Astro-particle physics activities (CSN2) @ LNF

A. Paoloni

LNF Scientific Committee

May 9th 2017

LNF group II in numbers

Since last presentation (November 2014) there has been a loss of FTE but with a rationalization of the activies (12 experiment open in 2014).
OPERA (since January 2016) and NAUTILUS (since July 2016) have been closed.
Wizard (PAMELA) will be closed from 2018.
In 2015 A. Longhin (now in Padova) has been awarded an ERC consolidator grant (ENUBET).

Experiment	FTE (persons)	LNF group II staff	postdoc
JUNO	1.0 (2)	1 R (R=researcher)	
KM3	1.3 (4)	1 T (T=technologist)	
CUORE	1.5 (3)	3 T	
Jem EUSO	2.0 (6)	1 R + 2 T (also in CUORE)	
Wizard	0.9 (2)		1 ADR (ToV)
Limadou	0.1 (2)		
Moonlight2	7.2 (12)	1 RTD + 2 T	3 ADR
QUAX	1.9 (5)	2 R + 1 T (also in CUORE)	

RTD =researcher, not permanent

1 RTD + 3 ADR paid with ASI funds.
1 ADR paid with headquarter funds (NASA/SSERVI.

LNF neutrino experiment perspectives

CUORE, KM3: Experiments with a long history, now entering in a critical phase.
CUORE started data taking; LNF is giving a technical contribution (cryogenics + technical management), which is expected to drop in the next years.
JUNO: 2 researcher lost in the last year. Additional manpower needed.

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OPERA legacy I

The LNF group strongly contributed to the OPERA experiment at LNGS (just an example: the technical coordinator of the experiment has always been an LNF group member).

During the CNGS run, 1.8×10^{20} pot were collected and the experiment observed 5 ν_τ events with 0.25 expected bkg events (no oscillation hypothesis excluded at 5.1 σ).

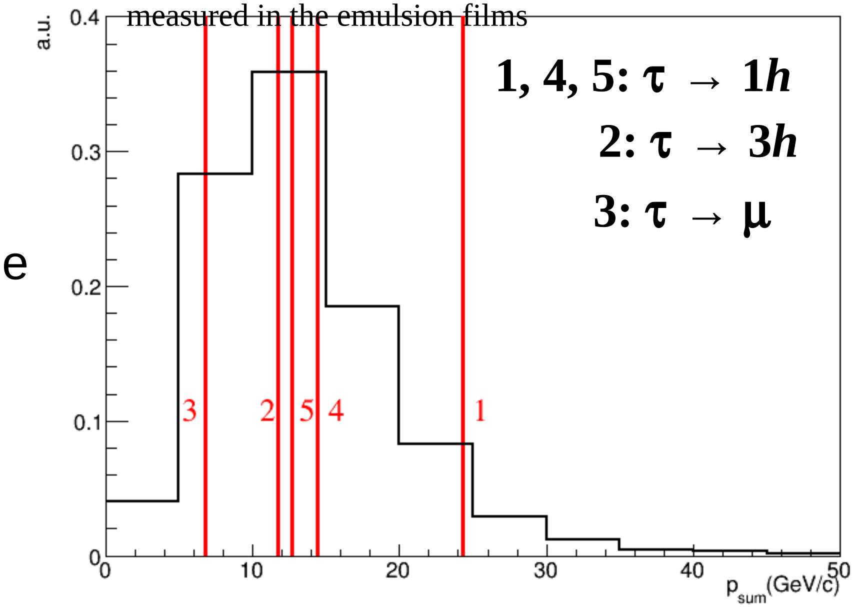
The scanning activity ended last year and the collaboration is ready to finish and publish the analyses.

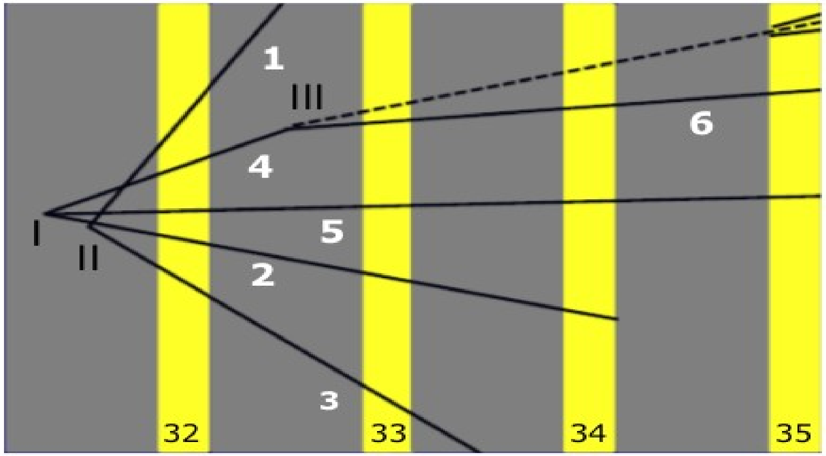
A data sample for open access will also be left at CERN.

A new, “minimum bias”, analysis has also been performed In the $\nu_\mu \rightarrow \nu_\tau$ appearance channel, with 10 candidates; separation from bkg using BDT techniques.

Among the 5 new ones, a peculiar event classified as charm production in a ν_τ CC interaction has also been found (the first one ever observed).

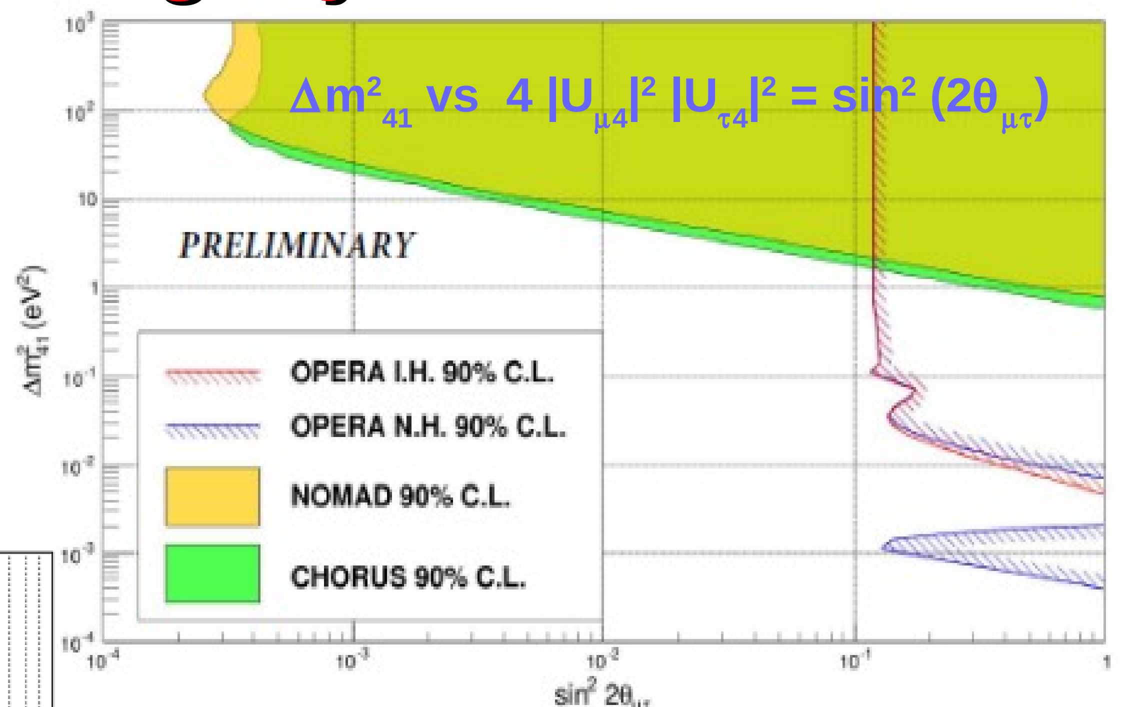
p_{sum} : scalar sum of the momenta of all particles measured in the emulsion films

