CENTRO FERMI
MUSEO STORICO DELLA FISICA E CENTRO STUDI E RICERCHE ENRICO FERMI

CENTRO RICERCHE ENRICO FERMI

INFN
Istituto Nazionale di Fisica Nucleare

Consiglio Nazionale delle Ricerche

CERN

INRiM
ISTITUTO NAZIONALE DI RICERCA METROLOGICA

Società Italiana di Fisica

PolarquEEEst

Raggi cosmici dall'Italia al Polo Nord

Luisa Cifarelli
University and INFN Bologna

Extreme Energy Events
Science inside Schools

POLARQUEST2018
81°14'N, 25°25'E
POLAR QUEEEst 2019
EEE@NyAlesund

Cosmic rays

- Every second each m^2 of the Earth is struck by several 10^3 **charged particles** travelling from **deep space** → **cosmic rays**
- Cosmic rays discovered more than a century ago but still very interesting and challenging to study
- Cosmic rays produced by astrophysical sources: stars (like the **Sun**) and exploding stars … Their origin is galactic and extra galactic
- The origin of very high-energy cosmic rays is a big mystery …
- But cosmic rays are also of interest beyond astrophysics → open questions
  - cosmic rays may influence cloud formation ? → implications for the evolution of Earth's climate
  - cosmic rays may trigger lightning ?
  - …

Cosmic ray showers

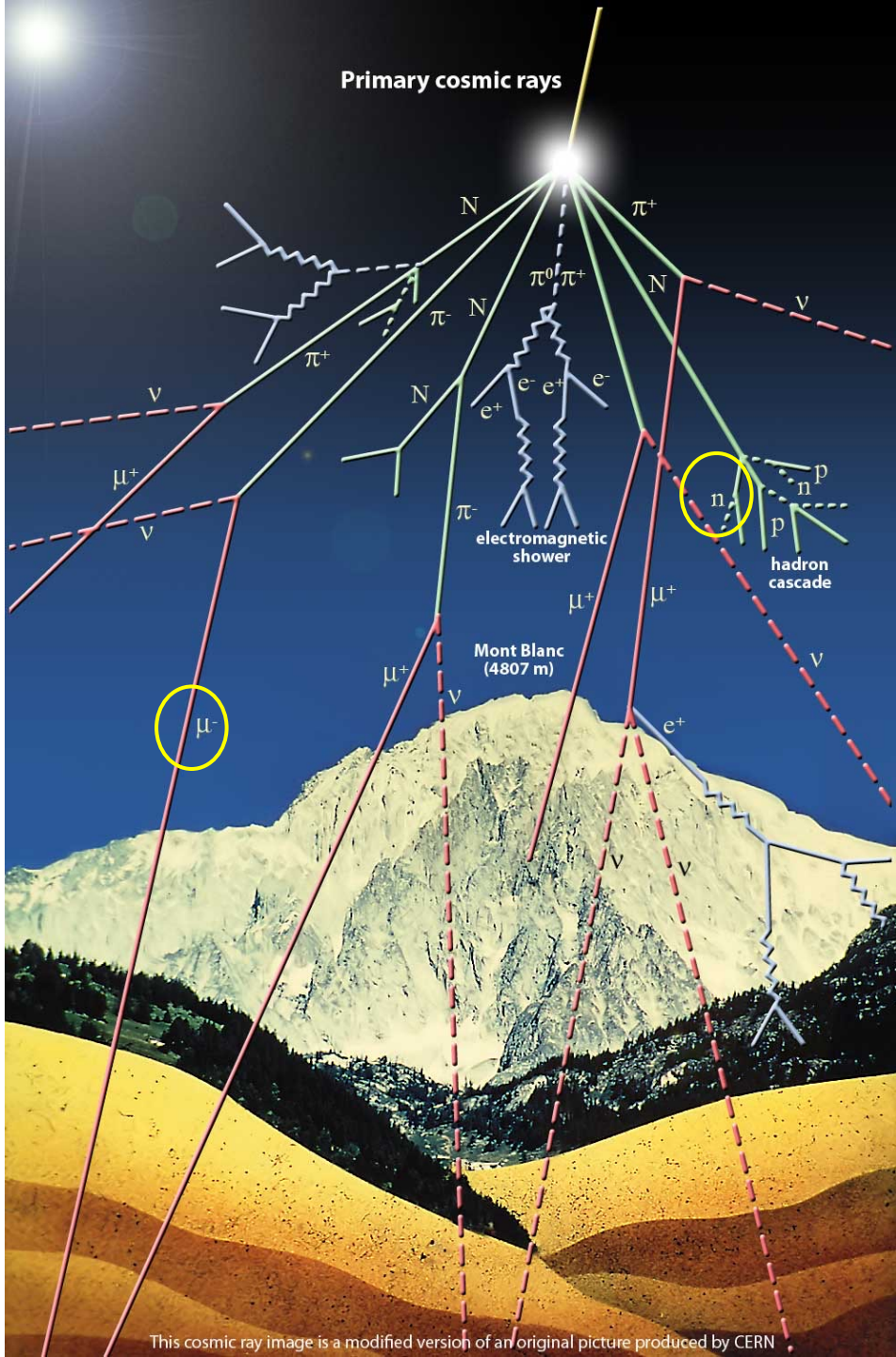
Apart from solar flares, **primary** cosmic rays come from outside the solar system

Primary cosmic rays (e, p, N) interacting with atoms and molecules in the atmosphere

→ Showers of **secondary** cosmic rays

Muon flux at sea level
≈ 1 muon / cm^2 min

Most of the (secondary) cosmic rays are **muons**



The EEE Project

Observatory to study cosmic rays on ground in Italy

- Proposed by A. Zichichi in 2004
- Presently coordinated by Centro Fermi and INFN in collaboration with CERN, INRIM, CNR, SIF and various universities

The EEE Project consists of about **60 telescopes** and allows unique studies of cosmic rays & cosmic showers including a search for very long distance correlations between cosmic showers

The EEE **telescopes** are each made of three **MRPCs** (Multigap Resistive Plate Chambers) **built at CERN by high-school students** which are installed and monitored in **high schools** by the students themselves

→ Extreme Energy Events – Science Inside Schools (EEE)

Physics goal of EEE Project

Detect atmospheric showers of very high or extreme energy by detecting secondary muons on ground coming from very high energy primary cosmic rays

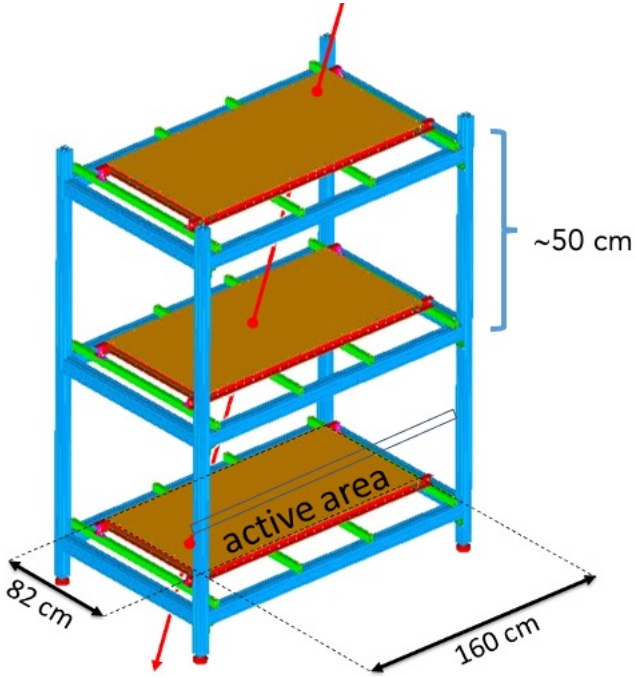
The EEE Project

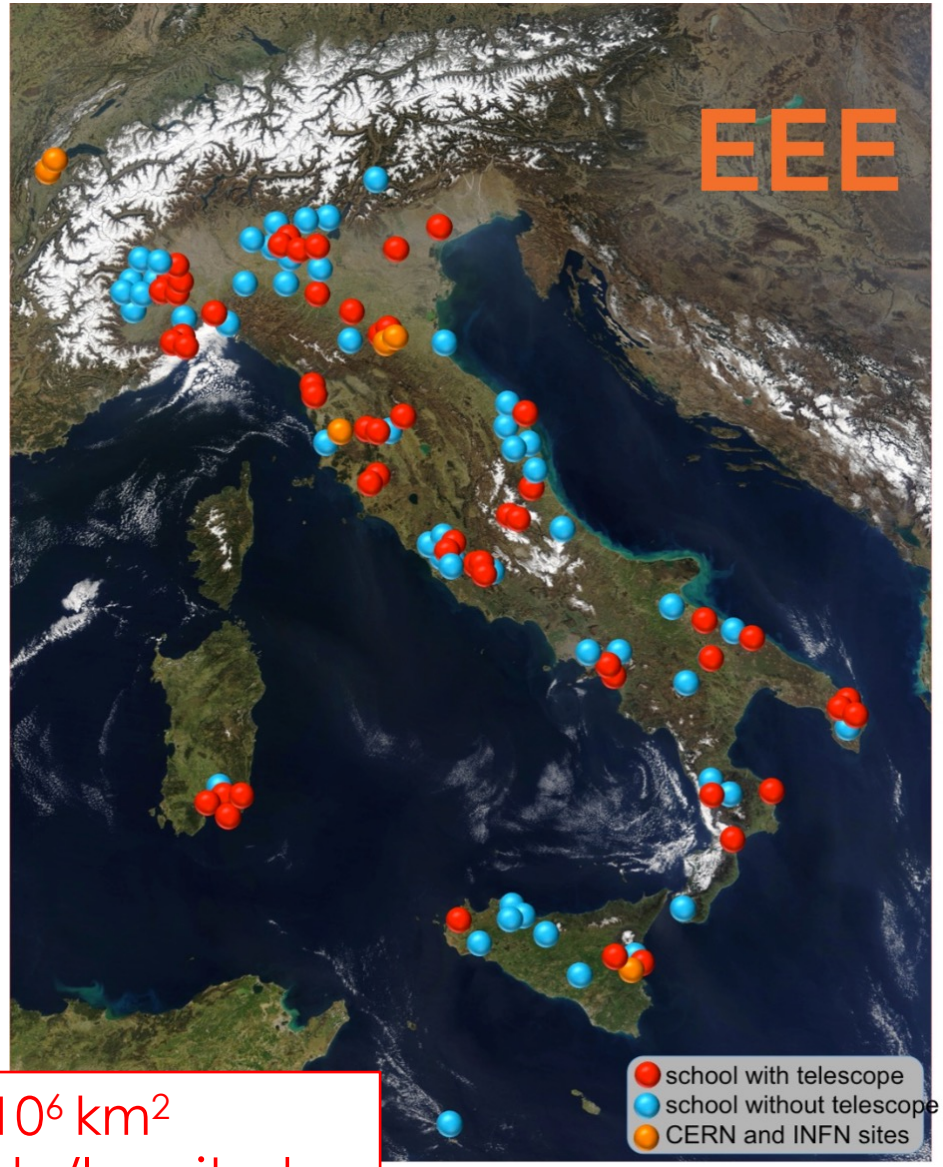
Extreme Energy Events
Science inside Schools

Dual role

- Cosmic ray **observatory**
- Scientific education tool

≈ 60 MRPC tracking telescopes in High Schools

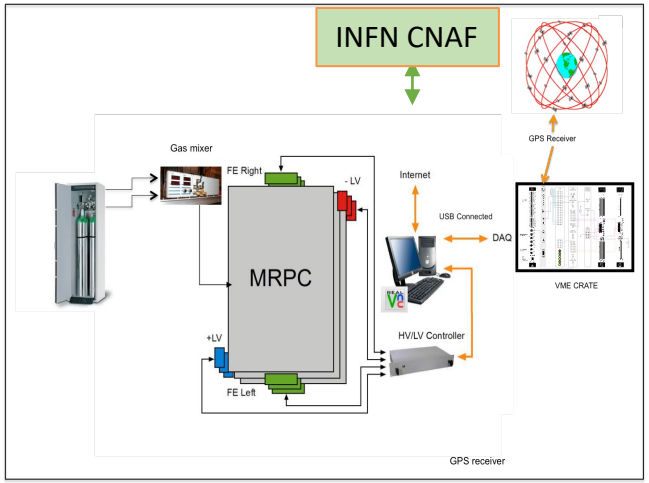




≈ 0.5 x 10^6 km^2
≈ 10° of latitude/longitude

The EEE Project

Extreme Energy Events
Science inside Schools



- Time stamp via GPS
- Data taken an transferred to INFN CNAF for track reconstruction & storage
- Overall statistics **since 2015**
  (yearly data taking runs of ≈ 50 telescopes)

→ **110 billion cosmic rays reconstructed & analysed**

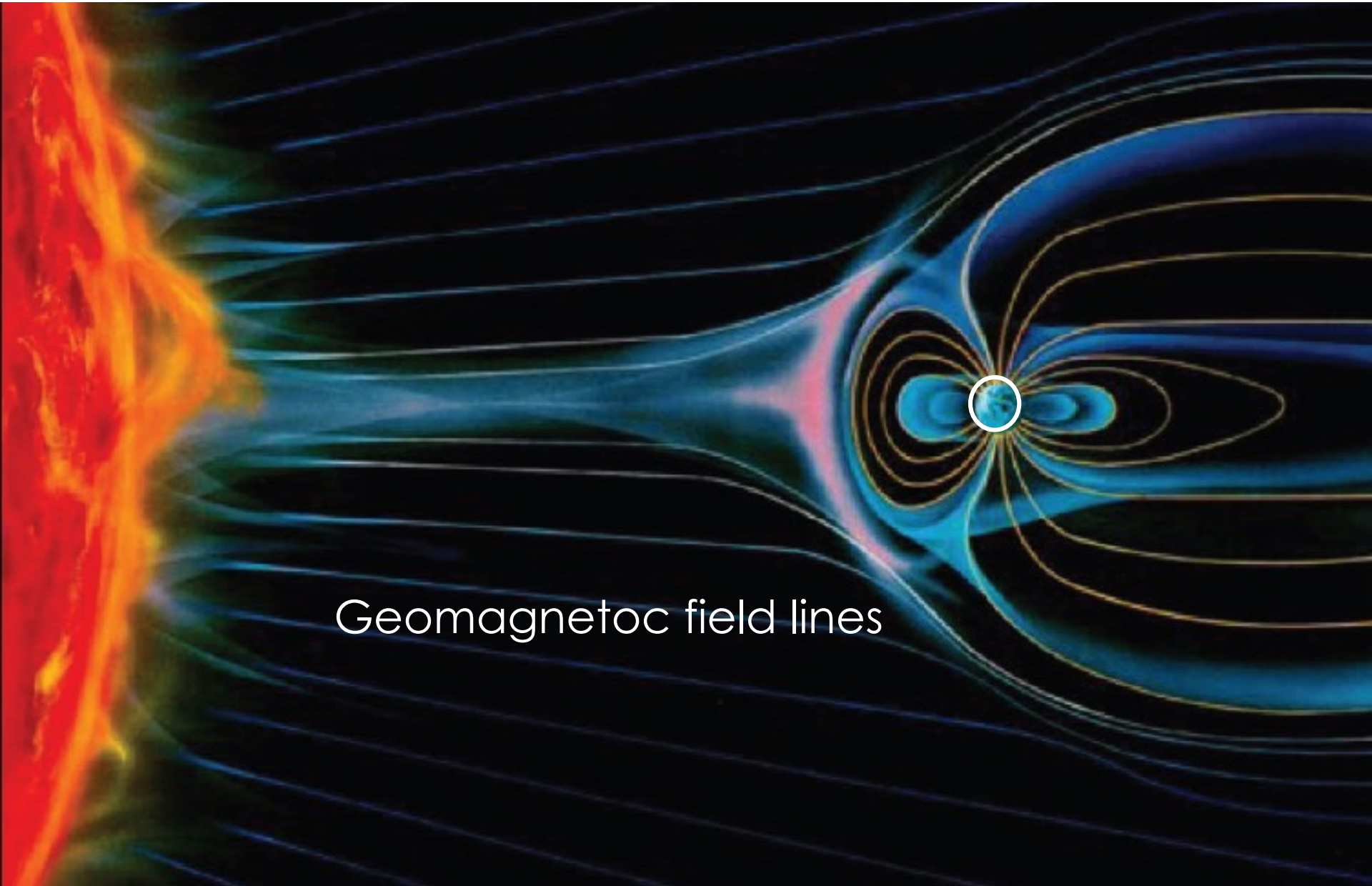
→ the EEE project allows many physics studies

