doi:10.1038/nature13433

# Precision measurement of the Newtonian gravitational constant using cold atoms

G. Rosi[1], F. Sorrentino[1], L. Cacciapuoti[2], M. Prevedelli[3] & G. M. Tino[1]

**About 300 experiments have tried to determine the value of the Newtonian gravitational constant, *G*, so far, but large discrepancies in the results have made it impossible to know its value precisely[1]. The weakness of the gravitational interaction and the impossibility of shielding the effects of gravity make it very difficult to measure *G* while keeping systematic effects under control. Most previous experiments performed were based on the torsion pendulum or torsion balance scheme as in the experiment by Cavendish[2] in 1798, and in all cases macroscopic masses were used. Here we report the precise determination of *G* using laser-cooled atoms and quantum interferometry. We obtain the value $G = 6.67191(99) \times 10^{-11}\ \mathrm{m^3\,kg^{-1}\,s^{-2}}$ with a relative uncertainty of 150 parts per million (the combined standard uncertainty is given in parentheses). Our value differs by 1.5 combined standard deviations from the current recommended value of the Committee on Data for Science and Technology[3]. A conceptually different experiment such as ours helps to identify the systematic errors that have proved elusive in previous experiments, thus improving the confidence in the value of *G*. There is no definitive relationship between *G* and the other fundamental constants, and there is no theoretical prediction for its value, against which to test experimental results. Improving the precision with which we know *G* has not only a pure metrological interest, but is also important because of the key role that *G* has in theories of gravitation, cosmology, particle physics and astrophysics and in geophysical models.**

the relevant gravitational signal. An additional cancellation of common-mode spurious effects was obtained by reversing the direction of the two-photon recoil used to split and recombine the wave packets in the interferometer[18]. Efforts were devoted to the control of systematics related to atomic trajectories, the positioning of the atoms and effects due to stray fields. The high density of tungsten was instrumental in maximizing the signal and in compensating for the Earth's gravitational gradient in the region containing the atom interferometers, thus reducing the sensitivity of the experiment to the vertical position and size of the atomic probes.

The atom interferometer is realized using light pulses to stimulate $^{87}$Rb atoms at the two-photon Raman transition between the hyperfine levels $F = 1$ and $F = 2$ of the ground state[19]. The light field is generated by two counter-propagating laser beams with wave vectors $k_1$ and $k_2 \approx -k_1$ aligned along the vertical direction. The gravity gradiometer consists of two vertically separated atom interferometers operated in differential mode. Two atomic clouds launched along the vertical direction are simultaneously interrogated by the same $\pi/2$–$\pi$–$\pi/2$ pulse sequence. The difference in the phase shifts detected at the output of each interferometer provides a direct measurement of the differential acceleration induced by gravity on the two atomic samples. In this way, any spurious acceleration induced by vibrations or seismic noise in the common reference frame identified by the vertical Raman beams is efficiently rejected.

# LETTER

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**Acknowledgements** G.M.T. acknowledges discussions with M. A. Kasevich and J. Faller and useful suggestions by A. Peters in the initial phase of the experiment. We are grateful to A. Cecchetti and B. Dulach for the design of the source mass support and to A. Peuto, A. Malengo, and S. Pettorruso for density tests on the tungsten masses. We thank D. Wiersma for a critical reading of the manuscript. This work was supported by INFN (MAGIA experiment).

**Author Contributions** G.M.T. had the idea for the experiment, supervised it and wrote the manuscript. G.R., F.S. and L.C. performed the experiment. M.P. contributed to the experiment and analysed the data.

# Commissione II

**A. Paoloni**

Consiglio di laboratorio
1 Luglio 2014

# Attivita' di CSN2 presso i laboratori

| Neutrino physics (mainly at LNGS) | | | | | |
|---|---|---|---|---|---|
| BOREXINO | HOLMES_2 | ICARUS | NESSIE-RD | OPERA | T2K |
| JUNO | | | | | |

| Search for rare processes (mainly at LNGS) | | | | | |
|---|---|---|---|---|---|
| CUORE | DAMA | DARKSIDE | GERDA | LUCIFER-RD | LVD |
| XENON | | | | | |

| Study of the cosmic rays by ground based and underwater experiments | | | | | |
|---|---|---|---|---|---|
| ARGO-YBJ | AUGER | CTA-RD | KM3 | MAGIC | |

| Study of the cosmic rays by experiments in the space | | | | | |
|---|---|---|---|---|---|
| AMS2 | DAMPE* | FERMI | GAMMA400 | JEM-EUSO-RD | WIZARD |

| Search for gravitational waves | | | | | |
|---|---|---|---|---|---|
| AURIGA | LISA-PATHFINDER | RARENOISE | ROG | VIRGO | |

| General physics | | | | | |
|---|---|---|---|---|---|
| G-GRANSASSO-RD | GGG | HUMOR | LARASE | MAGIA | MICRA |
| MIR | MOONLIGHT2 | PVLAS | SUPREMO* | | |

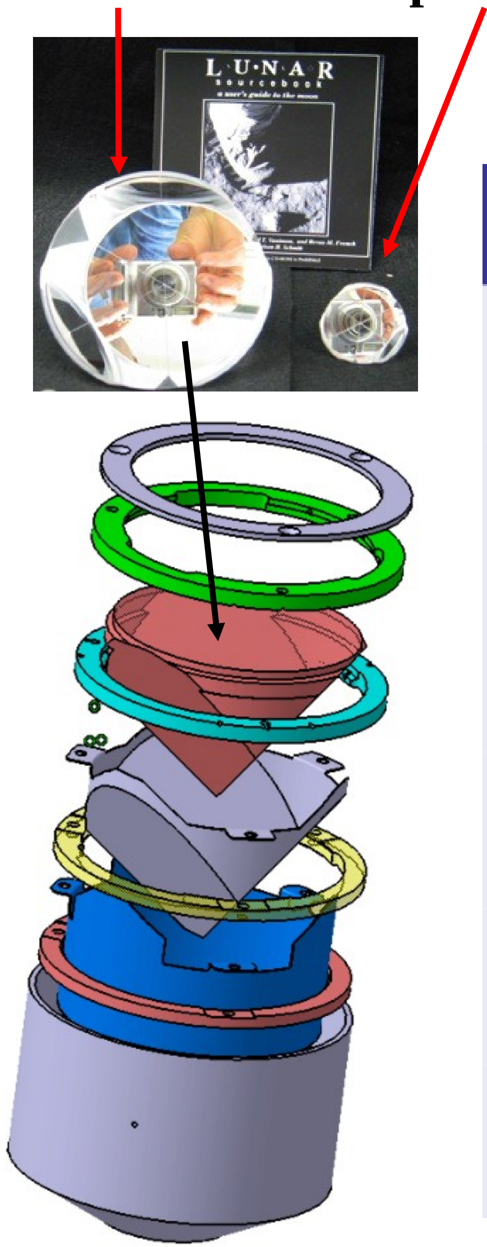
Circa 20 FTE (30 persone).



M. Ricci resp. Nazionale di Jem-Euso-RD. S. Dell'Agnello di Moonlight2.

# MoonLIGHT-2: 1-kg Lunar Reflector

**MoonLIGHT& Apollo**




- Goal: Precision tests of General Relativity
- Missions: Luna-27 (Russia, 2019), Chang'e-4/5 (China, 2015/2017); Astrobotic, Moon Express (US, commercial, 2016)

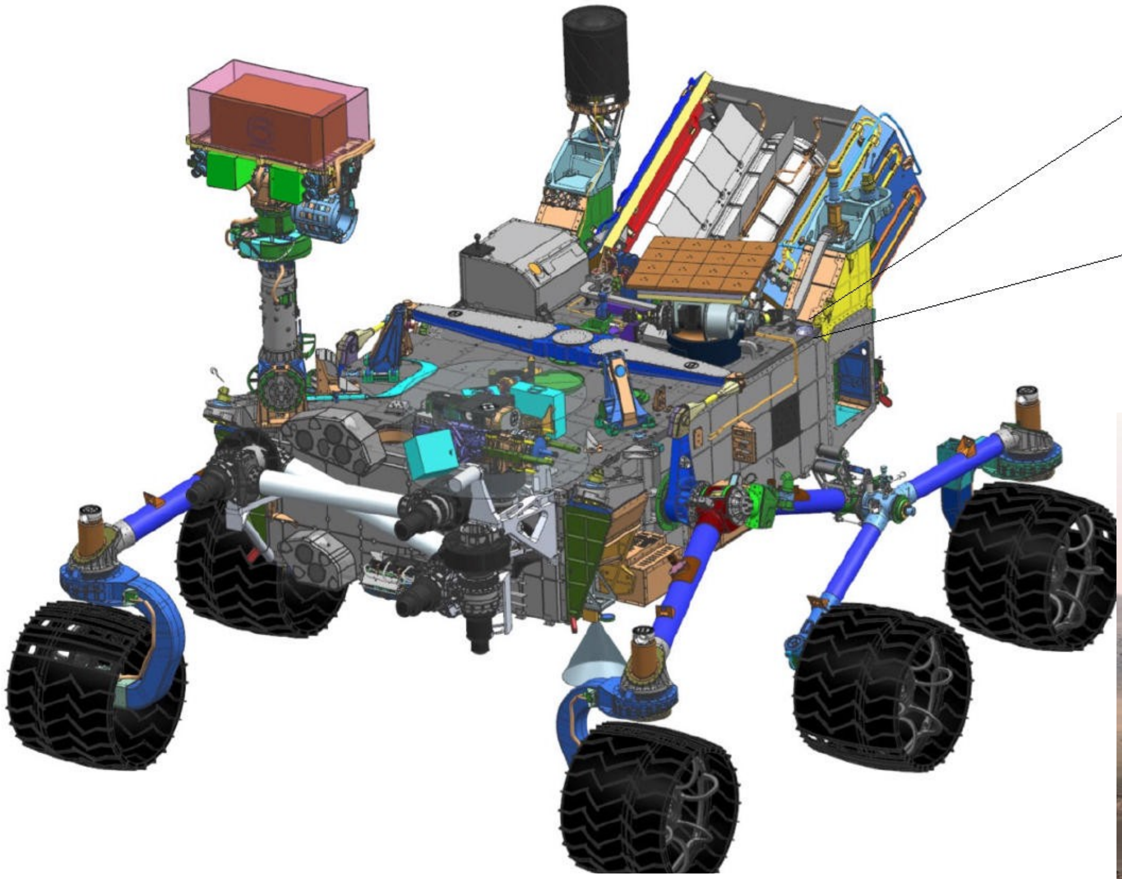
| Precision test of General Relativity | Time scale | Apollo/Lunokhod few cm accuracy* | MoonLIGHT 1 mm | MoonLIGHT 0.1 mm |
|---|---|---|---|---|
| Parameterized Post-Newtonian (PPN) β | Few years | \|β-1\|<1.1×10-4 | 10-5 | 10-6 |
| Weak Equivalence Principle (WEP) | Few years | \|Δa/a\|<1.4×10-13 | 10-14 | 10-15 |
| Strong Equivalence Principle (SEP) | Few years | \|η\|<4.4×10-4 | 3×10-5 | 3×10-6 |
| Time Variation of the Gravitational Constant | ~5 years | \|Ġ/G\|<9×10-13yr-1 | 5×10-14 | 5×10-15 |
| Inverse Square Law (ISL) | ~10 years | \|α\|<3×10-11 | 10-12 | 10-13 |
| Geodetic Precession | Few years | \|Kgp\|<6.4×10-3 | 6.4×10-4 | 6.4×10-5 |