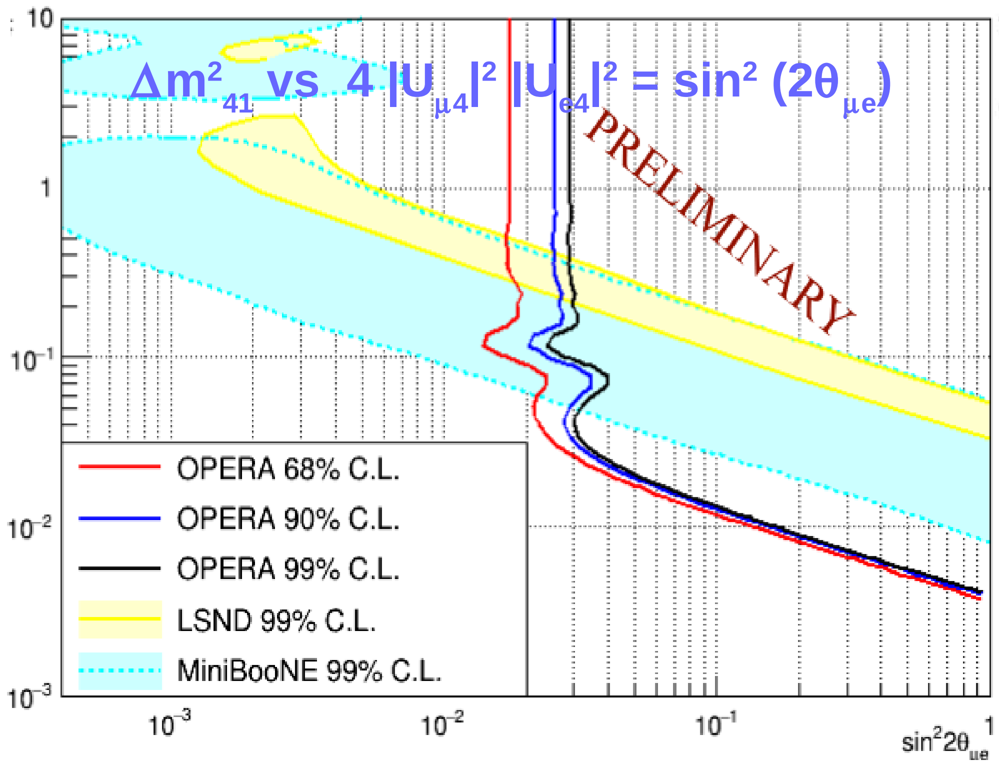


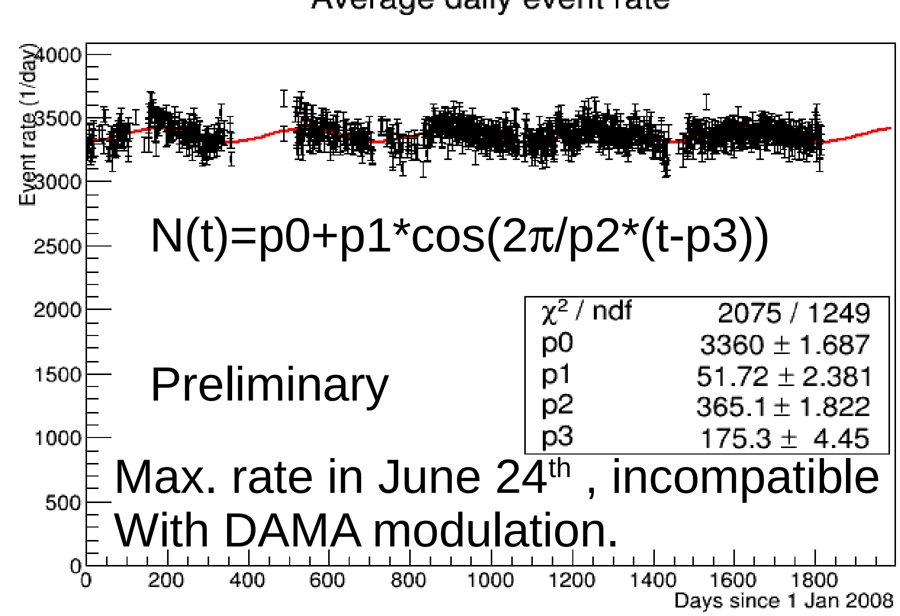


OPERA legacy II

The LNF group also contributed to data analysis, in intepretation of $\nu_\mu \rightarrow \nu_\tau$ and $\nu_\mu \rightarrow \nu_e$ in 3+1 model (sterile neutrino) as well as cosmic ray modulation.

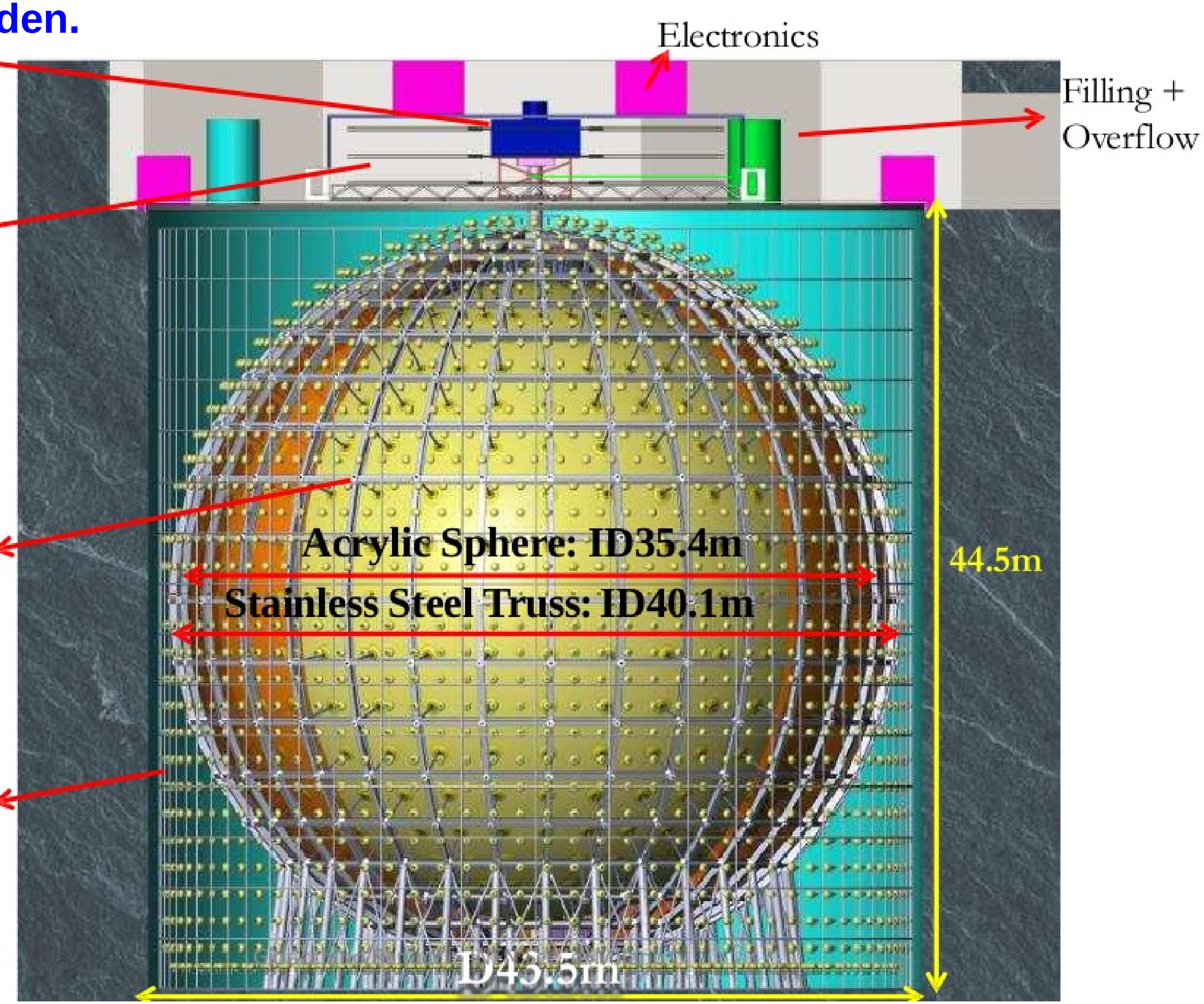






JUNO experiment

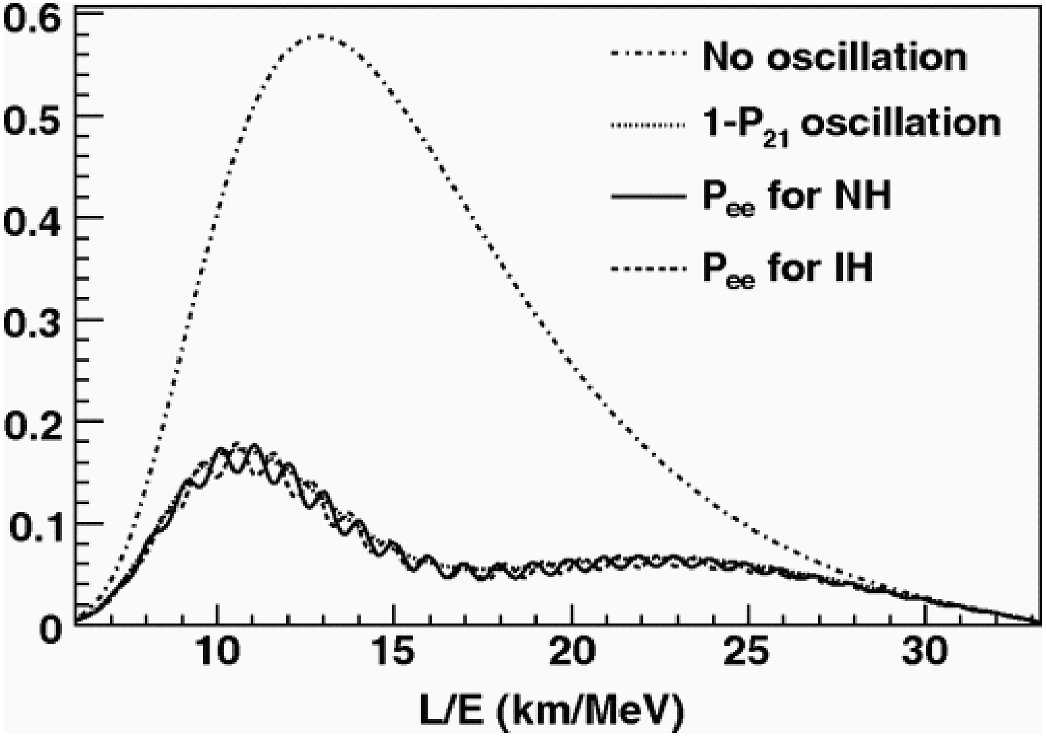
Oscillation experiment: anti-ν_e disappearance for mass hierarchy measurement.
50 km baseline from 2 nuclear power plants (power=26-36 Gw).
700 m rock overburden.



Central detector
Acrilic sphere+
20 kt Liquid scintillator+
17000 20" PMTs+
25000 3" PMTs
Water Cherenkov
2000 20" PMTs

Multi-purpose experiment: Determination of Δm^2_{21}, Δm^2_{31}, θ_{12} at sub % level.
Observation of neutrinos from natural sources (Sun, geo-neutrinos, Supernovae).

JUNO experiment



Mass hierarchy determination through interference with two oscillating amplitudes (solar and atmospheric).
Not dependent on θ_{23} and δ_{CP} like other competitors (Nova, ORCA, PINGU, Dune, INO) using ν_{μ} beams or atmospheric neutrinos.

3-4 σ can be reached in 6 years of operation, provided a factor of 2 improvement is achieved in the energy resolution of current Liquid Scintillator experiments.