BUT to study

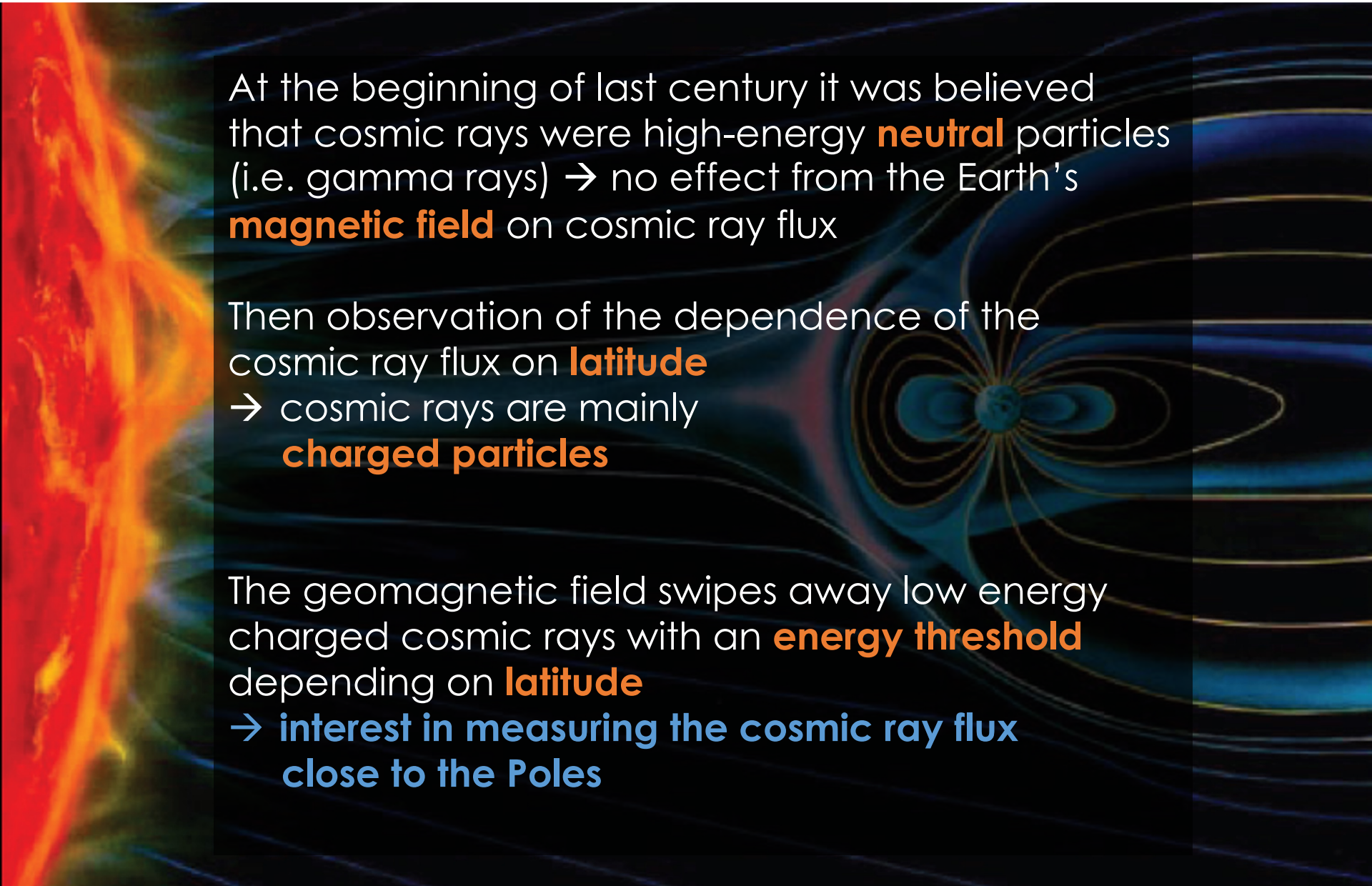
- the **effects of latitude** on cosmic ray flux over a large interval (≈50°)
- **very, very large distance** (several 10^3 km) shower correlations ...

→ the EEE project sails to North Pole !

Cosmic ray flux on Earth



Cosmic ray flux on Earth



At the beginning of last century it was believed that cosmic rays were high-energy **neutral** particles (i.e. gamma rays) → no effect from the Earth's **magnetic field** on cosmic ray flux

Then observation of the dependence of the cosmic ray flux on **latitude**
→ cosmic rays are mainly **charged particles**

The geomagnetic field swipes away low energy charged cosmic rays with an **energy threshold** depending on **latitude**
→ **interest in measuring the cosmic ray flux close to the Poles**

The EEE project sails to North Pole !

Polar QuEEEst 1928 – 2018

Airship Italia mission – 1928

Sailboat Nanuq mission – 2018

To measure cosmic ray flux
with 3 detectors
40° in latitude span
5000 km distance

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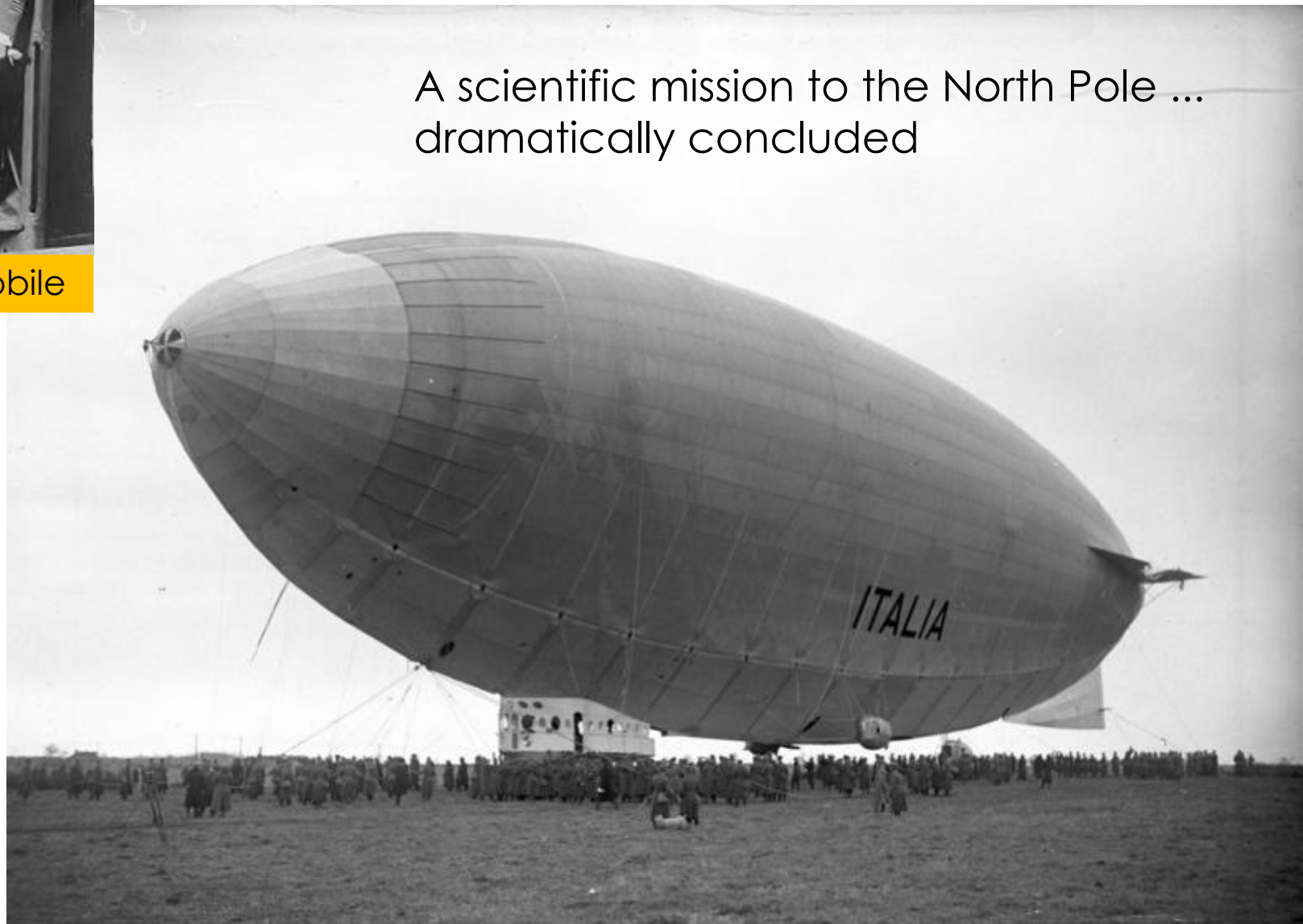
Extreme Energy Events
Science inside Schools

The ITALIA airship mission – 1928

Umberto Nobile

A scientific mission to the North Pole ...
dramatically concluded



Italia identical to the **Norge** airship both built in Ciampino, Rome, Italy

The Norge in 1926 **successfully reached the North Pole for the first time in history** travelling from Kings Bay (Ny Ålesund), Svalbard Islands to Alaska

The expedition included:

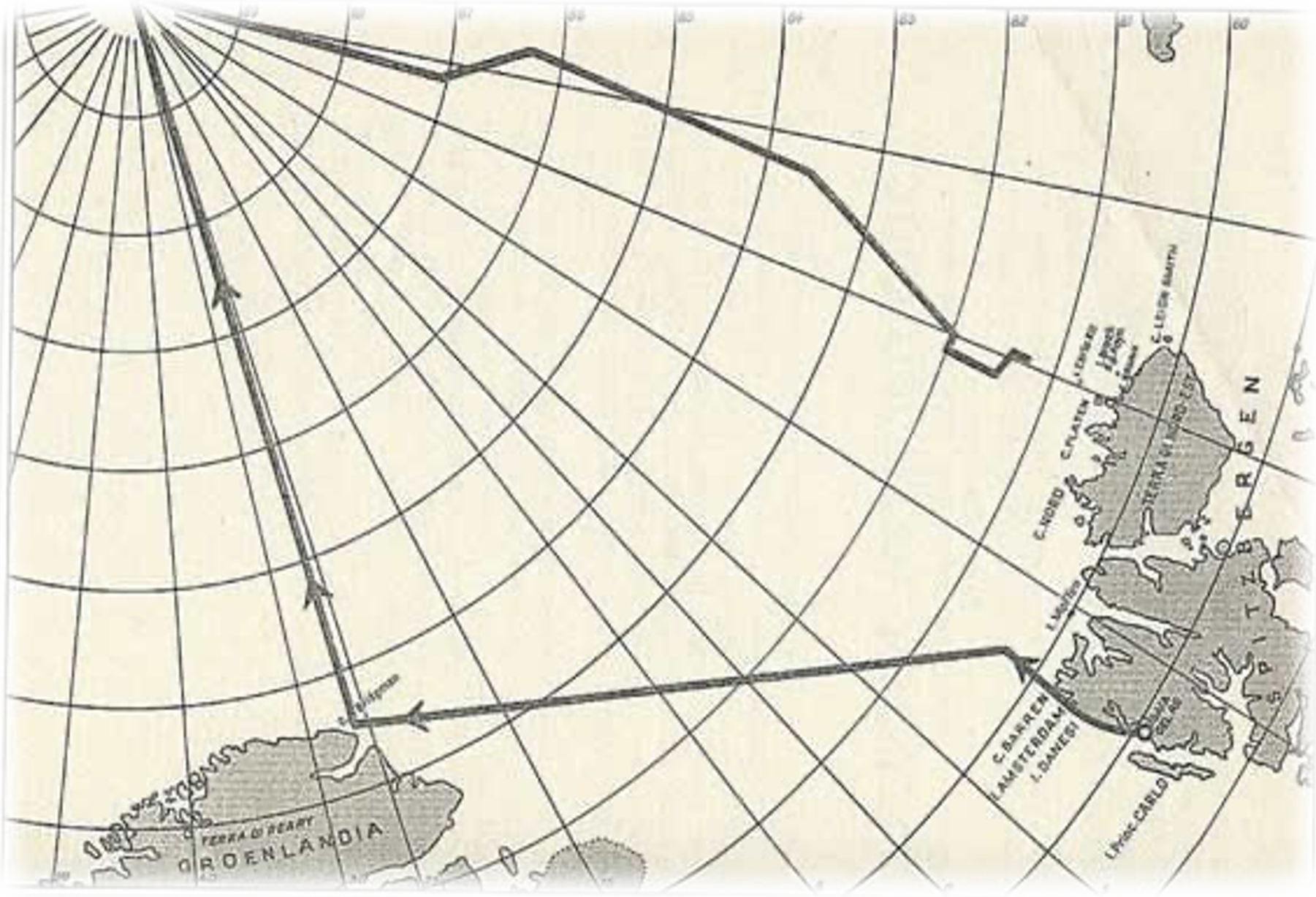
- Roald **Amundsen** (Norway), the expedition leader and navigator
- Umberto **Nobile** (Italy) the airship's designer and pilot
- Lincoln **Ellsworth** (USA), polar explorer and expedition sponsor

Aldo Pontremoli
Finn Malmgren

František Běhounek

At Ny Ålesund – Svalbard Islands

At Ny Ålesund – Svalbard Islands



The route of the ITALIA airship


DOMENICA DEL CORRIERE
Anno 63 - N. 3 - L. 40
Settimanale del CORRIERE DELLA SERA
15 gennaio 1961
La catastrofe della spedizione Nobile. Al ritorno dall
svolata polare l'aeronave precipita sulla
pittore Walter Molino ricostruisce
SPITZBERGEN

POLAR QUEST 1928 2018

The **eco-friendly vessel Nanuq** was used, especially designed for the Arctic, with passive technology, low consumption, low waste etc.

On board of Nanuq, a diverse team of researchers, science communicators, and sailors, carried out valuable **scientific investigations** about the Arctic environment and the impact of human activity on its fragile ecosystems

The expedition crossed the **80th parallel** North, into uncharted waters in the Northeast of the **Svalbard archipelago**

→ Complex expedition, with scientific and technological challenges and a sense for adventure

Thanks to Paola Catapano (CERN) Expediton Leader

The scientific motivation of the POLARQUEST expedition performed in 2018 on board of Nanuq around the Svalbard Archipelago was:

– measurement of cosmic rays at unprecedented northern latitudes where no systematic and accurate sea-level measurements have ever been performed

– investigation of the Arctic environment threatened nowadays by many factors, such as macro/microplastic pollution or temperature growth

– air (with drone) and water (with multibeam sonar) exploration of unknown Artic areas

In addition the mission had a **celebration** purpose and gathered at the Svalbard Islands the descendants of the participants of the airship Italia tragic expedition of 1928

