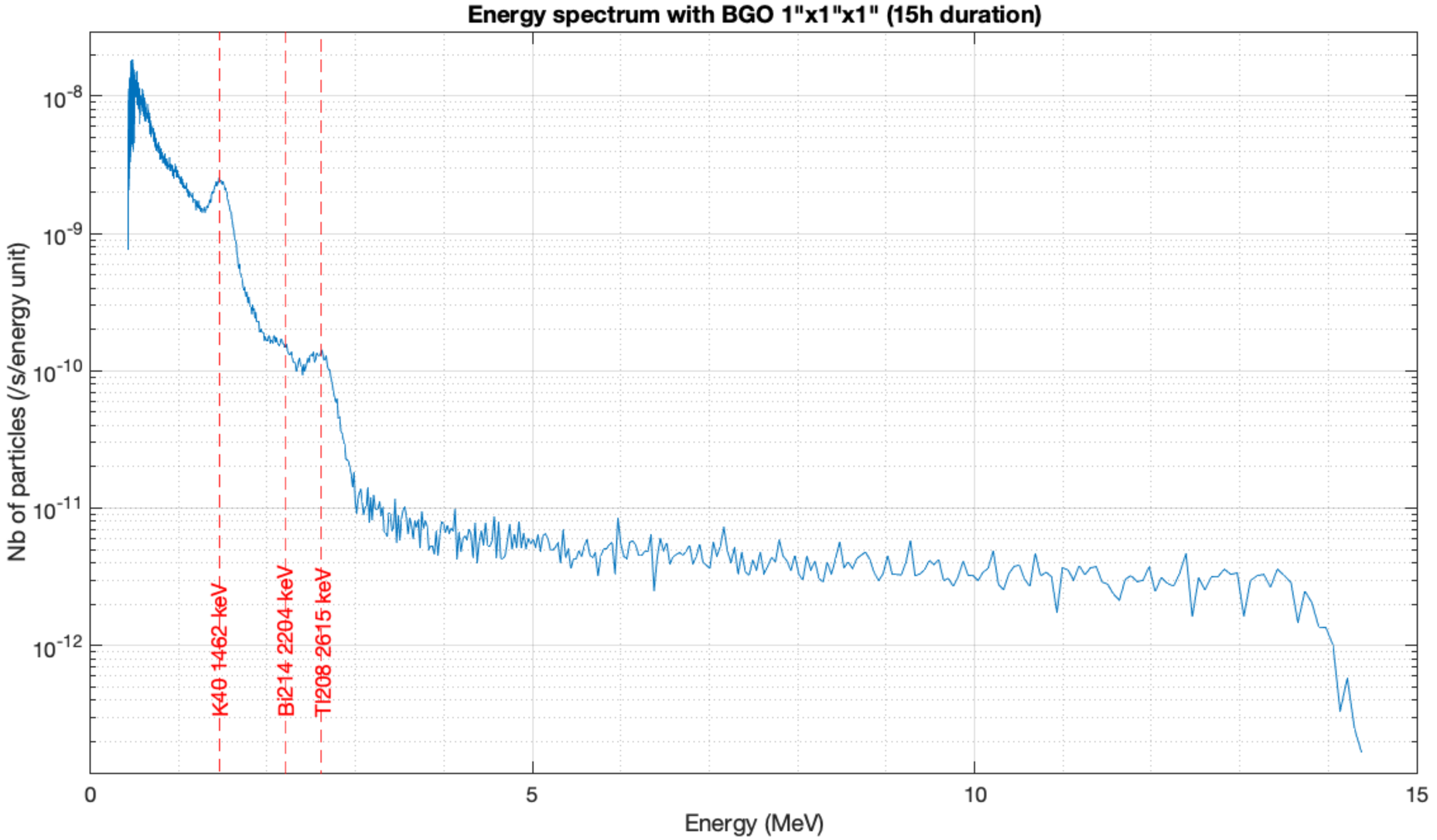
XStorm (Stratéole-2 version)





Crédit: Mélody Pallu, LPC2E.

Calibration on background

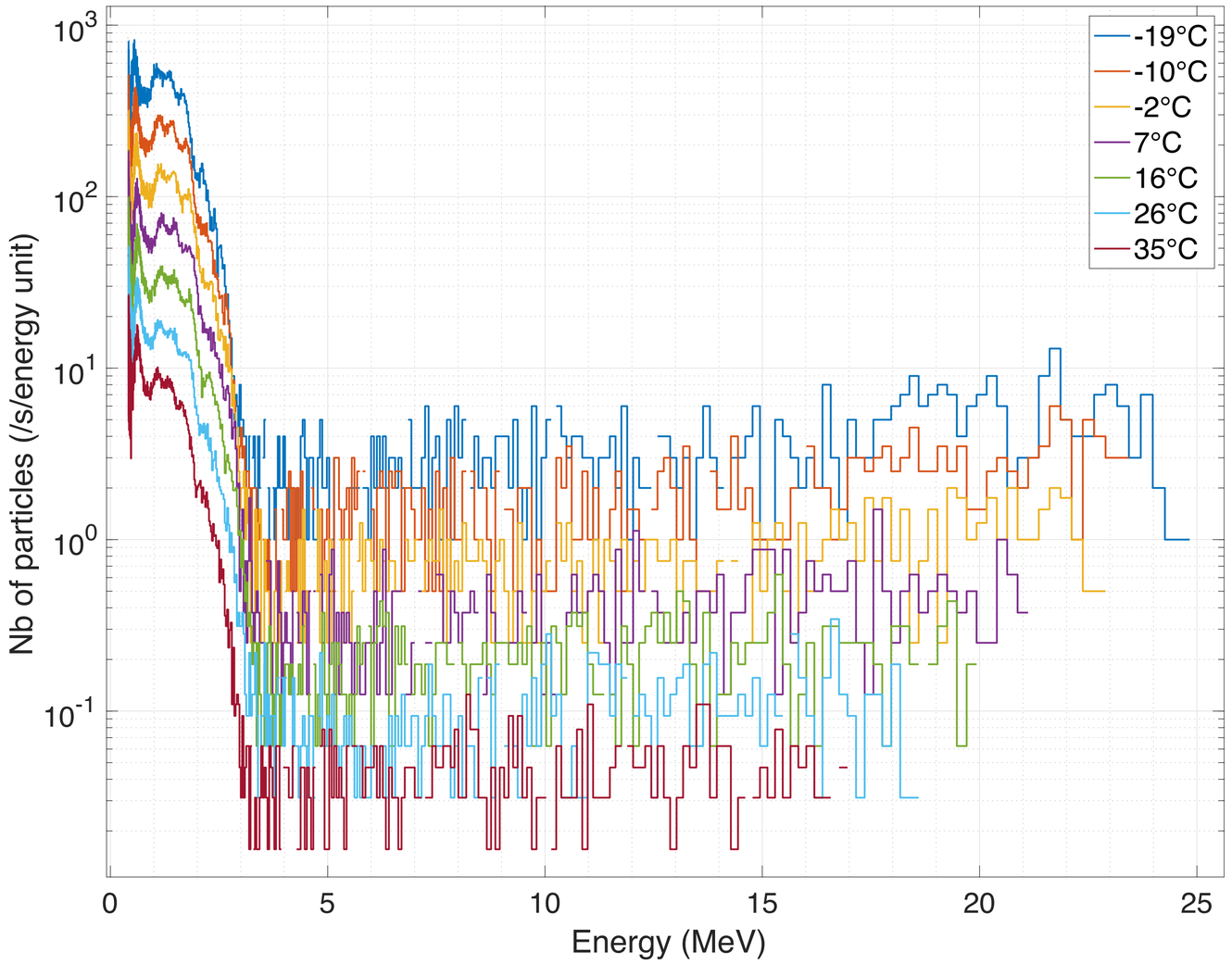


Background spectrum at LPC2E. Accumulation during 15h.

