LETTER

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 $\pi/2$–π–$\pi/2$ 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.

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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

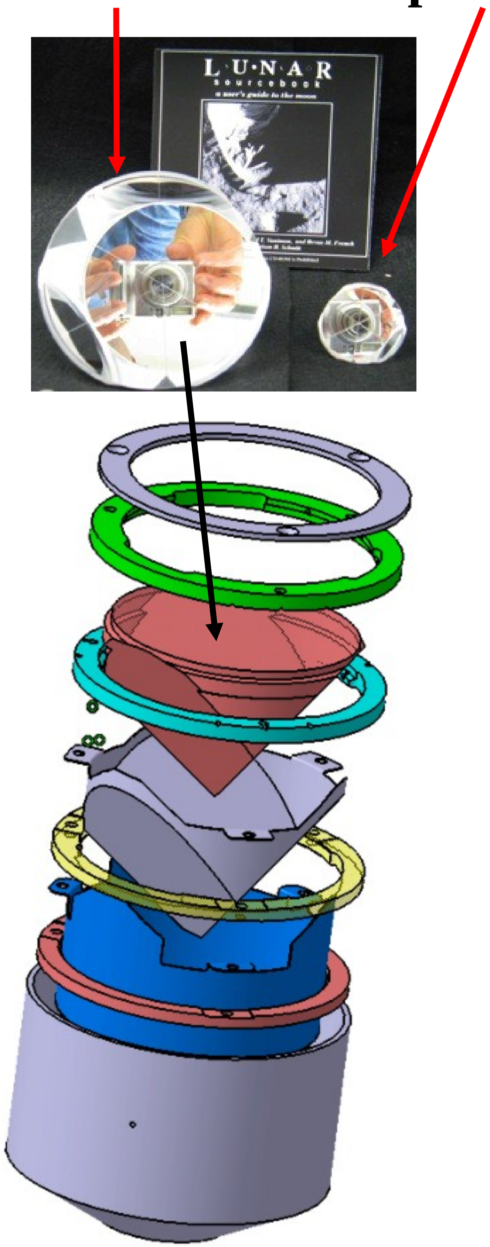
Attivita' di CSN2 presso i laboratori

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



Dell'Agnello, Currie & SCF_Lab

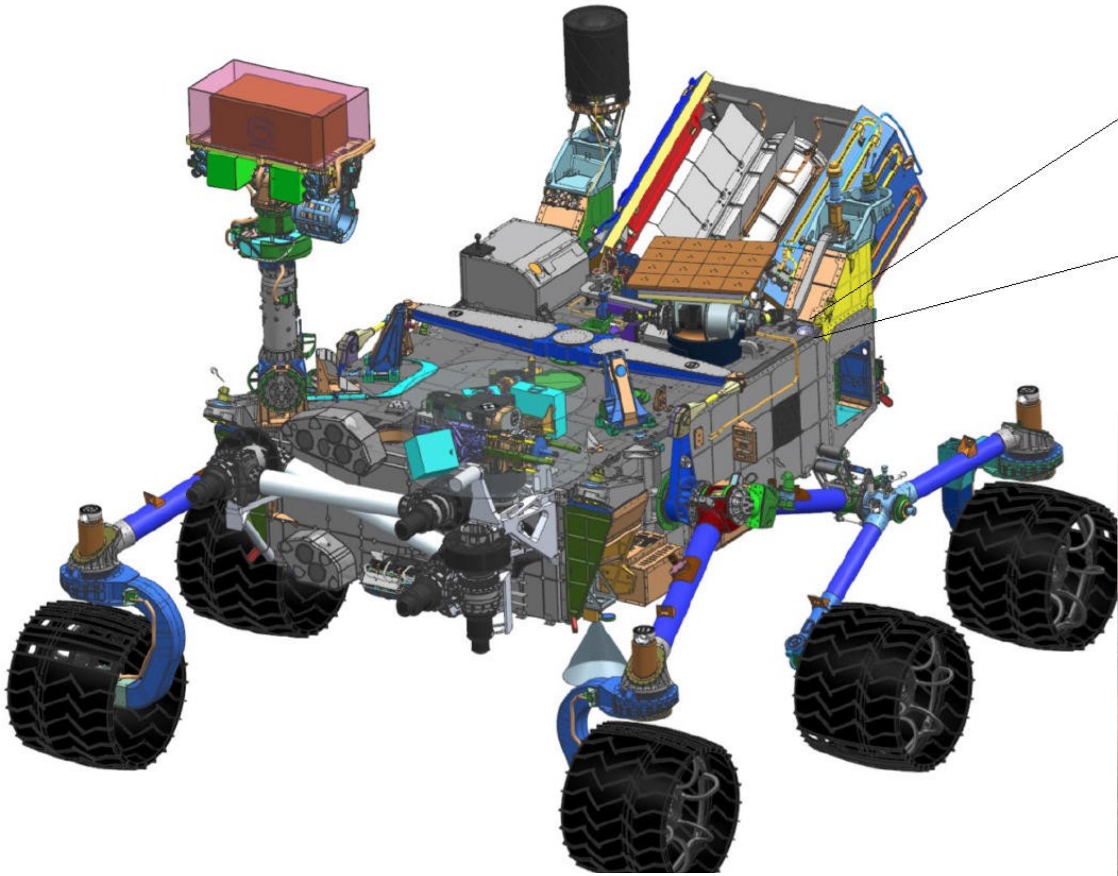
- Goal: Precision tests of General Relativity
- Missions: Luna-27 (Russia, 2019), Chang'e-4/5 (China, 2015/2017); Astrobotic, Moon Express (US, commercial, 2016)

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	|Δ*a*/*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

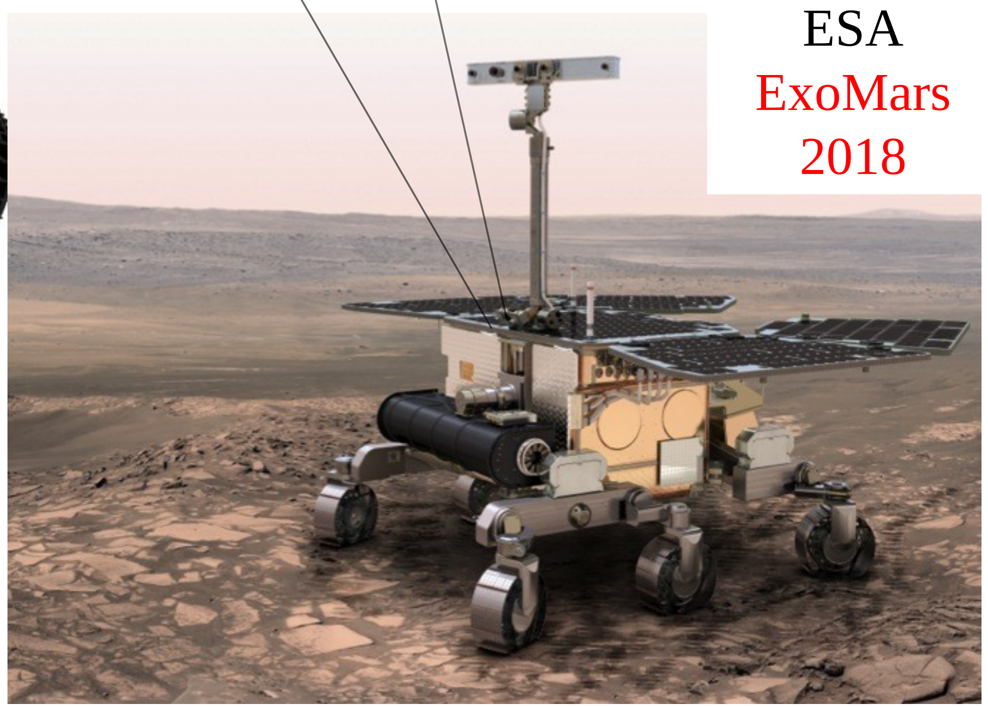
INRRI$2020:"
INstrument"for"landing1**R**oving"laser"**R**etroreflector"**I**nves5ga5ons"