# INRRI: 50-gr reflectors for Mars Rovers

**INRRI$2020**:"

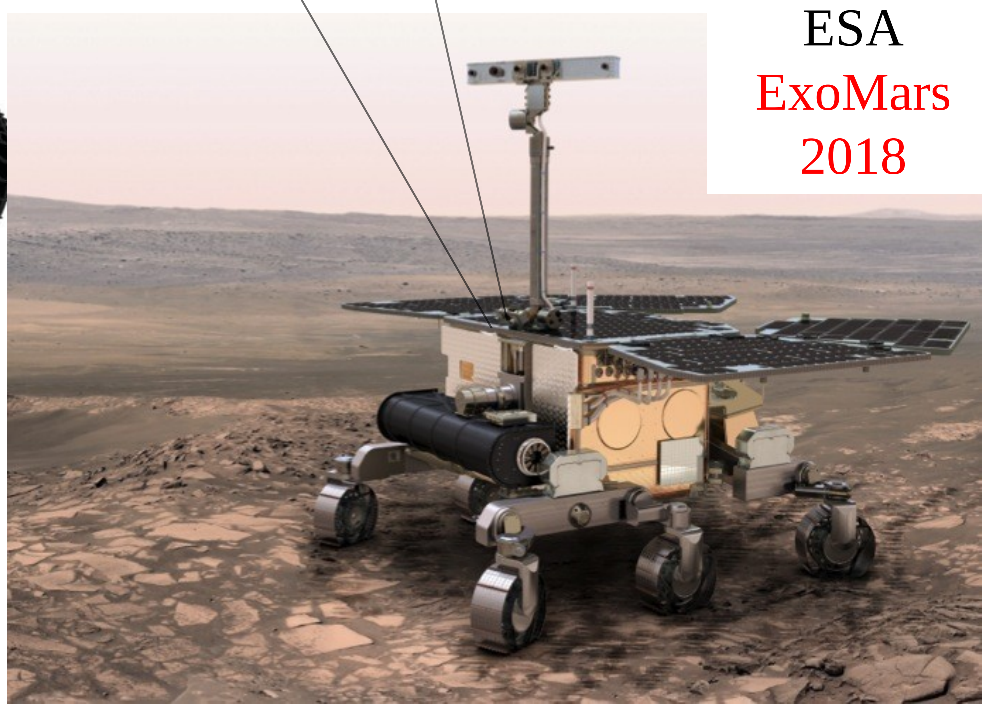
**IN**strument"for"landing1**R**oving"laser"**R**etroreflector"**I**nves5ga5ons"

for NASA Mars 2020



**Science**:

- Exploration
- Gravity
- Exolife



ESA
ExoMars
2018

# Team and Requests

- Total: **10.2 FTE** **(S. Dell'Agnello resp. naz.)**
  - INFN-LNF: 8.6 FTE
  - **NEW**: INFN-Padova, 2 FTE
    - Group of P. Villoresi (Univ. of Information Engineering)
    - Experience of laser quantum communications & encryption
    - Work at ASI laser station in Matera
- Requests to LNF Services
  - SPCM: 6 mo
  - Automation: 4 mo
  - Cryogenics: 2 mo
- Requests to CSN5: ~150 kEur

**SCF_Lab**
**MoonLIGHT-2: 8.6 FTE**

| | |
|---|---|
| Bellettini Giovanni | 70% |
| Dell'Agnello Simone | 70% |
| Delle Monache | 40% |
| Lops Caterina | 100% |
| Maiello Mauro | 50% |
| Emanuele Ciocci | 70% |
| March Riccardo | 60% |
| Martini Manuele | 100% |
| Porcelli Luca | 50% |
| Tauraso Roberto | 70% |
| Vittori Roberto | 40% |
| Nicola Intaglietta | 40% |
| Mattia Tibuzzi | 50% |

To be associated, also for Premiale MIUR “Laser Ranging to Galileo”

| | |
|---|---|
| Pippo Bianco (ASI) | 50% |

7

# NAUTILUS
# LNF - FRASCATI

Bar Al 5056 M = 2270 kg

L = 2.91 m ; Ø = 0.6 m

$\nu_A$=935Hz; T = 0.1 K; T = 3 K

Readout: Low gap transducer + dc SQUID

Cosmic ray detector

NAUTILUS gets 4 records:

. First ultralow T massive detector: 2.3 tons at 0.09 K.

. First acoustic detector of cosmic rays.

. Best displacement sensitivity: 7 x $10^{-22}$ m/$Hz^{-1/2}$

. Longest continuous science run: 11 years (in 2014).

# Gruppo ROG

La presa dati con Nautilus dovrebbe durare fino all’entrata in funzione di Virgo Advanced (2016 ?).

Al momento non e’ prevista alcuna richiesta paricolare ai servizi generali.

Tecnici LNF :

| | |
|---|---|
| M. Iannarelli | 40 % |
| R. Lenci | 50 % |

# CUORE.DTZ @LNF

Resp. A. Franceschi

A. Franceschi, T. Napolitano
Divisione Tecnica

\+

C. Ligi
Divisione Acceleratori

# Impegno CUORE LNF.DTZ 2015

**Responsabilità del gruppo LNF:**

Coordinamento Ingegneria:
- Ultrapulizia Rame
- Meccanica Criostato
- Schermature Piombo
- Installazione Apparati

Integrazione Apparato Sperimentale

Installazione Detector

Wiring Criogenico e Detector

| Anagrafica CSN2 | | 2013 | 2014 | 2015 |
|---|---|---|---|---|
| A.Franceschi | Dir. Tecnologo | 60% | 70% | 70%* |
| C.Ligi | Tecnologo | 40% | 20% | 20%* |
| T.Napolitano | Tecnologo | 60% | 70% | 70%* |

* indicative

# Richieste CIF a fine progetto (stima al 1 luglio 2014)

**II semestre 2014** (Tooling Installazione)

SPCM-Reparto Progettazione: ≈10 m.u.

**I semestre 2015** (Installazione Detector)

SPCM-Reparto Progettazione: ≈10 m.u.

**II semestre 2015** (Fine installazione – Eventuali code)

SPCM-Reparto Progettazione: ≈5 m.u. (?)

# KM3

## PORFIDO ULTIMI RISULTATI
## 4 PROBE FUNZIONANTI

- 20 maggio 2014 lettura dei 4 porfido installati sulla torre installata nel marzo 2013
- I 4 PORFIDO rispondono correttamente e inviano una lettura della temperatura coerente con quella aspettata data la bassissima sensibilita’ del termometro usato ($\pm 1^{o}$C)

# KM3

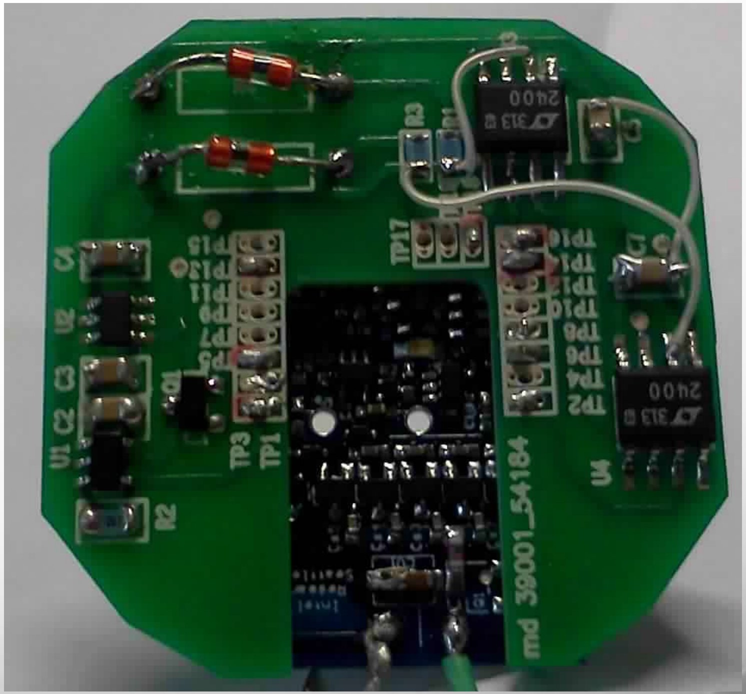
## PORFIDO 2

**Gia' realizzati:**

**Nuovi sensori di temperatura con precisione meglio di 10-3 oC**

**Nuova scheda collegata a WISP**:

- 2 ADC 24 bit
- 2 termistori NTC in vetro



**Sviluppo in corso di sensori di salinita' (1 ppm)**

# KM3

# 2015

- Ingegnerizzazione del prototipo di sensore di salinitá
- Realizzazione di 12 PORFIDO 2 da installare sulle 8 torri di KM3Net Phase 1
- Partecipazione allo sviluppo del software di console di KM3Net-Phase 1

# KM3

- Partecipanti:
  - Marco Cordelli I ricercatore 0.4 fte (CNSI)
  - Luciano Trasatti Ass. Pens. 2012 1 fte
  - Agnese Martini Tecnologo 0.6 fte (CNSI)
  - Orlando Ciaffoni C-Ter 0.5 fte

# JEM-EUSO
# Resp. Naz. M. Ricci

## The EUSO program

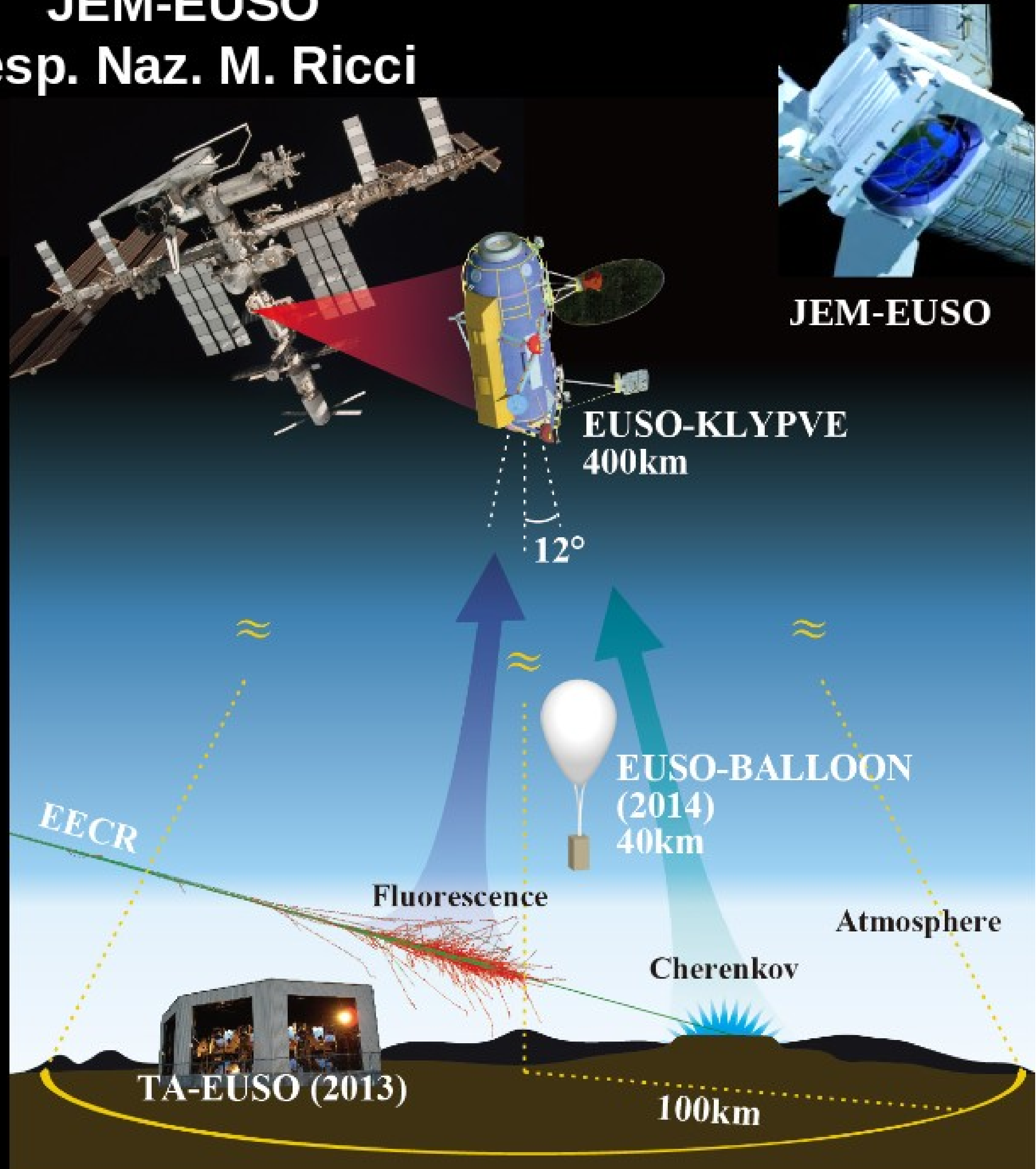
1. EUSO-TA: Ground detector at Telescope Array site (Utah): 2013-