Gamma ray spectrometer performance

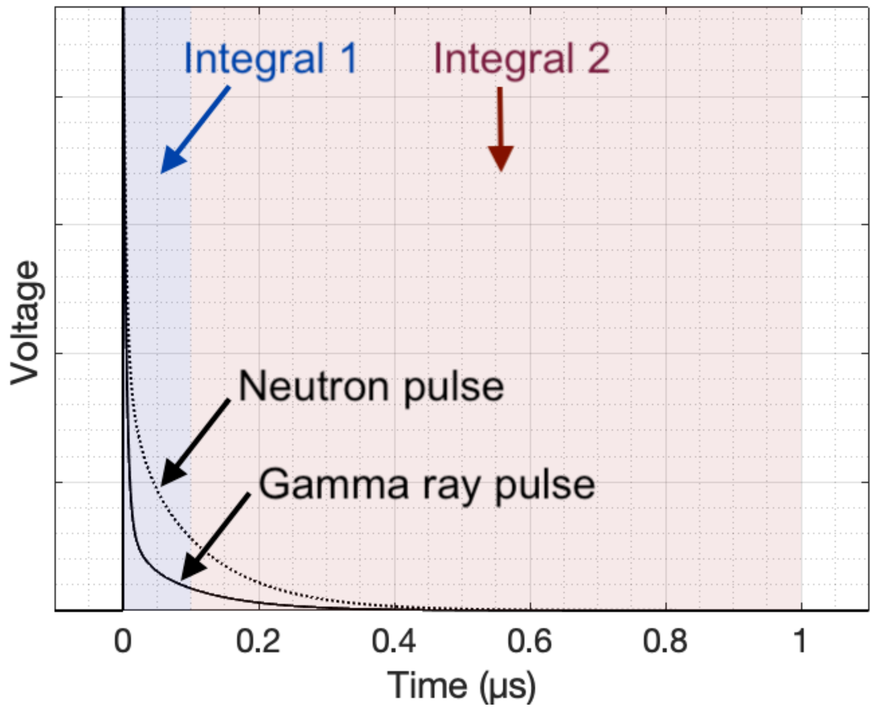
- Time-tagging accuracy: **100 ns** on UTC
- Energy range: **500 keV - 20 MeV**
- Relative energy precision: **~20%**
- Maximum rate: **~1 MHz** (pulse pile-up limited to 1 µs)
- Neutron discrimination in the plastic scintillator using a Pulse Shape Discrimination (PSD) method
- The whole data is saved on board and processed on the ground
- Temperature-stabilized response (see next slide)
- Tested under very high flux (TGF) with artificial pulses

Temperature-stabilized response

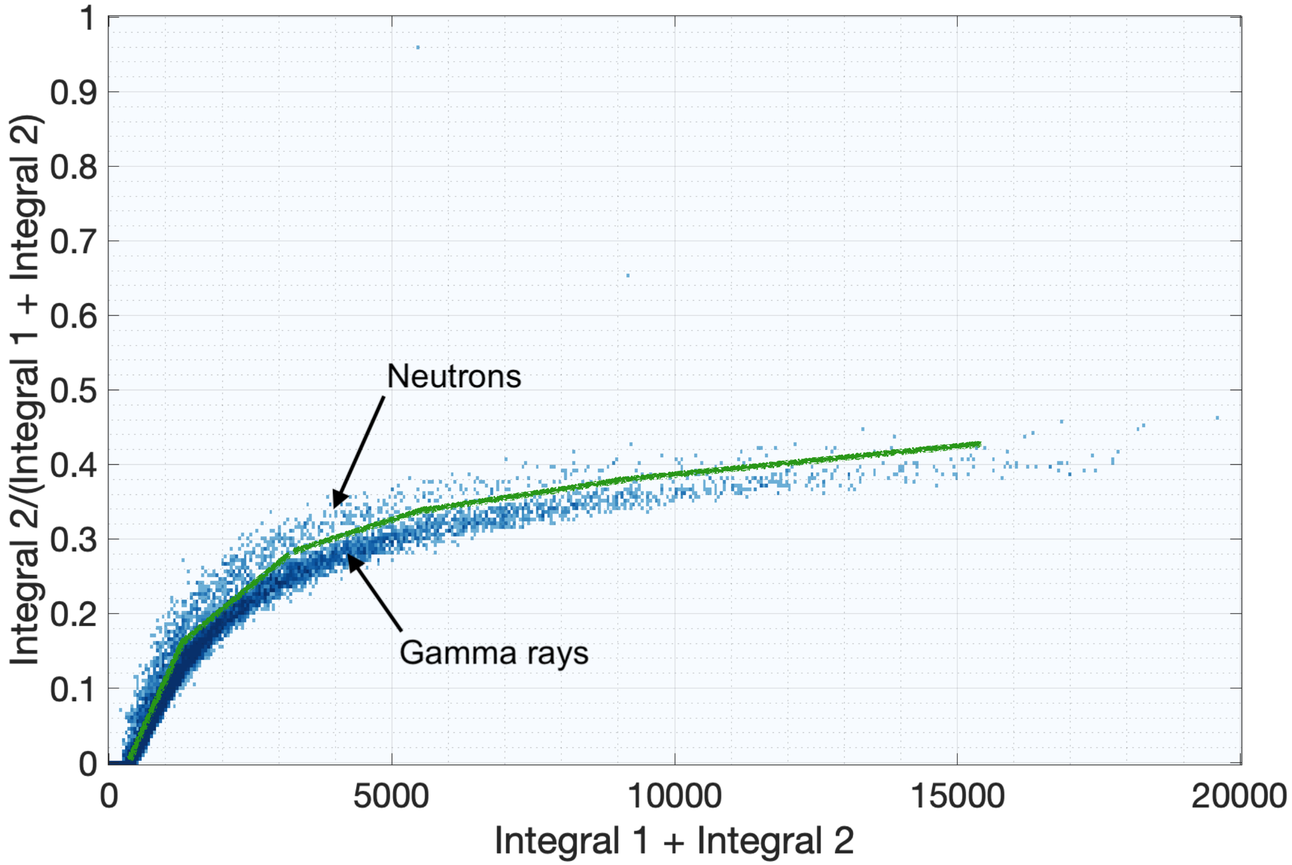


Stable background spectrum accumulated at various temperatures with the implementation of a temperature-dependent SiPM gain.