→ POLARQUEST was a polar expedition melting adventure, science and history

PolarquEEEst

GOAL: Measure cosmic rays at extreme latitudes

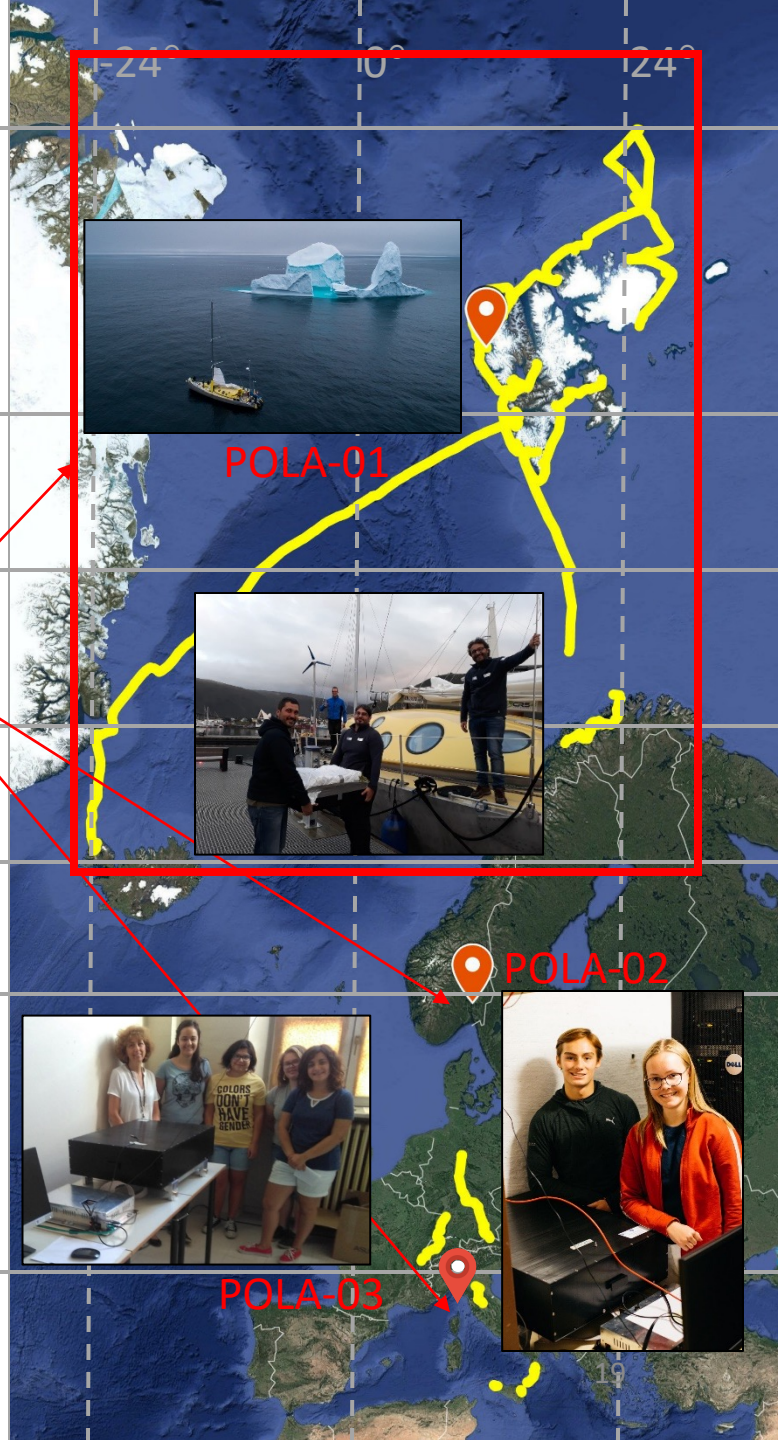
2018

PolarquEEEst2018

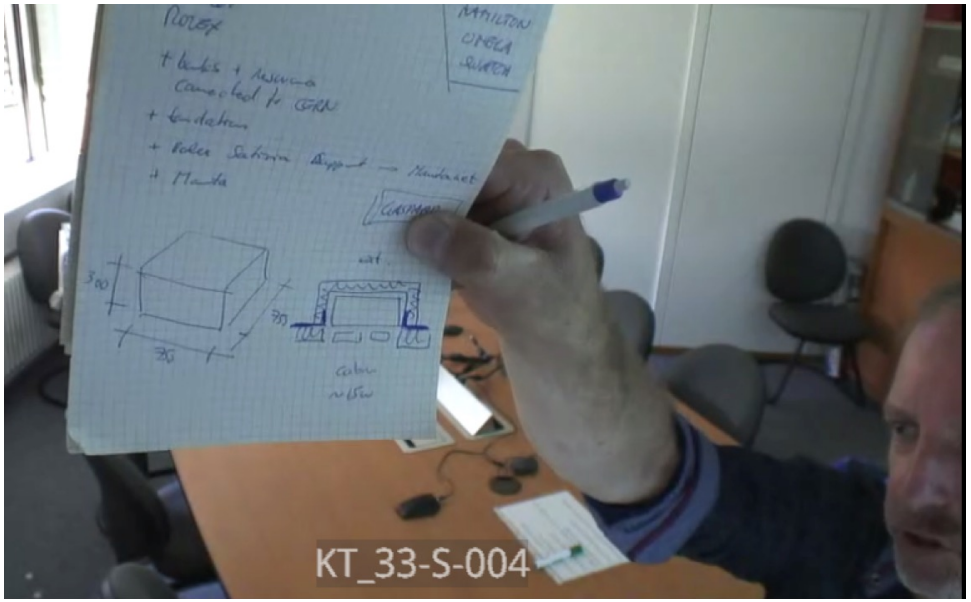
- 3 detectors (POLA-01, POLA-02, POLA-03)
- PolarquEEEst2018 → mission on board of sailboat Nanuq (Jul – Sept 18) +
  2 detectors at fixed sites: Bra (Italy) and Nessoden (Norway)

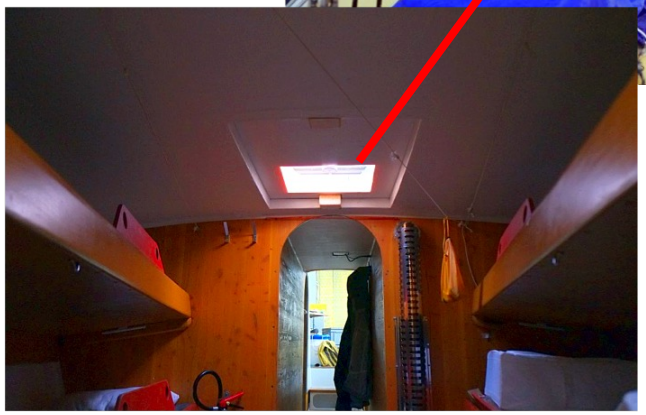
2019

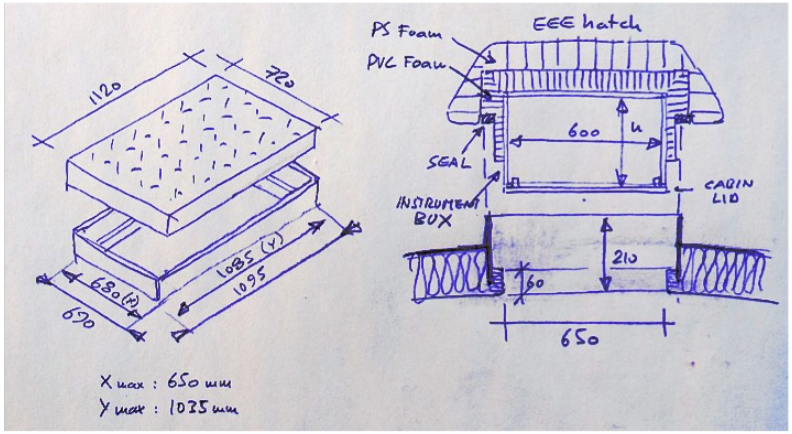
- (Dec 18 – Apr 19) → measurements at different latitudes (Italy, Germany, CERN)
- Construction of 4th detector (POLA-04)
- PolarquEEEst2019 → installation of 3 detectors at Ny Ålesund (Svalbard)



Requirements
for PolarQuEEEst detector





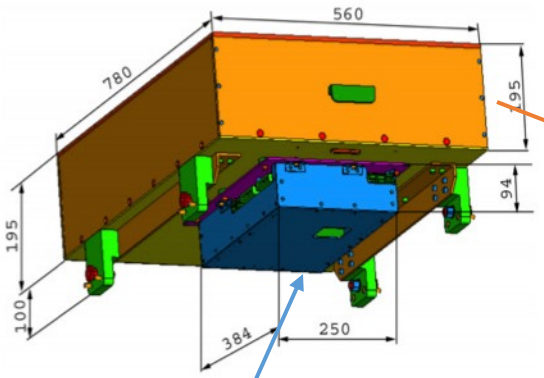


The Detector on the Polar Nanuq boat has been designed to fulfill the requests on

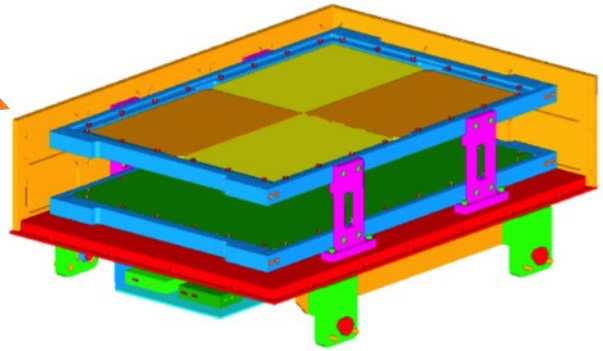
- dimension
- weight (~ 50 kg)
- power consumption (< 15 W)

The detector

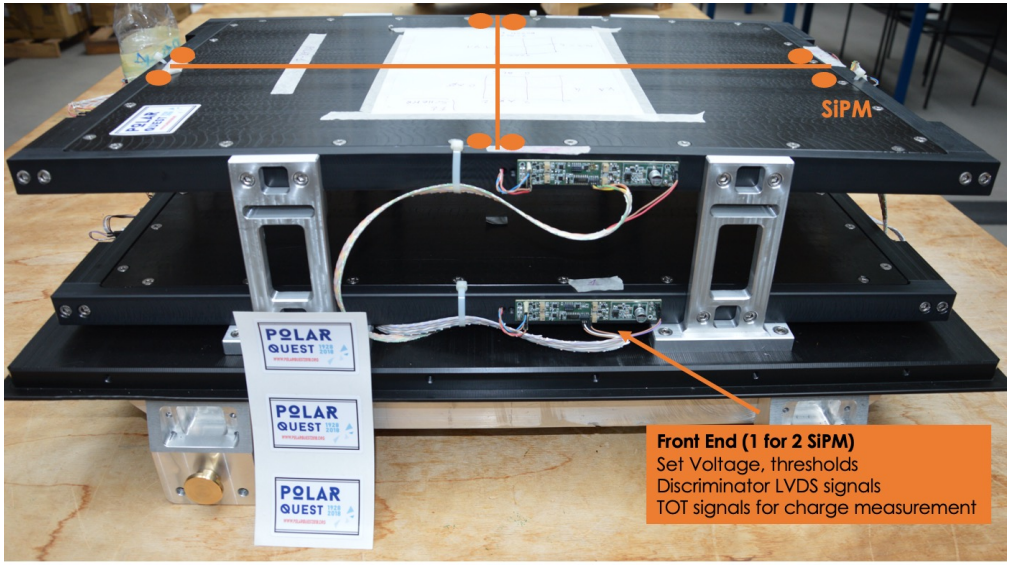
- 2 planes of plastic scintillators
- 4 tiles/plane: 30 x 20 cm^2
- Distance between planes: 11 cm
- 2 SiPMs/tile
- Efficiency > 96%
- Trigger: coincidence of signals from both planes (signals from at least 3 SiPMs)



Electronics box

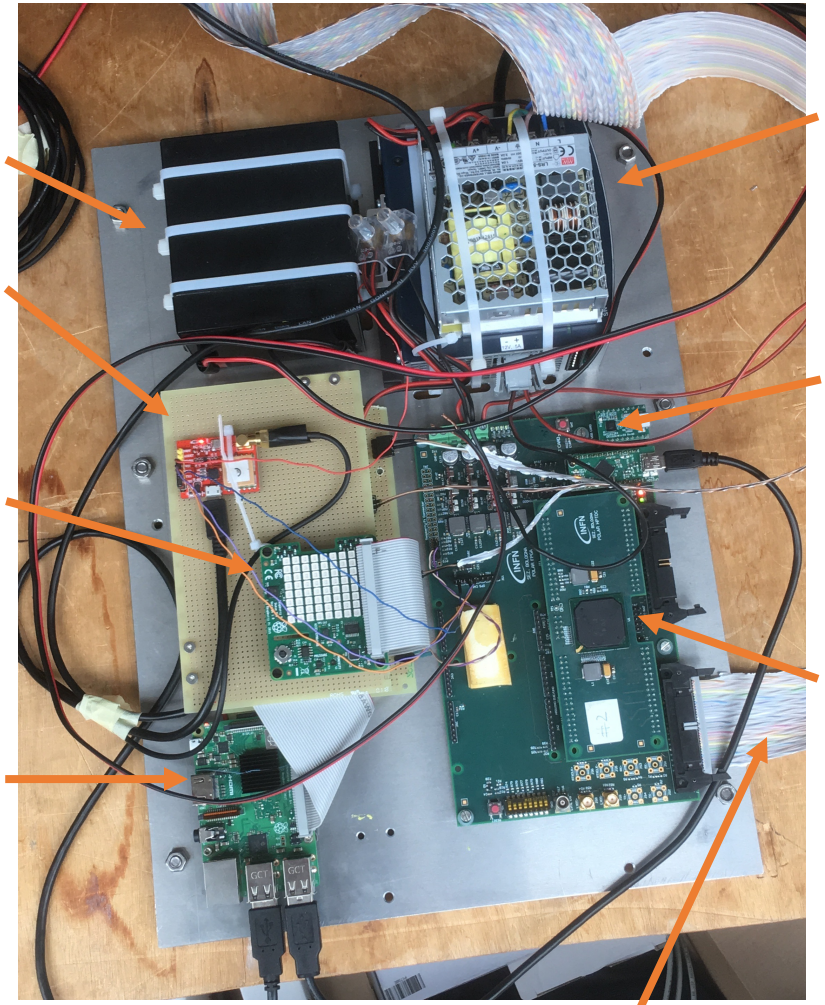


Students from the Italian, Swiss and Norwegian schools involved in the detector assembly at CERN



The PolarQuEEEst detector electronics

(overall power consumption: **12-13 W**)



Back-up Battery

GPS
GNSS-Ublox

Sense HAT
Gyroscope
Accelerometer
Magnetometer
Temperature
Barometric pressure
Humidity

Raspberry PI
Control readout

Power box

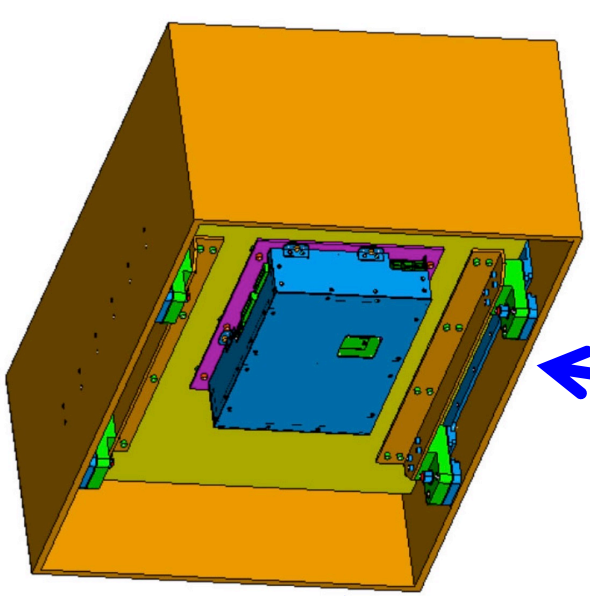
Readout board
FPGA Altera Cyclone 5
For Trigger and TDC readout

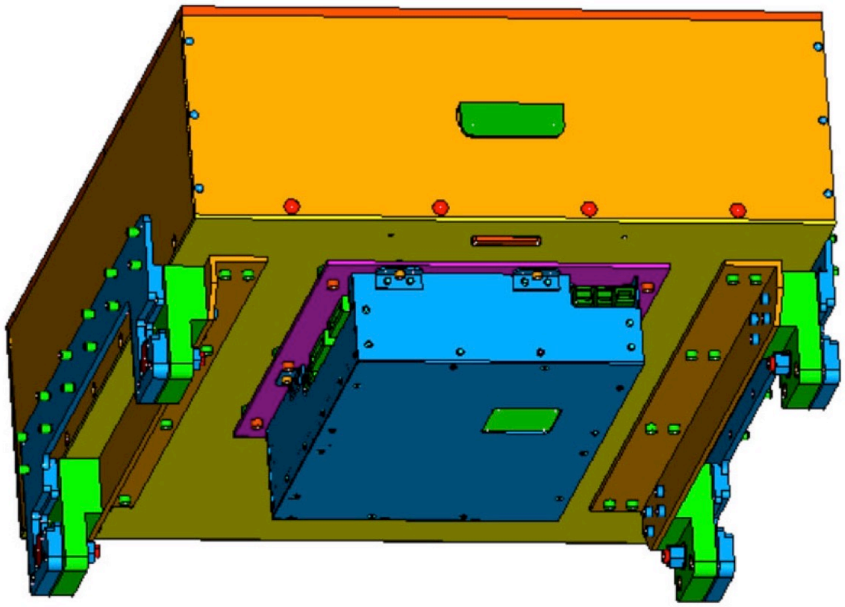
HPTDC piggy-back
for TDC readout

Signals from SiPMs

→ Data stored on SSD memory or transmitted via internet

Anchoring inside Nanuq





Cosmic hutch and anchoring system

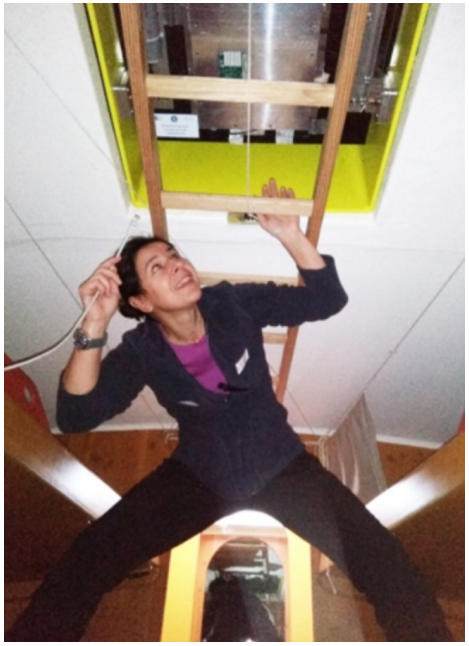
Installation

All the detectors installed by the end of July 2018

POLA-01 @ Isafjordur

POLA-02 @ Oslo (Nesodden)