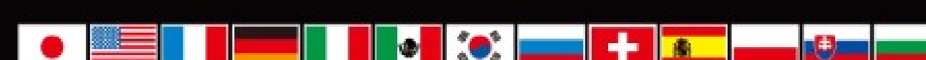
2. EUSO-BALLOON: 2-3 Balloon flights 1st from Timmins, Canada (French Space Agency CNES) Aug. 2014

3. Mini-EUSO on ISS (2016)

4. KLYPVE-EUSO (2018) (Russian Module ISS)

JEM-EUSO (>2020+)

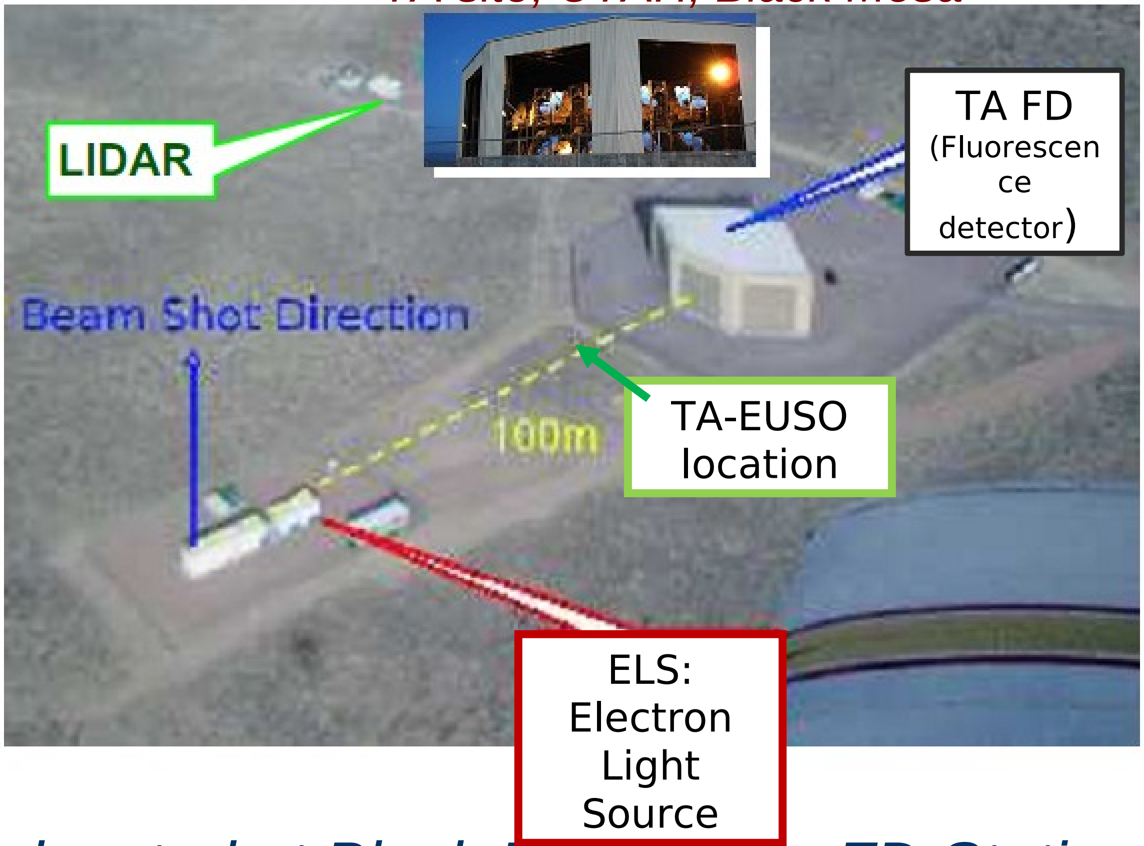


# Pathfinders: EUSO-TA

EUSO-TA:
*Cross-Calibration tests at the Telescope Array site* in Utah in collaboration with the ICRR in Tokyo and the TA collaboration
⟹*Integration of the PDM in RIKEN and Paris APC completed;*
*Data Taking start in Summer 2014*

*TA site, UTAH, Black Mesa*




*located at Black Rock Mesa FD Station*

- *Electron Light Source at 100m*
- *Most nearby SD is at ~3.5 km*
- *Central Laser Facility ~21km*

# Pathfinders: EUSO-Balloon

**Campaign and Mission managed by CNES (France)**

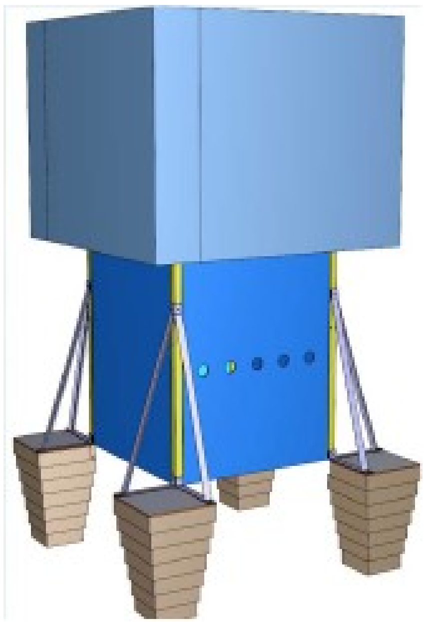
- Look down from a stratospheric balloon with an UV telescope

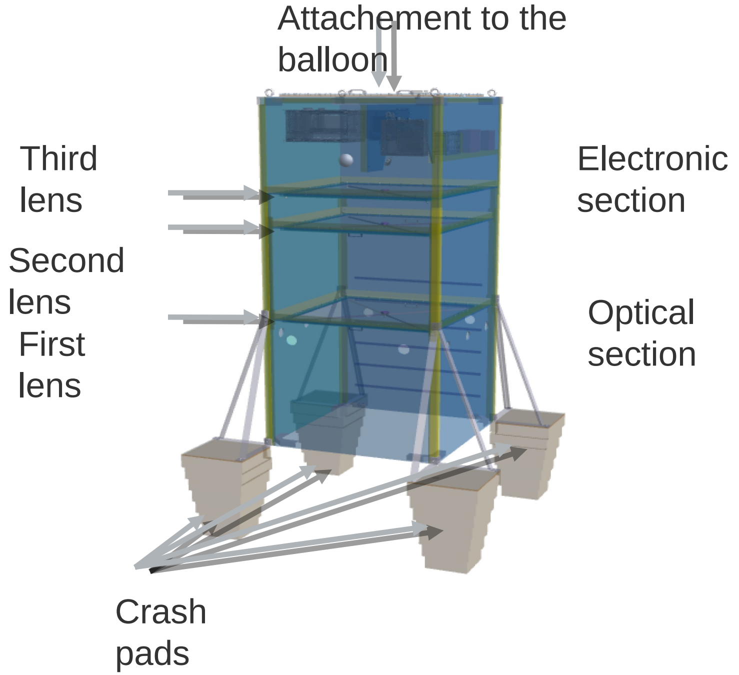
(PDM + 3 lenses system)

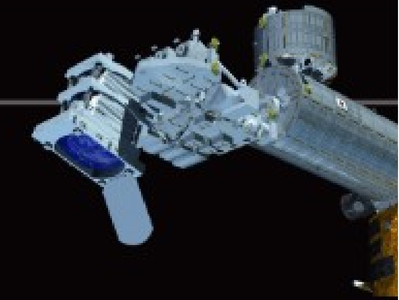
- *Engineering test*
- *Background test*
- Airshower from 40 km altitude

***Flight Readiness Review Passed in May 2014 at CNES***

**Will be *launched in mid-August 2014 from Timmins (Canada);***

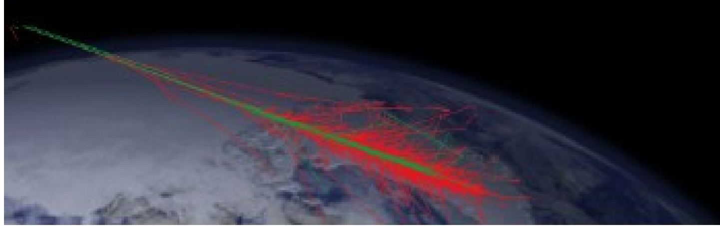






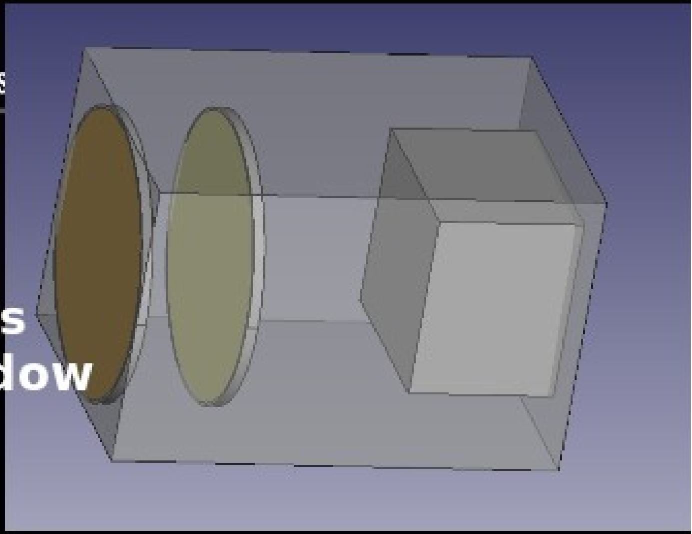
# mini-EUSO
# A precursor of JEM-EUSO
# on board ISS

Proposed to ASI (Italian Space Agency) in response to a call 2012 for Human Spaceflight
Selected by ASI, July 2013 (Resources, upload mass, crew time)
Approved by Roscosmos/STAC Committee May 2014 and selected for UV window on Zvesda Module, Russian Segment ISS