Neutron discrimination

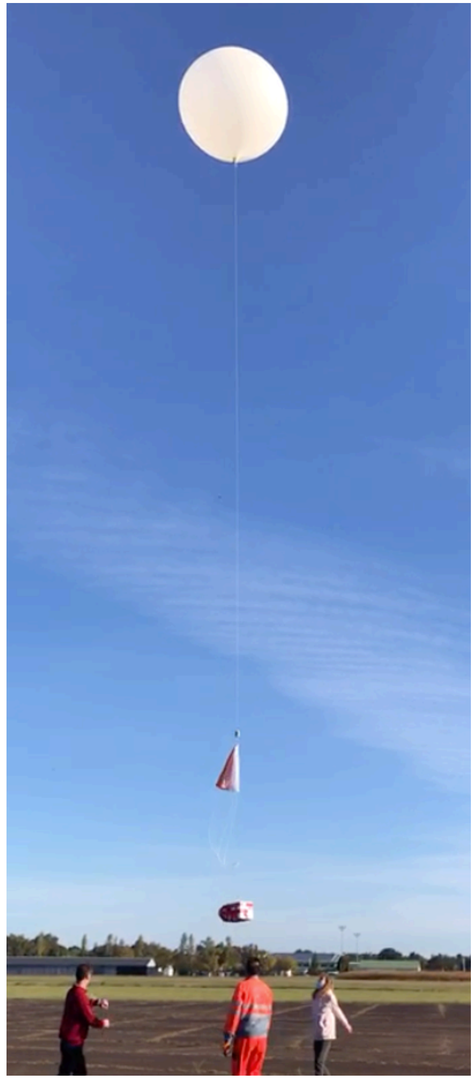


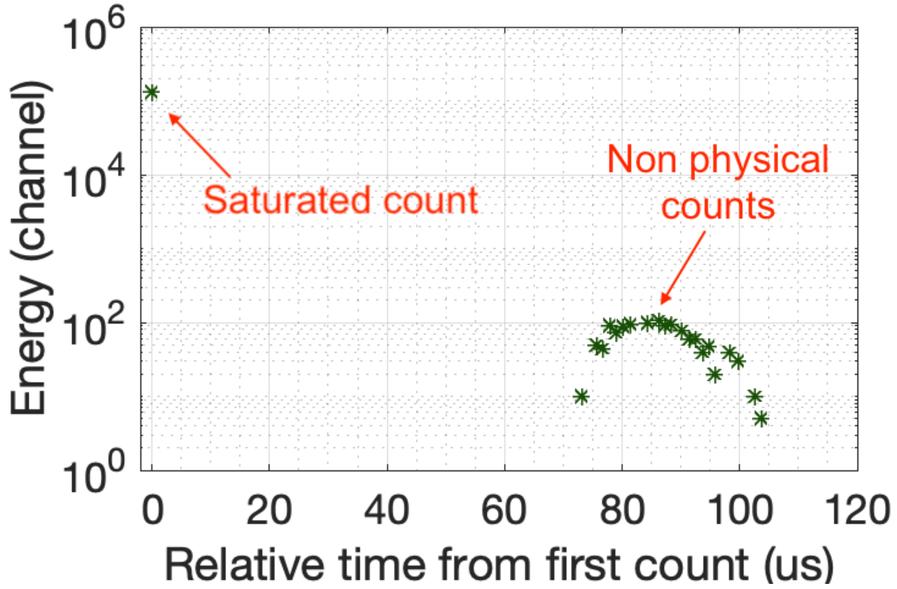
Pulse shape discrimination (PSD).



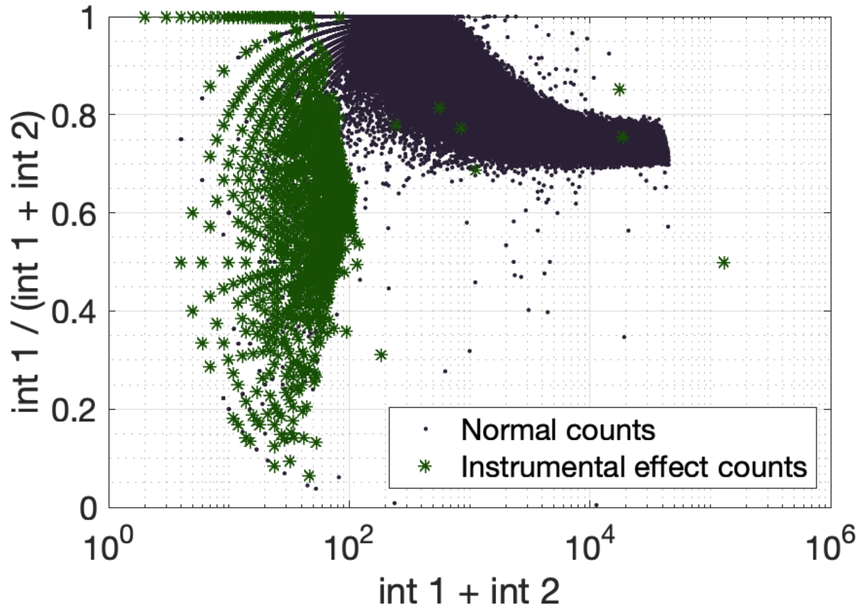
Discrimination evidence using our plastic scintillator (Source: Californium).

2020 & 2021 test flights (Stratofly & CNES)