INFN contributions:
Liquid scintillator purification (Mi/Pg)
FE electronics (Pd/RM3)
Top Tracker electronics (LNF)
Computing (RM3/CT)
Low activity (MiB)

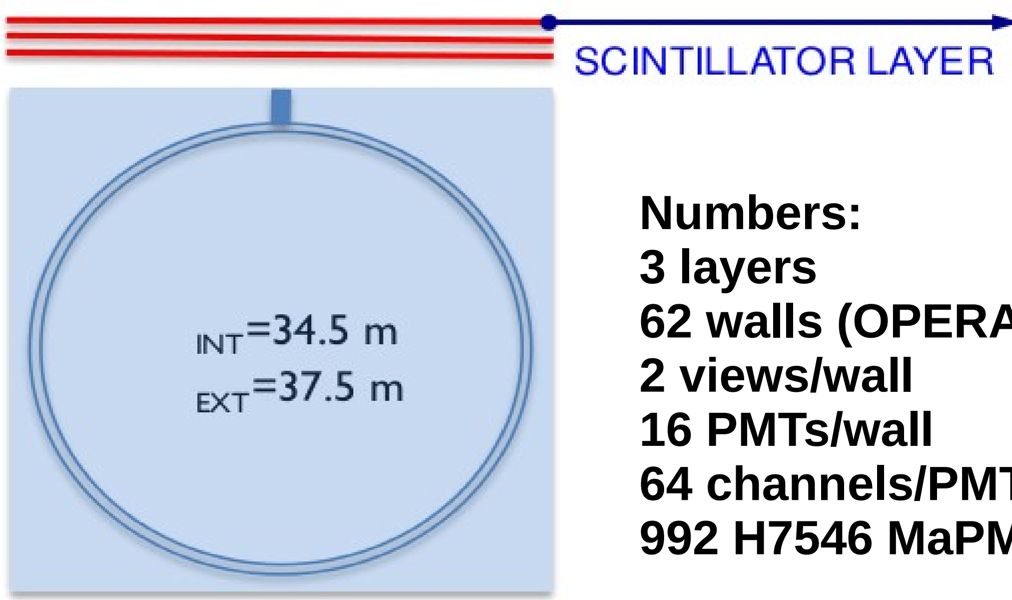
Energy resolution needed:
3% / √ E(MeV) + 1%

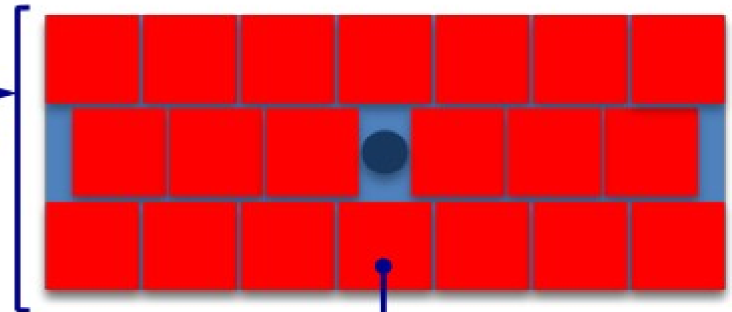
Statistic term:
Scintillator light yield: 10.4 kγ/MeV
Attenuation length: 20 m @430 nm
PMT coverage: 75%
PMT quantum efficiency: 35%

Systematic term:
Dedicated calibration system
Small PMT system (linearity at high energy values and peripheral events)

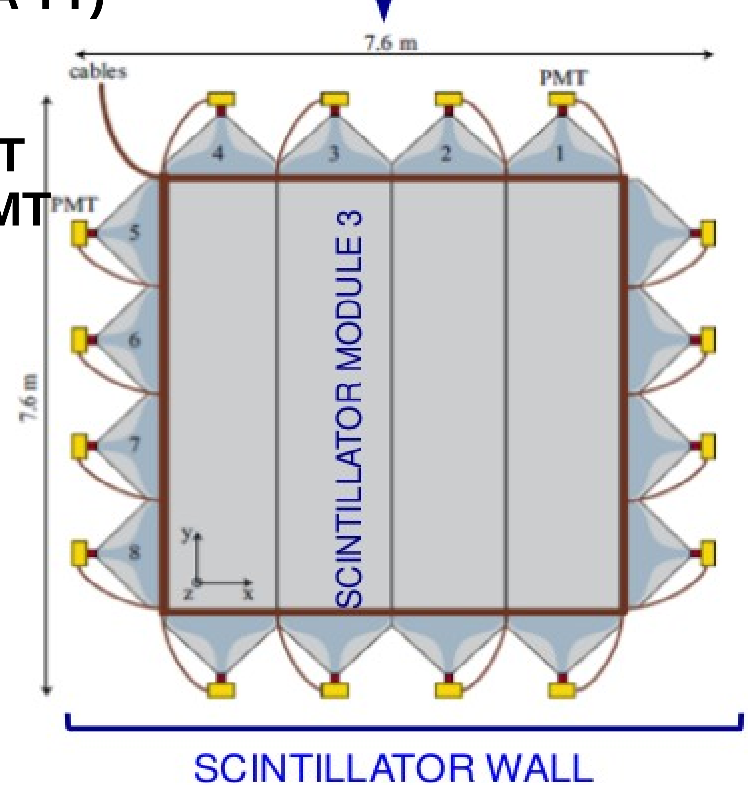
JUNO experiment Top Tracker

Background dominated by cosmogenic production of ^{9}Li and ^{8}Be.
Top Tracker for: tagging (50% coverage), precision study of background, Central Detector performances.
Plastic scintillator strips read-out with WLS fibers from OPERA experiment.





Numbers:
3 layers
62 walls (OPERA TT)
2 views/wall
16 PMTs/wall
64 channels/PMT
992 H7546 MaPMT

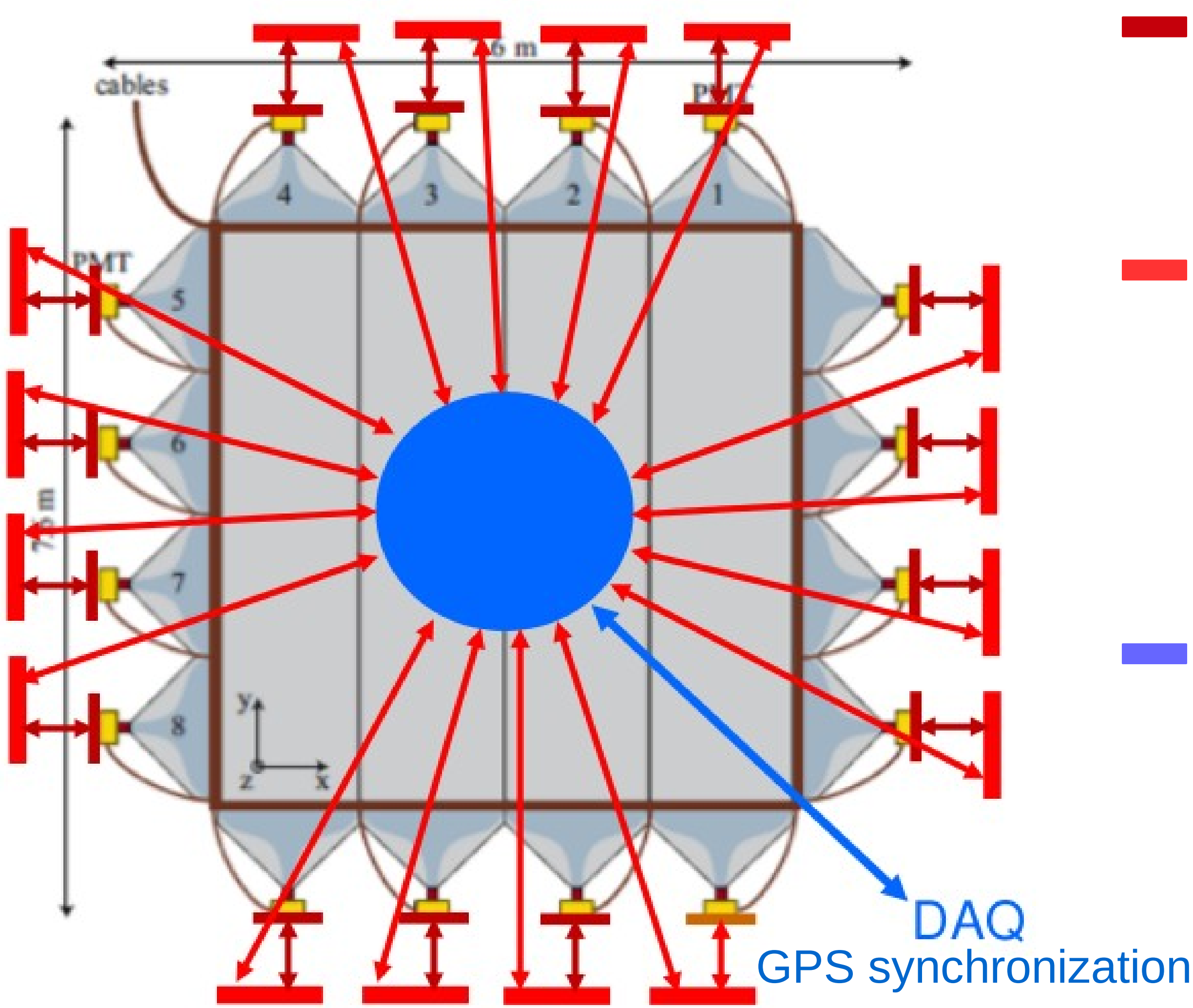


Single PMT maximum rate = 50 kHz
L1 (wall) trigger rate = 10 kHz (100 ns shaping)
Signal multiplicity = 6 fired strip/hit
Charge resolution = 8 bit
Time-stamp resolution = 1 ns

L1 (wall) trigger = AND of x and y views.

JUNO Top Tracker electronics

OPERA electronics and DAQ, designed for low rate, need to be replaced.
A. Paoloni L3 responsible for the electronics of the Top Tracker, realized in collaboration with Strasbourg and LLR-Paris groups.