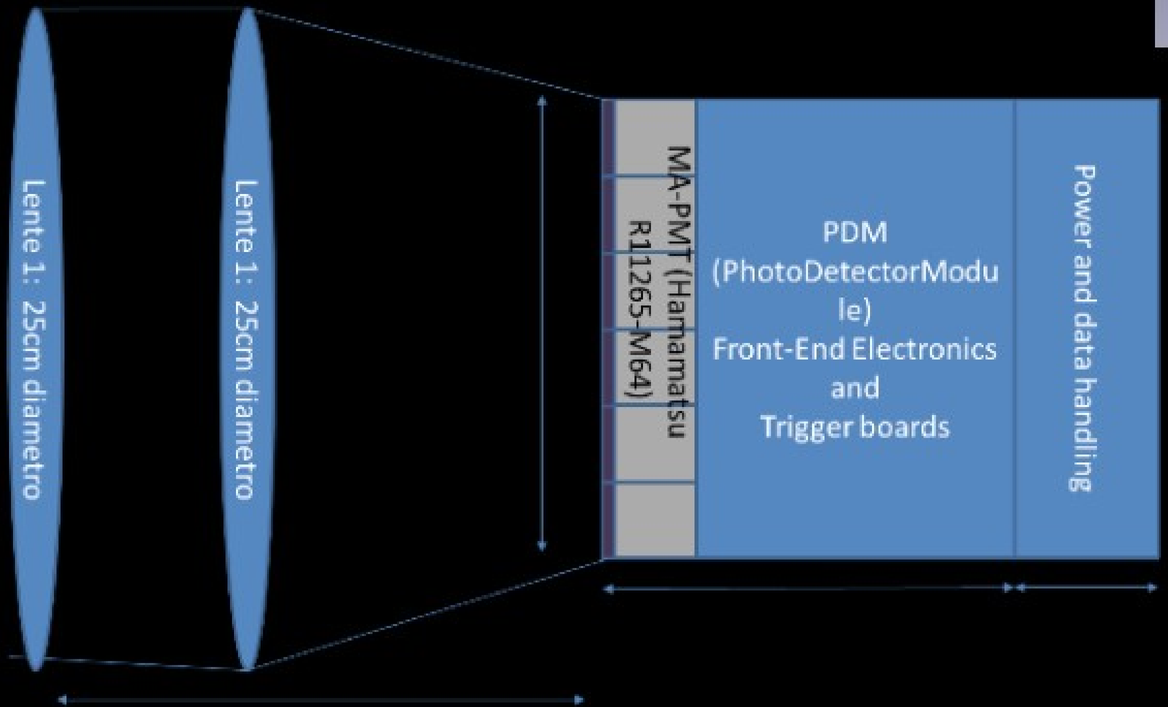


# JEM-EUSO on ISS explores the origin of the highest energy particles

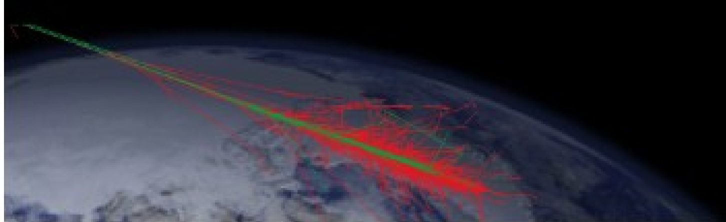


## Mini-EUSO

**Bring one PDM (36 PMTs) and two Fresnel lenses (25 cm diam.) to ISS and expose it to an ISS UV window**





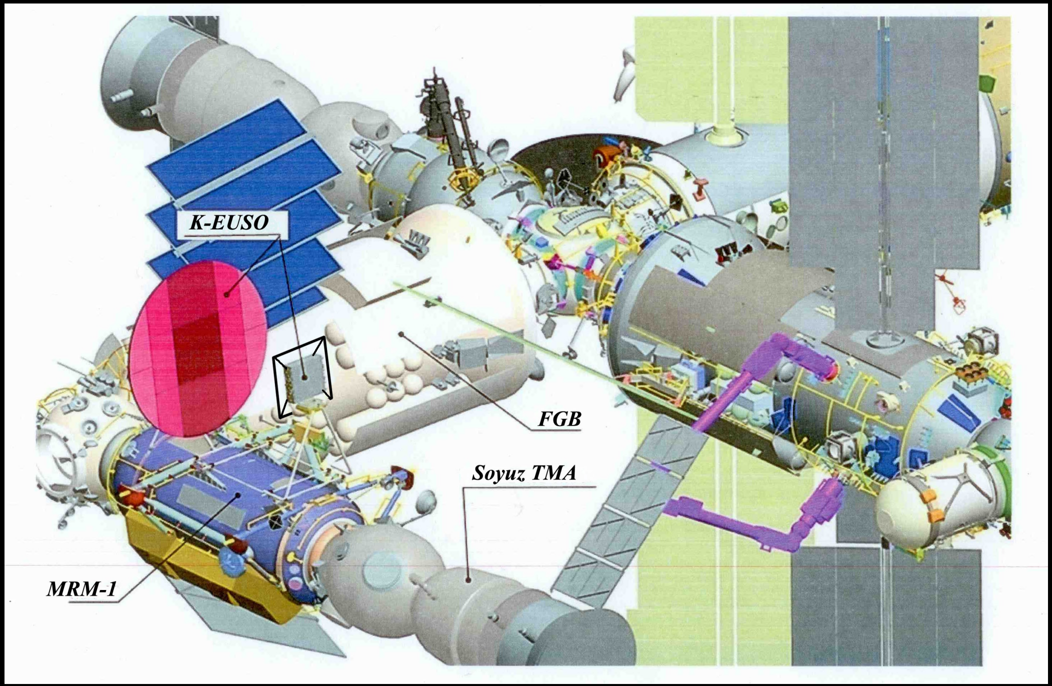


JEM-EUSO collaboration 13 Countries, 80 Institutes as of March, 2013

# The Main Mission Intermediate Step JEM-EUSO on Russian Module KLYPVE-EUSO

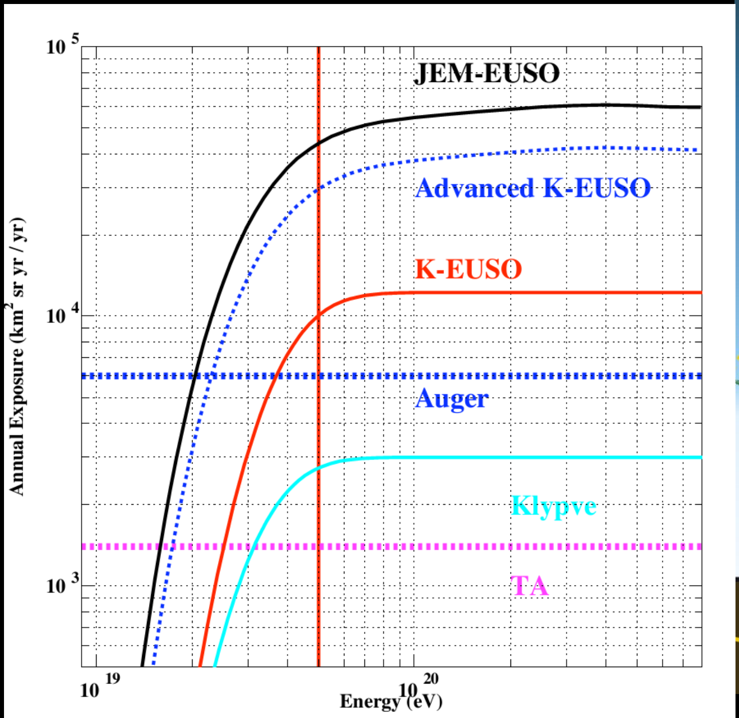
- Included in the Russian Federal Space Program
- Passed the stage of preliminary design (pre-phase A)
- Technical requirements (specifications) defined, based of the preliminary design
- Optimization studies (mainly on the optics)

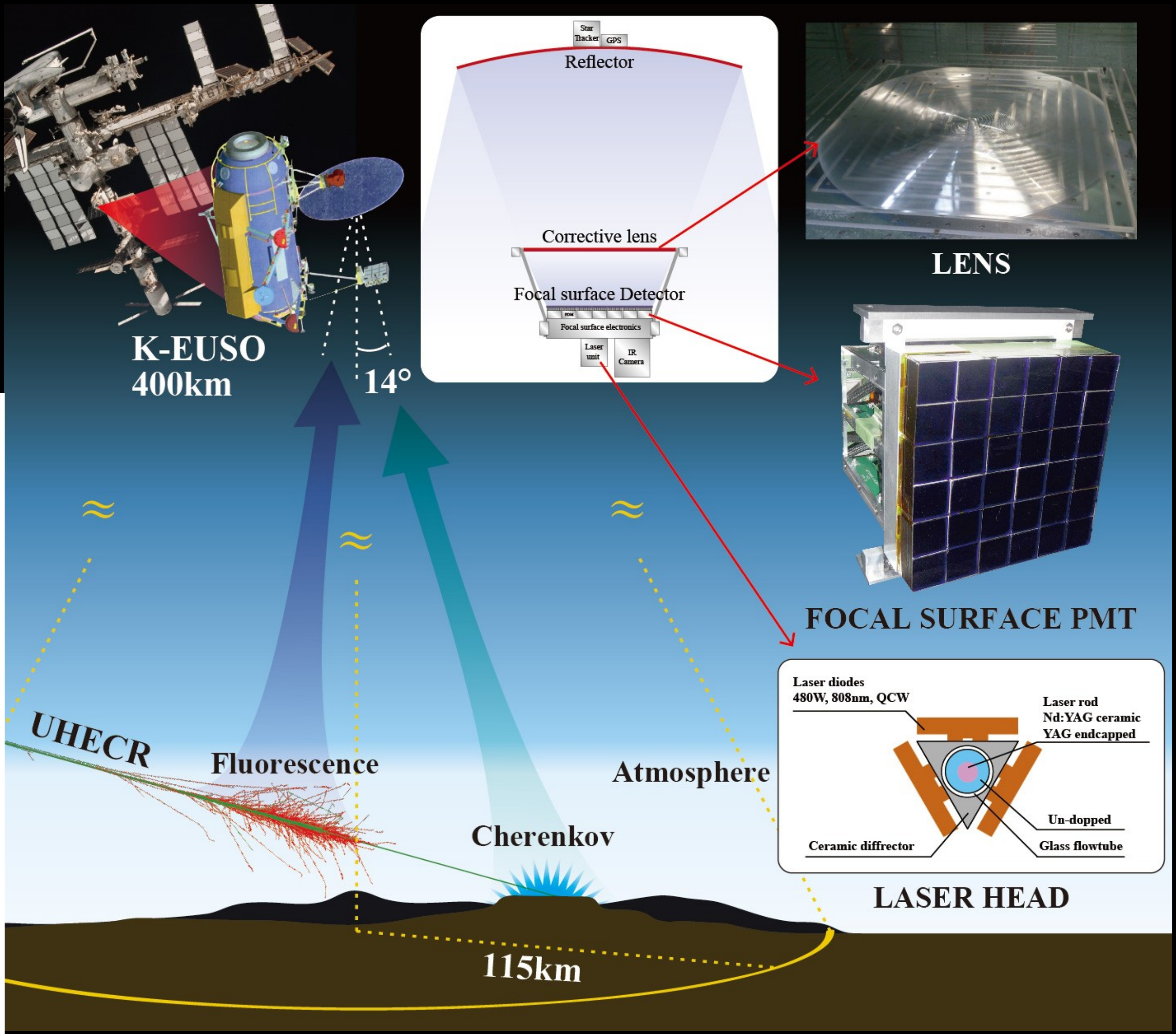
⟹ K-EUSO Official Mission Name



# From KLYPVE-EUSO to K-EUSO

- Lenses
- FS electronics
- Laser head



# JEM-EUSO richieste ai Servizi LNF per il 2015

**Prototipi PDM (Photo-Detector Module) in configurazione K-EUSO.**
**Produzione PDM aggiuntive per sviluppi e upgrade EUSO-Balloon e EUSO-TA**

**SPCM (A. Franceschi, T. Napolitano):**

- **Progettazione 1 mu**
- **Meccanica 2 mu**

**Possibile interesse anche per l'utilizzo delle facilities del laboratorio:**

- **BTF (test di fluorescenza)**
- **Dafne-light (caratterizzazione ottica e calibrazione)**

**Gruppo LNF:**
**A. Marini, G. Modestino, M.Ricci (Resp.), F. Ronga; A. Franceschi, T. Napolitano**

# LIMADOU-CSES

## (Chinese Seismo-Electromagnetic Satellite)

- Misura dallo Spazio di perturbazioni magnetosferiche e loro correlazioni con fenomeni sismici – Interazione tra Magnetosfera, Ionosfera e Terra

- Realizzazione di una serie di rivelatori e strumenti da collocare a bordo del Satellite Cinese CSES
  - Mini spettrometro magnetico
  - Rivelatore di campo elettrico
  - Rivelatore di campo magnetico
  - Rivelatore di onde e.m. a bassa frequenza

Lancio previsto a fine 2016

**Progetto premiale ASI**
**Partecipazione INFN, INGV**

Bologna
Laboratori Nazionali di Frascati
Perugia
Roma Tor Vergata
Trento
UniNettuno Roma
INGV

China Earthquake Administration
Chinese National Space Agency

## 2) OBBIETTIVI SCIENTIFICI DEL PROGETTO LIMADOU-MATTEO RICCI

**STUDIO DELL'INTERAZIONE TRA LA MAGNETOSFERA, LA IONOSFERA ED IL NOSTRO PIANETA**

Gli obiettivi del progetto CSES possono essere suddivisi in obiettivi scientifici, tecnologici e applicativi.

**OBIETTIVI SCIENTIFICI:**

- studiare le perturbazioni ionosferiche associate ai terremoti, soprattutto a quelli di maggiore intensità;
- investigare nuovi approcci metodologici per la predizione a breve termine degli stessi;
- individuare nuovi filoni teorici per l'analisi dei processi che precedono gli eventi sismici.
- ottenere informazioni, su scala globale, relative al campomagnetico terrestre, alle particelle energetiche e al plasma e ai fenomeni elettrici e magnetici associati.