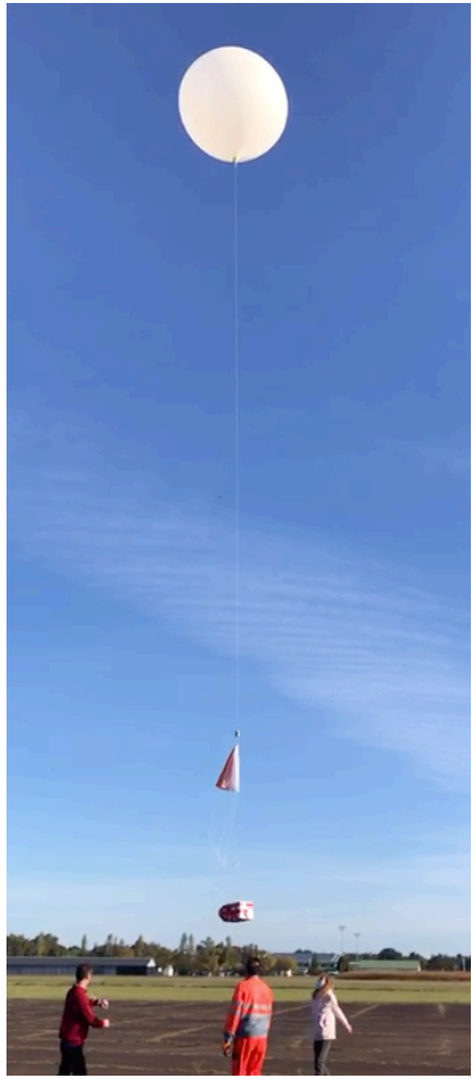


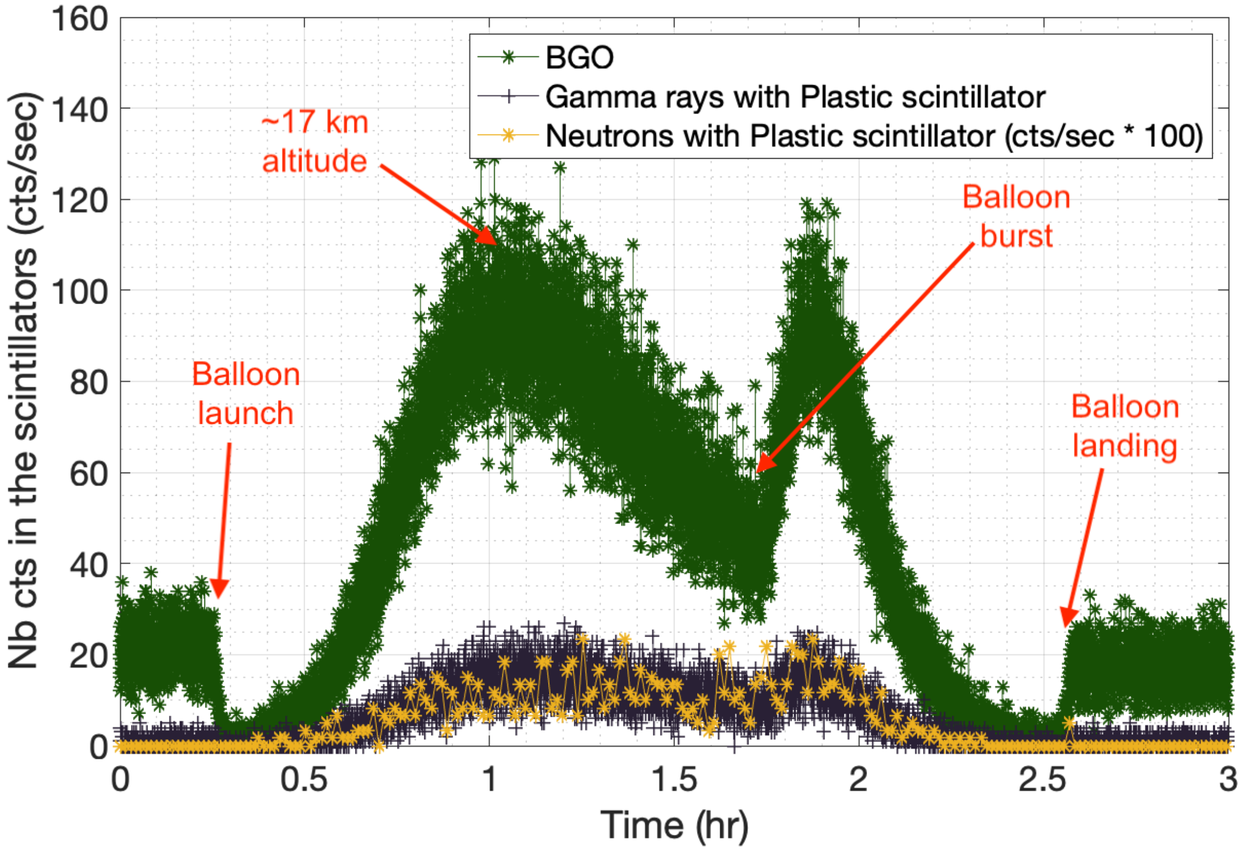
Spurious particle bursts generated by high-energy deposition in the sensor (474 for one test flight!)



Those spurious bursts can be rejected using the PSD in the BGO!

Oct. 2021 test flight (CNES)





Gamma ray and neutron profiles in the atmosphere. Cosmic ray neutron ~1% of particles as expected and none are detected from the ground.