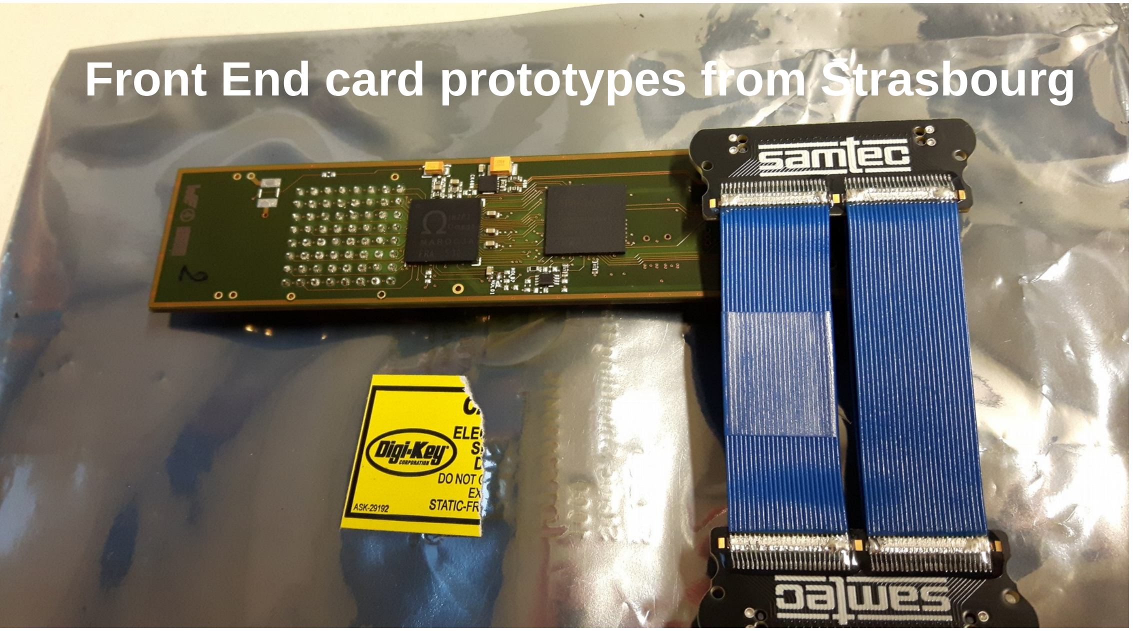
MAROC3 board (FEC):
It hosts MAROC3 chip and logic strictly required to make it work.
(Strasbourg: prototype validated)

Read-out board (ROB):
Manages MAROC3 setting and read-out.
Hosts PMT HV power supply.
Hosts FADC for charge read-out.
(INFN-LNF: prototype ready)

Concentrator board:
Generates wall trigger.
Trigger time-stamp with respect to GPS signal.
Collect read-out data and send them to DAQ.
Deliver DCS commands to read-out boards.
(LLR-Paris-under development)

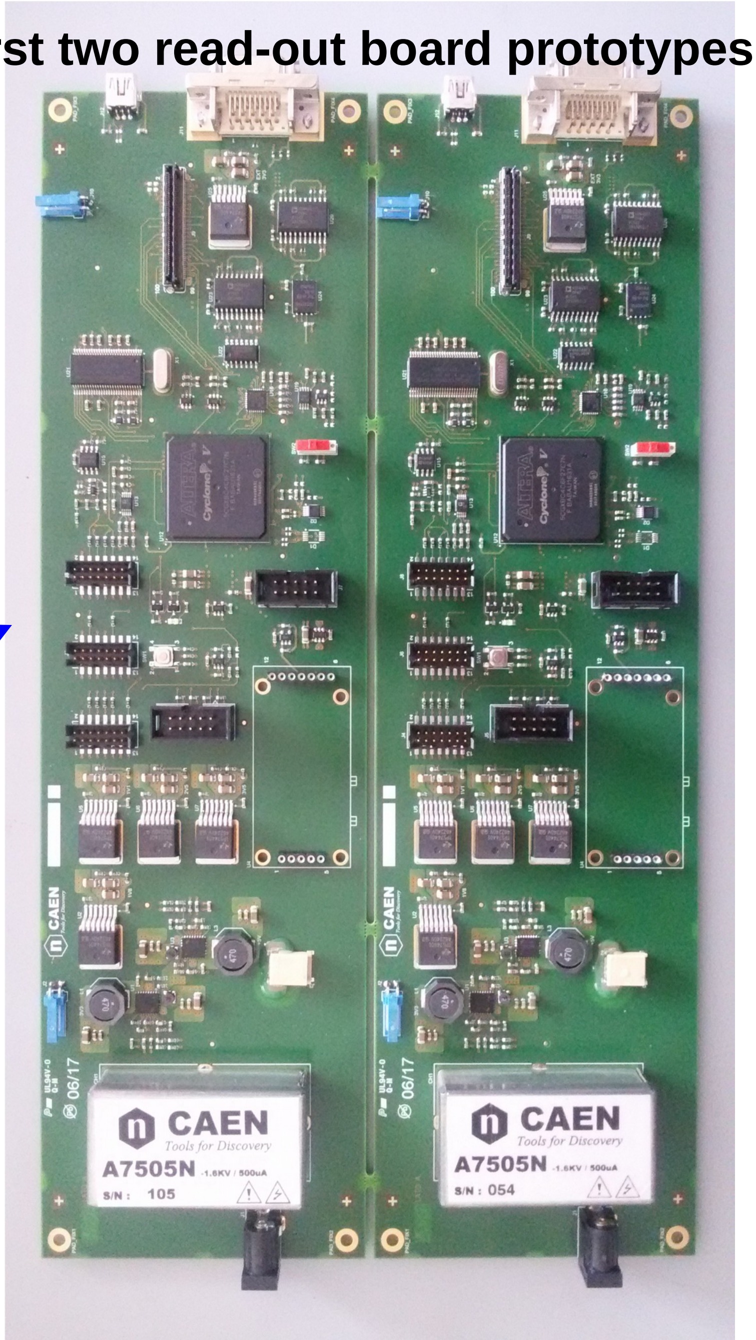
Installation foreseen in second half of 2020. Data taking expected in 2021.

Top Tracker electronics prototypes



Front End card prototypes from Strasbourg

First two read-out board prototypes.



Read-out Board developed and realized by AgeScientific srl.
Power: 12 V, 130 mA (no PMT and FE card connected).

- RO Board design: completed.
- RO PCB design: completed.
- RO PCB production: completed.
- RO Board assembling: completed.
- RO board VHDL coding: first version ready.
- RO Board validation: May 2017.
- FE-RO Boards system validation: First half of June 2017.

LNF cosmic ray experiment perspectives

One group in three experiments (Wizard-PAMELA is closing).
Long term collaboration with Tor Vergata group.
M. Ricci National Responsible of Jem-EUSO INFN groups.
Collaboration with LNF SPCM for mechanical project of mini-EUSO Photo-Detector Module and engineering model realization.

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The EUSO program:

Ultra-High Energy cosmic rays from space.

EUSO-TA:

Ground test detector installed in 2013 at Telescope Array site: currently operational;

EUSO-BALLOON:

Balloon flight from Timmins, Canada (French Space Agency) Aug 2014;

EUSO-SPB:

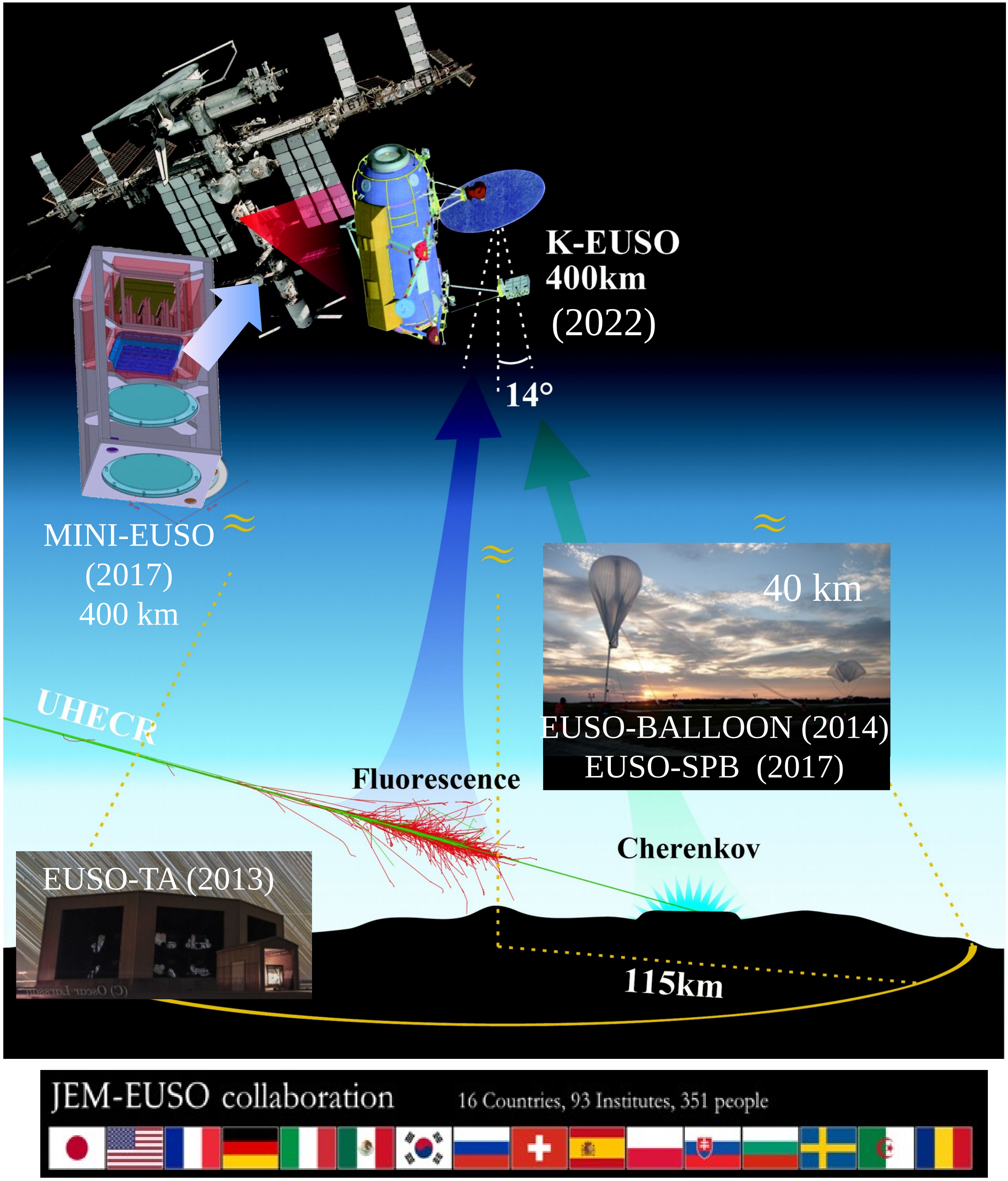
NASA Ultra long duration balloon flight: April 2017, New Zealand;