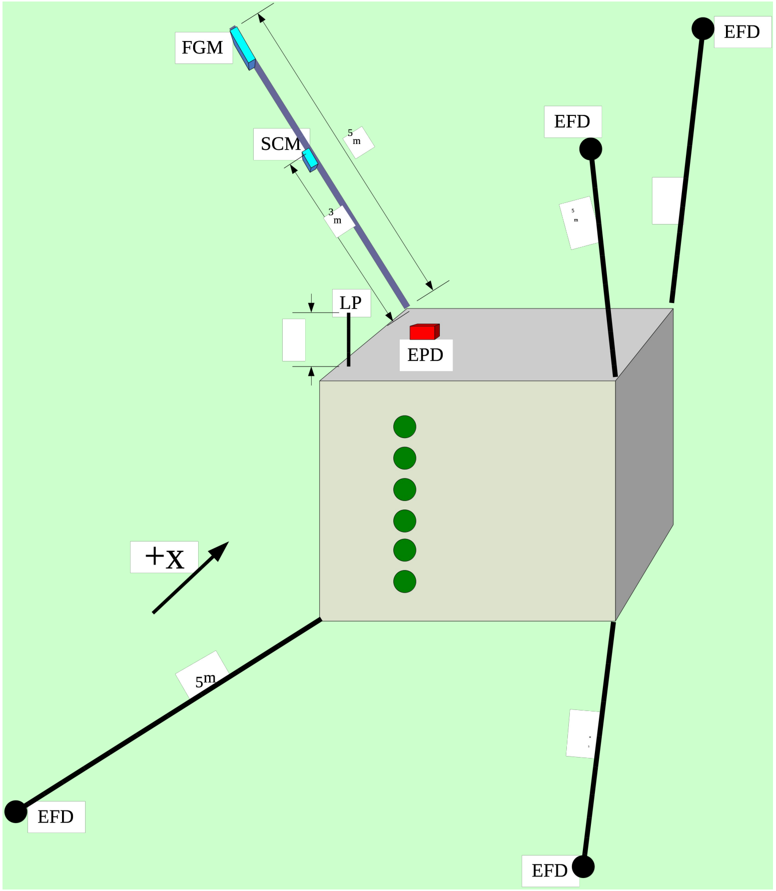
**OBIETTIVI TECNOLOGICI:**

- verificare l'efficacia di un sistema di monitoraggio satellitare dedicato al monitoraggio sismico;
- particolare attenzione sarà posta al monitoraggio in tempo reale del territorio cinese al fine di rafforzare e coordinare il sistema di monitoraggio terrestre con quello satellitare.

**OBIETTIVI APPLICATIVI:**

- studiare i fenomeni elettromagnetici associati a terremoti di magnitudo $M \geq 6$ su scala locale (area di circa 1000 km centrata sulla Cina) e $M \geq 7$ per fenomeni sismici su scala planetaria;
- analizzare i caratteri sismo-ionosferici delle perturbazioni elettromagnetiche al fine di verificare la possibilità di anticipare su scale di tempo dell' ordine o minori del giorno il verificarsi di terremoti;
- mettere a disposizione della comunità scientifica internazionale i dati raccolti, nell'ottica di favorire studi e cooperazioni a livello globale;
- validare l'efficacia e l'affidabilità delle rilevazioni sismo-magnetiche effettuate dal satellite a livello ionosferico e satellitare.

# Satellite




## Payload Instruments:

- **Particle Detector Analyser** (PDA).
  - Energy range: 300 KeV÷ 100 Mev
  - Pitch angle accuracy < 4° with particle identification

- **Electric Field Analyser** (EFA)
  - frequency range: ~DC ÷ 10 MHz
  - accuracy: 300 nV/m
  - dynamic range: 120 dB

- **Magnetic Field Analyser** (MAFA)
  - FLUX – GATE: • frequency range: ~DC ÷ 10 Hz
    - accuracy: a few (6-8) pT
    - resolution: 24 bit
  - SEARCH – COIL: • frequency range: ~10 Hz ÷ 100 kHz
    - sensitivity:10-2 pT /(Hz)½ (at 1 kHz)

- **Langmuir Probe & Retarding Potential Analyser**
  - LP: • electron temperature: 300 ÷ 15000 K
    - electron density: 102 ÷ 107 cm-3
  - RPA: • ionic temperature: 300 ÷ 10000 K
    - ionic density: 102 ÷ 107 cm-3

# Work Packages

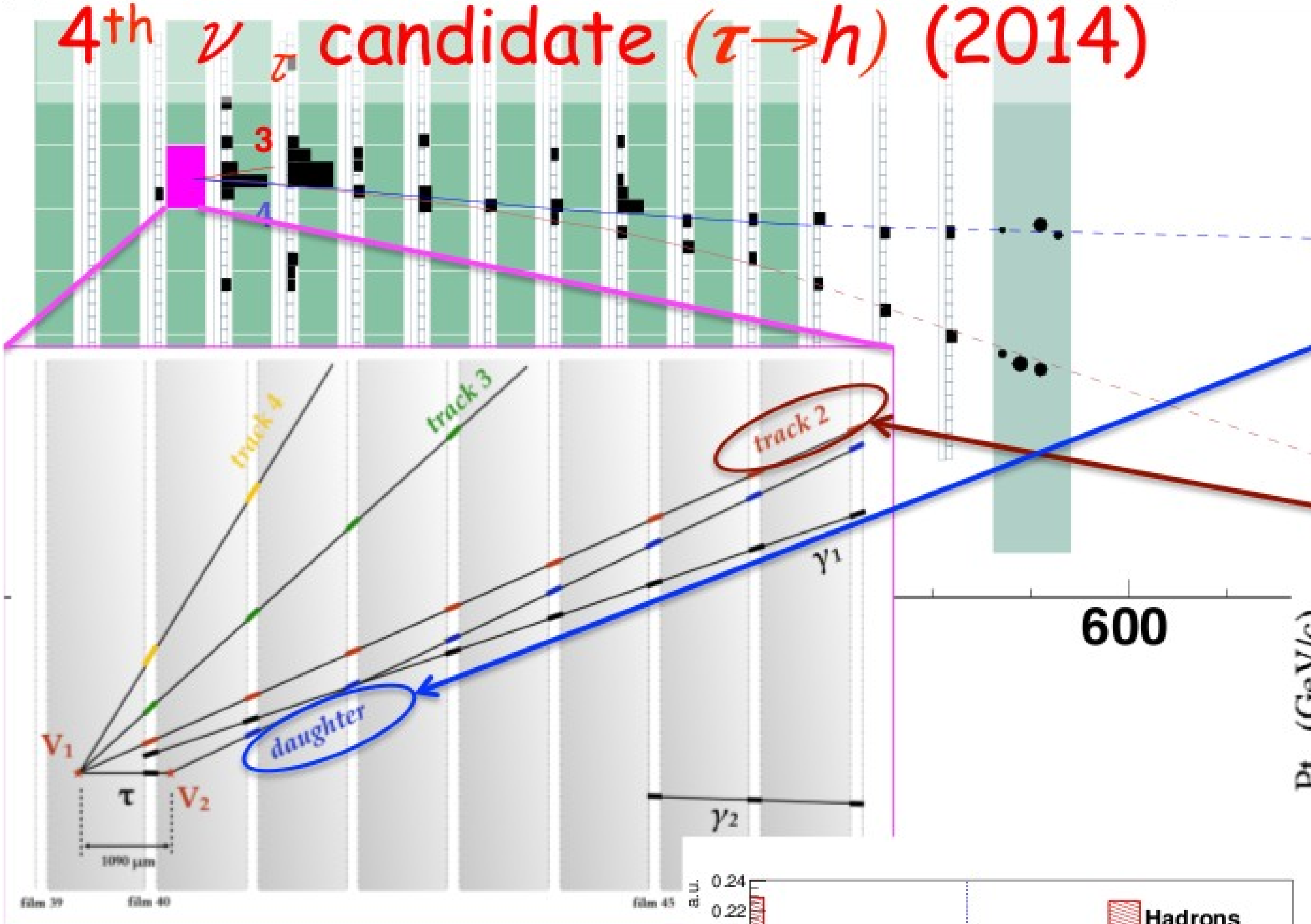
- WP1) Provide the High Energy Particle Detector (HEPD) (design, build, test, qualify, integrate, commission, calibration, analysis)
- WP2) Collaborate on the development of the Electric Field Detector (design, test, qualification, analysis) - LNF (Rad. Hard Tests, e- beam lines BTF, LINAC)
- WP3) Develop modeling and analysis tool to analyze and understand CSES data, in particular HEPD and EFD - LNF (simulations)
- WP4) Develop modeling and analysis tool towards an integrated modeling of space-based observations useful for earthquake early warning from space

An additional area which will be developed is

- WP5) the area of data download to the Matera station and CSES ground segment

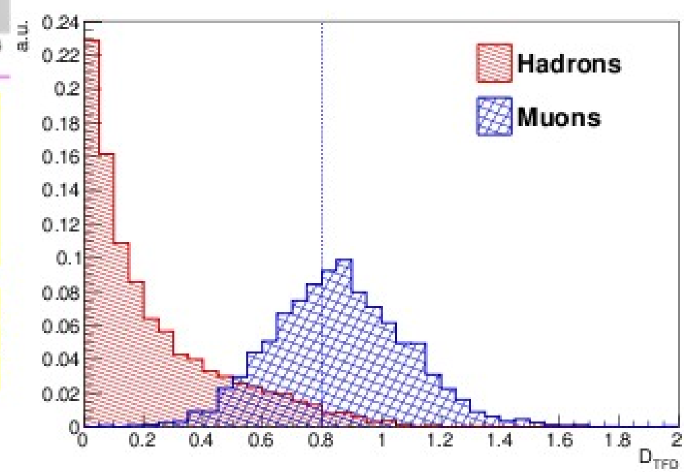
# 4th $\nu_\tau$ candidate $(\tau \rightarrow h)$ (2014)

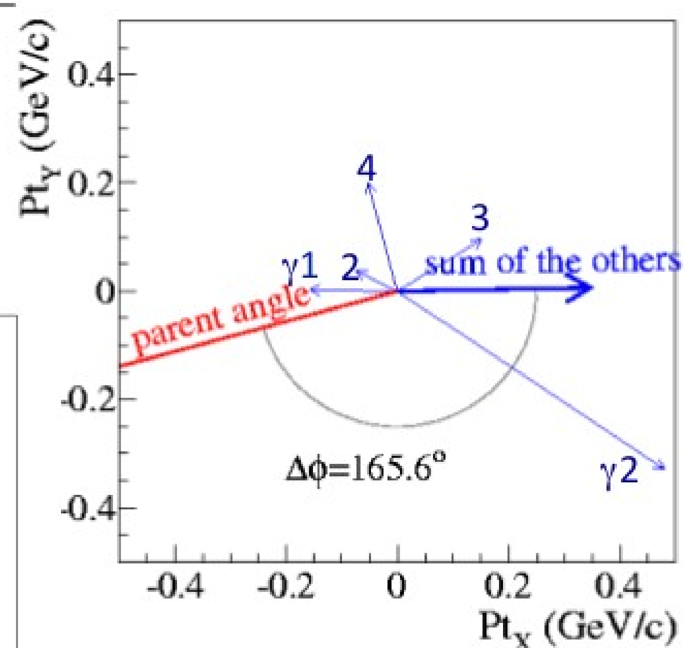
**OPERA**




Track 2 from neutrino interaction vertex, p = 1.9 GeV stopping in first iron slab of the magnet

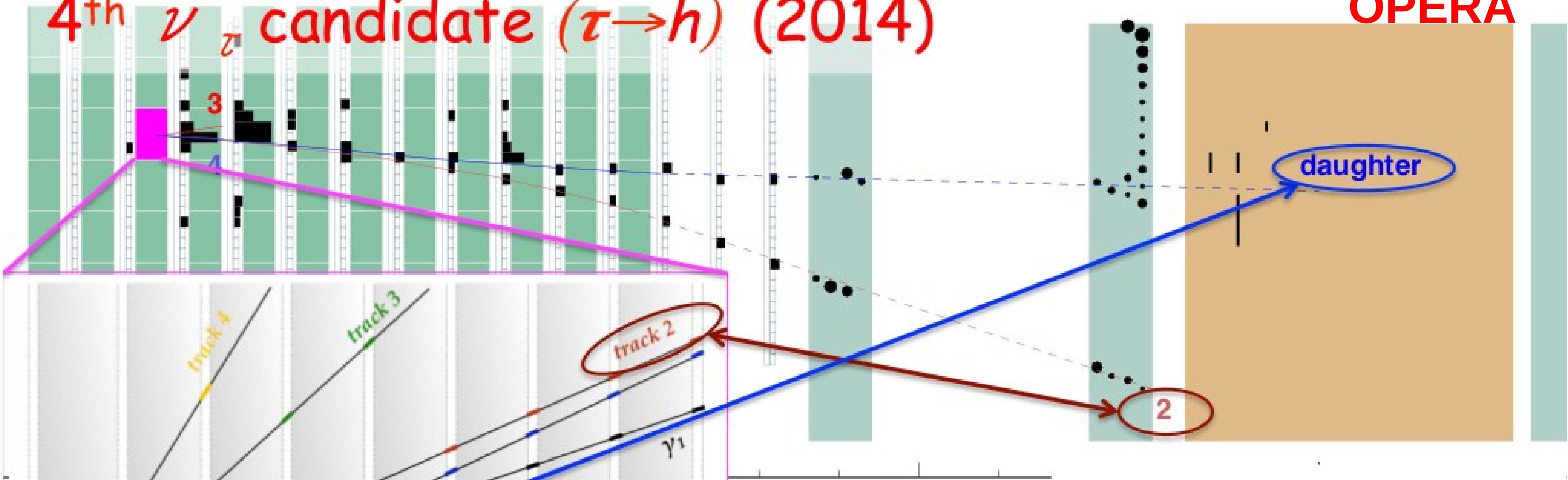
$$D = \frac{L}{R_{lead}(p)} \frac{\rho_{average}}{\rho_{lead}} = 0.40^{+0.04}_{-0.05}$$