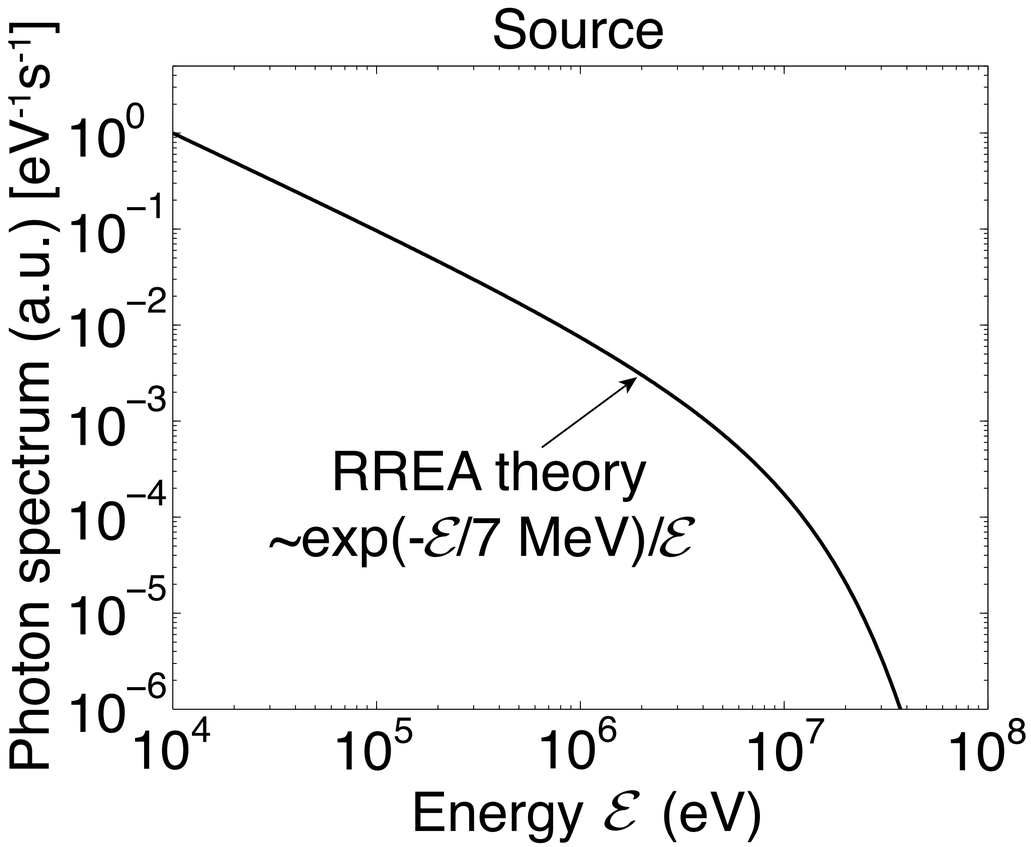
Conclusions

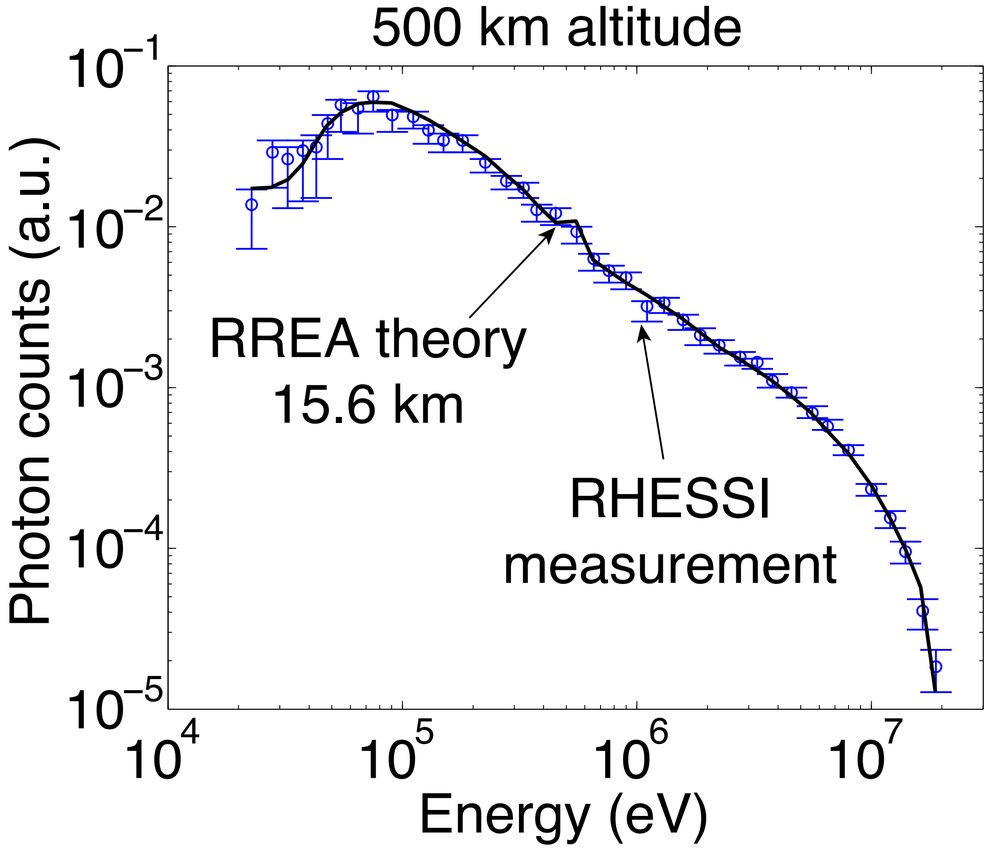
- XStorm is a lightweight gamma ray spectrometer designed to detect and characterize particle acceleration in thunderstorms
- Measuring spatial layout and dynamics of acceleration regions
- Gamma ray spectrometer *ready* / Field mill *in progress*
- OREO gondola design constrained by the electrostatic field measurement
- OREO launching strategies to be designed
- Next Stratéole-2 campaign: end of 2024. Deliver 4 XStorm + 1 spare

Thank you for your attention

OREO & STRATELEC projects are funded by CNES / CTB & SHM
We also acknowledge support from *Institut Universitaire de France* (IUF)

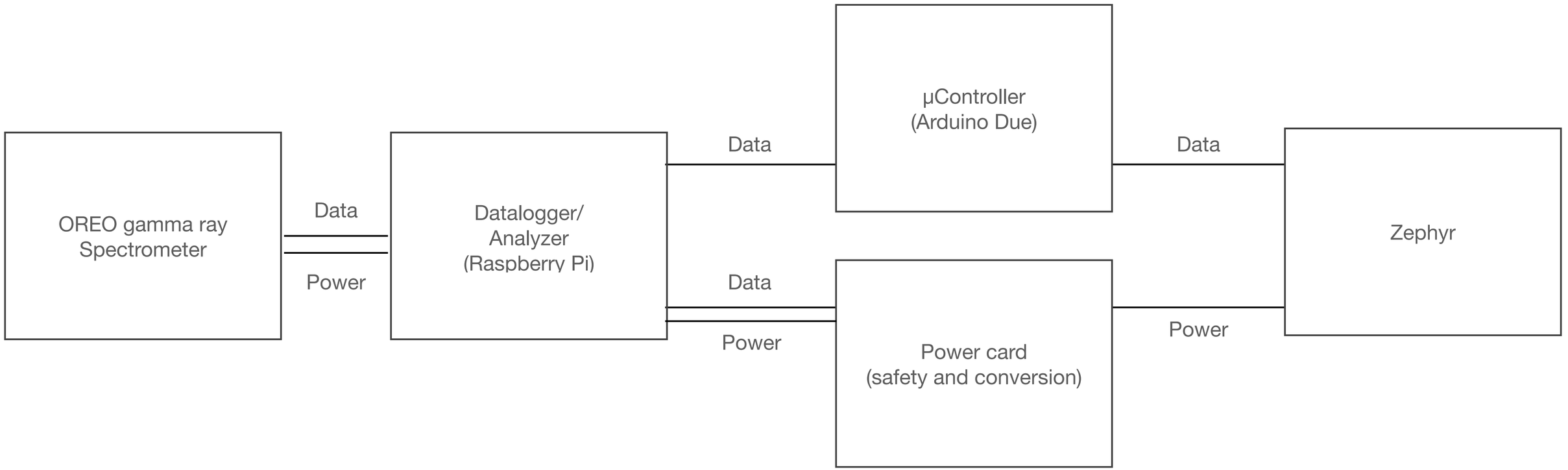
We're closing in…





- *But we have been closing in for over 15 years…* (above result obtained for the first time by Dwyer & Smith [GRL, 32, L22804, 2005])

STRATELEC-XStorm block diagram



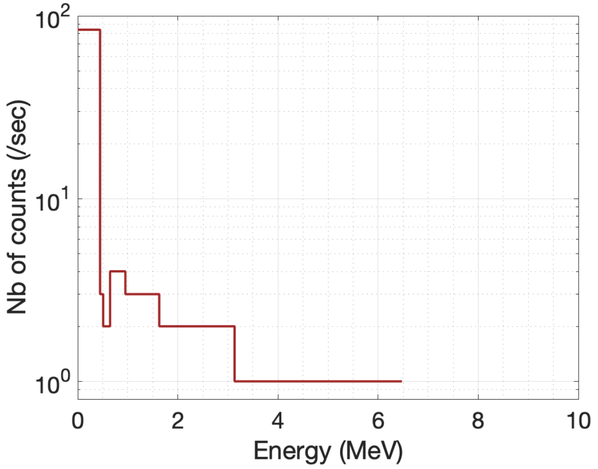
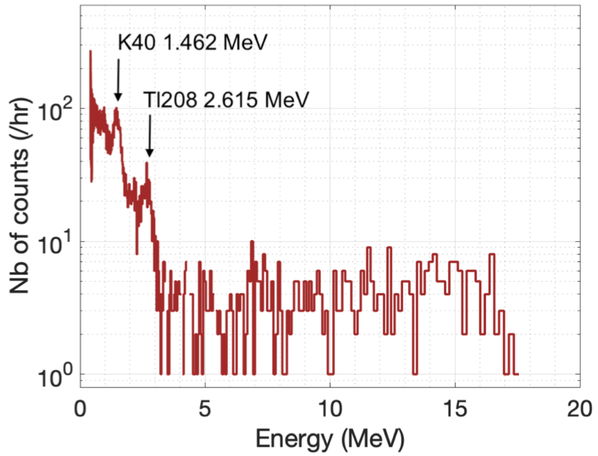
Architecture inherited from LOAC with significant adaptation