UV-ATMOSPHERE MINI-EUSO (2017):

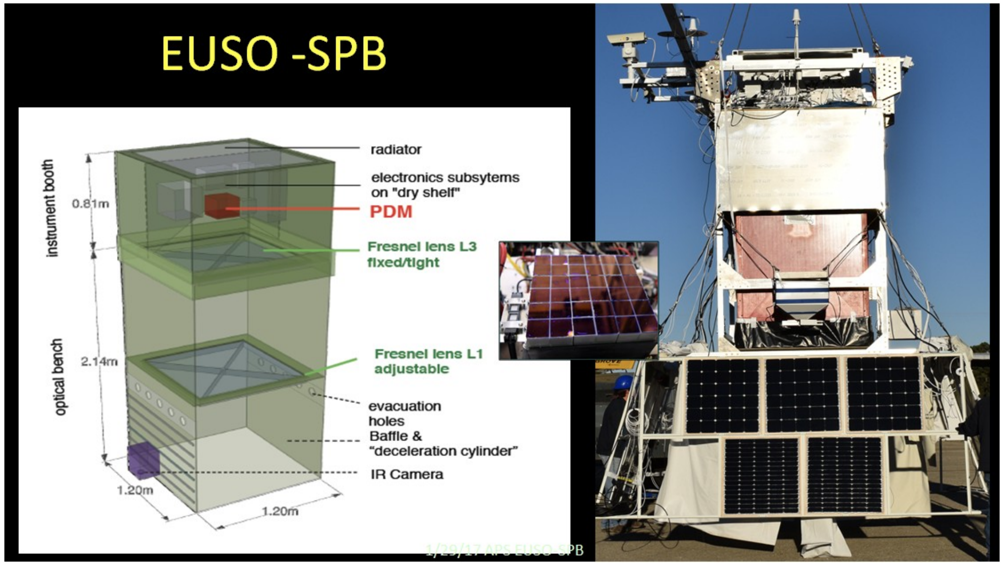
Precursor mission at International Space Station (ISS) late 2017;

K-EUSO (2022):

ISS Approved by Russian Space Agency Roscosmos.



EUSO-SPB Balloon flight, launched 25 April, 2017
Wanaka, New Zealand



NEWS INFN

UNIVERSO ESTREMO: LANCIATO IL TEST SU PALLONE DELLA NASA EUSO-SPB

Il pionieristico osservatorio EUSO-SPB (Extreme Universe Space Observatory – Super-Pressure Ballon) è stato

NASA-CSBF Mission

2nd Payload built by the JEM-EUSO Collaboration.
New lenses, Focal Surface, Improved Electronics.
More than 30 days flight duration.

Main Goal: First UV UHECR shower observation from top of atmosphere

ASI - AGENZIA SPAZIALE ITALIANA
NEWS

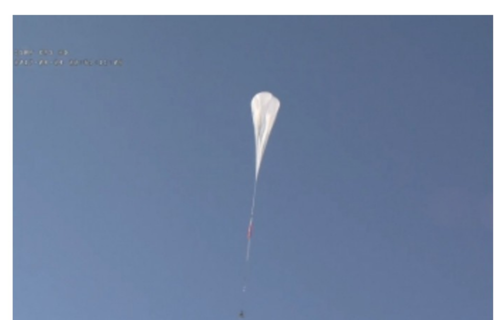
Home > News > Cento giorni stratosferici

PALLONE IN VOLO A 33,5 KM DI ALTEZZA

Cento giorni stratosferici

Al via l'esperimento NASA EUSO-SPB su pallone stratosferico. Testerà tecnologie chiave utili alla realizzazione di un futuro osservatorio spaziale di raggi cosmici di altissima energia. Tra i partner anche l'Italia con l'ASI e l'INFN

di Redazione ASI — Follow @ASI_Spazio — Martedì 25 Aprile 2017



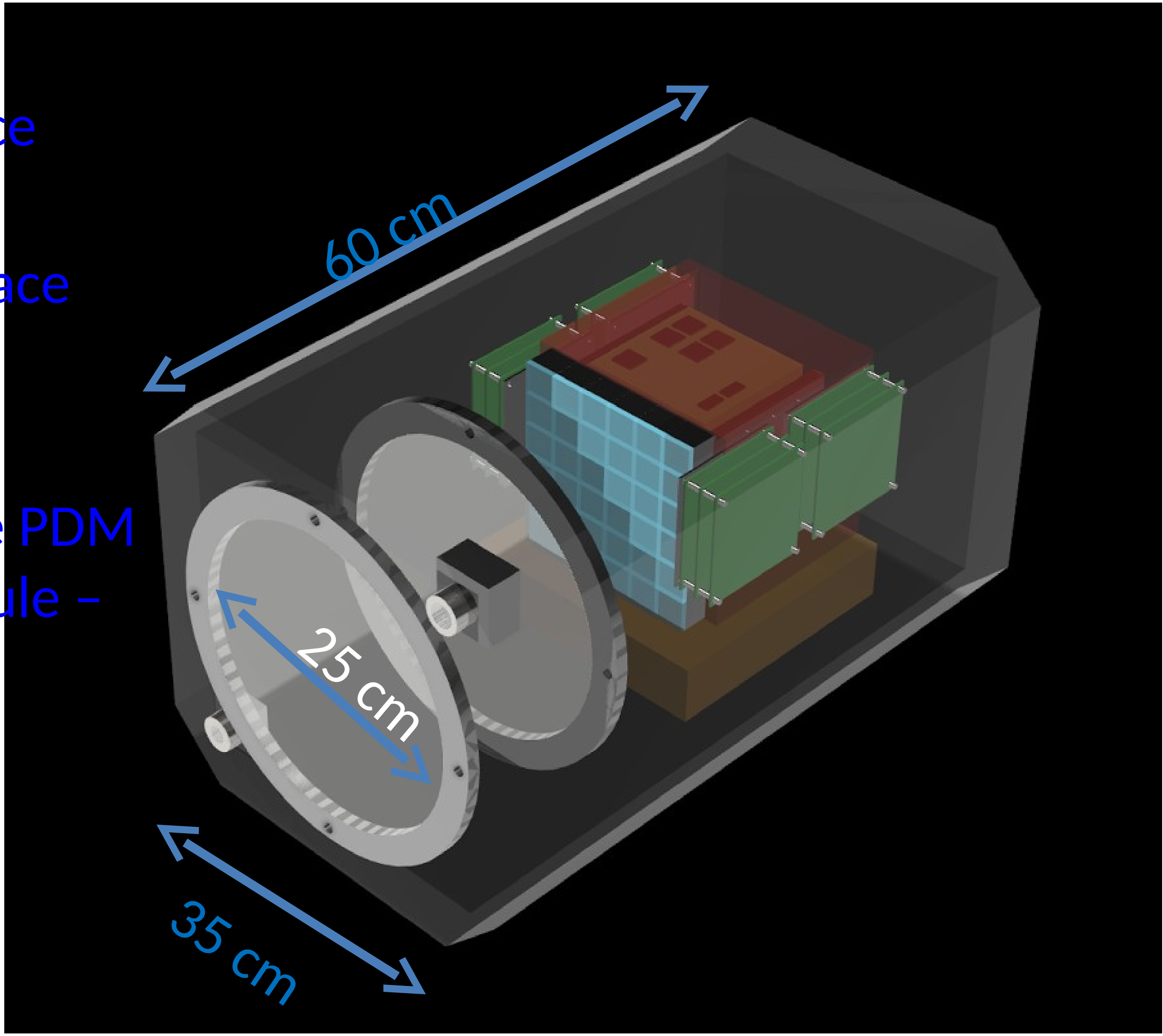
Il pionieristico osservatorio **EUSO-SPB** (Extreme Universe Space Observatory – Super-Pressure Ballon) è stato lanciato alle 00.50 del 25 aprile (in Italia) con successo dalla **NASA** dalla base di Wanaka, Otago, in Nuova Zelanda. A bordo di un **pallone stratosferico** che mantiene sempre una pressione interna positiva rispetto all'ambiente nel quale sta volando, la strumentazione scientifica è prevista fluttuare per almeno **100 giorni nella stratosfera**, all'altezza di 33,5 km.