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%

NAUTILUS
LNF - FRASCATI

Bar Al 5056 M = 2270 kg

L = 2.91 m ; Ø = 0.6 m

ν_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

M.A. Franceschi

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

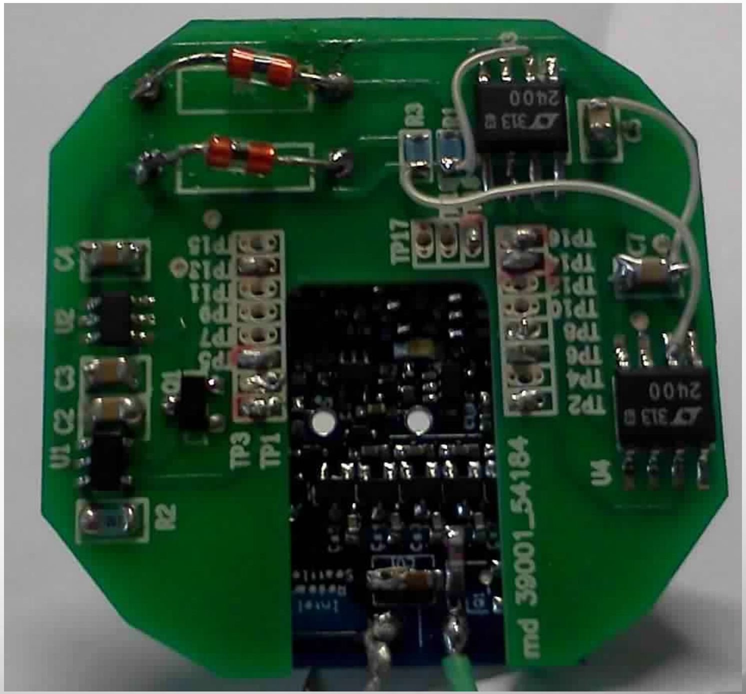
PORFIDO 2

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

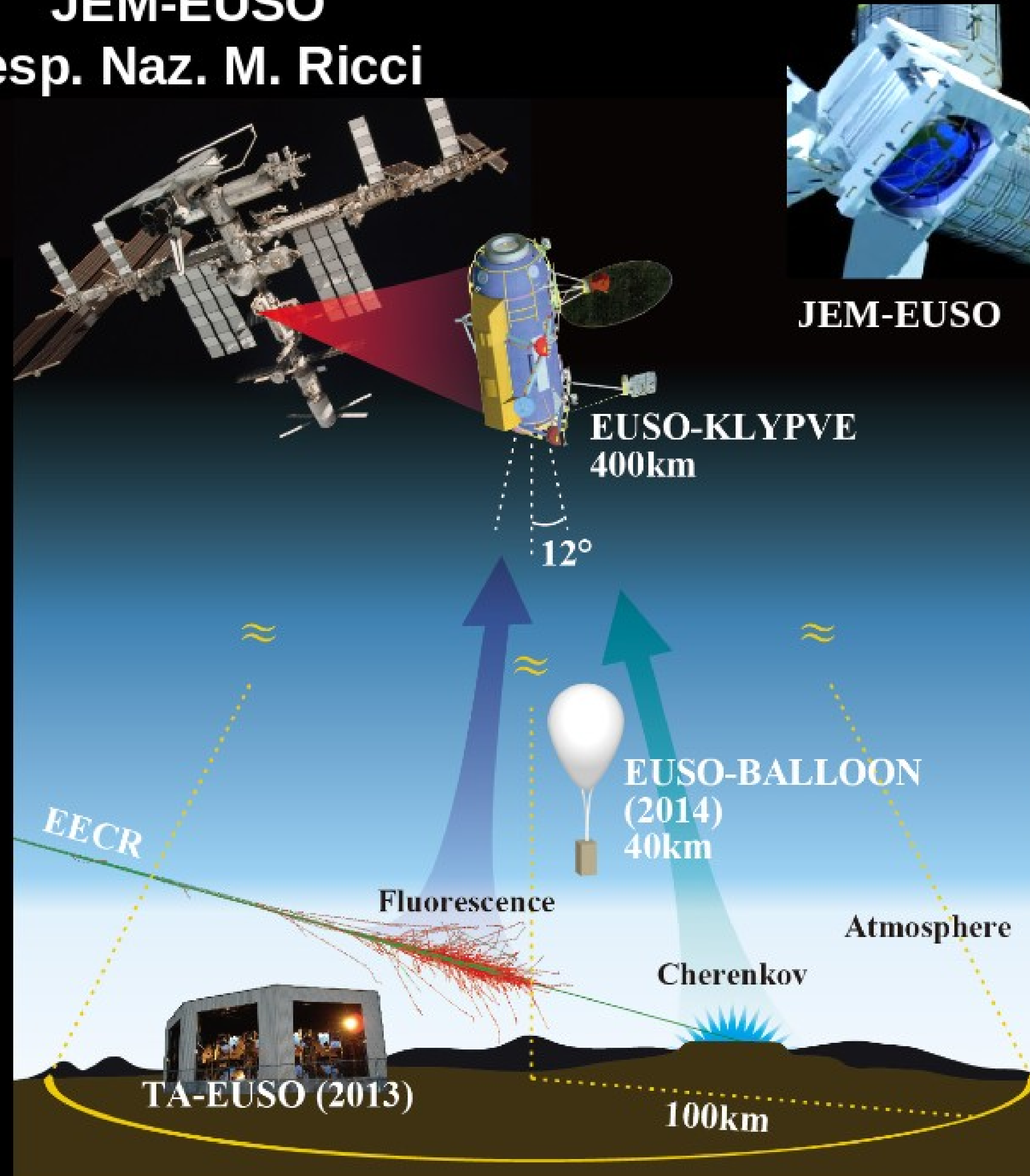
- Partecipanti:
  - Marco Cordelli I ricercatore 0.4 fte (CNSI)
  - Luciano Trasatti Ass. Pens. 2012 1 fte
  - Agnese Martini Tecnologo 0.6 fte (CNSI)
  - Orlando Ciaffoni C-Ter 0.5 fte

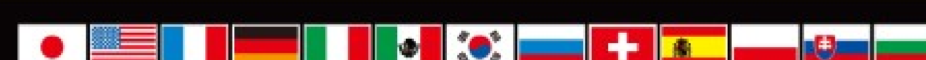
JEM-EUSO
Resp. Naz. M. Ricci

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)

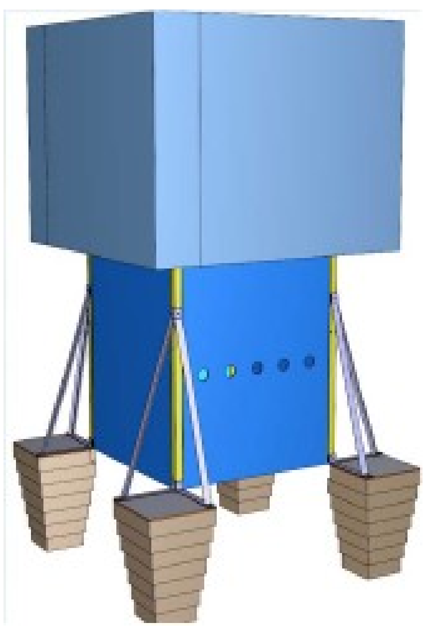
- Look down from a stratospheric balloon with an UV telescope

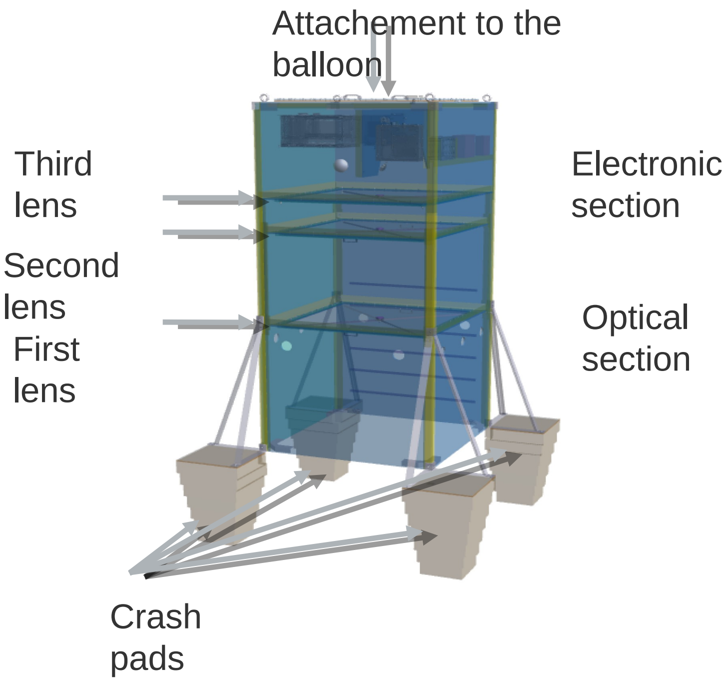
(PDM + 3 lenses system)

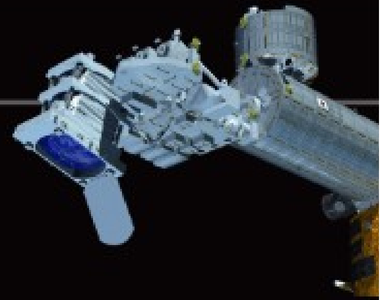
- *Engineering test*
- *Background test*
- Airshower from 40 km altitude