Working modes

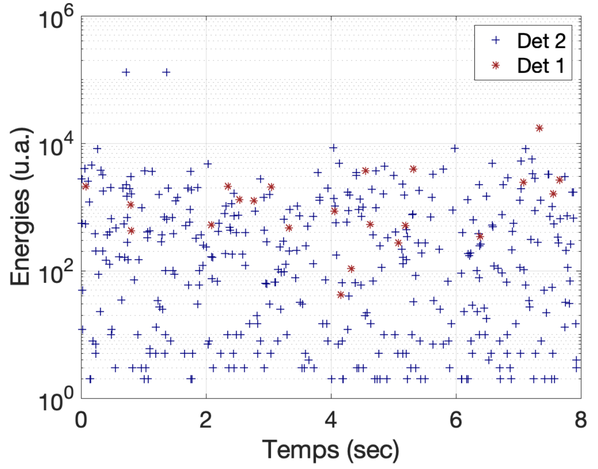
Two differents modes are possible to acquire data:

- In default mode, data available for every particle detected: arrival time + integral of the pulse $\rightarrow$ **too much data for a satellite communication link!**
- We needed to develop two observation modes:

SURVEY MODE

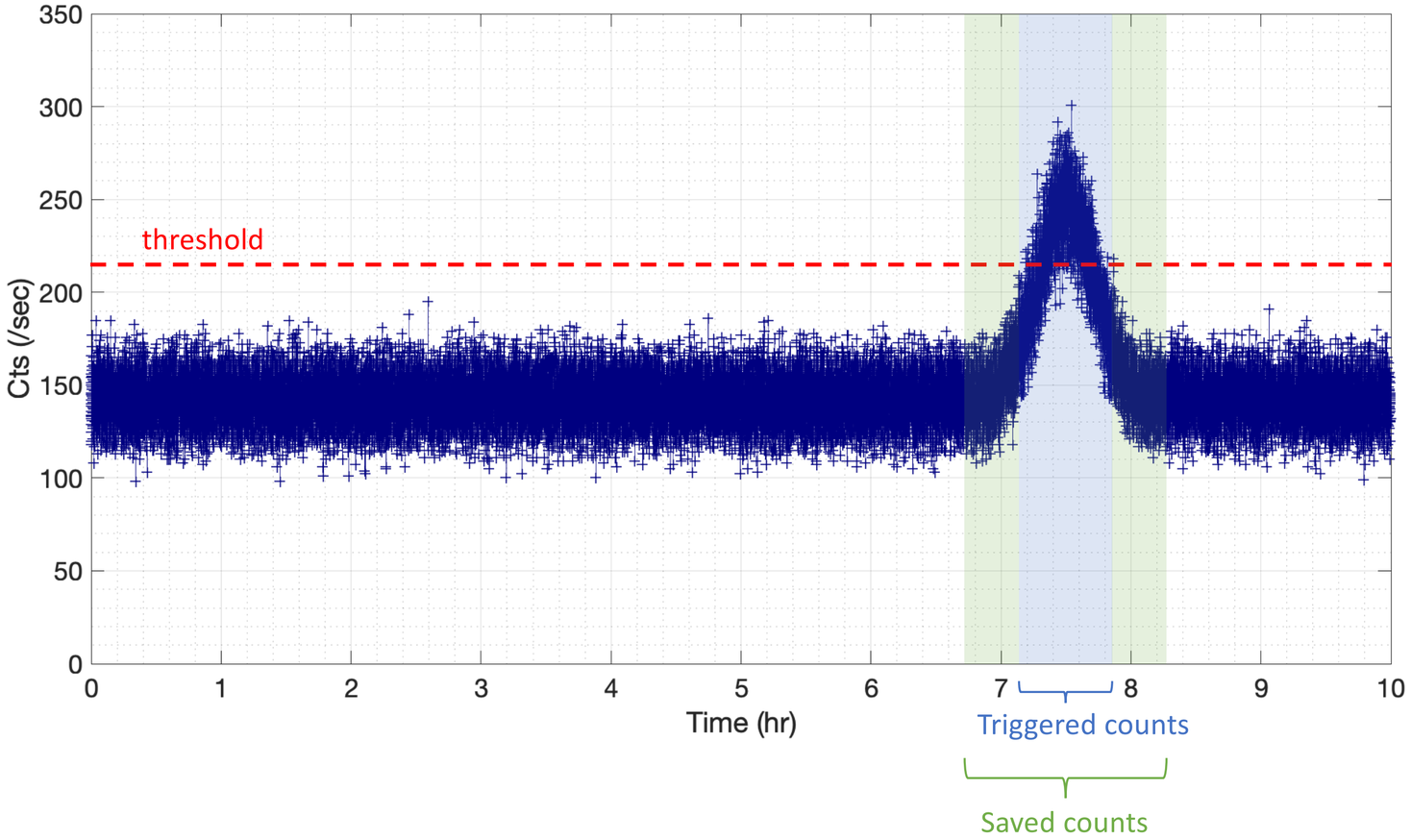
1/sec:	1/hr:
Low resolution spectrum (10 energy bins)	High resolution spectrum (1000 energy bins)
	