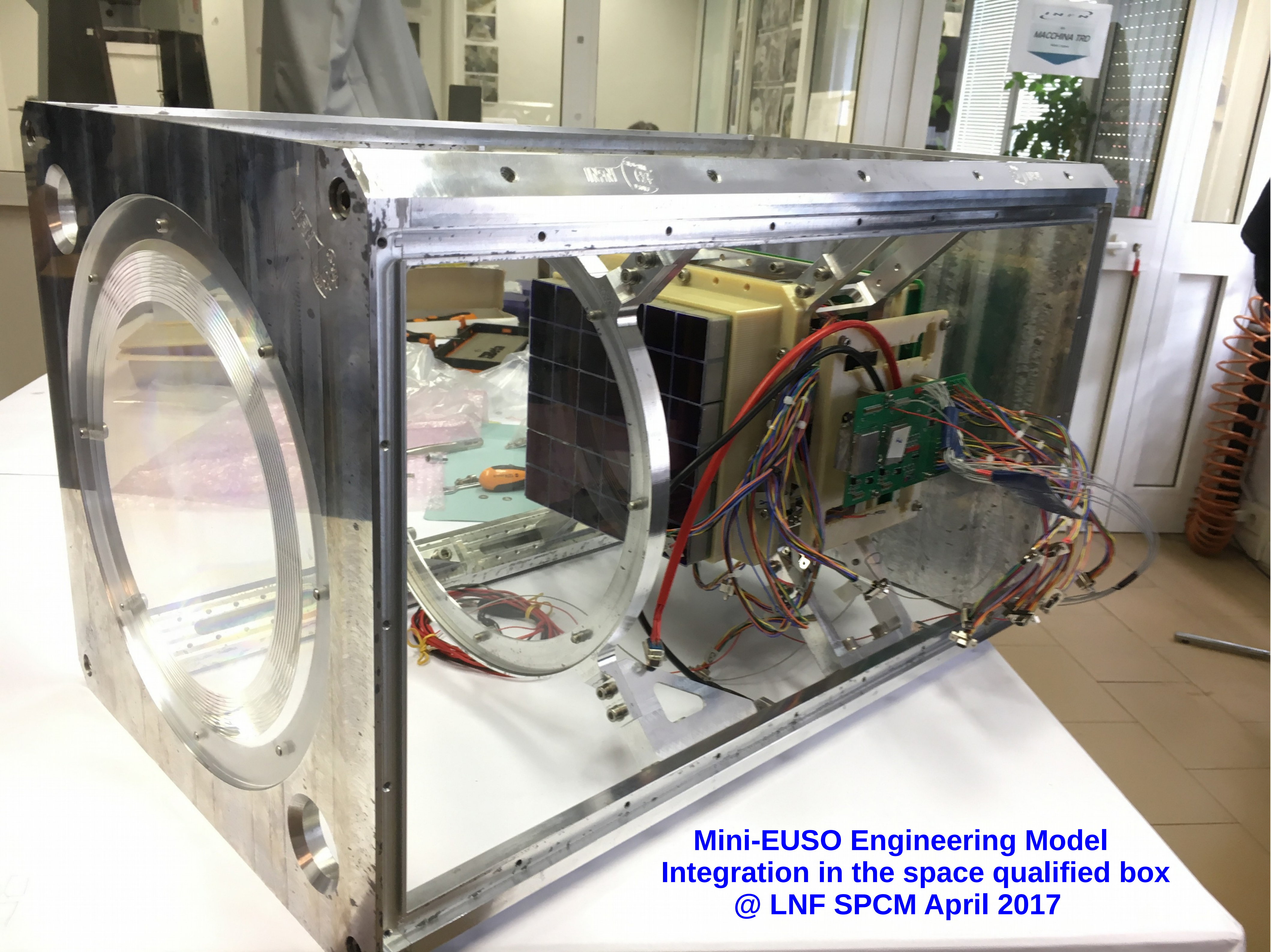
L'esperimento, frutto di una collaborazione internazionale alla quale partecipano **16 Paesi**, tra cui l'Italia con **l'INFN e l'Agenzia Spaziale Italiana** (ASI), rappresenta un test per **JEM-EUSO**, il futuro osservatorio spaziale di **raggi cosmici di altissima energia** (**UHECR**, Ultra High Energy Cosmic Rays), di cui dovrà verificare la tecnologia e la fattibilità.

MINI-EUSO/UV-Atmosphere

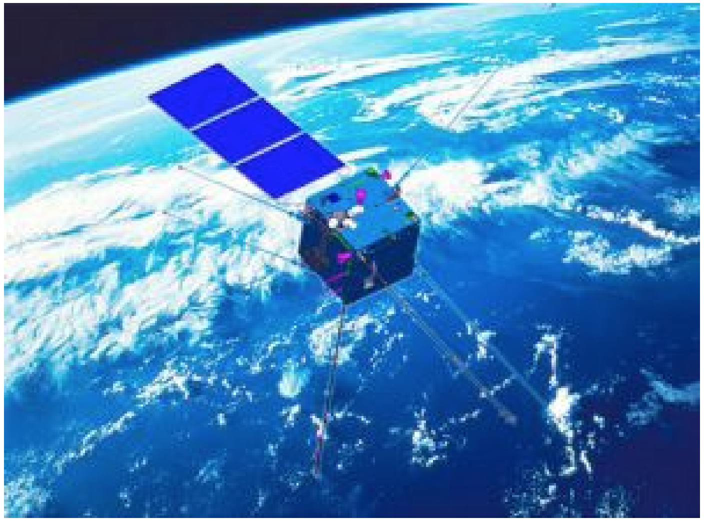
A precursor of EUSO on board ISS Russian Modulefor the observation of Atmosphere and Earth in the UV spectrum

- Approved by Italian Space Agency
- Approved by Russian Space Agency
- Inside the ISS late 2017
- 2 Fresnel lenses and one PDM (Photo Detector Module – 36 PMT's)
- FoV: ± 19°
- Power: 60 W @ 27 V
- Weight: 30 kg





Mini-EUSO Engineering Model
Integration in the space qualified box
@ LNF SPCM April 2017



LIMADOU-CSES

(Chinese Seismo-Electromagnetic Satellite)

ASI INFN INGV project
Chinese National Space Agency
China Earthquake Administration

Main Scientific Objectives:

- Measurement from space of magnetospheric perturbations and correlations with seismic phenomena
- Interactions between Magnetosphere, Ionosphere and Earth

Instruments on board CSES Satellite:

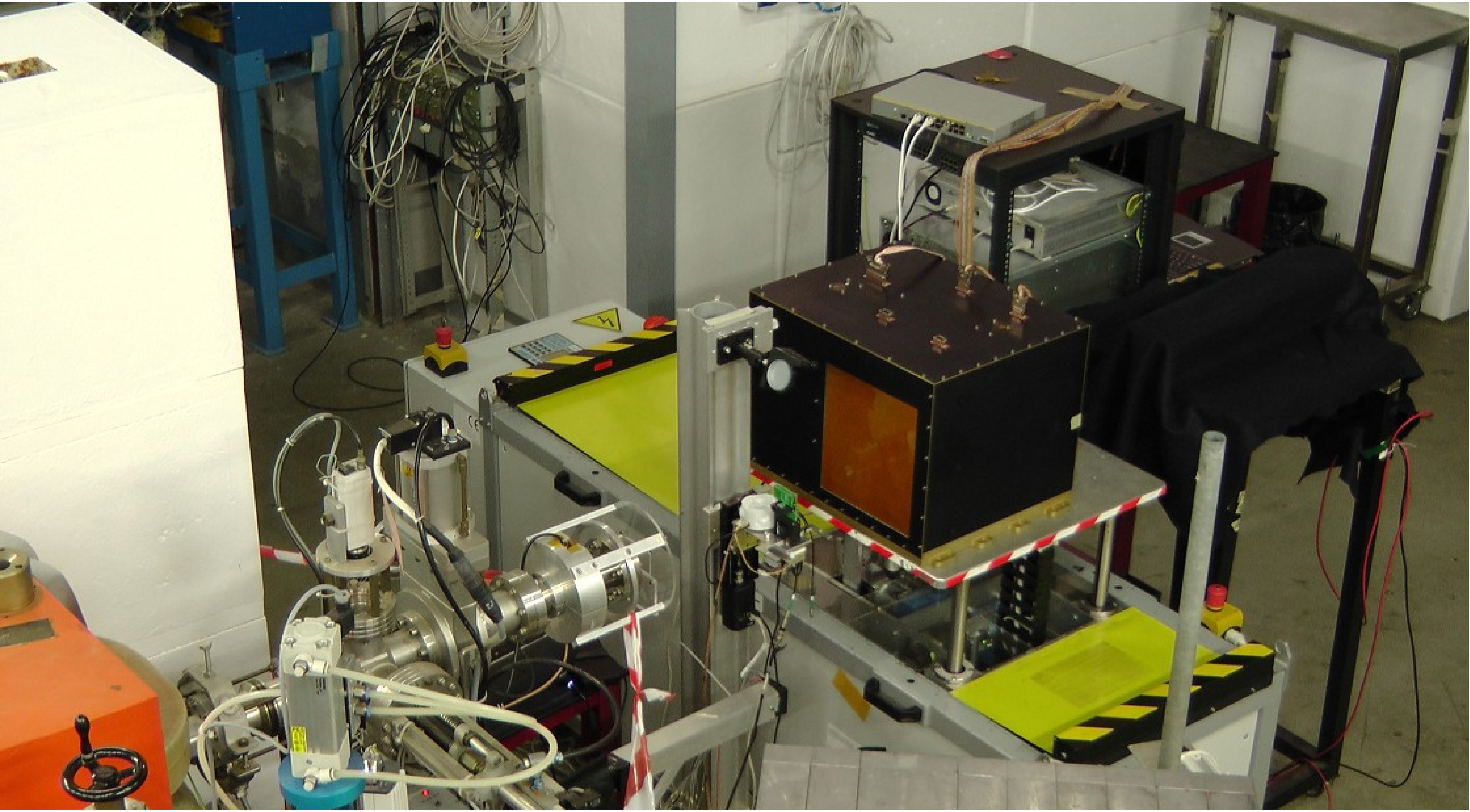
- Magnetic Spectrometer
- Electric Field Detector
- High Energy Particle Detector
- Magnetic Field Detector
- Low-frequency e.m. wave detector

Launch mid-August 2017

Jiuquan Satellite Launch Center, Gansu (Inner Mongolia)

CSES- LIMADOU High Energy Particle Detector (HEPD) Flight Model Electron Beam Test @ BTF, Frascati, 3-5 October 2016

→ **Energy: 30 MeV, 45 MeV, 60 MeV, 120 MeV**



LNF Gravitation experiment perspectives

Moonlight2: Laser ranging as a probe of General Relativity.
S. Dell'Agnello is National Responsible.
The group includes also researchers from universities and Matera Laser Ranging Observatory associated to LNF.