Flight Readiness Review Passed in May 2014 at CNES

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

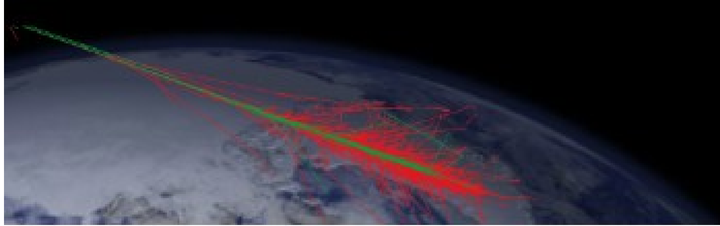


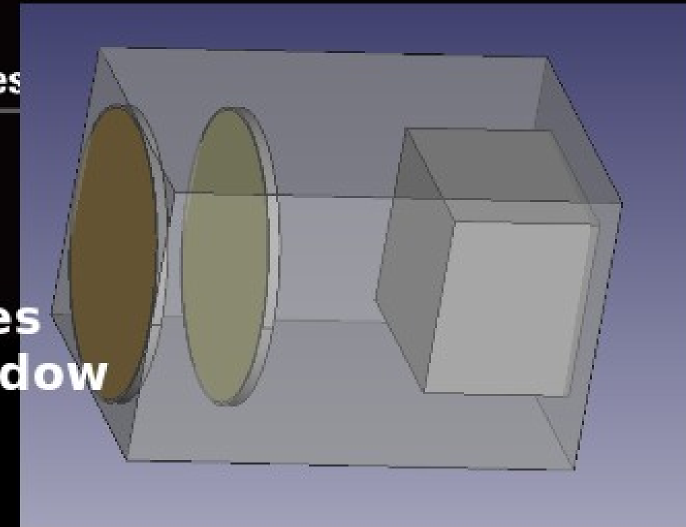




mini-EUSO
A precursor of JEM-EUSO
on board ISS

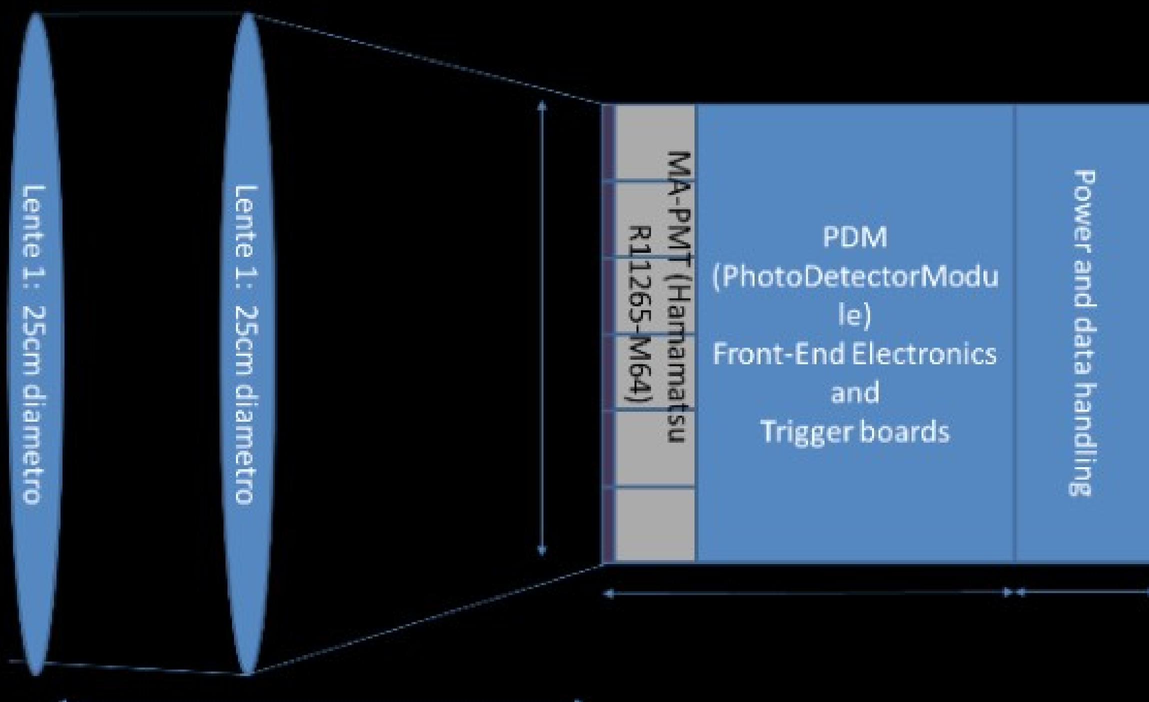
Proposed to ASI (Italian Space Agency) in response to a call 2012 for Human Spaceflight
Selected by ASI, July 2013 (Resources, upload mass, crew time)
Approved by Roscosmos/STAC Committee May 2014 and selected for UV window on Zvesda Module, Russian Segment ISS

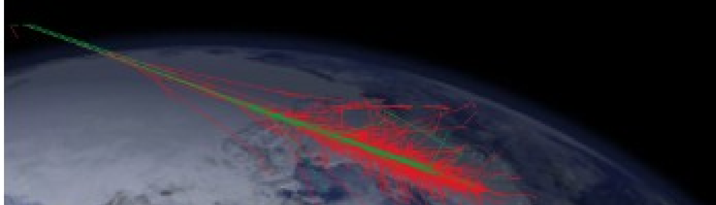




Mini-EUSO

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

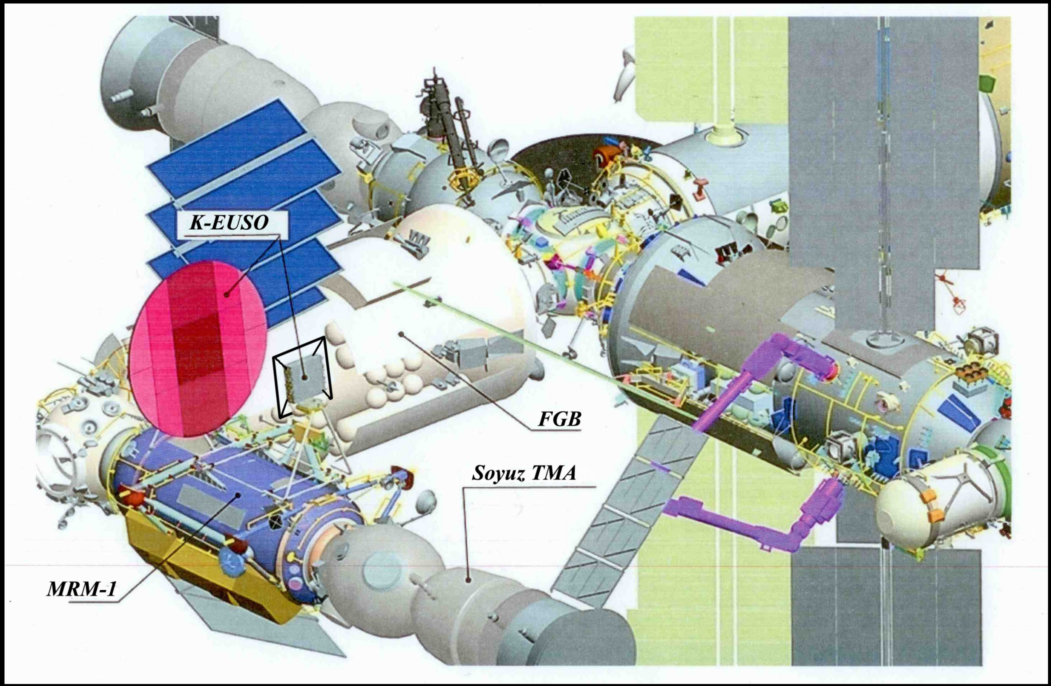




The Main Mission Intermediate Step JEM-EUSO on Russian Module KLYPVE-EUSO

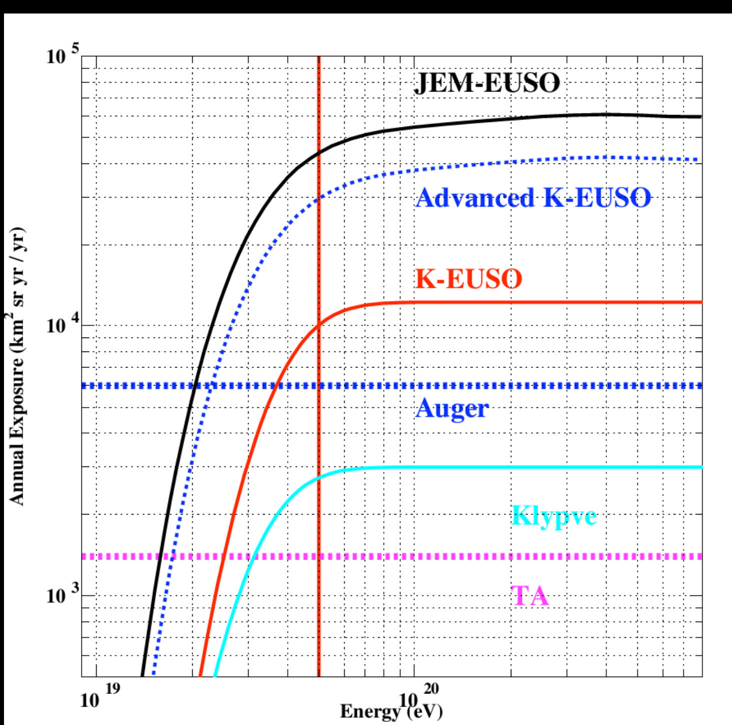
- Included in the Russian Federal Space Program
- Passed the stage of preliminary design (pre-phase A)
- Technical requirements (specifications) defined, based of the preliminary design
- Optimization studies (mainly on the optics)