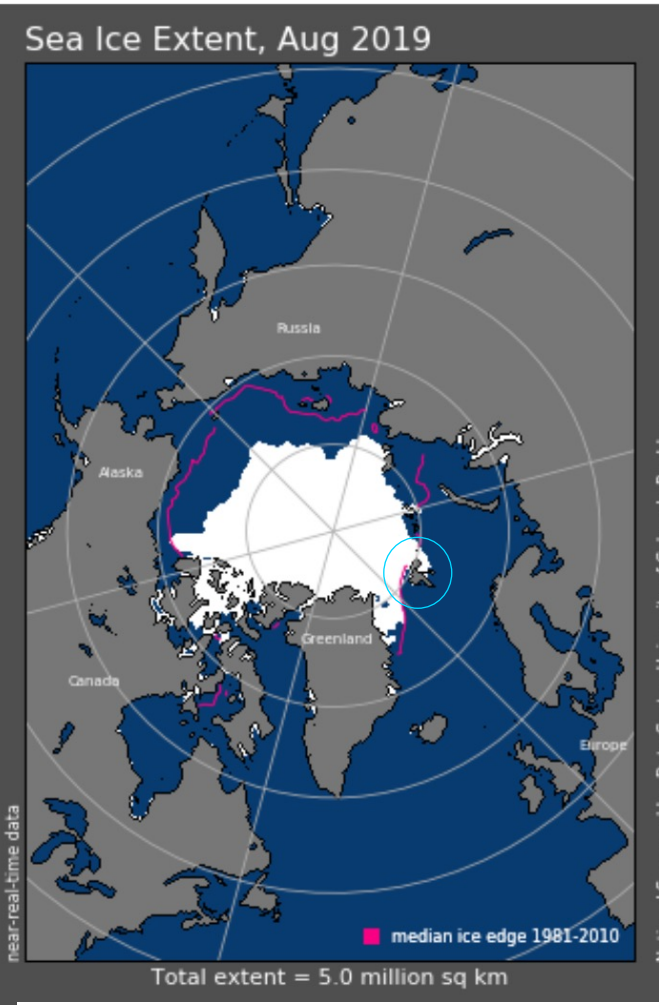
POLA-01 on board



POLA-03 @ Torino (Bra)


Sea Ice Extent, Aug 2017
Russia
Alaska
Greenland
Canada
Europe
median ice edge 1981-2010
Total extent = 5.5 million sq km


Sea Ice Extent, Aug 2018
Russia
Alaska
Greenland
Canada
Europe
median ice edge 1981-2010
Total extent = 5.6 million sq km


Sea Ice Extent, Aug 2019
Russia
Alaska
Greenland
Canada
Europe
median ice edge 1981-2010
Total extent = 5.0 million sq km

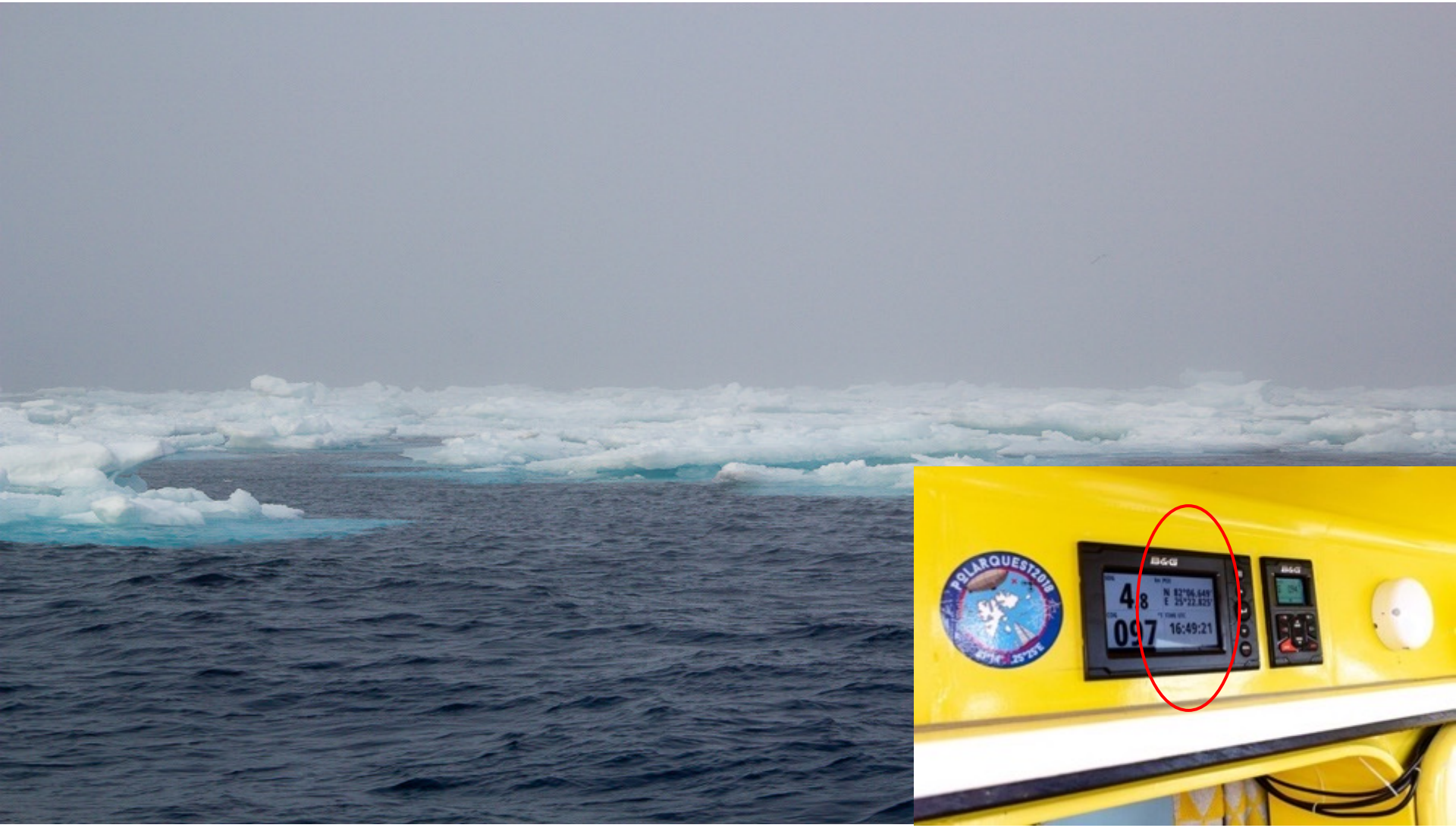
Nanuq en route to the Svalbard Islands

Nanuq en route to the Svalbard Islands

Nanuq at the Svalbard Islands

Nanuq at the Svalbard Islands

approaching a glacier



Nanuq reaching the limit of the polar pack ice
82° 07'N 25° 23' E

On board of Nanuq

Navigation shift on Nanuq

PolarQuEEEst Statistics

Extreme Energy Events
Science inside Schools

Trip length

Nanuq sailed for **45 days** covering about **3500 NM**

Duty cycle

The POLA-01 cosmic ray detector has taken data almost continuously for about **984 hours**

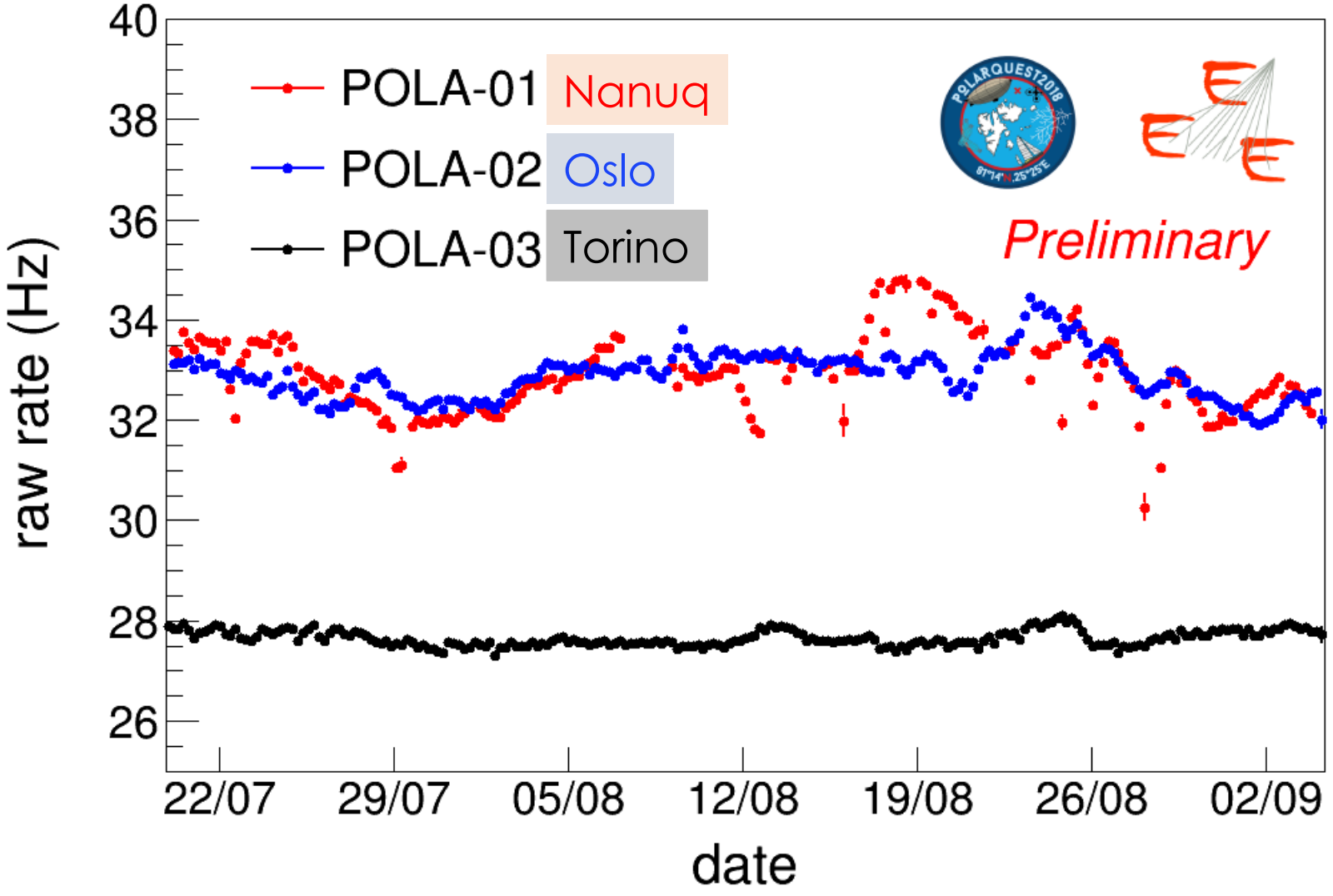
Detector efficiency

- for **POLA-01: about 91%** efficiency due to various reasons (main power down, difficult weather conditions, detector reset ….)
- for POLA-02 and POLA-03: essentially 100% efficiency (they were functioning during the whole period)

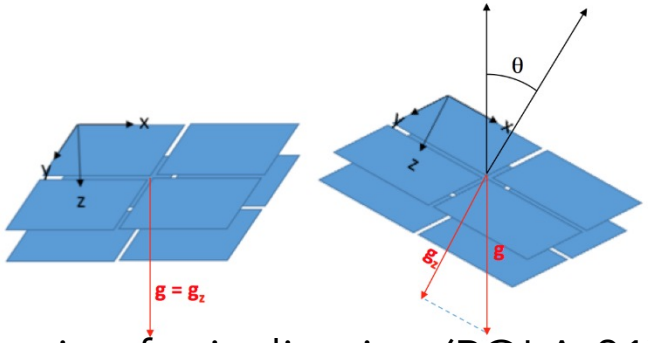
Collected muons

In total, more than **100.000.000 muon tracks per detector** were collected

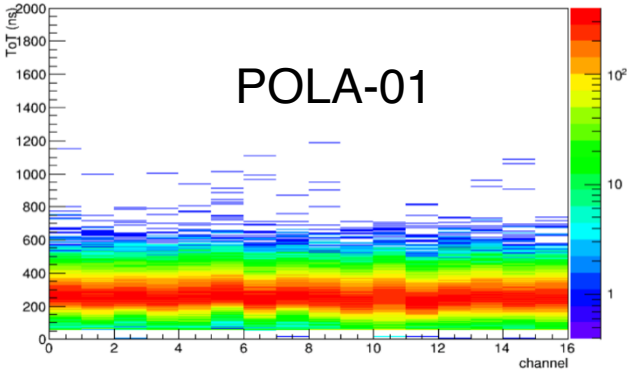
Rate (uncorrected)



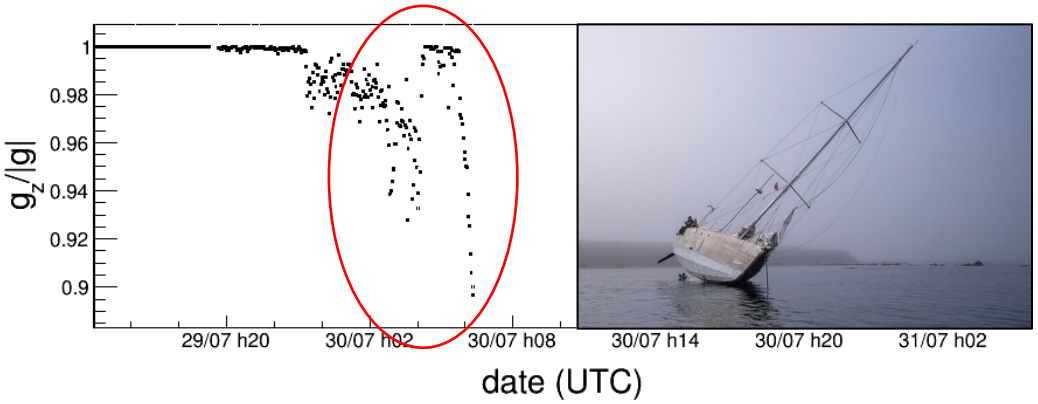
Detector performance



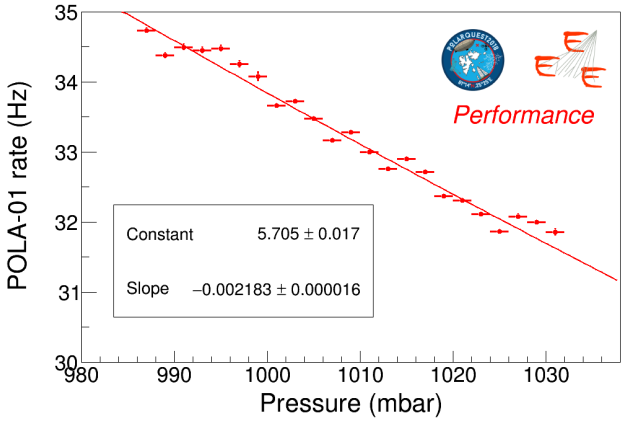
Channel equalization (thresholds)



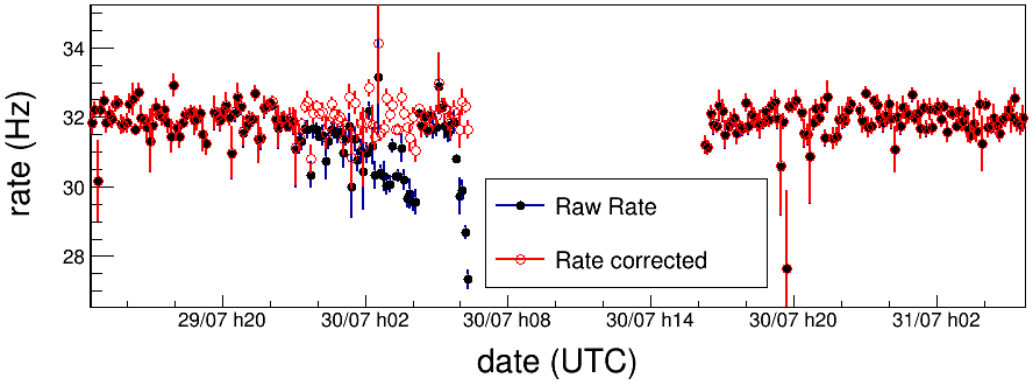
Correction for inclination (POLA-01)