# 4th $\nu_\tau$ candidate $(\tau \rightarrow h)$ (2014)

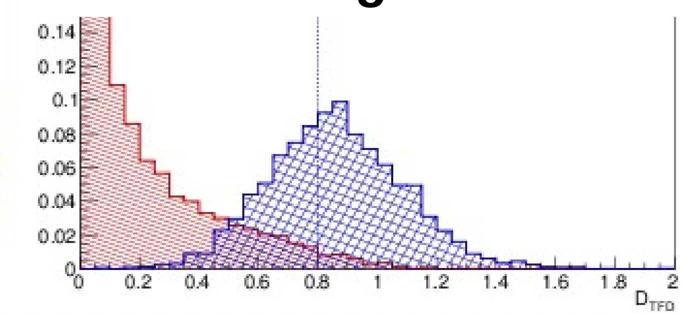
**OPERA**

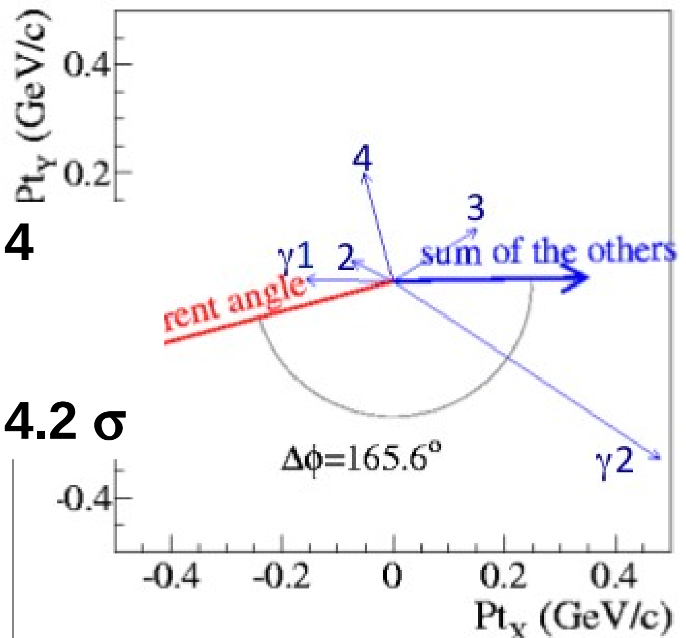



Track 2 from neutrino interaction vertex, p = 1.9 GeV stopping in first iron slab of the magnet

$$D = \frac{L}{R_{lead}(p)} \frac{\rho_{average}}{\rho_{lead}} = 0.40^{+0.04}_{-0.05}$$

**Number of observed τ = 4**
**Expected τ = 2.1**
**Expected bkg = 0.22**
**Statistical significance : 4.2 σ**



# Sterile neutrinos

$$\Delta_{ij} = \frac{\Delta m^2_{ij} L}{2E}$$

Tau appearance in the presence of sterile neutrino (3+1)

Solar driven oscillation neglected $\Delta_{21} \sim 0$

~ standard oscillation

pure exotic oscillation

$$P_{\nu_\mu \to \nu_\tau} = 4|U_{\mu 3}|^2 |U_{\tau 3}|^2 \sin^2 \frac{\Delta_{31}}{2} + 4|U_{\mu 4}|^2 |U_{\tau 4}|^2 \sin^2 \frac{\Delta_{41}}{2}$$

interference terms

$$+2\Re[U^*_{\mu 4} U_{\tau 4} U_{\mu 3} U^*_{\tau 3}] \sin\Delta_{31} \sin\Delta_{41}$$

$$-4\Im[U^*_{\mu 4} U_{\tau 4} U_{\mu 3} U^*_{\tau 3}] \sin^2 \frac{\Delta_{31}}{2} \sin\Delta_{41}$$

$$+8\Re[U^*_{\mu 4} U_{\tau 4} U_{\mu 3} U^*_{\tau 3}] \sin^2 \frac{\Delta_{31}}{2} \sin^2 \frac{\Delta_{41}}{2}$$

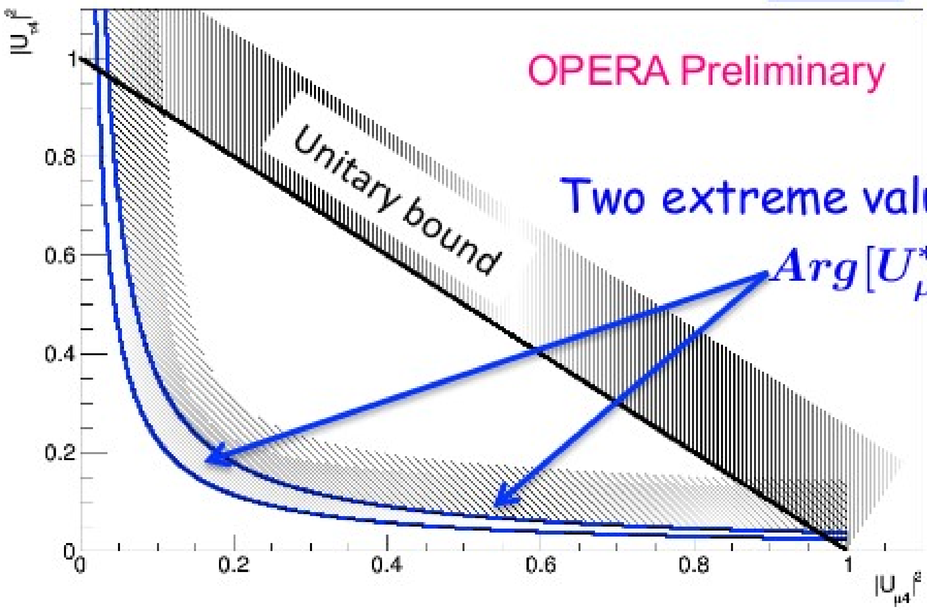
$$+4\Im[U^*_{\mu 4} U_{\tau 4} U_{\mu 3} U^*_{\tau 3}] \sin\Delta_{31} \sin^2 \frac{\Delta_{41}}{2}$$

Normal hierarchy

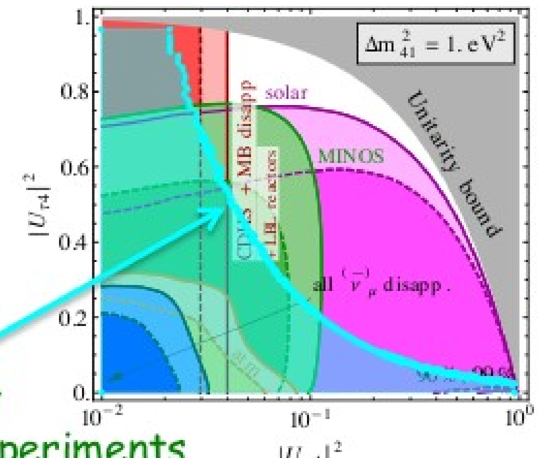
Profile likelihood using Tau rate only

$$\Delta m^2_{32} = 2.32 \times 10^{-3} eV^2$$

90% CL bounds on $U_{\tau 4}$ and $U_{\mu 4}$




Two extreme values (π/2, 3π/2) of $Arg[U^*_{\mu 4} U_{\tau 4} U_{\mu 3} U^*_{\tau 3}]$




Kopp et al. JHEP 1305 (2013) 050

Complementary measurement wrt disappearance experiments

# Opera decommissioning: weekly iperaggressive plan (1)

Weeks 1 - 40

| date | 29/12/14 | 05/01/15 | 12/01/15 | 19/01/15 | 26/01/15 | 02/02/15 | 09/02/15 | 16/02/15 | 23/02/15 | 02/03/15 | 09/03/15 | 16/03/15 | 23/03/15 | 30/03/15 | 06/04/15 | 13/04/15 | 20/04/15 | 27/04/15 | 04/05/15 | 11/05/15 | 18/05/15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| week | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| Brick/BMS | | SM2 | | | | | | | | | | | | | | | | | | | |
| HPT (1&2) | | | | | | | | | | | | | | | | | | | | | |
| Veto | | | | | | | | | | | | | | | | | mVet | | | | |
| Elec's/Cabl | | | | | | | | | | | | | | | | | | | | | |
| TT/Wall | | | | | | | | | | | | | | | | | | St TT | grigl | | |
| MainStruc | | | | | | | | | | | | | | | | | | | | SM2 | |
| Magnet 2 | | gas | hv | ref | cool | | | | | | | | | | | | | | | | |
| Magnet 1 | | gas | hv | ref | cool | | | | | | | | | | | | | | | | |
| RPC 1&2 | | | | | | | | | | | | | | | | | | | | | |
| BaseStruc | | | | | | | | | | | | | | | Elev | Scala | pav | | | | |

| date | 25/05/15 | 01/06/15 | 08/06/15 | 15/06/15 | 22/06/15 | 29/06/15 | 06/07/15 | 13/07/15 | 20/07/15 | 27/07/15 | 03/08/15 | 10/08/15 | 17/08/15 | 24/08/15 | 31/08/15 | 07/09/15 | 14/09/15 | 21/09/15 | 28/09/15 | 05/10/15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| week | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 |
| Brick/BMS | | | | | LS | Allig | SM1 | | | | | | | | | | | | | |
| HPT (1&2) | | | | | | | | | | | | | | | | | | | | |
| Veto | | | | | | | | | | | | | | | | | | | | |
| Elec's/Cabl | | | | | | | | | | | | | | | | | | | | |
| TT/Wall | | | | | | SM2 | | | | | | | | | | | | | | |
| MainStruc | | | | | rail | | | | | | | | | | | | | | | |
| Magnet 2 | | | | | | | | | | | | | | | | SM2 | | | | |
| Magnet 1 | | | | | | | | | | | | | | | | | | | | |
| RPC 1&2 | | | | | | | | | | | | | | | XPC2 | | | | | |
| BaseStruc | | | | | | | | | | | | | | | | | | | | |

32

# Opera decommissioning: weekly iperaggressive plan (2)

Weeks 40 - 80

End SM2 (week 47) — End SM1 (week 75)

| date | 05/10/15 | 12/10/15 | 19/10/15 | 26/10/15 | 02/11/15 | 09/11/15 | 16/11/15 | 23/11/15 | 30/11/15 | 07/12/15 | 14/12/15 | 21/12/15 | 28/12/15 | 04/01/16 | 11/01/16 | 18/01/16 | 25/01/16 | 01/02/16 | 08/02/16 | 15/02/16 | 22/02/16 | 29/02/16 | 07/03/16 | 14/03/16 | 21/03/16 | 28/03/16 | 04/04/16 | 11/04/16 | 18/04/16 | 25/04/16 | 02/05/16 | 09/05/16 | 16/05/16 | 23/05/16 | 30/05/16 | 06/06/16 | 13/06/16 | 20/06/16 | 27/06/16 | 04/07/16 | 11/07/16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| week | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 |
| Brick/BMS | | | | | | | | | | | | | | LS | BMS | | | | | | | | | | | | | | | | | | | | | | | | | | |
| HPT (1&2) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Veto | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Elec's/Cabl | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| TT/Wall | | | | | | | | | | | | | | | | SM1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| MainStruc | | | | | | | | | | | | SM1 | | binar | BMS | | | | | | SM1 | | | | | | | | | | | | | | | | | | | | |
| Magnet 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Magnet 1 | | | | | | | | | | | | | | | | | | | | | | | | | SM1 | | | | | | | | | | | | | | | | |
| RPC 1&2 | | | | | | | | | | | | | | | | | | | | | | | | XPCZ | | | | | | | | | | | | | | | | | |
| BaseStruc | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | Port | |