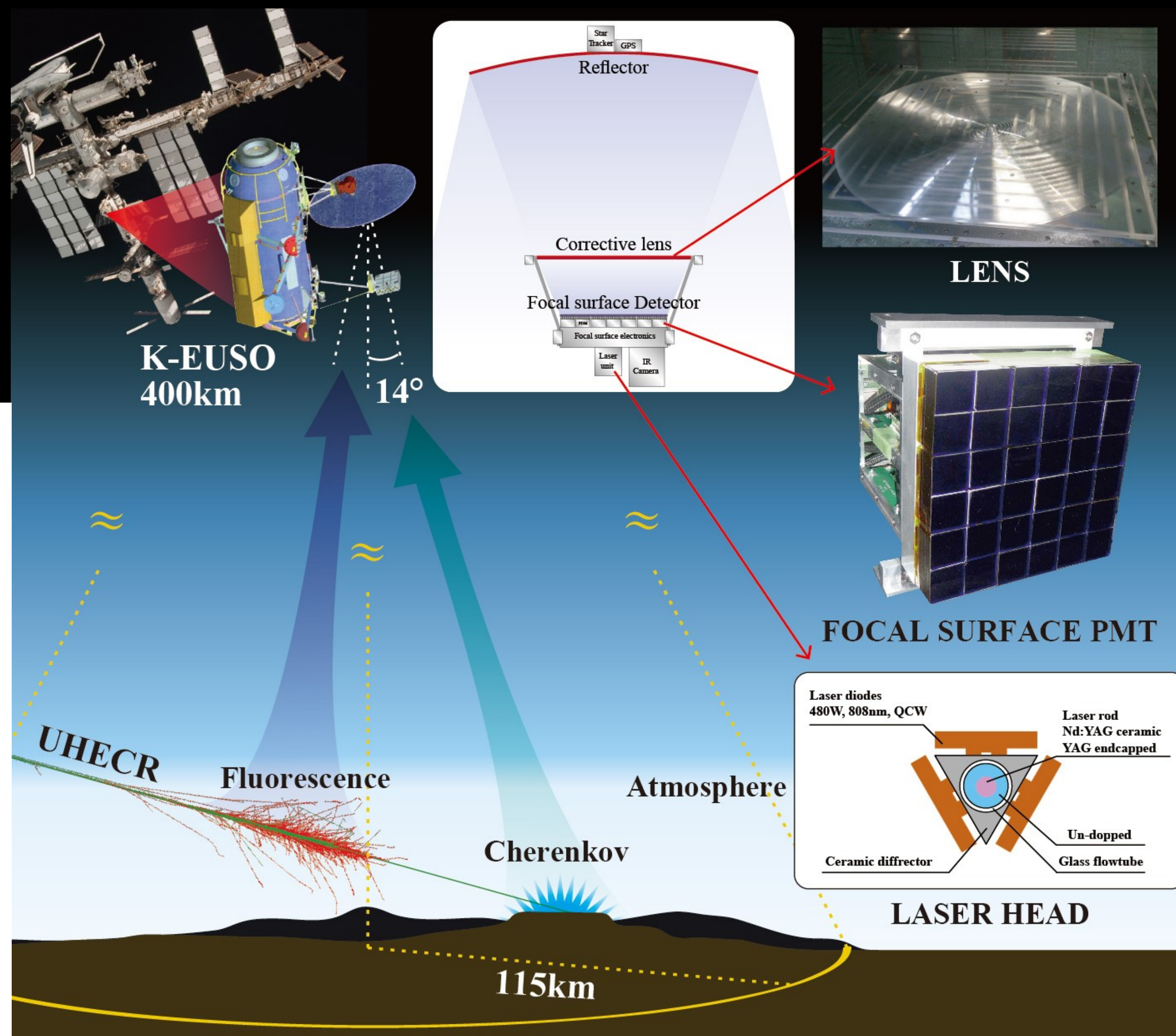
⟹ K-EUSO Official Mission Name



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

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

Progetto premiale ASI
Partecipazione INFN, 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.

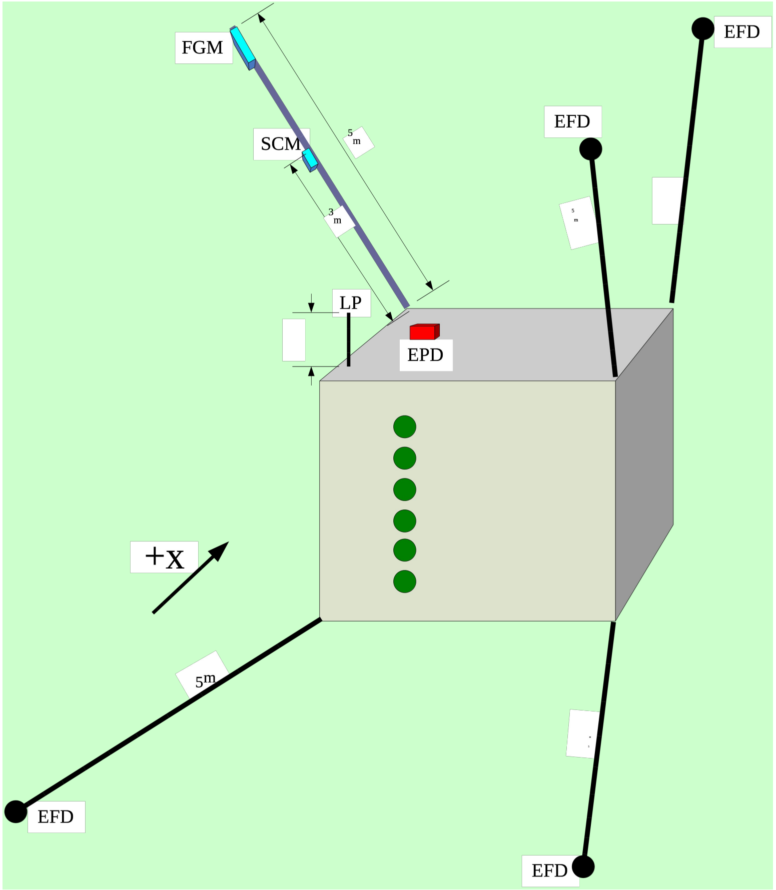
OBIETTIVI TECNOLOGICI:

- 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

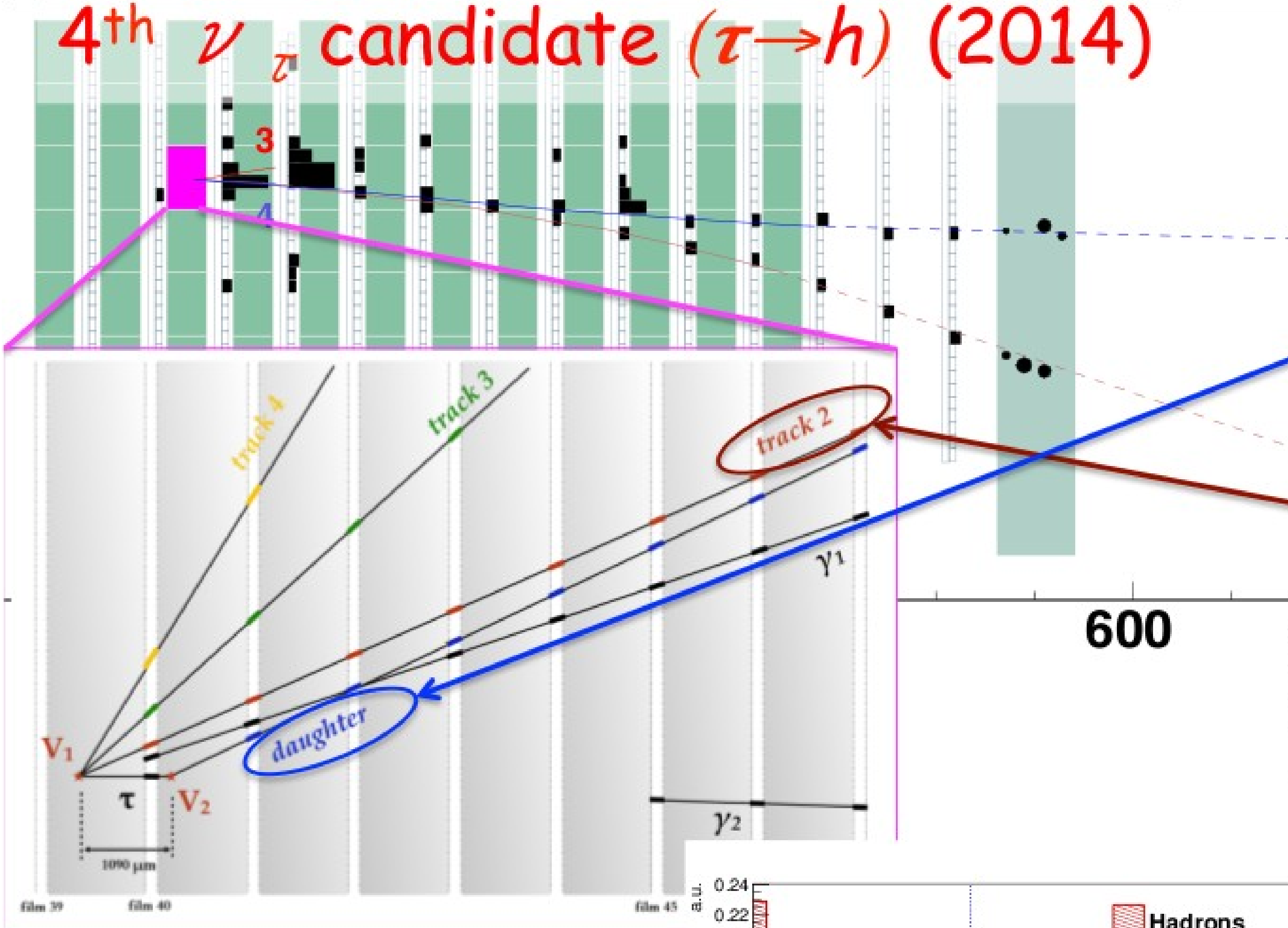
- WP1) Provide the High Energy Particle Detector (HEPD) (design, build, test, qualify, integrate, commission, calibration, analysis)
- WP2) Collaborate on the development of the Electric Field Detector (design, test, qualification, analysis) - LNF (Rad. Hard Tests, e- beam lines BTF, LINAC)
- WP3) Develop 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

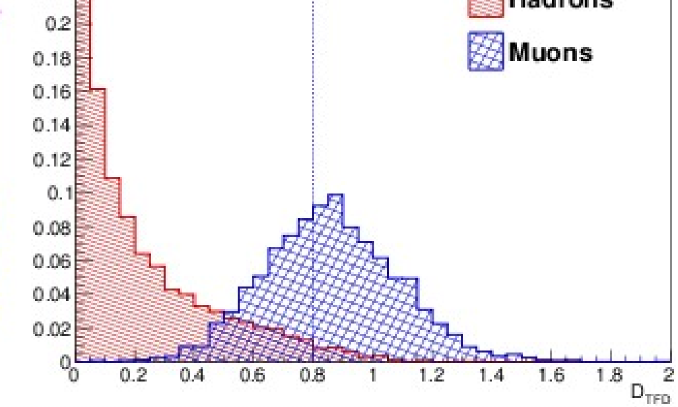
An additional area which will be developed is

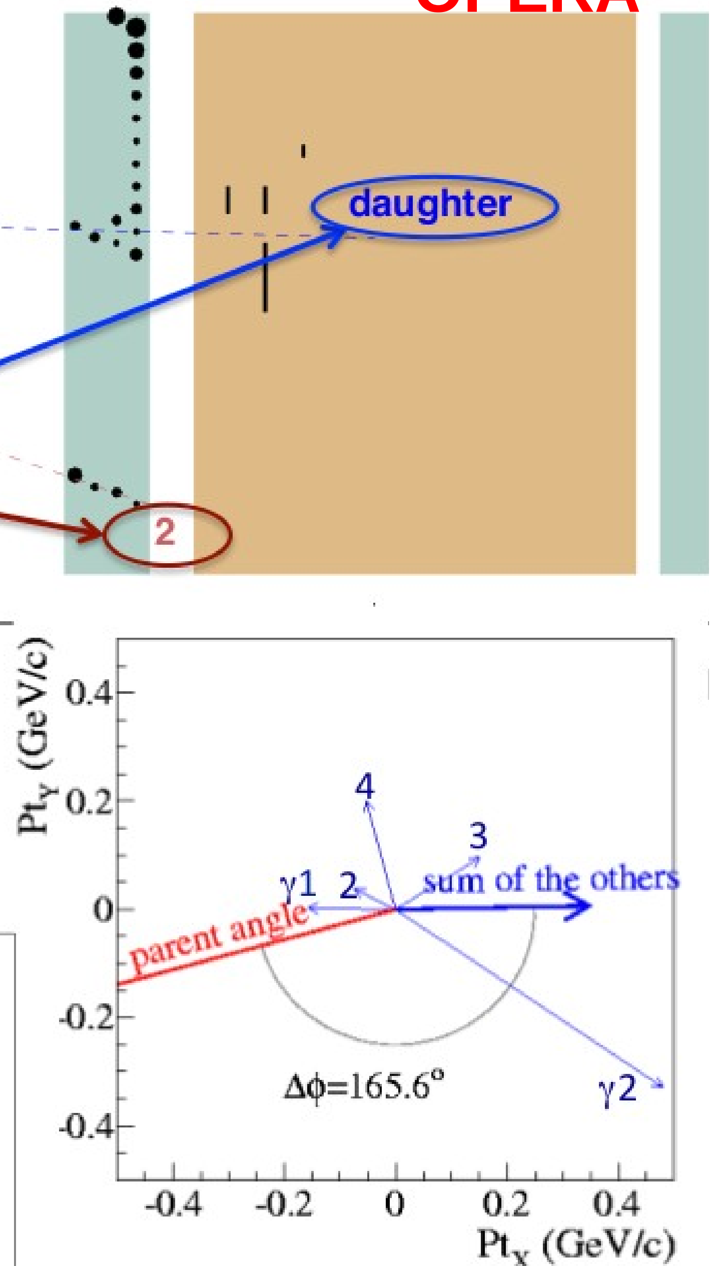
- WP5) the area of data download to the Matera station and CSES ground segment

4th ν_τ candidate ($\tau \rightarrow h$) (2014)