Correction for pressure

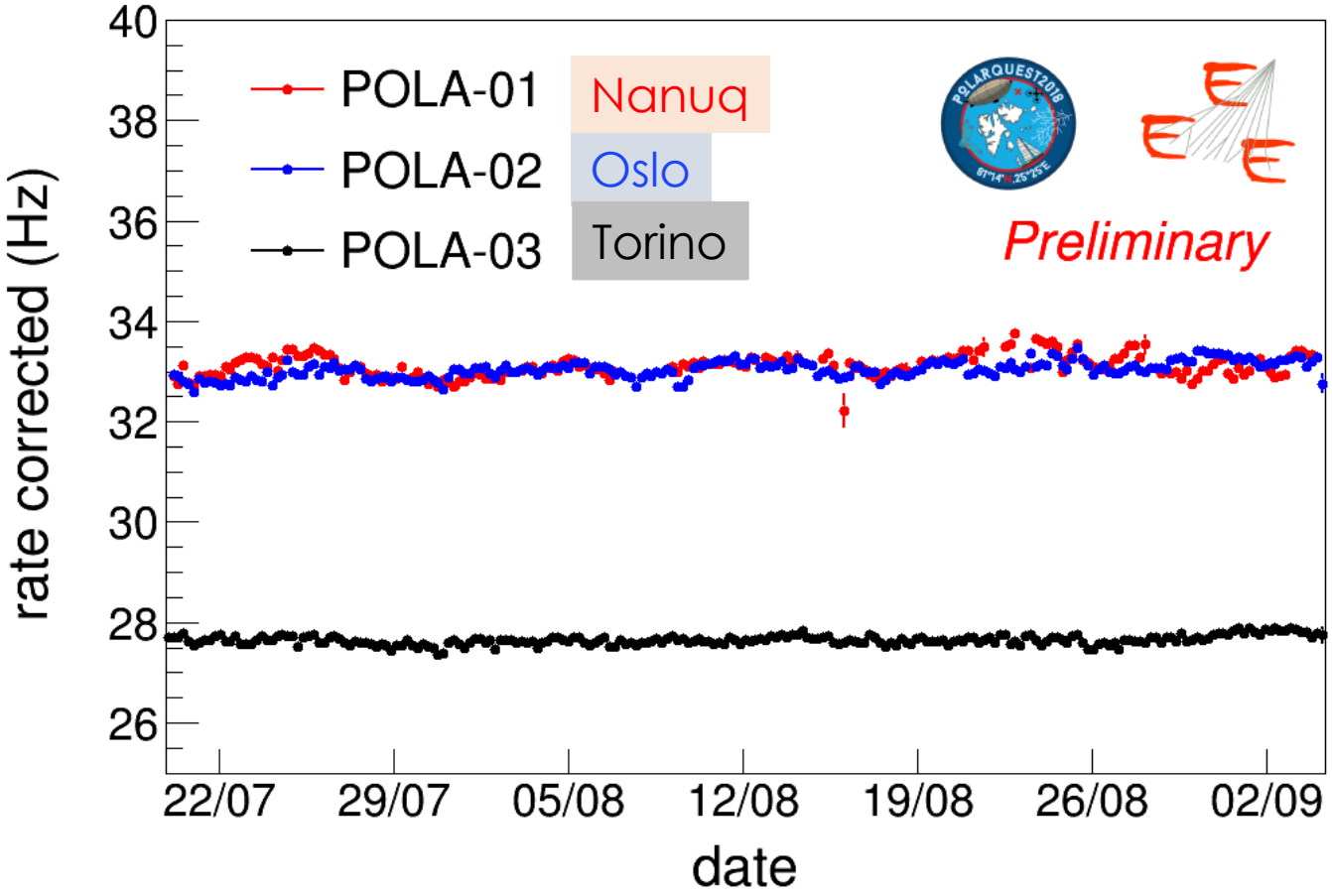


"Calibration run" on 30/07/18




Nanuq stranded
at the Svalbard Islands
waiting for high tide

Rate (corrected)

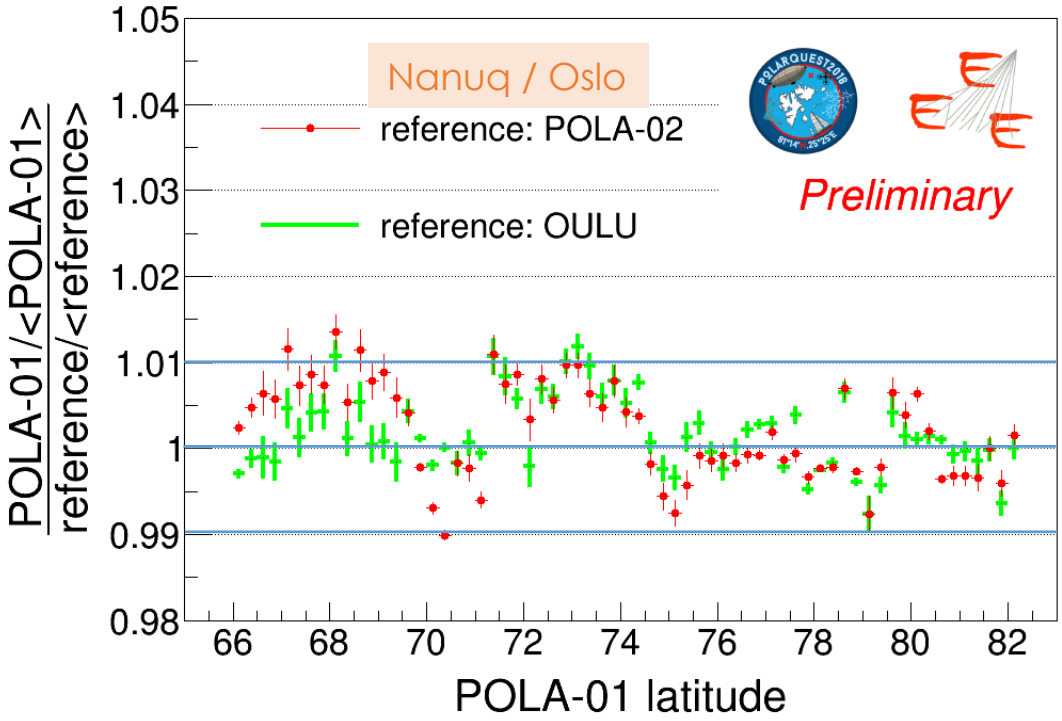


Difference of POLA-03 w.r.t. POLA-01/02 is ≈ **20%** and is due to:

- material budget on top of detector (mostly)
- latitude

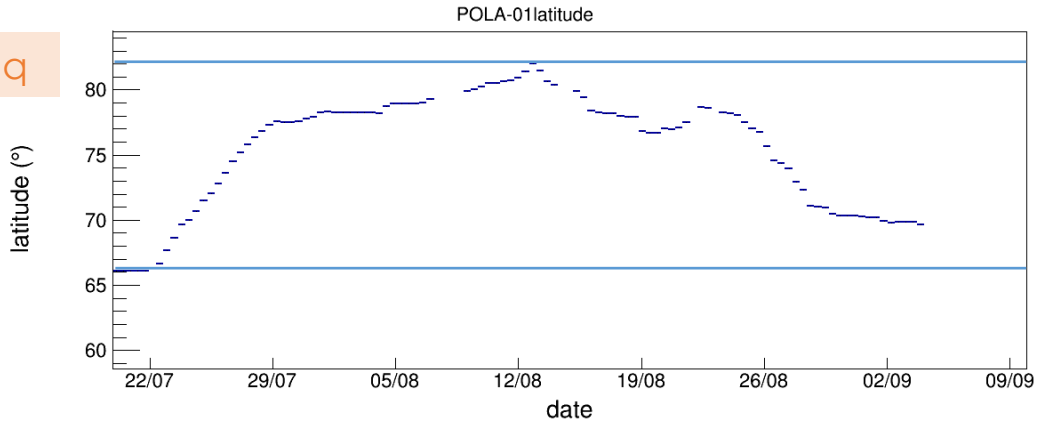
Rate vs. latitude

POLA-02 (in Oslo @ 59° N) used as reference since closer in latitude than POLA-03 (in Torino @ 45° N)



No significant effect observed
→ possible variation < 1%

Nanuq



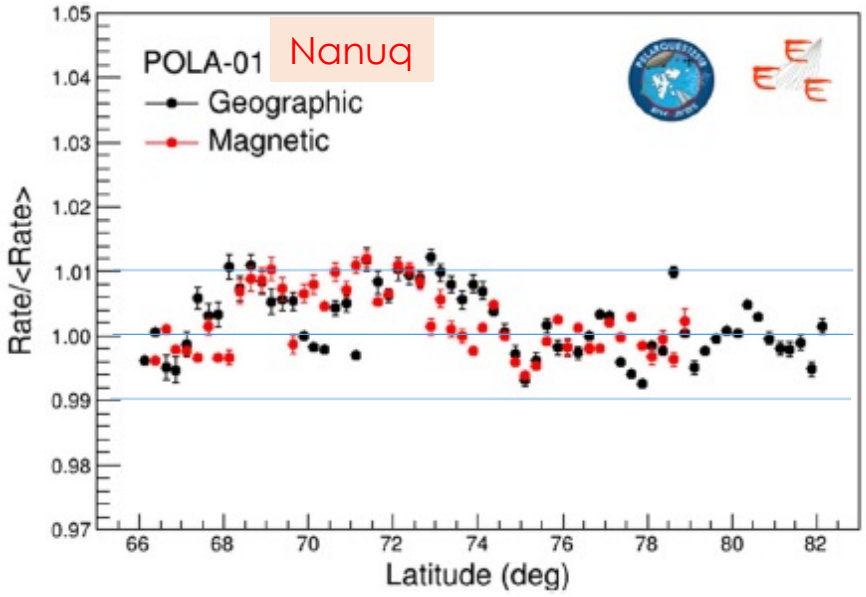
82° N (max) – North of Svalbard

POLA-01 on Nanuq

66° N (min) - Iceland

Thanks to PolarQuEEEst

- **an extreme and unprecedented latitude reached at sea level (82° 07' N)** by an efficient cosmic ray detector
- **high precision measurements** of cosmic rays achieved with the **same kind of detectors** over a very large latitude range up to **Arctic latitudes → unprecedented (± 1%)**



"New high precision measurements of the cosmic charged particle rate beyond the Arctic Circle with the PolarquEEEst experiment", EEE Collaboration, Eur. Phys. J. C (2020) 80: 665

The arrival in Longyearbyern after Svalbard circumnavigation

Extreme Energy Events
Science inside Schools

Gianluca Casagrande, Paola Catapano, Peter Gallinelli, Alwin Courcy, Safiria Buono, Mathilde Gallinelli Gonzalez, Dolores Gonzalez, Mike Struik, Ombretta Pinazza, Rémy Andrean

DOCUMENTARIES

2019 **Polarquest**

2020 **Nanuq** – An Arctic journey from past to future

PolarquEEEst

GOAL: Measure cosmic rays at extreme latitudes

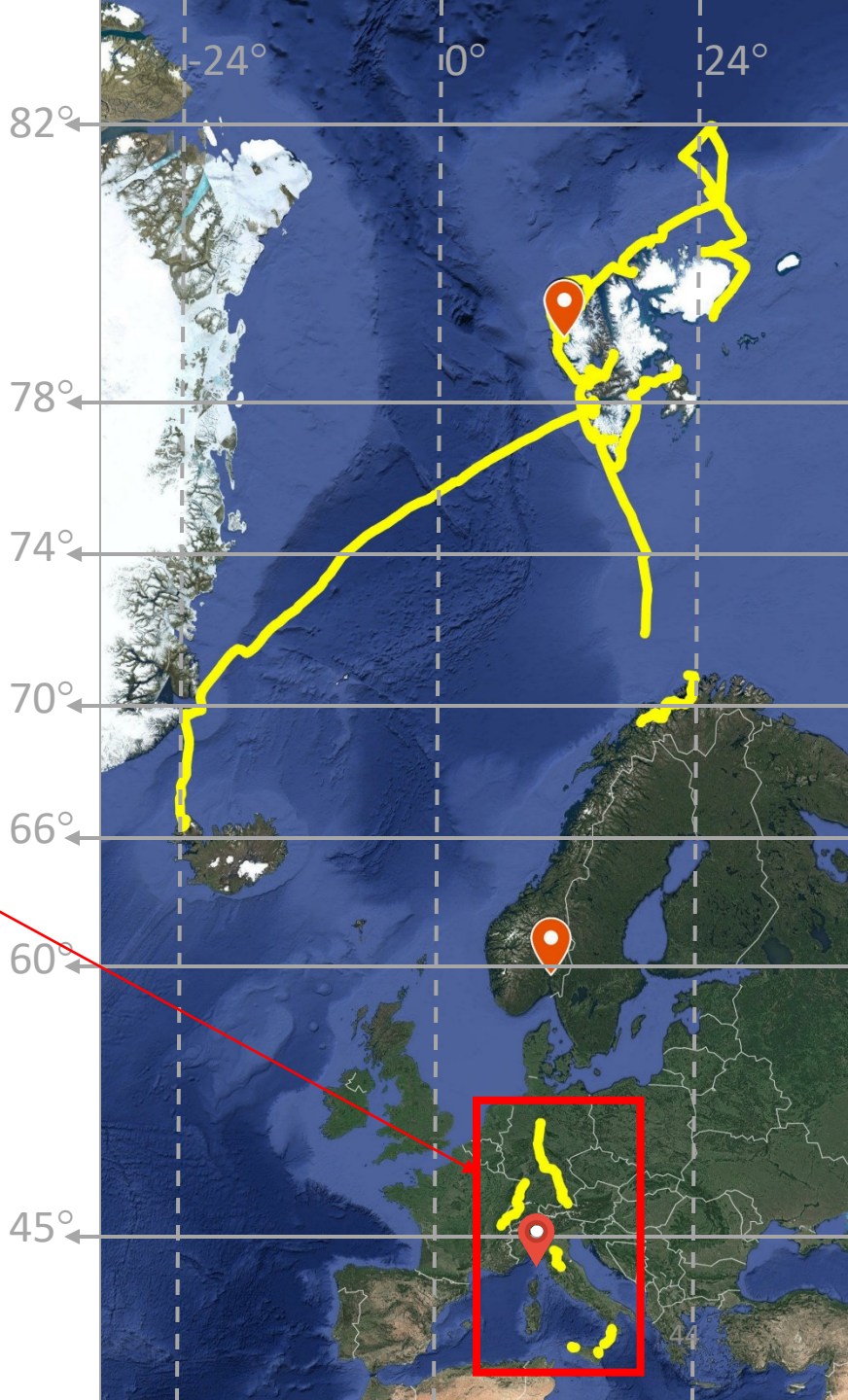
2018

- 3 detectors (POLA-01, POLA-02, POLA-03)
- PolarquEEEst2018 → mission on board of sailboat Nanuq (Jul – Sept 18) + 2 detectors at fixed sites: Bra (Italy) and Nessoden (Norway)

2019

Towards PolarquEEEst2019

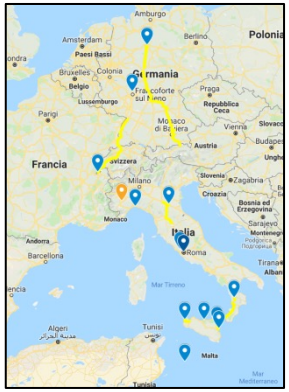
- (Dec 18 – Apr 19) → measurements at different latitudes (Italy, Germany, CERN)
- Construction of 4th detector (POLA-04)
- PolarquEEEst2019 → installation of 3 detectors at Ny Ålesund (Svalbard)



Cosmic ray flux vs latitude

Travel "on the road" of POLA-01 in Italy/Germany

POLA-01 at Cosenza



Other stops:

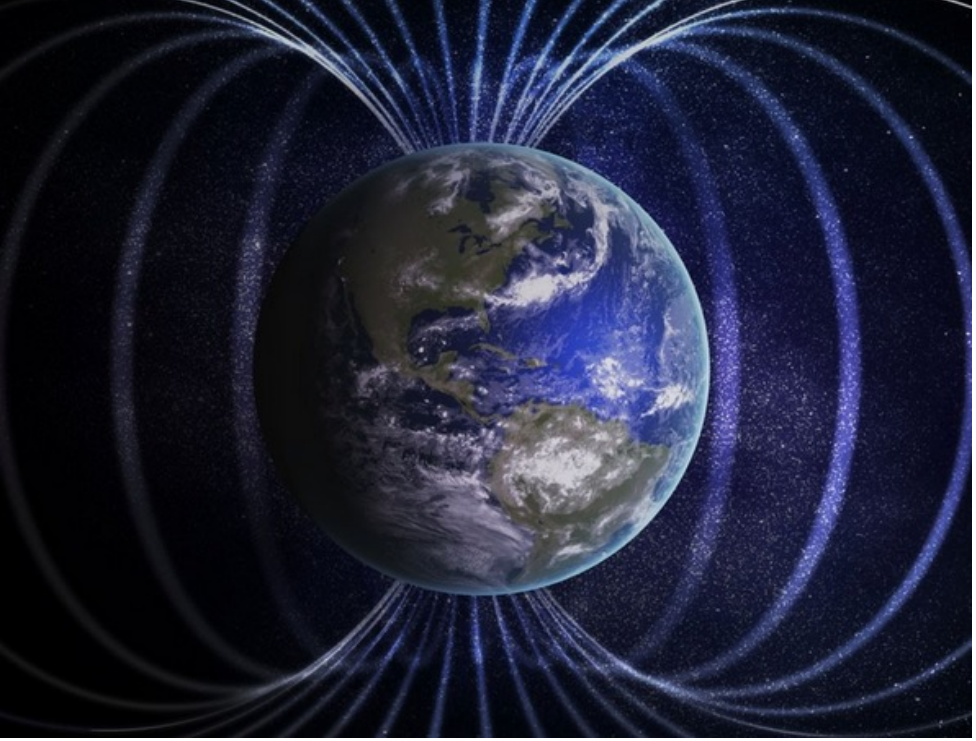
- Bologna
- Vigna di Valle
- Erice
- Catania