# OPERA requests to LNF

**CNGS data taking stopped in 2012.**
**OPERA decommissioning to start in January 2015 and last 18 months.**
**Tail of brick analysis expected in 2015: 800-1000 bricks (second, third and fourth bricks in location priority ranking, mainly in first SM).**
**Data analysis ongoing.**

**LNF group for 2015:**
**V. Chiarella (0.3), A. Paoloni (0.5), A. Longhin (0.4), L. Votano (0.6), M. Spinetti (0)**
**A. Paoloni Technical Coordinator (M. Spinetti deputy)**
**Activity on analysis (background on muon channel, sterile neutrinos, cosmic rays)**
**Support to decommissioning and brick handling.**

**Tecnici:**
**A. Mengucci – brick handling support + decommissioning.**
**M. Ventura – brick handling support + decommissioning.**
**N. Intaglietta (30%) - turni di scanning**
**T. Tonto (20%) - supporto informatico laboratorio di scanning LNF.**

**Requests for 2015:**
**SSE – 12 mu (A. Cecchetti) coordinamento interventi meccanici e manutenzione dell'apparato. Studio e pianificazione della procedura di smontaggio di OPERA.**
**SEA – 1 mu (U. Denni) supporto infrastrutture laboratorio di scanning LNF.**

# NESSiE, Neutrino Experiment with SpectrometerS in Europe (FERMILAB)

CERN e USA, seguendo le indicazioni dello European Strategy Panel e del P5 (strategia in USA) → accordo per fare:

- R&D per I futuri progetti sul neutrino al CERN
- gli esperimenti negli USA (short-baseline e LBNF)

NESSiE ha sottomesso:

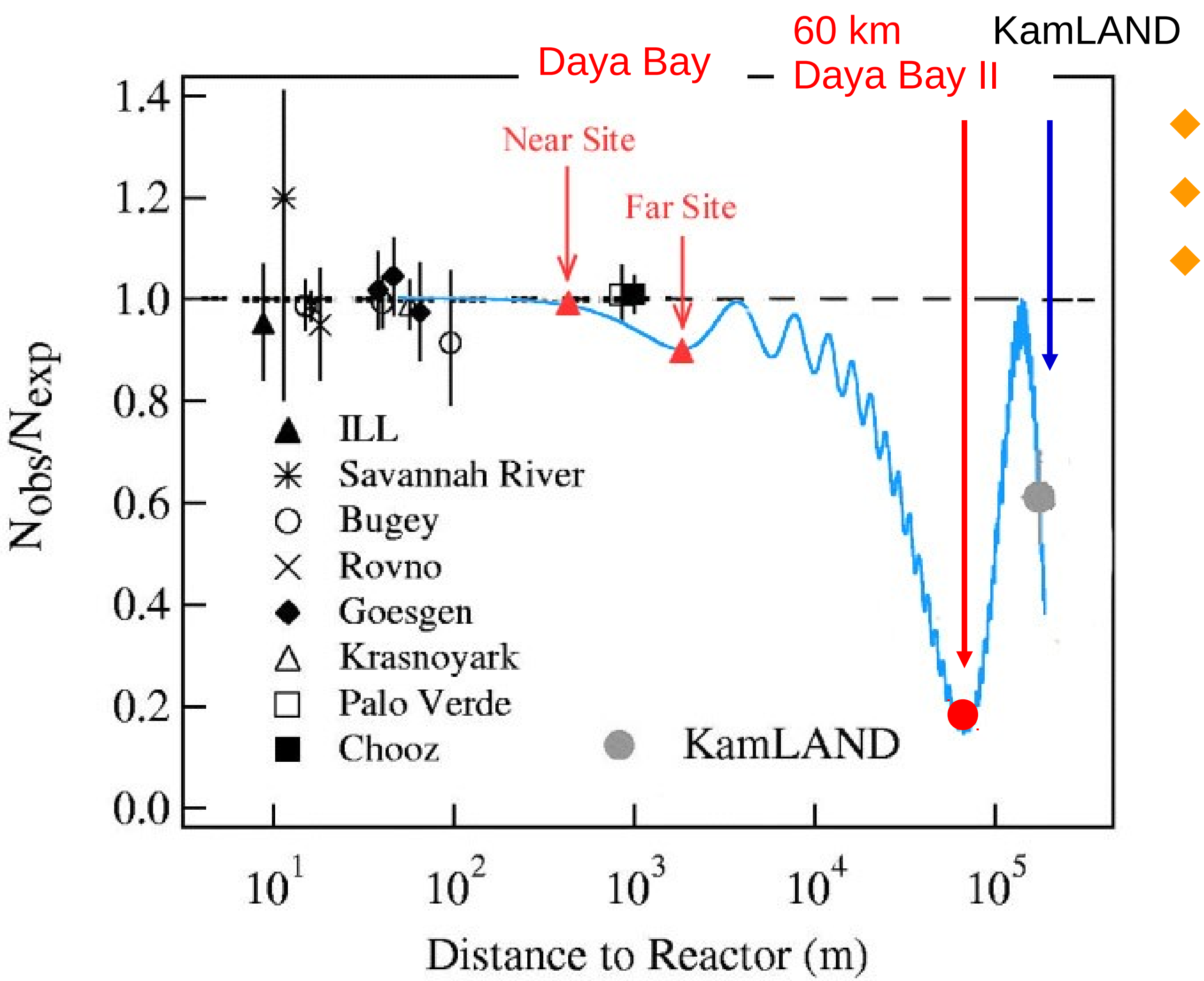
- un Technical Report al CERN-SPSC
  - Magnetizzazione di grossi volumi (magnete in aria / coils superconduttive)
- un proposal di fisica al Physics Advisory Committee del FNAL, P-1057)
  - $\nu_\mu$ disappearance con un doppio sito al Booster Neutrino Beam per la ricerca di neutrini sterili

LNF: meccanica dello spettrometro (ruolo centrale), rivelatori RPC, simulazione fascio → e' piu' naturalmente coinvolto nell'eventuale esperimento a FNAL che sara` valutato dal FERMILAB al PAC autunnale.

La CERN Neutrino Platforn e' stata approvata e finanziata la settimana scorsa (~ 50 MCHF). Estensione del building EH1N1 alla north-Area.

Gli esperimenti WA-104-ICARUS, WA104-NESSiE, WA105 (LAGUNA-LBNO LAr) hanno gia' definito dei MoU.

# The JUNO Experiment




- 20 kton LS detector
- 3% energy resolution
- Rich physics possibilities
  - **Mass hierarchy**
  - **Precision measurement of 4 mixing parameters**
  - **Supernovae neutrinos**
  - **Geoneutrinos**
  - **Sterile neutrinos**
  - **Atmospheric neutrinos**
  - **Exotic searches**

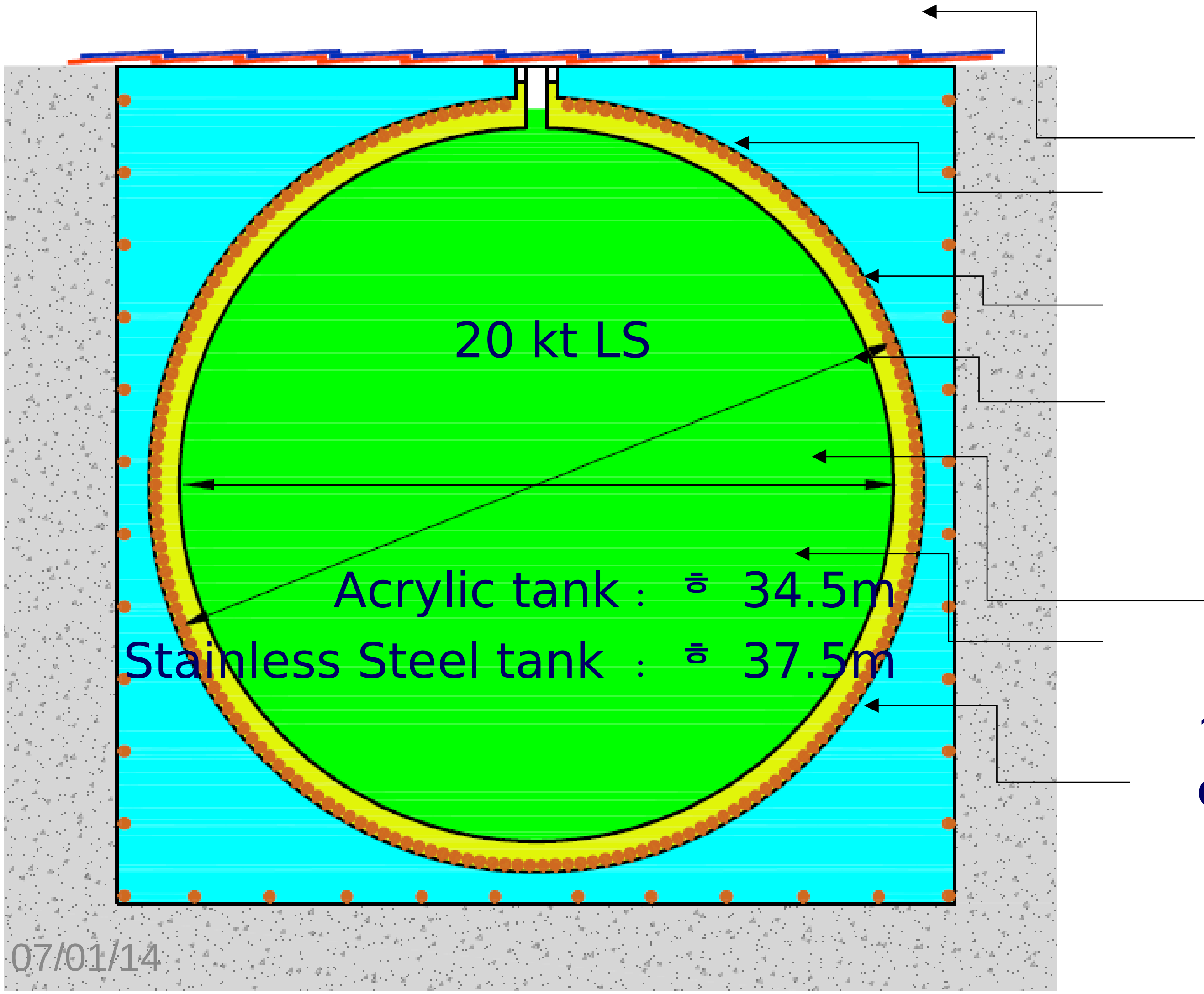
Talk by Y.F. Wang at ICFA seminar 2008, Neutel 2011; by J. Cao at Nutel 2009, NuTurn 2012 ;
Paper by L. Zhan, Y.F. Wang, J. Cao, L.J. Wen, PRD78:111103,2008; PRD79:073007,2009

| | Daya Bay | Huizhou | Lufeng | Yangjiang | Taishan |
|---|---|---|---|---|---|
| Status | Operational | Planned | Planned | Under construction | Under construction |
| Power | 17.4 GW | 17.4 GW | 17.4 GW | 17.4 GW | 18.4 GW， 9.2 by 2020 |