OPERA





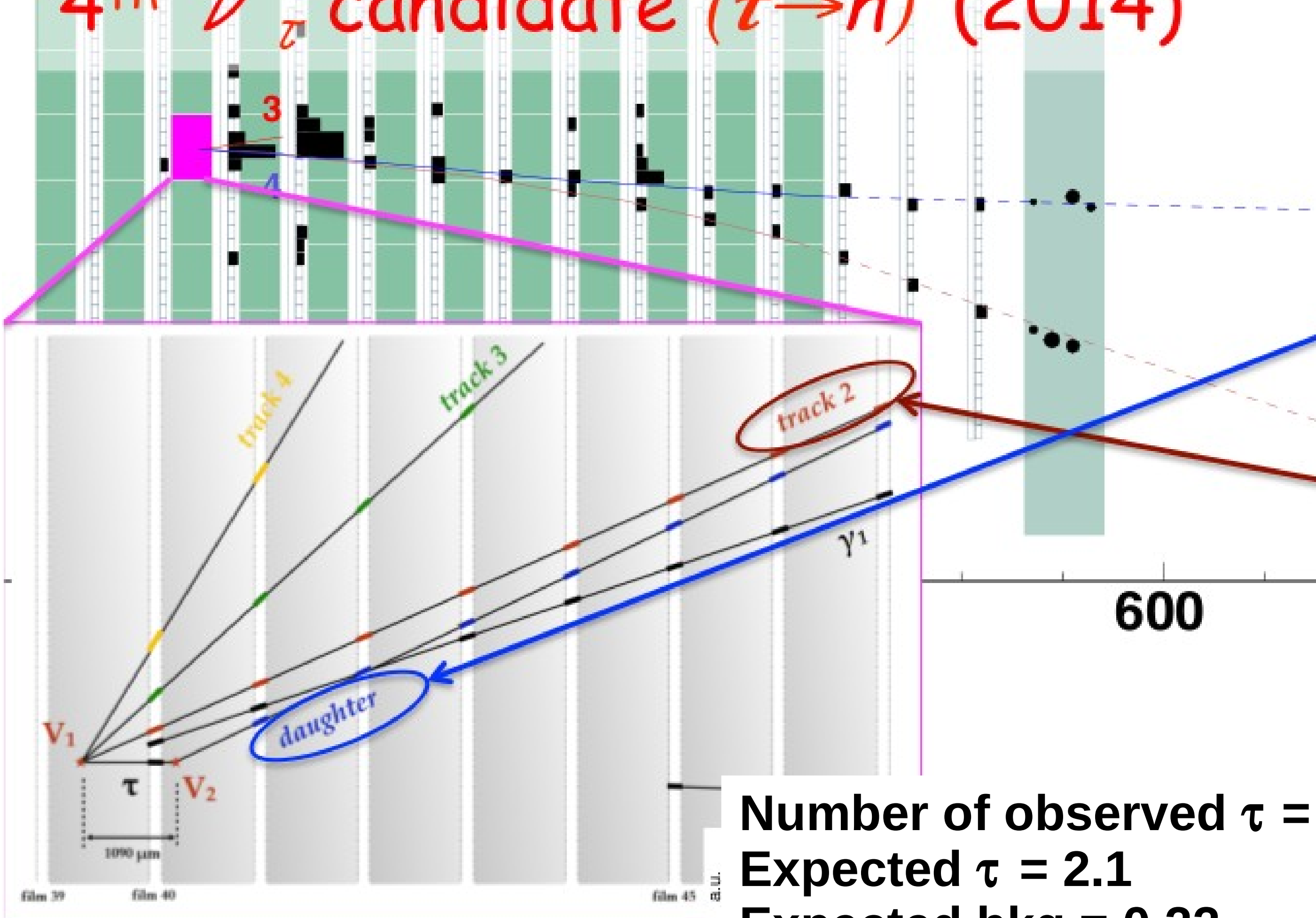


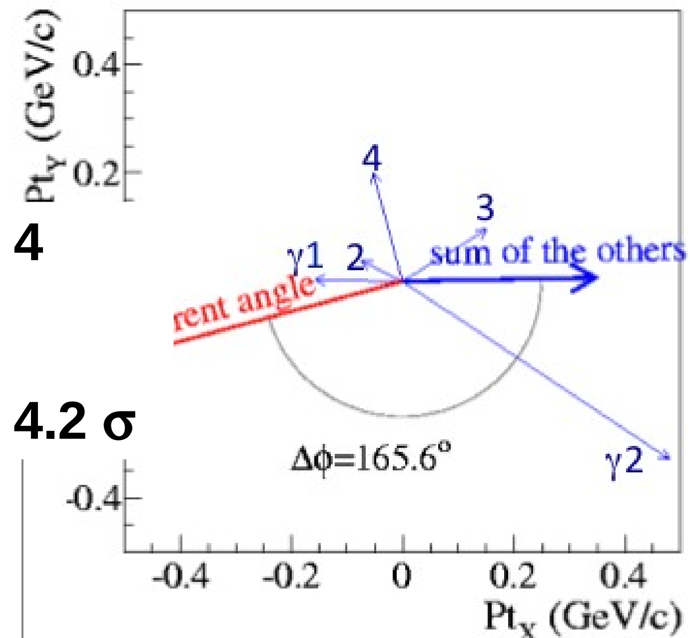
Track 2 from neutrino interaction vertex, p = 1.9 GeV stopping in first iron slab of the magnet

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

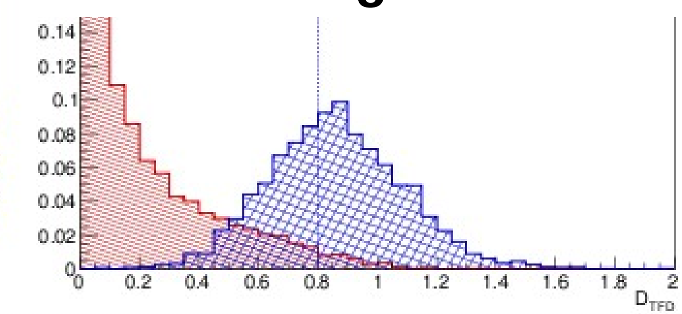
4^{th} ν_τ candidate ($\tau \rightarrow h$) (2014)

OPERA





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



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

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

Sterile neutrinos

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

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

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

~ standard oscillation

pure exotic oscillation

interference terms

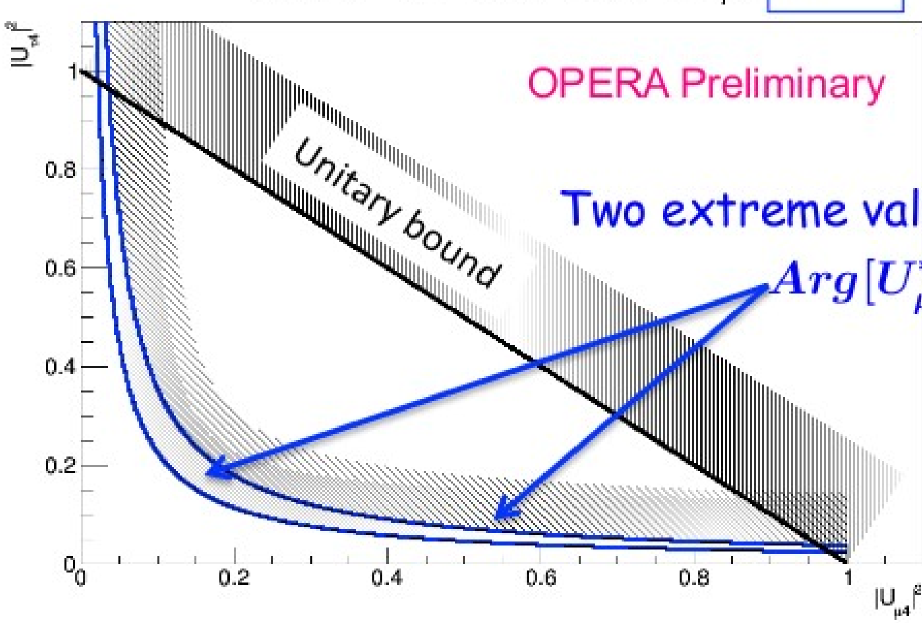
$$P_{\nu_\mu \to \nu_\tau} = 4|U_{\mu 3}|^2 |U_{\tau 3}|^2 \sin^2 \frac{\Delta_{31}}{2} + 4|U_{\mu 4}|^2 |U_{\tau 4}|^2 \sin^2 \frac{\Delta_{41}}{2}$$
$$+2\Re[U^*_{\mu 4} U_{\tau 4} U_{\mu 3} U^*_{\tau 3}] \sin\Delta_{31} \sin\Delta_{41}$$
$$-4\Im[U^*_{\mu 4} U_{\tau 4} U_{\mu 3} U^*_{\tau 3}] \sin^2 \frac{\Delta_{31}}{2} \sin\Delta_{41}$$
$$+8\Re[U^*_{\mu 4} U_{\tau 4} U_{\mu 3} U^*_{\tau 3}] \sin^2 \frac{\Delta_{31}}{2} \sin^2 \frac{\Delta_{41}}{2}$$
$$+4\Im[U^*_{\mu 4} U_{\tau 4} U_{\mu 3} U^*_{\tau 3}] \sin\Delta_{31} \sin^2 \frac{\Delta_{41}}{2}$$

Normal hierarchy

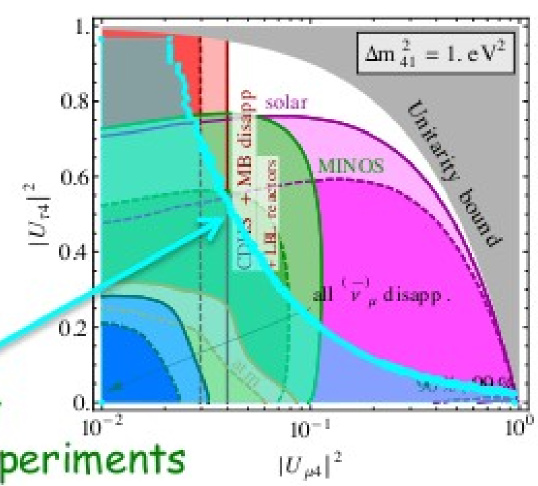
Profile likelihood using Tau rate only

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

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



Two extreme values ($\pi/2$, $3\pi/2$) 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																				