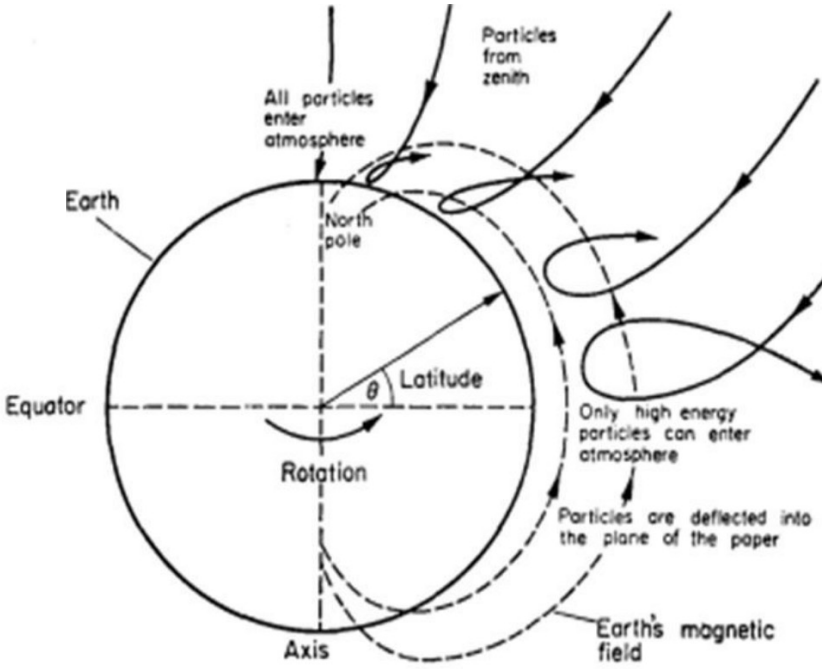
POLA-01 at Lampedusa
(reached by ferry boat)

POLA-01 on the Etna

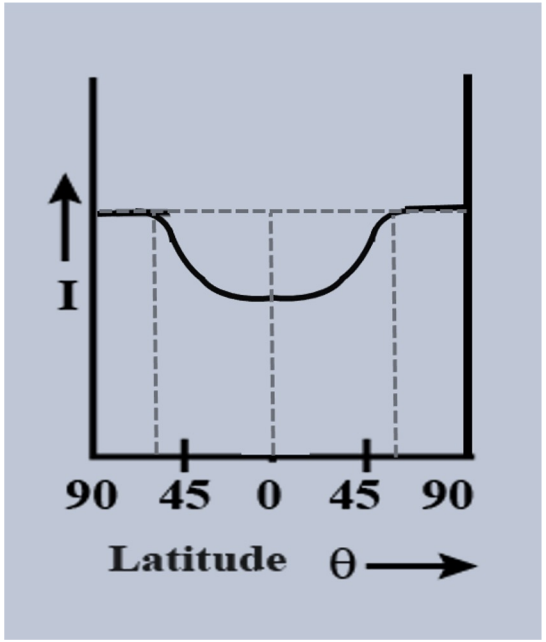
POLA-01 at Cefalù

POLA-01 in Germany:
Frankfurt, Hannover



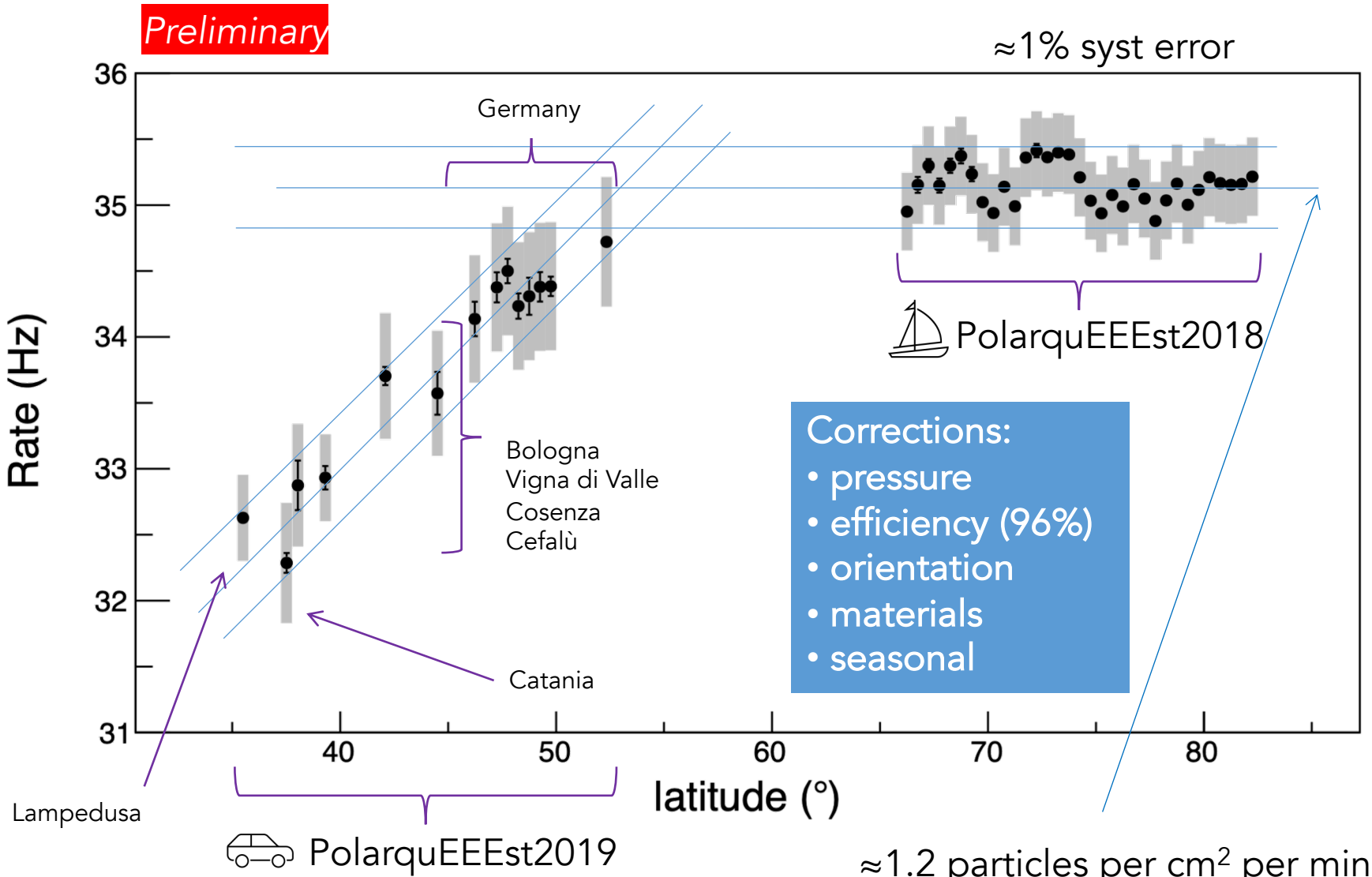


Geomagnetic field effect



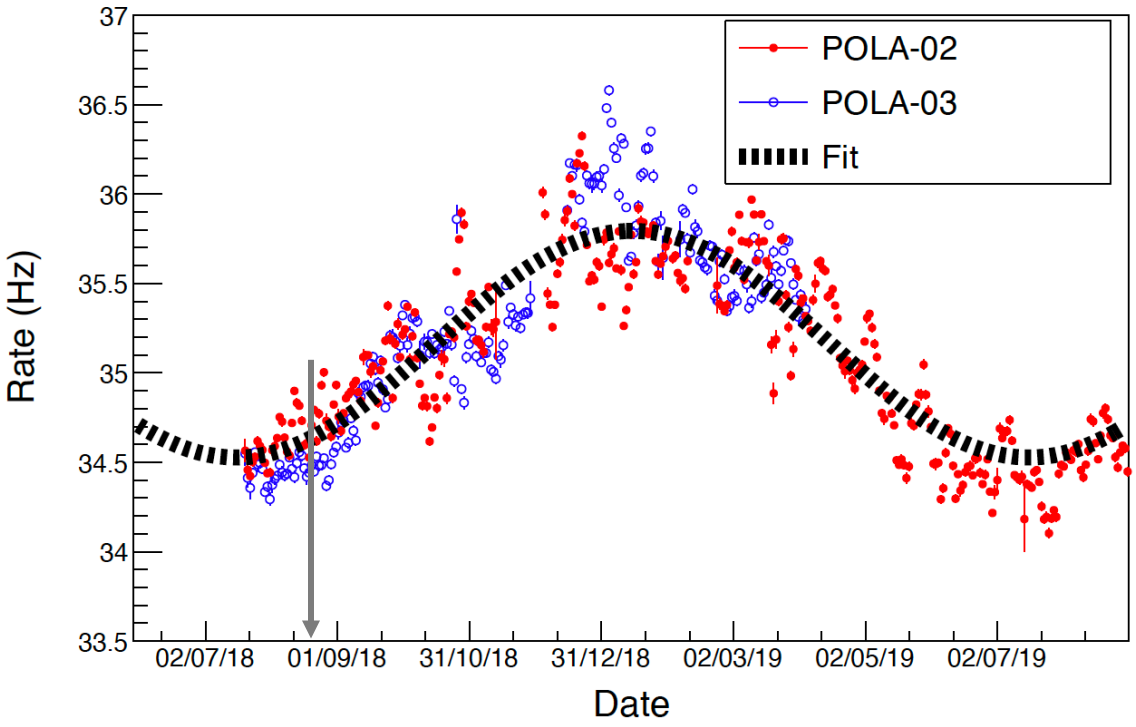
Acceptance (assuming $\cos^2\theta$ distribution) = 0.741 x (40x60 cm^2)

Cosmic ray flux vs latitude



≈1.2 particles per cm^2 per minute
consistent with PDG value for muons

Seasonal variation



Preliminary

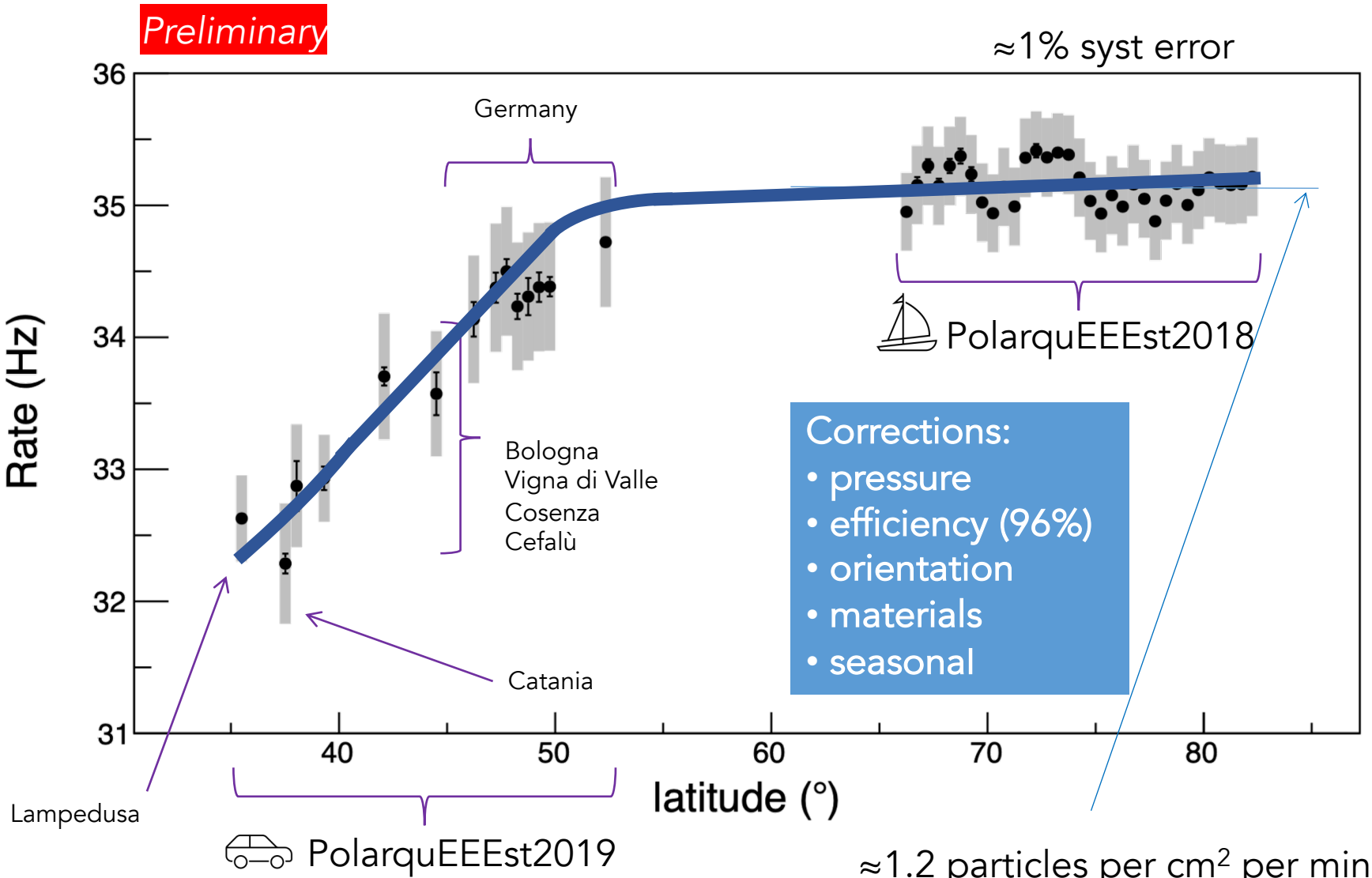
The cosmic ray flux seems to be sensitive to atmospheric & climate parameters such as the **temperature**

→ The study and observation of cosmic rays could be **a nice tool to investigate and monitor atmospheric & climate changes**

±1.8% modulation (max in winter, min in summer)
consistent with
R.R.S. de Mendonça *et al*, The Astrophysical Journal, 830:88 (2016)

Acceptance (assuming $\cos^2\theta$ distribution) = 0.741 x (40x60 cm^2)

Cosmic ray flux vs latitude



≈1.2 particles per cm^2 per minute
consistent with PDG value for muons

A.H. Compton, Phys Rev 43 387 (1933)
G. Lemaître and M.S. Vallarta, Phys Rev 42 914 (1932)