EVENT MODE

For each particle:
Arrival time + Energy


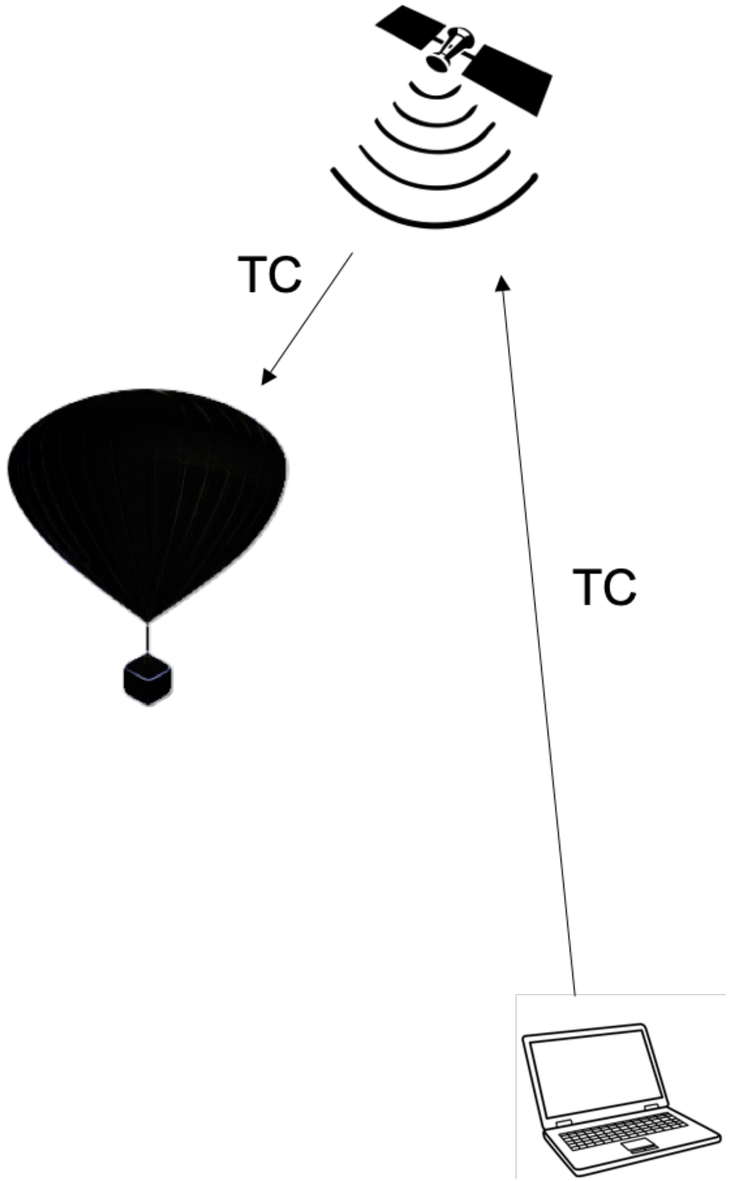
Event triggering protocol

- **Gamma Ray Glows:** Calculation of a threshold depending on the background radiation level (within 3h) based on **Poisson statistics to have less than 1 false-positive event per month** (see Figure)
- **TGFs:** The threshold is fixed at 5 counts in less than 100 μs to minimize the number of false positives



Example of a simulated glow

Strategy on TCs

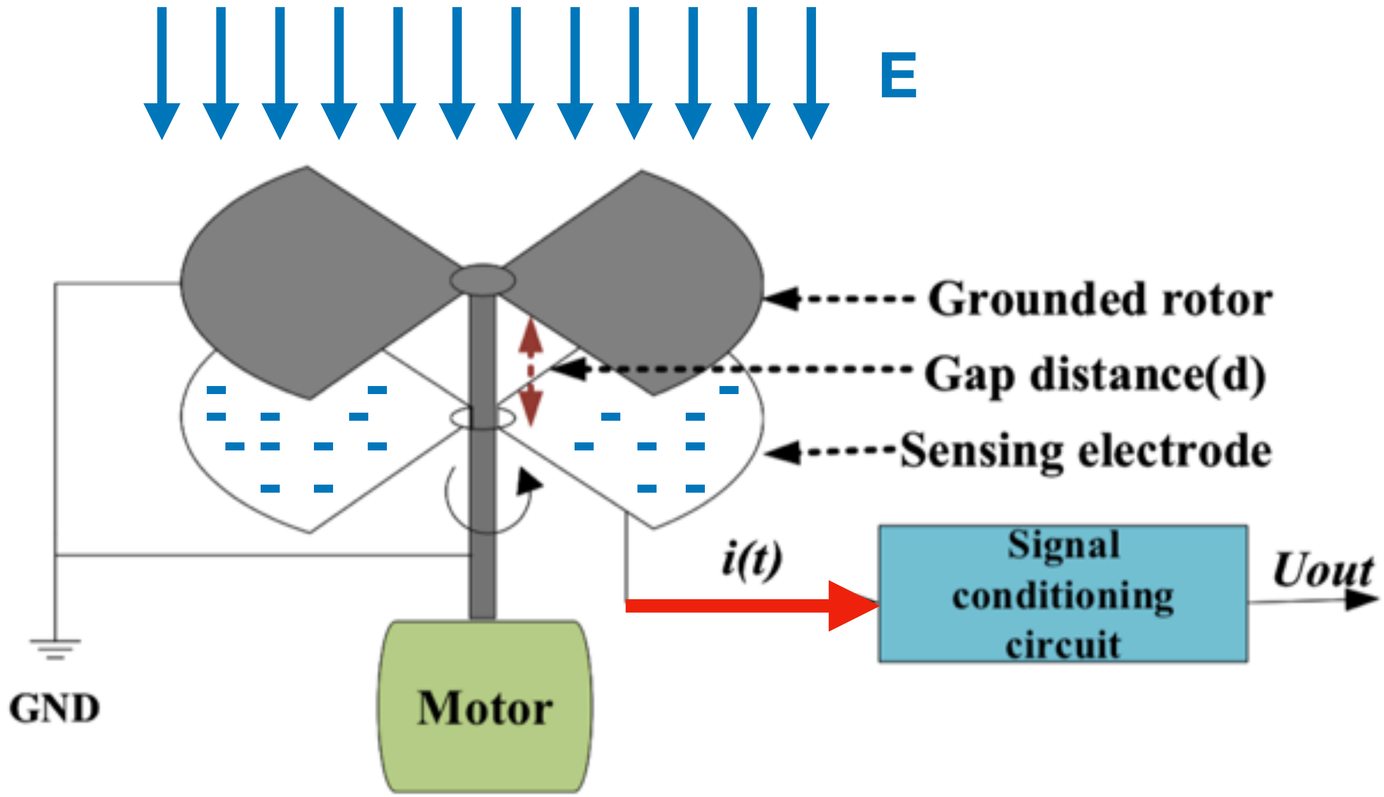


Several telecommands (TCs) have been implemented:

- Possibility to trigger an event from ground $\rightarrow$ get HR data for a given duration
- Possibility to change some parameters in the code (criteria for the thresholds, configuration parameters, ...)
- Possibility to delete all the data on the RPi in case of problem
- Possibility to make changes on the data logger/analyzer (RPi) directly with BASH commands

Electrostatic field instrument: field mill

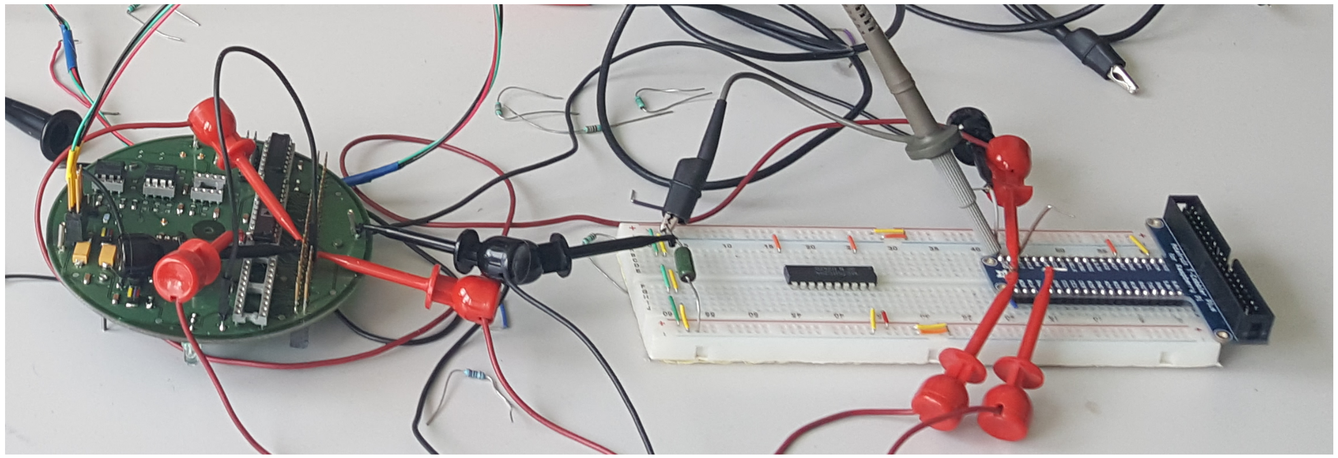
Principle



Reproduced from [Cui et al., IEEE Trans. Ind. Elec., 65, 608-615, 2018]