Opera decommissioning: weekly iperaggressive plan (2)

Weeks 40 - 80

End SM2 (week 47/48) — End SM1 (week 75/76)

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
week	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Brick/BMS														LS	BMS						
HPT (1&2)																					
Veto																					
Elec's/Cabl																					
TT/Wall																SM1					
MainStruc												SM1		binar	BMS						SM1
Magnet 2																					
Magnet 1																					
RPC 1&2																					
BaseStruc																					

date	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	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
Brick/BMS																				
HPT (1&2)																				
Veto																				
Elec's/Cabl																				
TT/Wall																				
MainStruc																				
Magnet 2																				
Magnet 1				SM1																
RPC 1&2			XPC2																	
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:

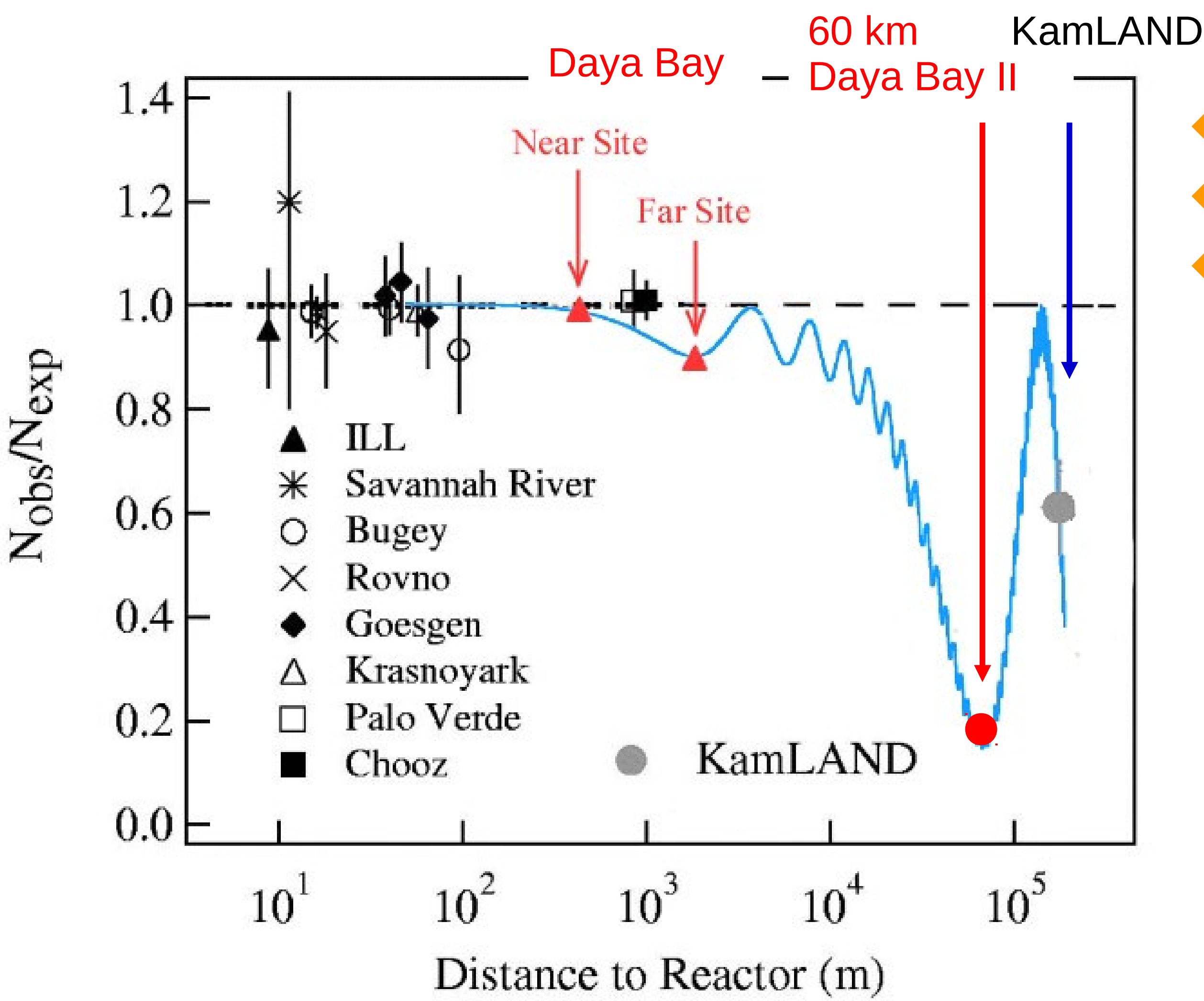
- un Technical Report al CERN-SPSC
  - Magnetizzazione di grossi volumi (magnete in aria / coils superconduttive)
- un proposal di fisica al Physics Advisory Committee del FNAL, P-1057)
  - ν_μ disappearance con un doppio sito al Booster Neutrino Beam per la ricerca di neutrini sterili