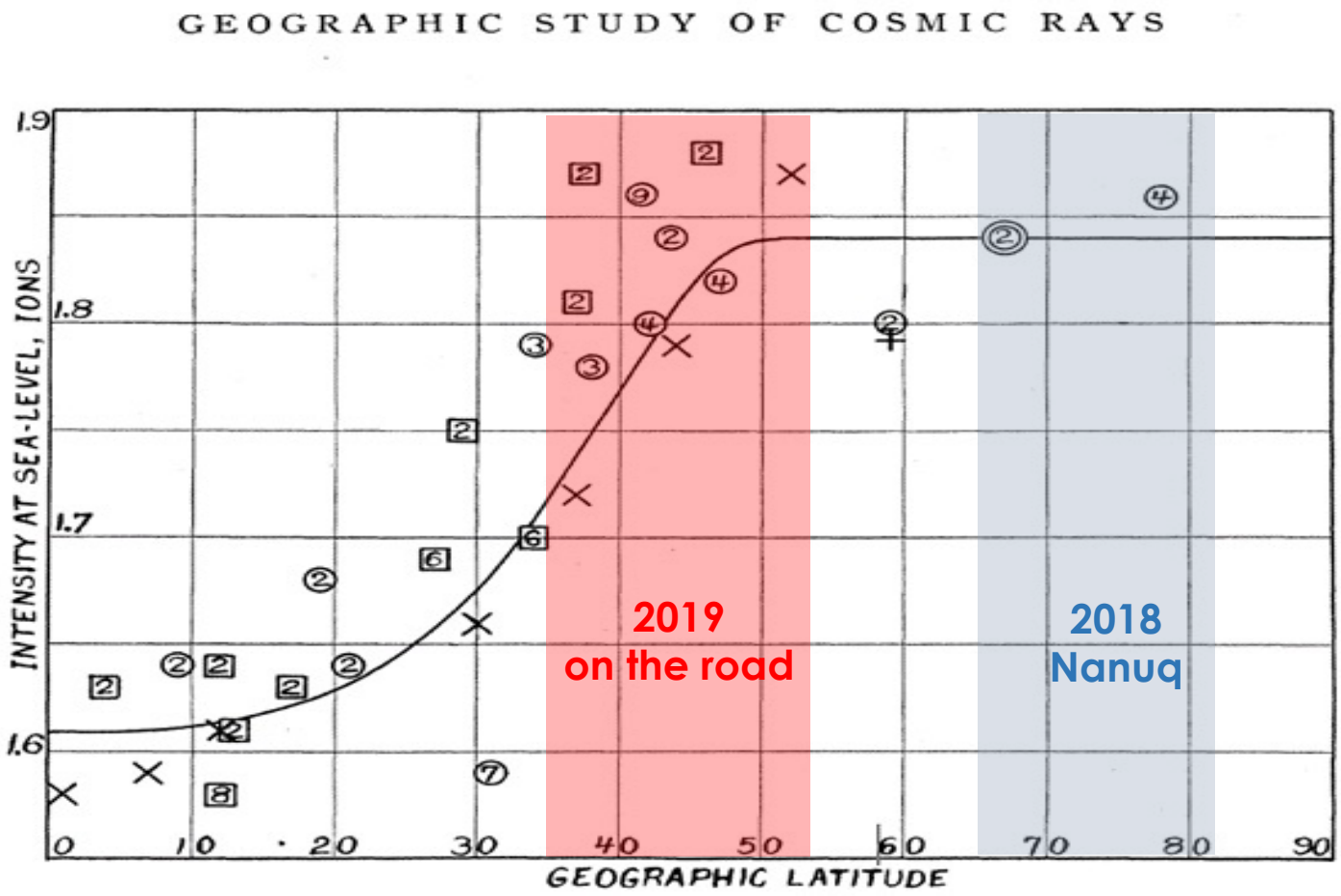
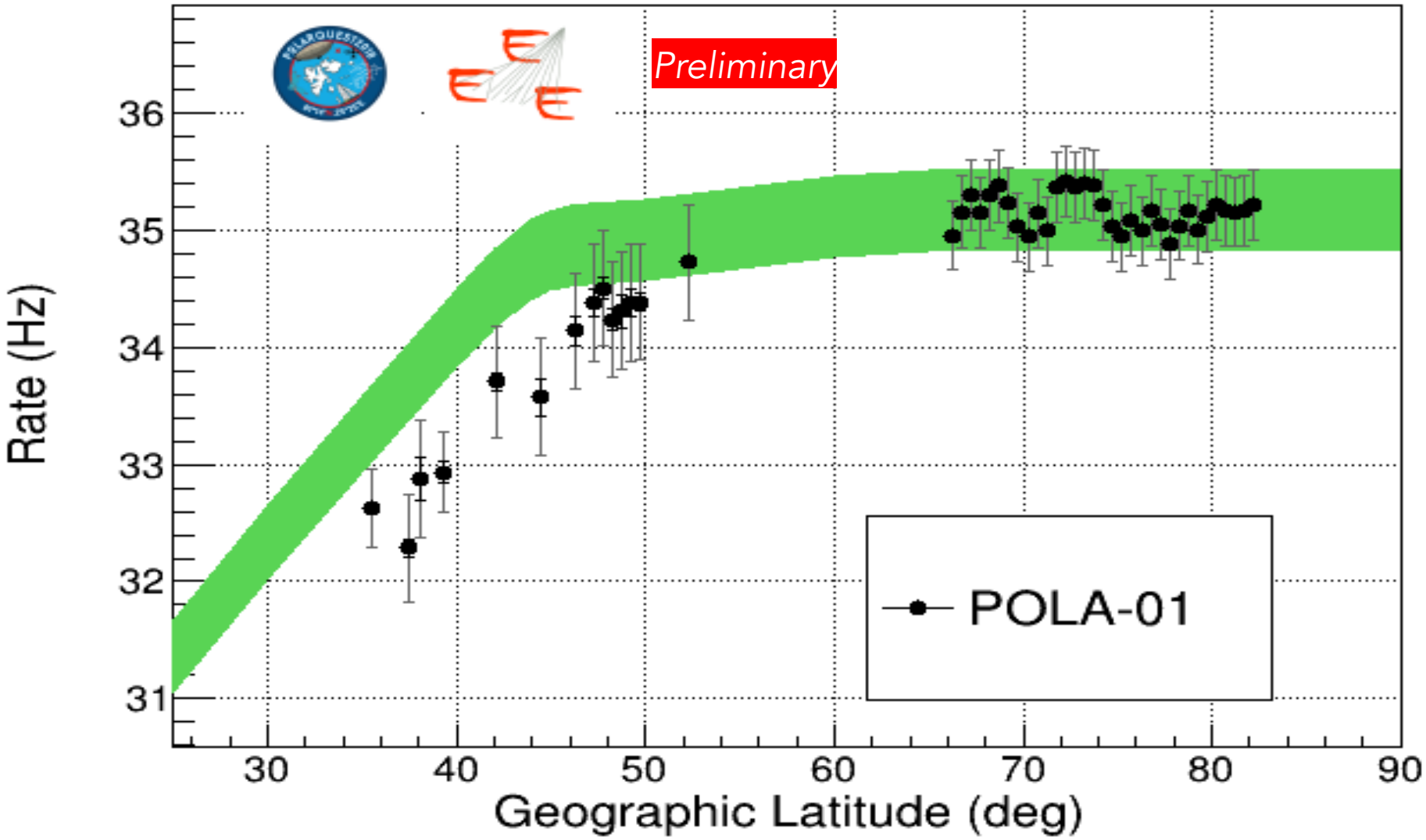


FIG. 8. Intensity *vs.* geographic latitude.

Model
PARMA CR vertical intensity (2018)
+ $\cos^2\theta$ distribution
+ FLUKA for detector acceptance



PolarquEEEst

GOAL: Measure cosmic rays at extreme latitudes

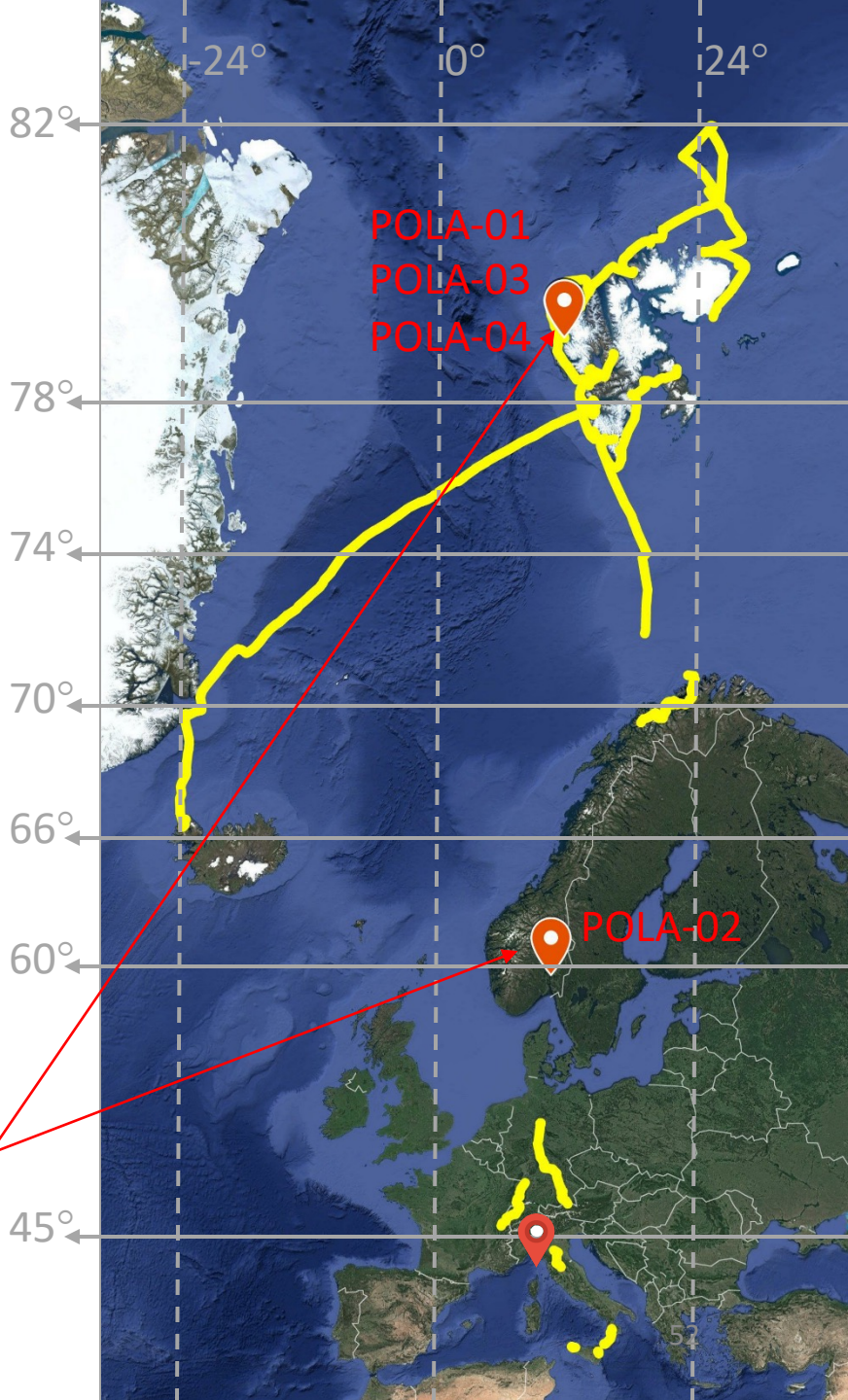
2018

- 3 detectors (POLA-01, POLA-02, POLA-03)
- PolarquEEEst2018 → mission on board of sailboat Nanuq (Jul – Sept 18) + 2 detectors at fixed sites: Bra (Italy) and Nessoden (Norway)

2019

- (Dec 18 – Apr 19) → measurements at different latitudes (Italy, Germany, CERN)
- Construction of 4th detector (POLA-04)
- PolarquEEEst2019 → installation of 3 detectors at Ny Ålesund (Svalbard)

PolarquEEEst2019



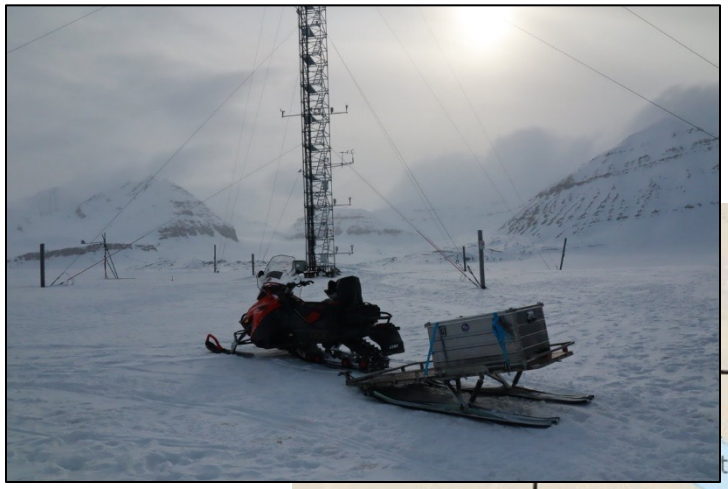
PolarquEEEst2019@Ny Ålesund

Installation at Ny Ålesund

The Polar task arriving at Ny Ålesund

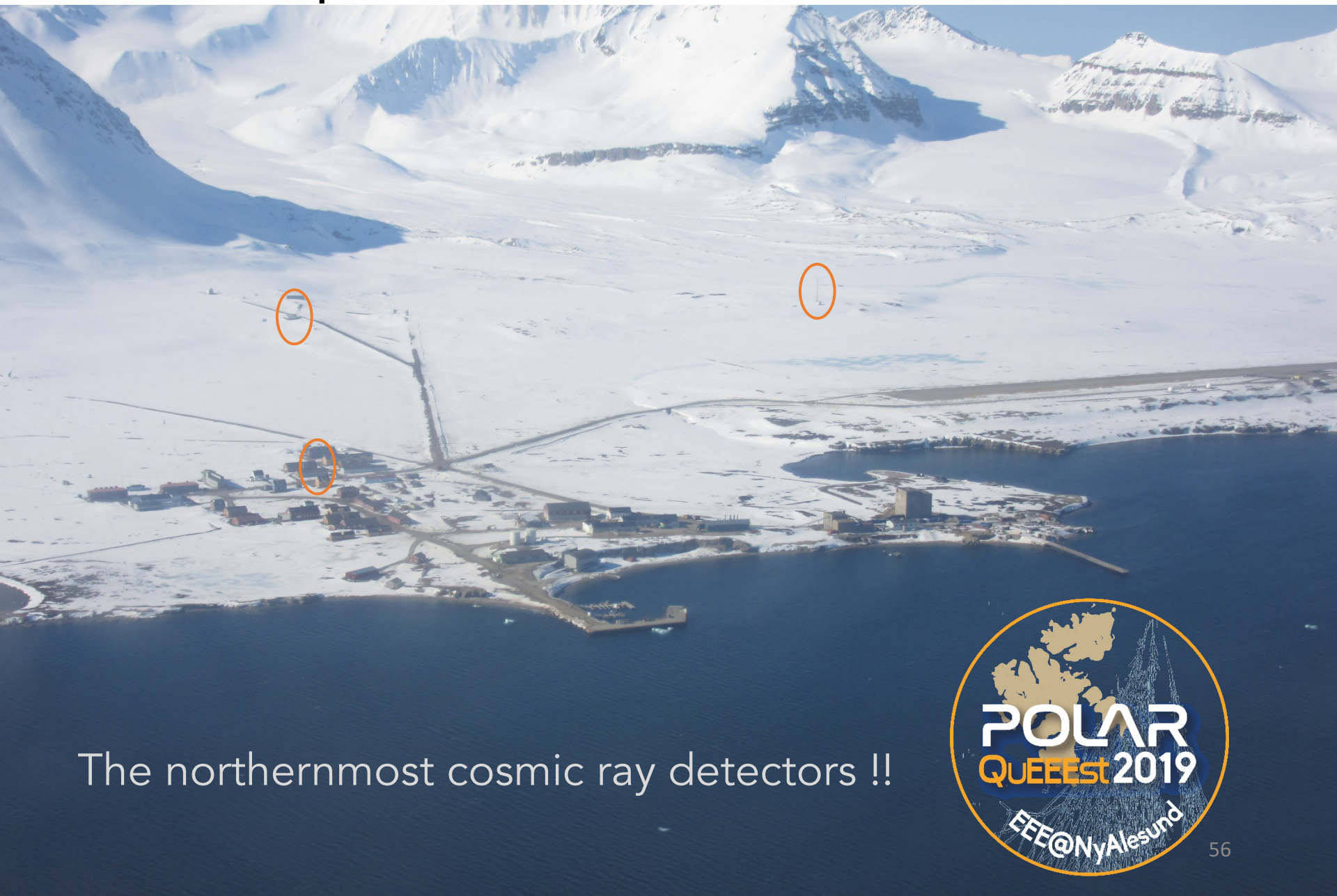
At the *Dirigibile Italia* (*Italia Airship*) station with the CNR staff

POLA-01 on its way to the CNR "Climate Change Tower"



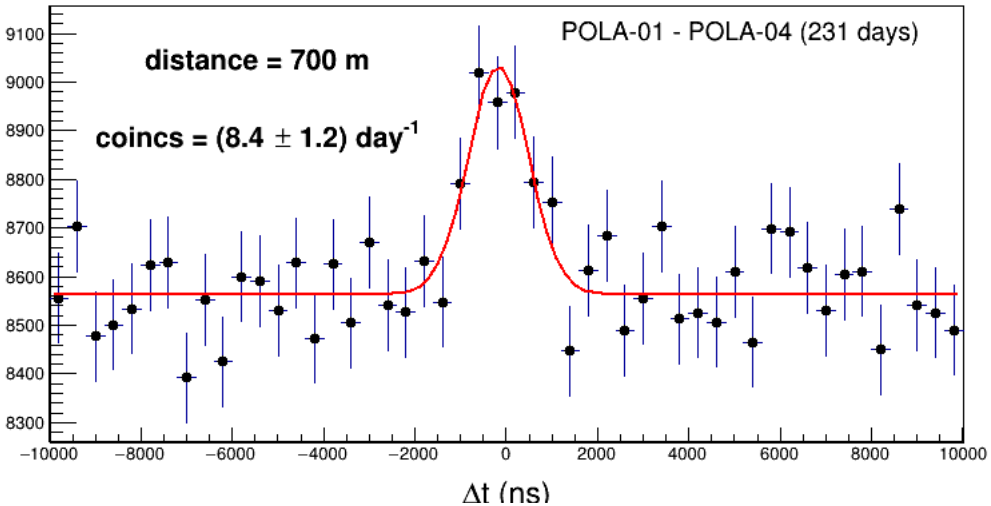

Thiis-
bukta
78°55'30"
78°55'30"
Dirigibile Italia
POLA-03
Amudsen-Nobile
Climate Change Tower
POLA-01
1.27 km
11°52'
Kol-
augen
11°54'
11°56'
0.95 km
Westby-
elva
0.7 km
Gruvebadet
POLA-04
78°55'00"
Tvilling-
vatnet