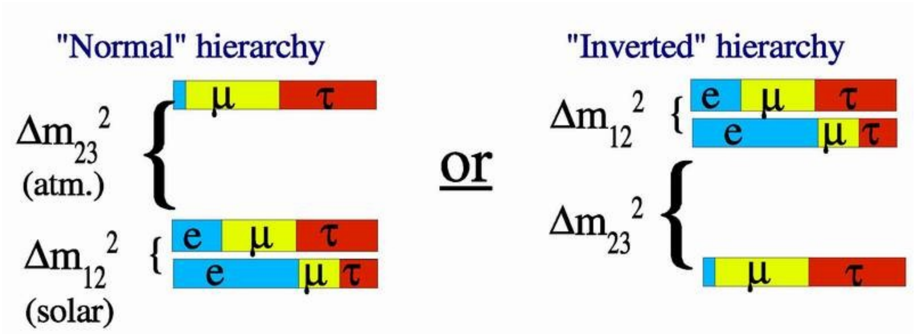
# The plan: a large LS detector

- LS volume: × 20➔ for more mass & statistics
- light(PE) × 5➔ for resolution

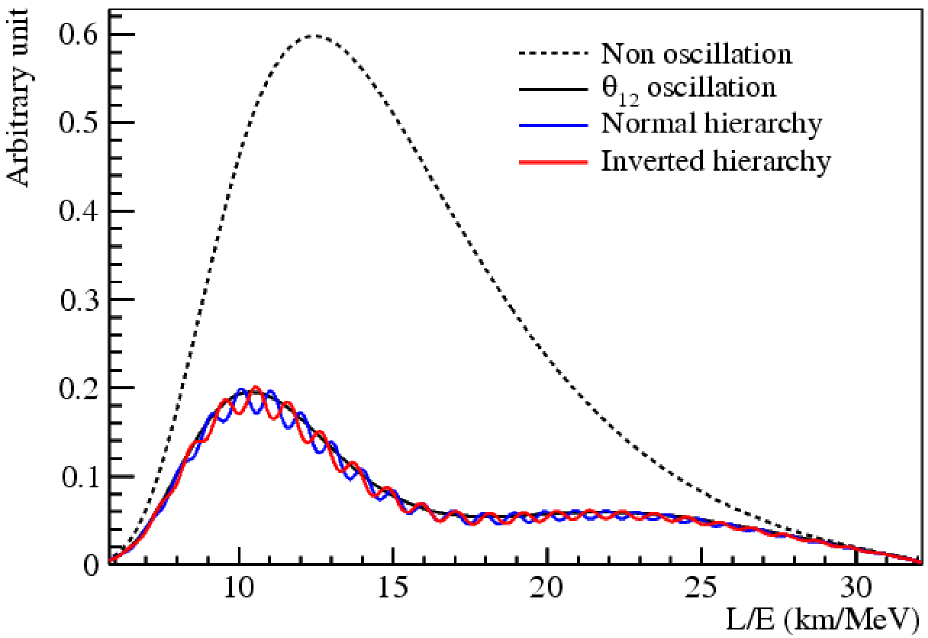
40 events/day



# Mass Hierarchy at Reactors




$$\Delta m^2_{31} = \Delta m^2_{32} + \Delta m^2_{21}$$
$$\mathrm{NH}: \ |\Delta m^2_{31}| = |\Delta m^2_{32}| + |\Delta m^2_{21}|$$
$$\mathrm{IH}: \ |\Delta m^2_{31}| = |\Delta m^2_{32}| - |\Delta m^2_{21}|$$




$$\begin{aligned} P_{ee}(L/E) &= 1 - P_{21} - P_{31} - P_{32} \\ P_{21} &= \cos^4(\theta_{13}) \sin^2(2\theta_{12}) \sin^2(\Delta_{21}) \\ P_{31} &= \cos^2(\theta_{12}) \sin^2(2\theta_{13}) \sin^2(\Delta_{31}) \\ P_{32} &= \sin^2(\theta_{12}) \sin^2(2\theta_{13}) \sin^2(\Delta_{32}) \end{aligned}$$

**Significance > 3 σ obtainable after 6 years exposure if target energy resolution is reached.**

# Precision measurement of mixing parameters

| | Current | Daya Bay II |
|---|---|---|
| $\Delta m^2_{12}$ | 3% | 0.6% |
| $\Delta m^2_{23}$ | 5% | 0.6% |
| $\sin^2\theta_{12}$ | 6% | 0.7% |
| $\sin^2\theta_{23}$ | 20% | N/A |
| $\sin^2\theta_{13}$ | 14% ➔ 4% | ~ 15% |

4040

# Current Status & Brief Schedule

- Project approved by CAS for R&D and design
- Geological survey completed
- Granite rock, tem. ~ 31 °C, little water
- Engineering design underway, contract signed
- Land is acquired, civil construction approval underway


Schedule:

Civil preparation： 2013-2014
Civil construction： 2014-2017
Detector R&D： 2013-2016
Detector component production： 2016-2017
PMT production： 2016-2019
Detector assembly & installation： 2018-2019
Filling & data taking： 2020

# La collaborazione

**Oltre ai gruppi cinesi:**

**INFN (Milano, Ferrara, Frascati, Padova)**
**France (Paris, Strasbourg)**
**Germany (Munich, Achen, Tubingen)**
**Russia (Dubna)**
**USA**

**Meeting dei gruppi europei il 9 Luglio**
**Primo meeting della collaborazione: Pechino 28-30 Luglio**

**Task dei gruppi INFN:**
**Scintillatore liquido (Milano)**
**VETO (Frascati, Padova) in collaborazione con Strasburgo e Dubna.**

# Attivita' sul veto (Top Tracker)

Il compito del Top Tracker e' tracciare i raggi cosmici incidenti nel detector per vetare (stimare) il fondo di $^{9}Li$ / $^{8}He$ prodotti dai cosmici per spallazione

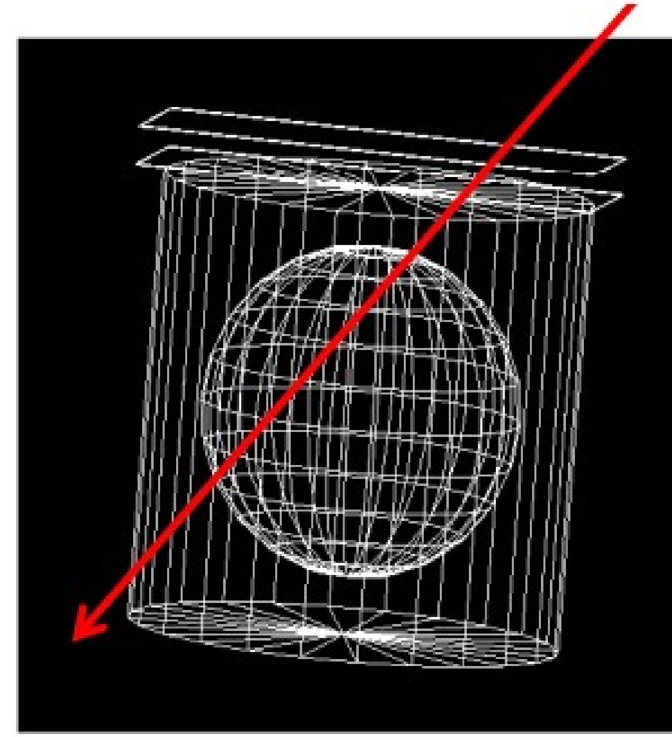
Per il top tracker si pensa al riutilizzo del Target Tracker di OPERA. LNF sono assegnatari dei PMT.

Attivita' nei prossimi anni:
Simulazione (stima fondi, disegno ottimale del sistema).
Aggiunta RPC ?
Modifica del front-end (MAROC3)
Acquisizione del MAROC3
Disegno del trigger

Installazione prevista nel 2019.

Task sharing da decidere nei meetings di Luglio.

# Top Tracker design study

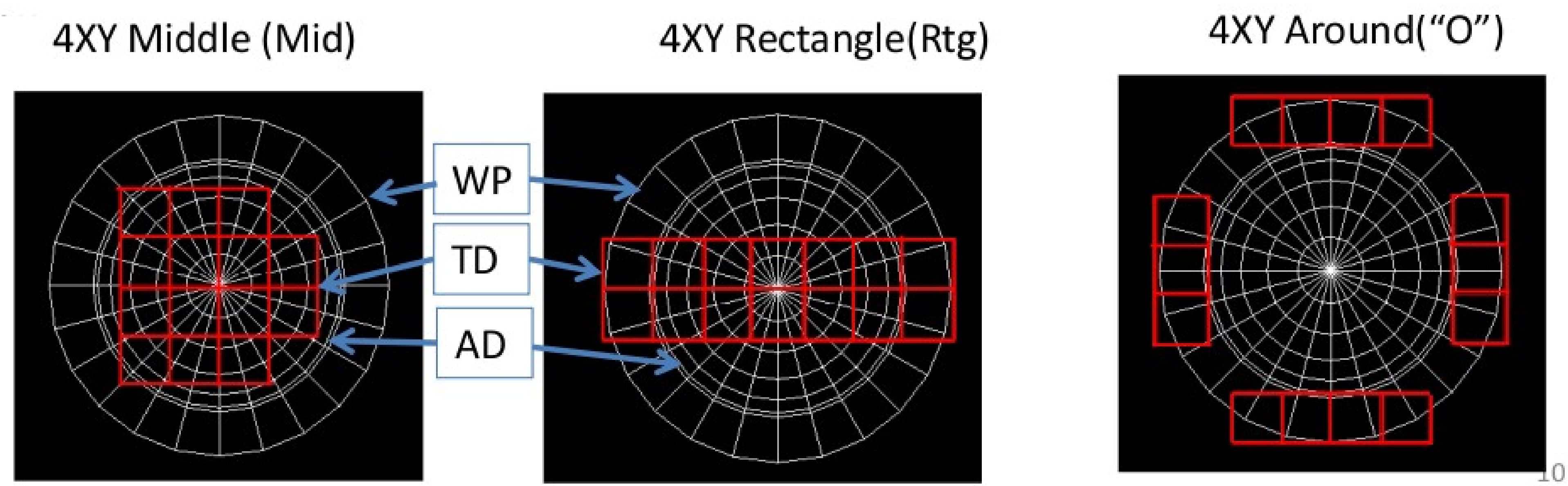


**Da OPERA:**
**62 piani di area 6.7*6.7 m$^2$, lettura x-y su due lati.**
**Insufficienti per coprire l'intera superficie.**

**Esistono gia' studi preliminari.**
**Soluzione rettangolare favorita.**

**Investigazioni in corso per migliorare la copertura.**

**Stima preliminare della radioattvita' ambientale: fino a 600 k fotoni/(m$^2$ sec) da U,Th, $^{40}$K nella roccia (da confermare)**



# Dettaglio Anagrafica per il 2015 (preliminare)

| Gruppo | Ricercatori FTE (pers) | Tecnologi FTE (pers) | Tecnici FTE (pers) |
|---|---|---|---|
| OPERA | 1.8 (5) | | 2.5 (4) |
| Juno.DTZ | 0.3 (1) | | |
| Nessie-RD.DTZ | 0.1 (1) | | |
| ICARUS.DTZ | 0.2 (3) | | |
| T2K.DTZ | 0.4 (1) | | |
| CUORE | | 1.6 (3) | |
| KM3 | 1.4 (2) | 0.6 (1) | 0.5 (1) |
| Wizard | 1.8 (4) | | |
| JEM-EUSO-RD | 2.4 (4) | 0.4 (2) | |
| LiMadou.DTZ | 0.1 (1) | 0.4 (1) | |
| ROG | 2.2 (5) | | 0.9 (2) |
| Moonlight2 | 7.3 (11) | 0.4 (1) | 0.9 (2) |

# CSN2 @ LNF numeri e prospettive

**20 FTE / 30 ricercatori e tecnologi.**
**Circa il 50% degli FTE impegnato presso i LNF (ROG+Moonlight2), buona parte del resto in laboratori INFN (LNGS, LNS).**

**2 responsabili nazionali (M. Ricci, S. Dell'Agnello).**
**1 technical coordinator di una collaborazione internazionale (A. Paoloni).**

**Due linee di ricerca in fase di transizione:**

**1) Raggi cosmici nello spazio**
**Wizard e' in sola analisi dati, transizione verso JEM-EUSO.**
**LiMadou viene lanciato nel 2016, poca sovrapposizione di personale con JEM-EUSO.**

**2) Fisica del neutrino**
**OPERA e' destinato ad andare in chiusura e Juno ne puo' raccogliere l'attivita'.**
**ICARUS e T2K piccole partecipazioni senza richiesta di risorse.**
**Nessie-RD e' un proposal di un esperimento al FermiLab. Se venisse approvato se ne ridiscutera'....**

# Dettaglio delle richieste ai servizi per il 2015 (preliminare)

| Gruppo | SPAS | SEA | SPCM | Other |
|---|---|---|---|---|
| OPERA | 12 mu | 1 mu (automaz) | | |
| JEM-EUSO-RD | | | 1 mu (progett)<br>2 mu (mecc) | |
| CUORE | | | 15 mu (progett) | |
| Moonlight2 | | 4 mu (automaz) | 6 mu | 2 mu (cryog) |