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JUNO	1.0 (2)	1 R (R=researcher)	
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INFN solar system science assets

- MoonLIGHT, the *big* Lunar laser retroreflector
  - Moon Laser Instrumentation for General relativity High accuracy Tests, next-generation lunar (see D. Currie's talk)
- INRRI, the Solar System *micro*reflector
  - Instrument for landing-Roving laser Retroreflector Investigations
- PEP, the Planetary Ephemeris Program *orbital SW*
  - Lunar/Martian positioning data: with PEP, developed in USA at the Harvard-Smithsonian Center for Astrophysics (CfA), by Shapiro, Reasenberg, Chandler since 1960/70s

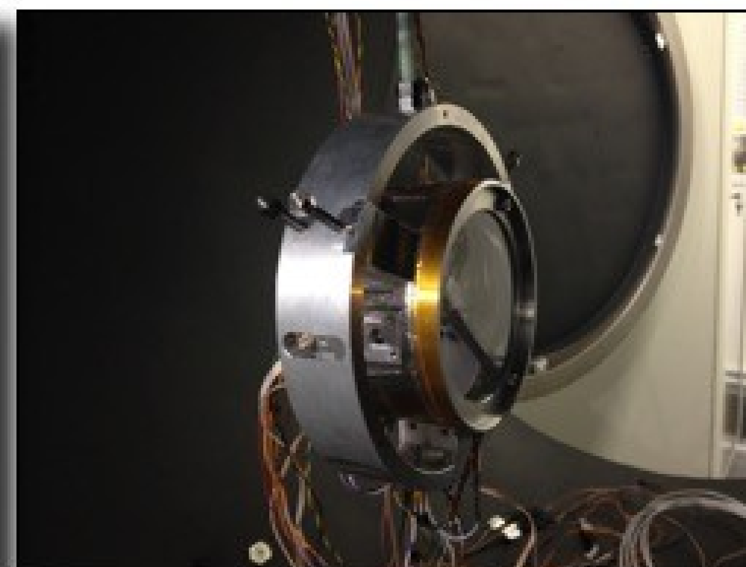
MoonLIGHT, next-generation

Lunar Laser Ranging (LLR) Retroreflector

- INFN-Frascati, U. Maryland, INFN/Univ. Padua
- Lunar stations: ASI-MLRO (Italy), APOLLO (US), OCR (France)

MoonLIGHT (100 mm) **GNSS (33 mm)**

MoonLIGHT package



Lunar Laser Ranging test of General Relativity

- Improvements of the space segment up to ×100 with MoonLIGHTs on near side in addition to Apollo/Lunokhods

Science measurement / Precision test of violation of General Relativity	Apollo/Lunokhod * few cm accuracy	MoonLIGHTs ** mm	sub-mm
Parameterized Post-Newtonian (PPN) β	$\lvert\beta-1\rvert < 1.1\times10^{-4}$	10^{-5}	10^{-6}
Weak Equivalence Principle (WEP)	$\lvert\Delta a/a\rvert < 1.4\times10^{-13}$	10^{-14}	10^{-15}
Strong Equivalence Principle (SEP)	$\lvert\eta\rvert < 4.4\times10^{-4}$	3×10^{-5}	3×10^{-6}
Time Variation of Gravitational Constant	$\lvert\dot{G}/G\rvert < 9\times10^{-13}\text{yr}^{-1}$	5×10^{-14}	5×10^{-15}
Inverse Square Law (ISL) - Yukawa	$\lvert\alpha\rvert < 3\times10^{-11}$	10^{-12}	10^{-13}
Geodetic Precession	$\lvert K_{gp}\rvert < 6.4\times10^{-3}$	6.4×10^{-4}	6.4×10^{-5}

* J. G. Williams et al PRL 93, 261101 (2004)

** M. Martini et al Plan. & Space Sci. 74 (2012) 276–282; M. Martini PhD thesis 2016

MEDIA RELEASE

Daven Maharaj / 650-241-8577
media@moonexpress.com

FOR RELEASE: May 15th, 2015 @ 2:00PM GMT

Moon Express Announces First International Multi-Mission Payload Agreement with The INFN National Laboratories of Frascati and the University of Maryland

"MoonLIGHT" Lunar Laser Ranging Array Will Bring New Insights into General Relativity

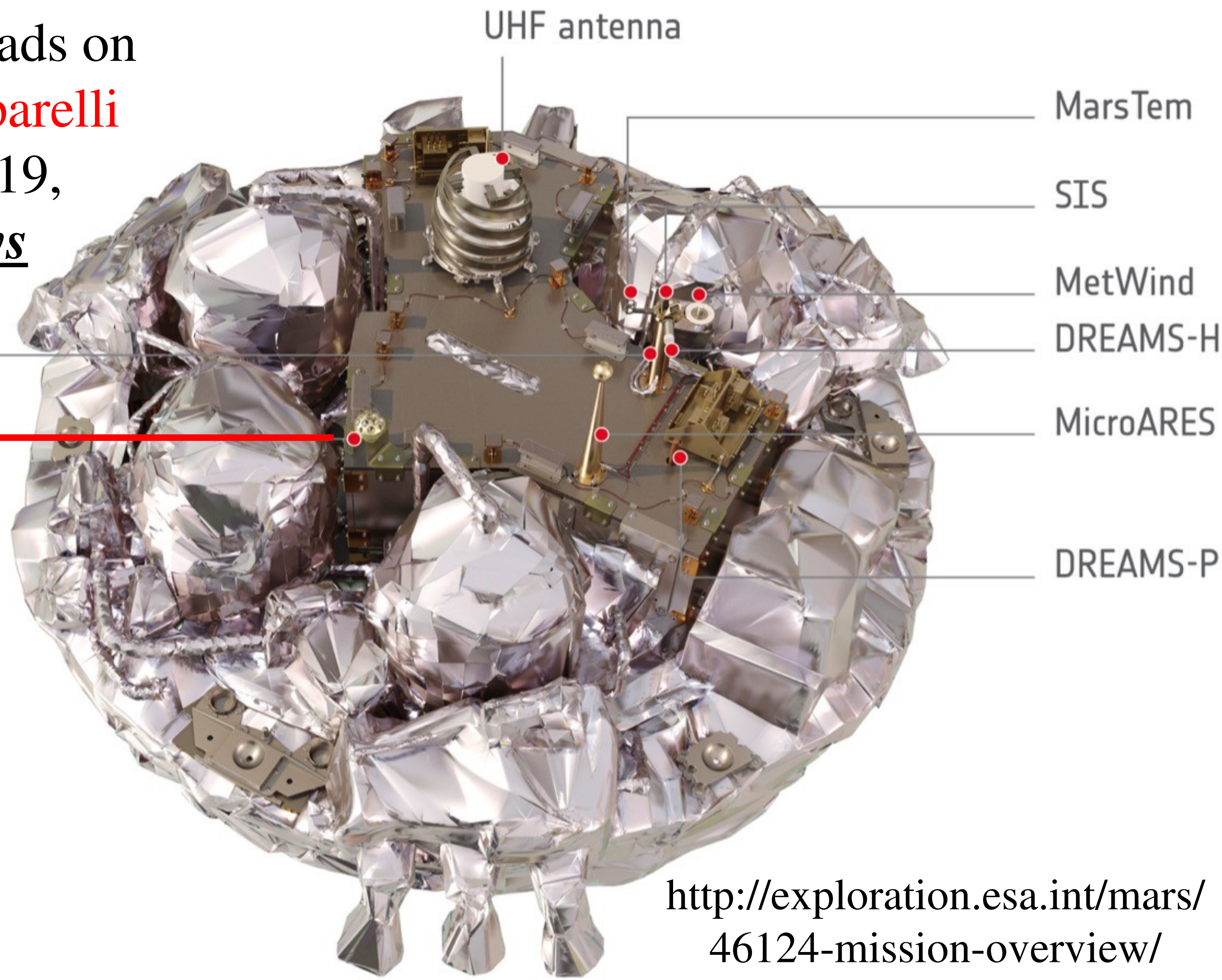
Frascati, Italy (May 15th, 2015) – Moon Express, Inc. (MoonEx) has announced a multi-mission payload agreement with The National Laboratories of Frascati (INFN-LNF) and the University of Maryland to deliver a new generation of lunar laser ranging arrays to the Moon. Under the agreement, "MoonLIGHT" instruments will be carried on the first four Moon Express missions and used in conjunction with Apollo Cube Corner (CCR) Retroreflector arrays to test principles of Einstein's General Relativity theory, add to international scientific knowledge of the Moon, and increase lunar mapping precision that will support the company's future lander missions.

"MoonLIGHT" Payload Agreement Announcement in Frascati, Italy. L-R: Jack Burns, CU; Doug Currie, UMD; Simone Dell'Agnello, INFN-LNF; Bob Richards, Moon Express

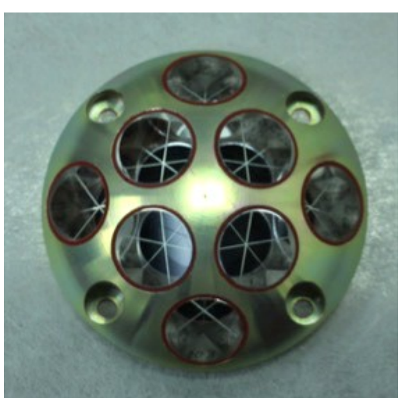
The payload announcement was made today in Frascati, Italy, right after the European Lunar Symposium, during a Global Exploration Roadmap workshop of the International Space Exploration Coordination Group (ISECG), attended by officials

ExoMars 2016: 1st laser retroreflector on Mars

Science payloads on Lander Schiaparelli
Landing: Oct 19, 2016, ***<u>in 6 days</u>***



INRRI
25 gr
~5cm×2cm



http://exploration.esa.int/mars/46124-mission-overview/

National Aeronautics and Space Administration

Headquarters
Washington, DC 20546-0001

July 14, 2016

SMD/Mars Exploration Program

Dr. Enrico Flamini
Chief Scientist
Agenzia Spaziale Italiana
Via del Politecnico snc
00133 Rome
Italy

Dear Dr. Flamini:

NASA is agreeable to hosting the Agenzia Spaziale Italiana (ASI) Laser Retroreflector Array (LRA) on the Mars 2020 rover, as we see the instrument to be of mutual benefit, holding the potential to improve the accuracy of geospatial maps that the scientific community has been building for the last several decades. We are also exploring the possibility of including an ASI LRA on NASA's Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight) mission.