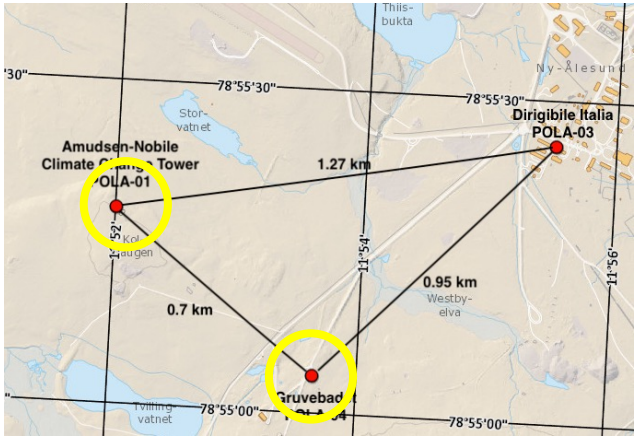
PolarquEEEst2019@Ny Ålesund

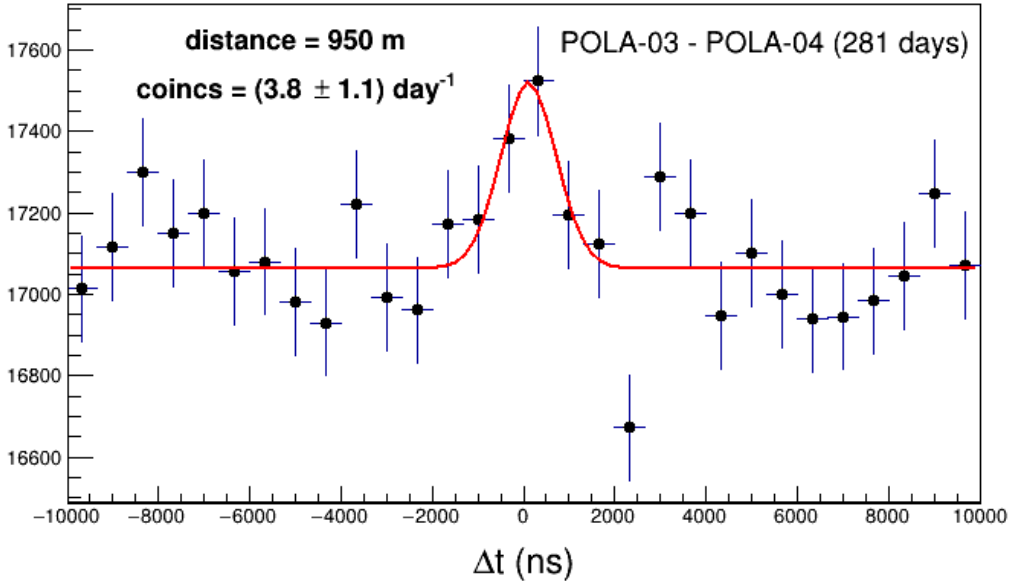


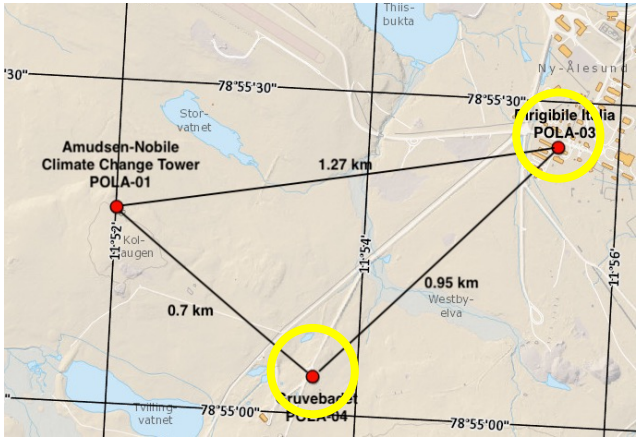
The northernmost cosmic ray detectors !!

Preliminary









CENTRO FERMI
MUSEO STORICO DELLA FISICA E CENTRO STUDI E RICERCHE ENRICO FERMI

CENTRO RICERCHE ENRICO FERMI

INFN
Istituto Nazionale di Fisica Nucleare

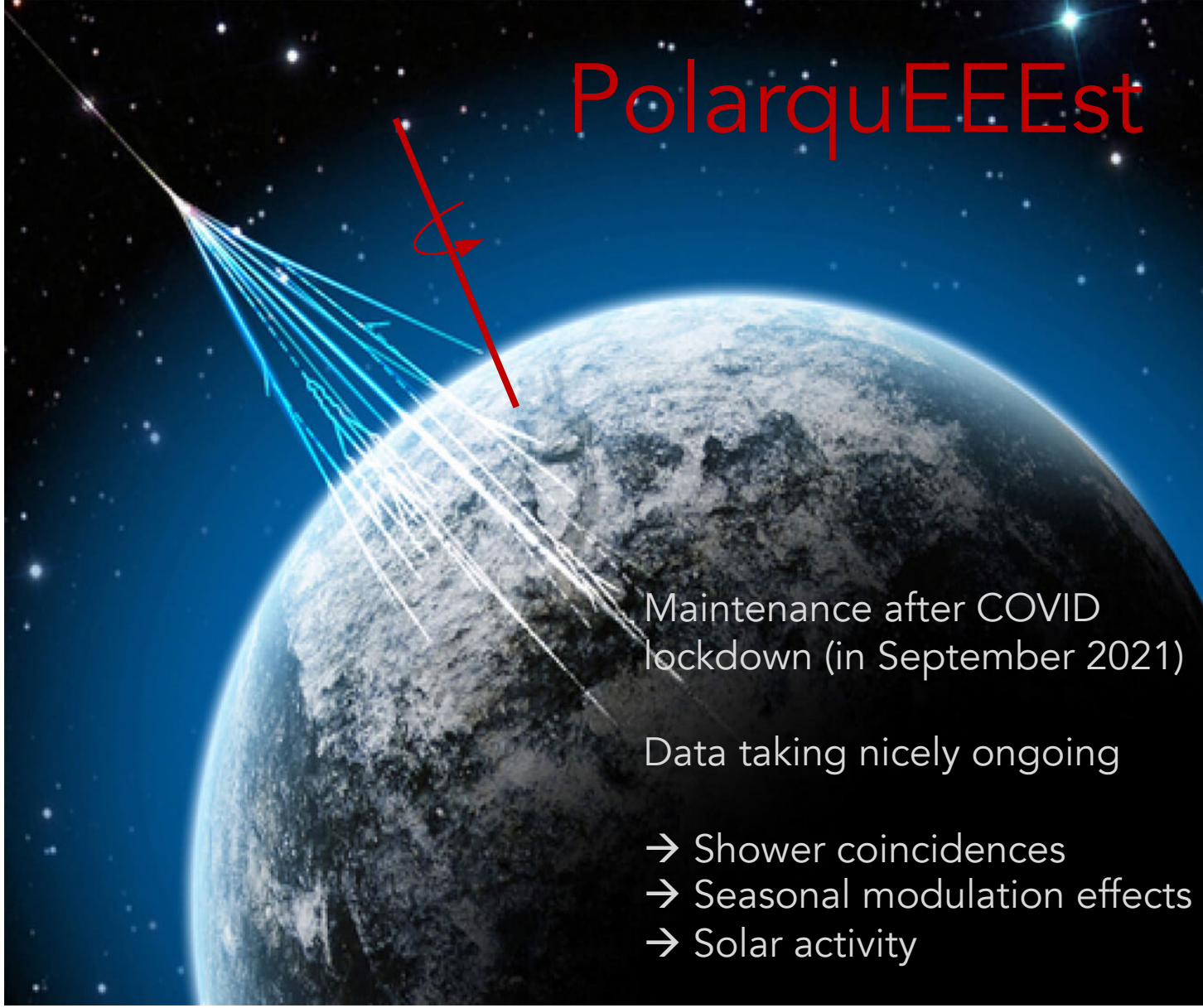
Consiglio Nazionale delle Ricerche

CERN

INRiM
ISTITUTO NAZIONALE DI RICERCA METROLOGICA

Società Italiana di Fisica

PolarquEEEst



Maintenance after COVID lockdown (in September 2021)

Data taking nicely ongoing

→ Shower coincidences
→ Seasonal modulation effects
→ Solar activity

Extreme Energy Events
Science inside Schools

POLARQUEST2018
81°14'N.25°25'E

POLAR QUEEEST 2019
EEE@NyAlesund

INFN
Istituto Nazionale di Fisica Nucleare

CENTRO RICERCHE
ENRICO FERMI

Extreme
Energy
Events
Science inside Schools

CERN

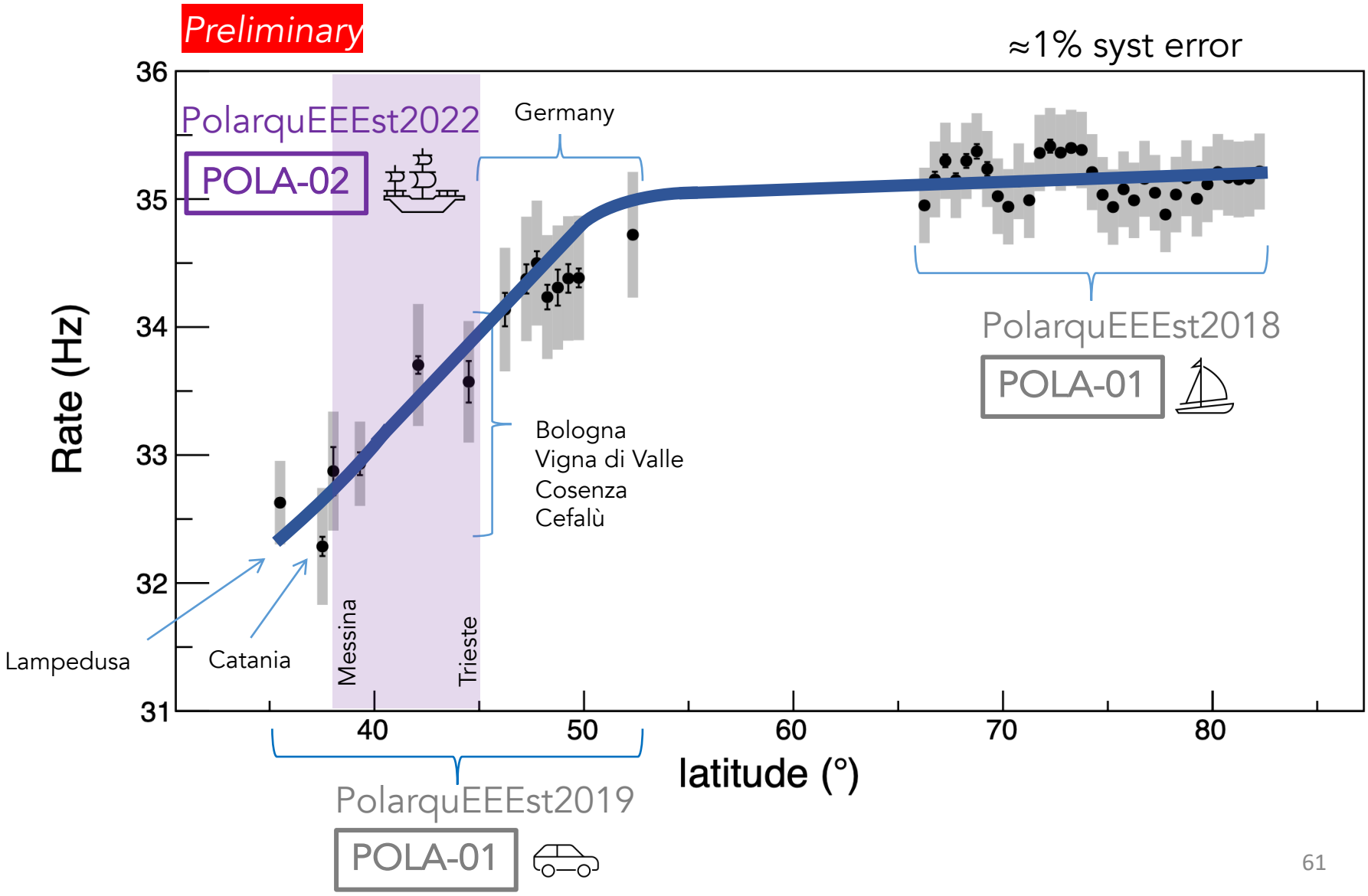
125
YEARS
SIF
1897-2022

PolarquEEEst 2022

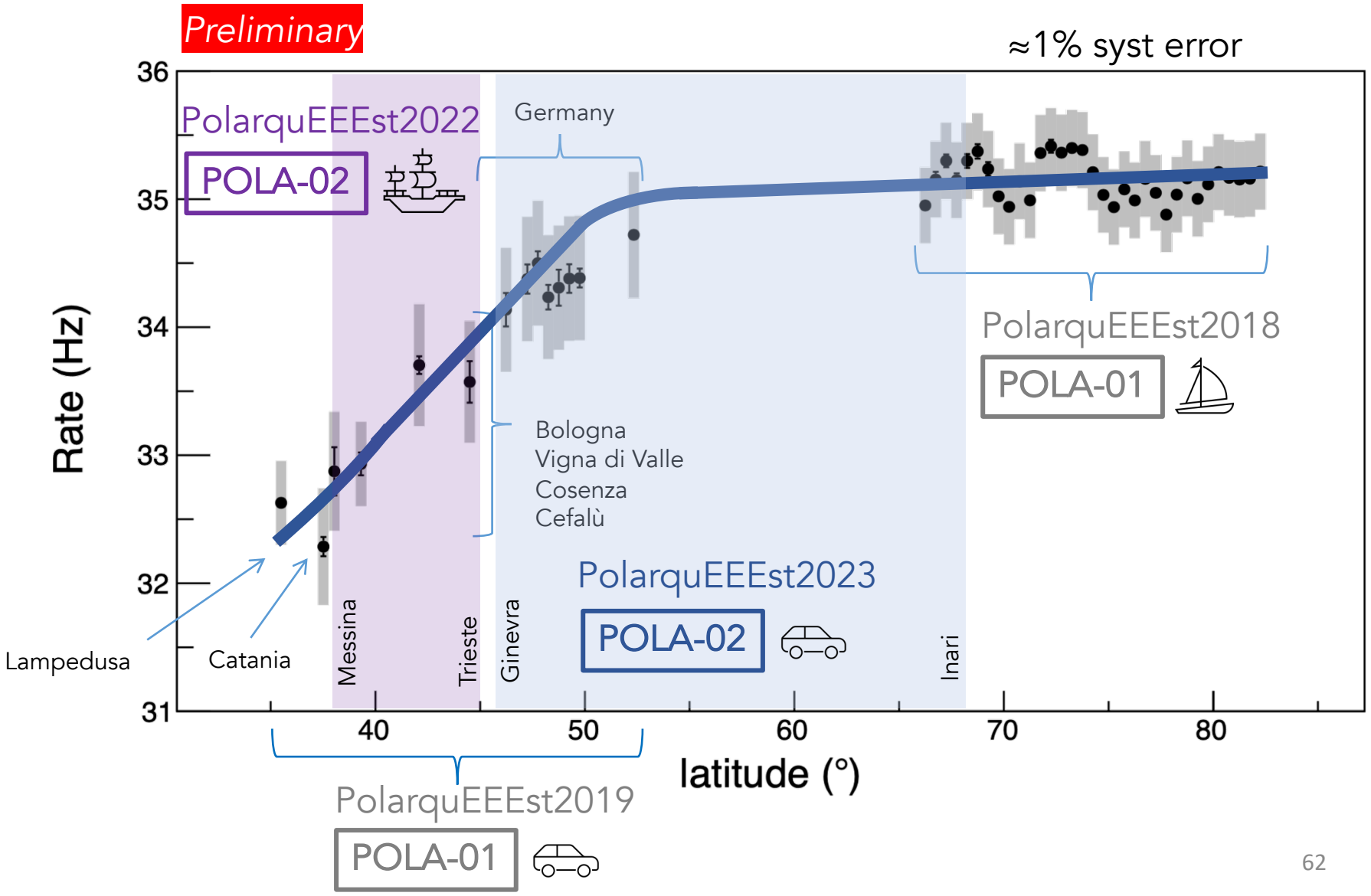
A bordo dell'Amerigo Vespucci per la misura delle particelle provenienti dal cosmo

Crediti: marina.difesa.it

Cosmic ray flux vs latitude



Cosmic ray flux vs latitude



Extreme Energy Events
Science inside Schools

- Thanks to PolarQuEEEst

→ **Precision study of the cosmic ray intensity at high latitudes up in the Arctic polar region where no published data exist**

→ **Check of the saturation of the cosmic ray intensity at higher latitudes and of the suppression of the intensity at lower latitudes**

→ **Very useful probe to monitor the configuration of the Earth magnetic field, the primary cosmic ray energy spectrum affected by the Sun activity and maybe the status of the Earth atmosphere**