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

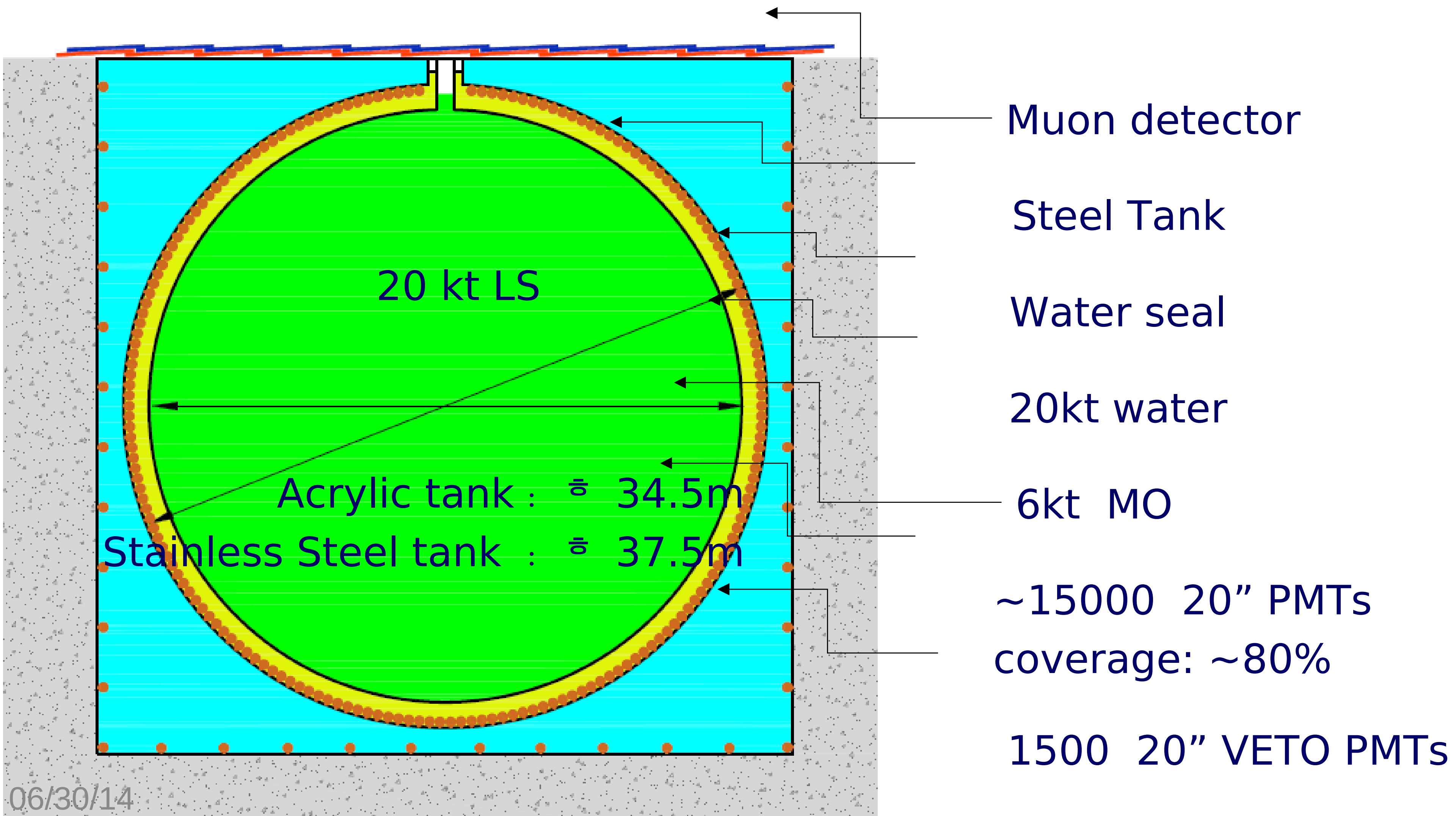
The Site

	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

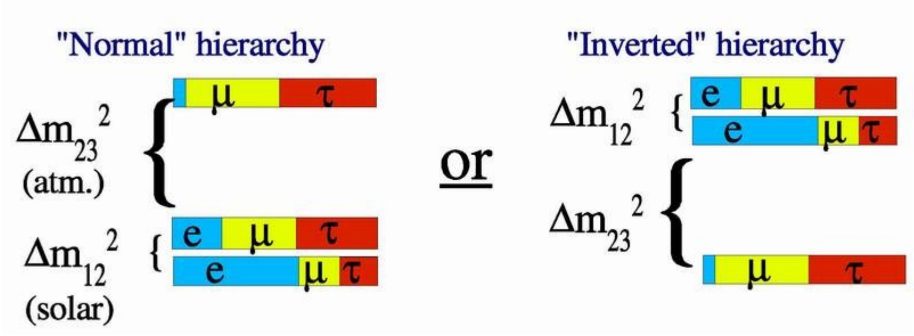
The plan: a large LS detector

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

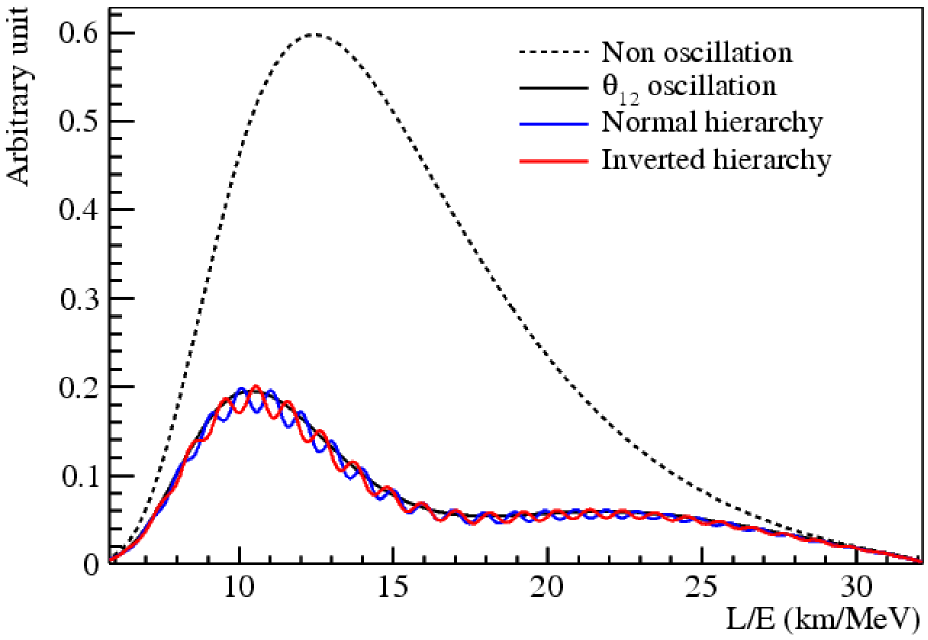
40 events/day



Mass Hierarchy at Reactors



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



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

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

Precision measurement of mixing parameters

	Current	Daya Bay II
Δm^2_{12}	3%	0.6%
Δm^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%

Current Status & Brief Schedule

- Project approved by CAS for R&D and design
- Geological survey completed
- Granite rock, tem. ~ 31 ^{o}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

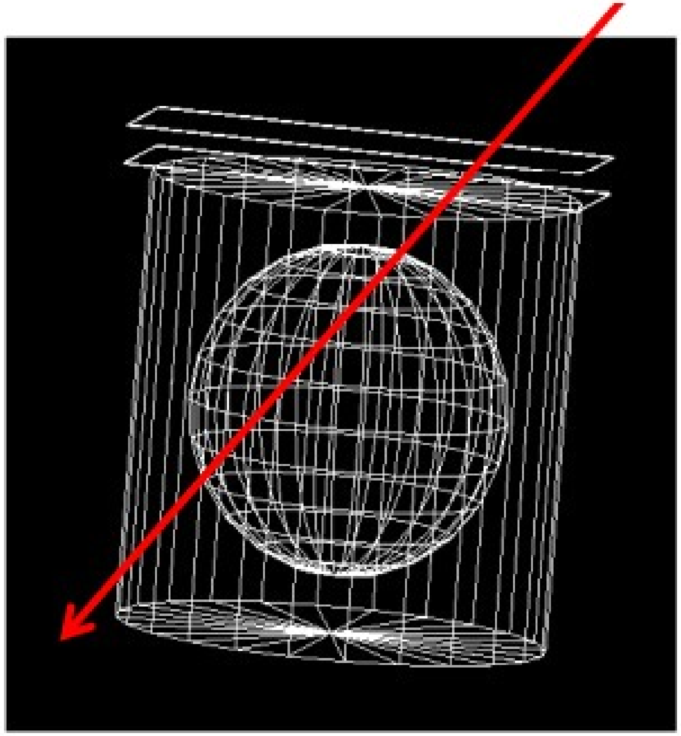
Per il top tracker si pensa al riutilizzo del Target Tracker di OPERA.
LNF sono assegnatari dei PMT.

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



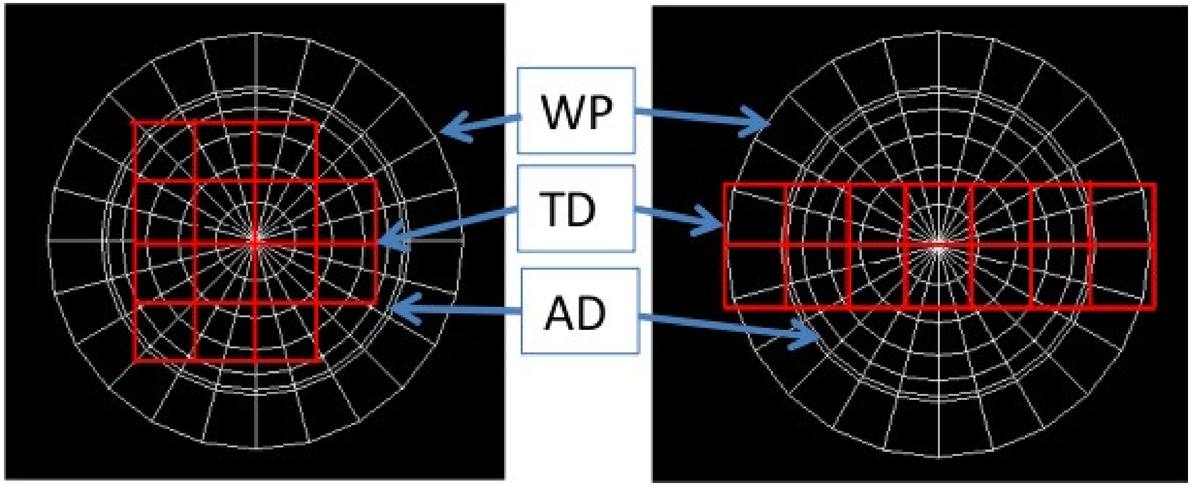
Da OPERA:
62 piani di area 6.7*6.7 m^2, lettura x-y su due lati.
Insufficienti per coprire l'intera superficie.

Esistono gia' studi preliminari.
Soluzione rettangolare favorita.

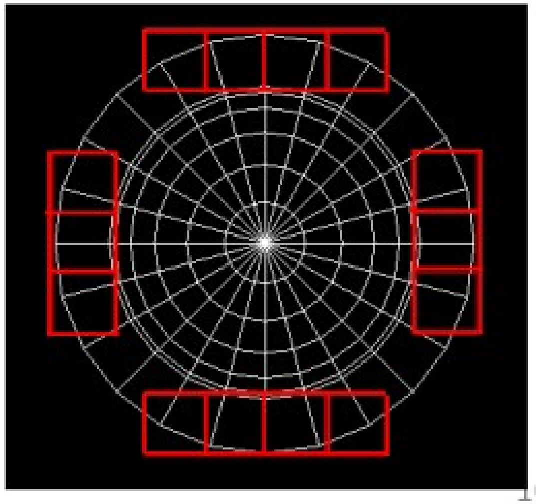
Investigazioni in corso per migliorare la copertura.

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

4XY Middle (Mid) 4XY Rectangle(Rtg)



4XY Around("O")



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	1.2 (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) 2 mu (mecc)	
CUORE			15 mu (progett)	
Moonlight2		4 mu (automaz)	6 mu	2 mu (cryog)