InSight lander launch in May 2018.
Test Readiness Review today @LNF, with NASA-JPL and ASI.
Bruce Banerdt, mission PI, also present.

Mars test of GR (PEP simulations)

- MGN, Mars Geo/physics Network of INRRIs
- Test of non-ideal MGN (~all north, weather/accuracy limitations)

  Phoenix Lander (68N, 234E), Curiosity Rover (4S, 137E), Opportunity Rover (2S, 354E), Viking1 lander (22N, 50W), Viking 2 Lander (48N, 258W)
- Data: 1 laser normal point (NP) every 7 Sols for 10 years
  - Or >1 NP every 7 Sols for < 10 years
- Preliminary, but based on consolidated lunar PEP analysis
- Accuracy: 10cm–10m (current ephemeris ~50m)

INRRI: Time/Accuracy	Accuracy on β-1	Accuracy on γ-1	Accuracy on $\dot{G}/G$
10 years / 10 m	1.7 x E-04	7.2 x E-04	3.8 x E-14
10 years / 1 m	3.7 x E-05	1.6 x E-05	1.4 x E-14
10 years / 10 cm	7.4 x E-07	3.2 x E-06	2.9 x E-15
Best accuracy now Data *Analysis group*	**1 x E-04** Lunar Laser Ranging *JPL, Harvard-INFN*	**2.3 x E-05** Cassini *Bertotti et al*	**9 x E-13** Lunar Laser Ranging *JPL, Harvard-INFN*

LNF Dark Sector experiment perspectives

QUAX: Brand new activity on axion reasearch (also in CSN2).
1.5 FTE from CSN1 and CSN5.
An increase of interest at LNF on this sector, with the opening of other experimental activities,
Is expected in the next years.

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Axion: CP violation in QCD

$$\mathcal{L}_{QCD} = ... + \theta \frac{\alpha_s}{8\pi} G_{a\mu\nu} \tilde{G}_a^{\mu\nu}$$

This term violates T (CP) symmetry and induces a neutron electric dipole moment (EDM)

Predicted:

$$d_n \simeq \theta \frac{m_q}{M_n} \frac{e}{M_n} \sim \theta \times 10^{-3} e \text{ GeV}^{-1} \sim \theta \times 10^{-15} e \text{ cm}$$

Measured:

$$d_n < 2.9 \times 10^{-26} e \text{ cm} \qquad \theta < 10^{-10}$$

PRL 82(5) (1999) p.904ß

Moreover θ gets further contributions from quark mass matrix. Why so small?

Axion Solution

$$\mathcal{L}_{QCD} = ... + \frac{\alpha_s}{8\pi}(\theta - \frac{a}{f_a})G_{a\mu\nu}\tilde{G}^{\mu\nu}_a$$

"a" is a new scalar field.

Peccei Quinn Weinberg Wilczek

Axions Cold Dark Matter

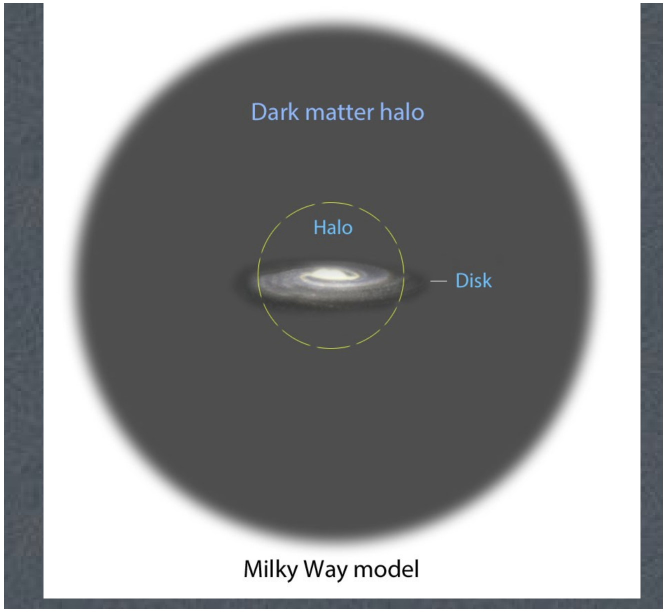
$$\rho \simeq 0.3GeV/cm^3$$

$$n_a \simeq 3 \times 10^{12} \left(\frac{100\mu eV}{m_a}\right) 1/\mathrm{cm}^3$$

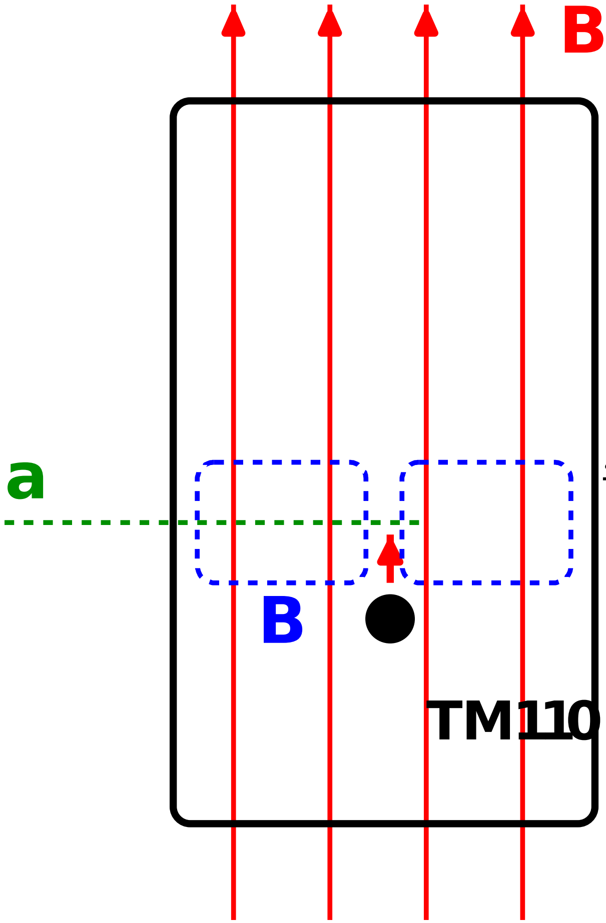
$$\beta_a \sim 10^{-3}$$

$$\frac{\delta\omega}{\omega} \sim 10^{-6} \qquad \frac{\omega}{2\pi} = 24(\frac{m_a}{100\mu eV})\mathrm{GHz}$$

$$a = a_0 \cos\omega t$$



Quax Experiment



Search for galactic axions through their coupling to electrons: axion “wind” flips an electron spin inside a resonant cavity exciting its mode TM110.
Very low power signals expected, measurebale with a single microwave photon counter.

$$\frac{g_p \hbar}{2m} \sigma \cdot \nabla a$$

$$P_S \sim 5 \times 10^{-26} \mathrm{W}$$

$$R_S \sim 1 \times 10^{-3} \mathrm{Hz}$$

$$m_a = 200 \mu \mathrm{eV}$$

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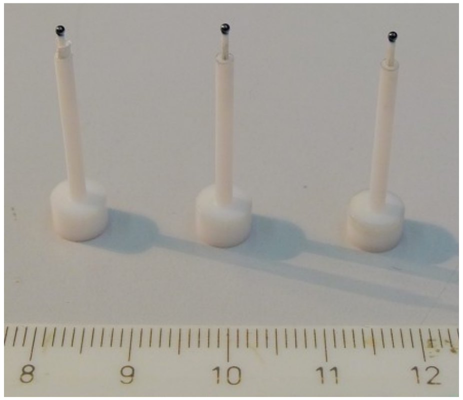
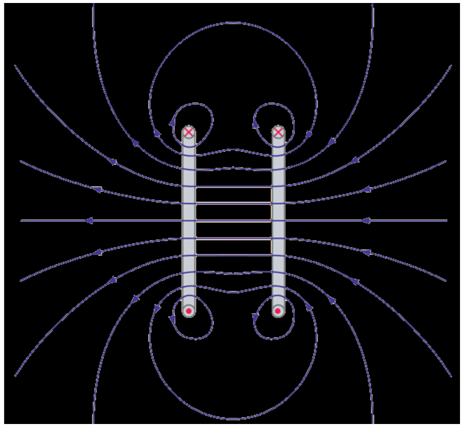
Quax R&D

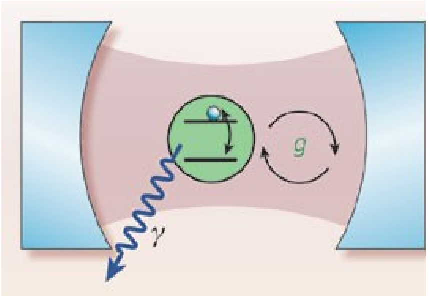


1) R&D on paramegnetic/ferrimagnetic materials (high spin density $10^{28}/m^3$) (Pd/LNL/To)

2) R&D on SC resonant cavities operating in strong B field (LNF)



3) R&D on magnets with strong (2T) and uniform (10 ppm) magnetic field. (Na/Salerno)



4) R&D on Single microwave photon counters (LNL/Pd/LNF/Trento)

Request of LNF services:
Research division mechanical workshop.
1 month*person for cavity project.
Support for cryogenics (He liquefier).

LNF group II summary

Small number of experiment participations, mostly with high level technological contributions.
Small requests to LNF services (cryogenics, SC resonant cavities, mechanical services for space activities).
Need for additional manpower (especially critical on neutrino experiments).
Open of new research activity on dark matter.

Experiment	FTE (persons)	LNF group II staff	postdoc
JUNO	1.0 (2)	1 R (R=researcher)	
KM3	1.3 (4)	1 T (T=technologist)	
CUORE	1.5 (3)	3 T	
Jem EUSO	2.0 (6)	1 R + 2 T (also in CUORE)	
Wizard	0.9 (2)		1 ADR (ToV)
Limadou	0.1 (2)		
Moonlight2	7.2 (12)	1 RTD + 2 T	3 ADR
QUAX	1.9 (5)	2 R + 1 T (also in CUORE)	

RTD =researcher, not permanent

1 RTD + 3 ADR paid with ASI funds.
1 ADR paid with headquarter funds (NASA/SSERVI.