Field Mill

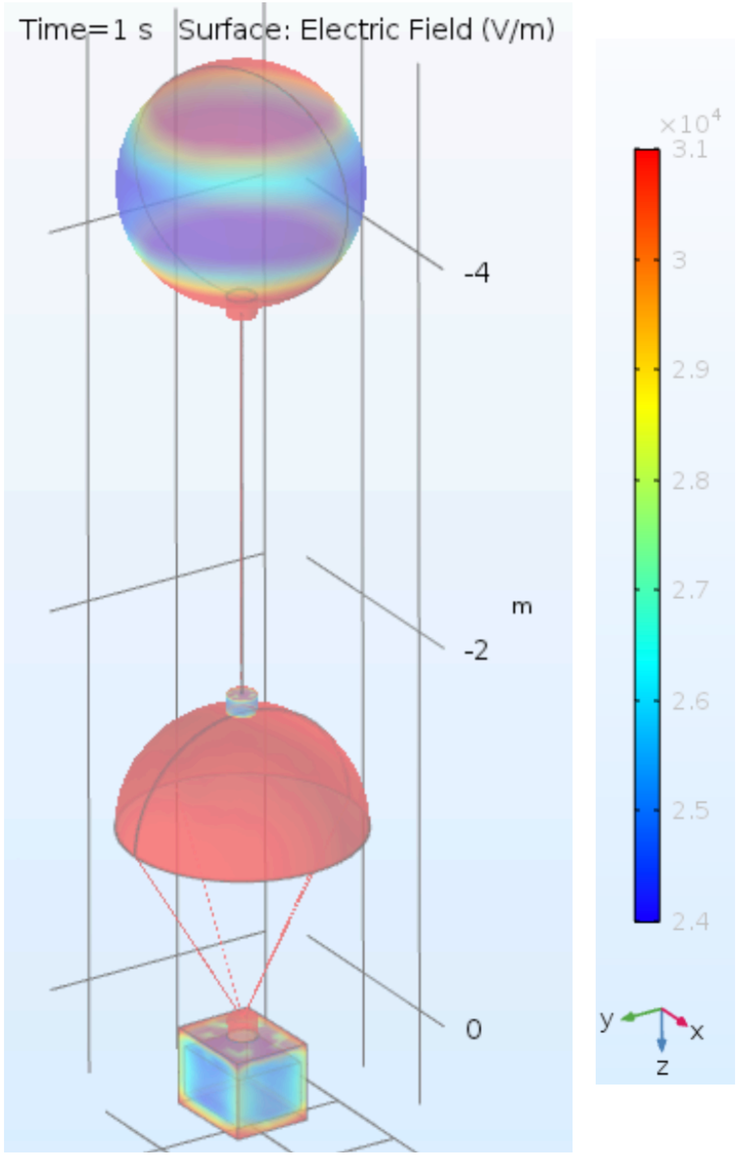
Status



Front-end electronics developed at LPC2E (credit: Ted Hachemi)

To do

- Charge amplifier to be tested (expected perf.: <0.5-10 kV/cm)
- Whole sensor system to be tested in lab / on ground
- Whole system to be tested in flight



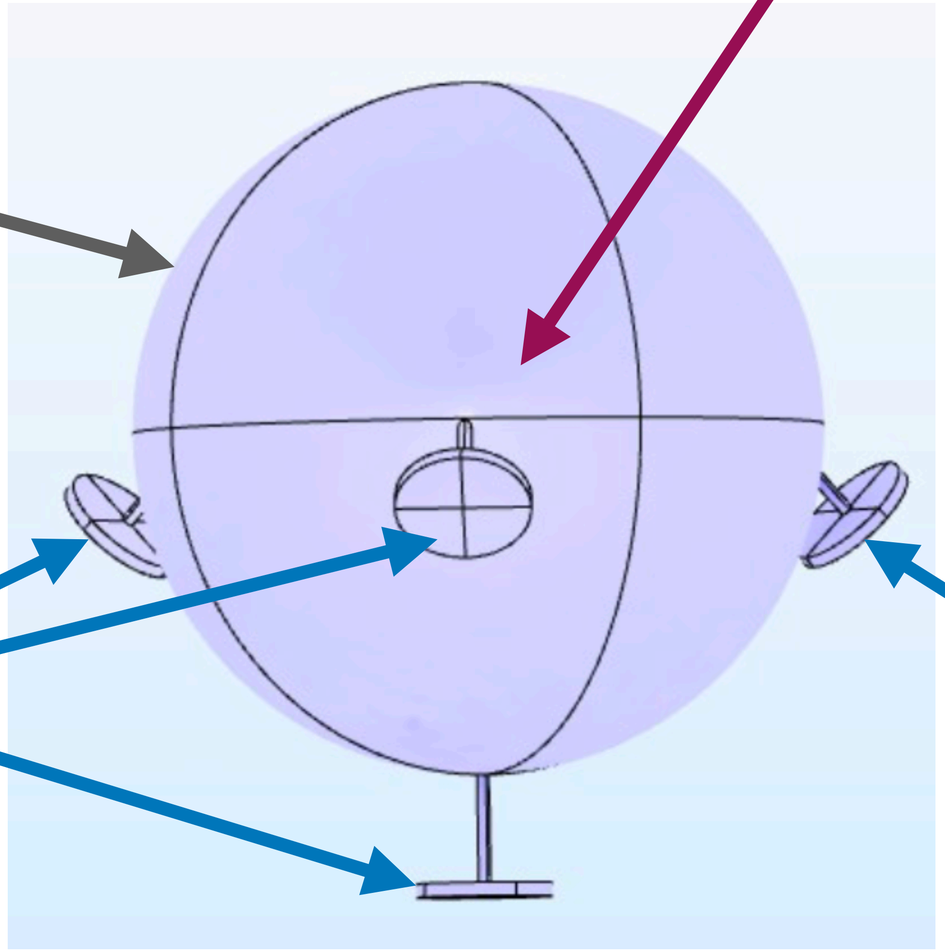
Calculation of the electrostatic field perturbation by the box

Gondola design

In progress

Gamma ray spectrometer + electronics inside

Conducting wrapping
(e.g., aluminum foil)



Field mills

Field mill