Summary of astro-particle physics activities (CSN2) at LNF

A. Paoloni

LNF Scientific Committee
9 May 2013

Summary of CSN2 activities at LNF

Neutrino physics (mainly at LNGS)					
BOREXINO	ICARUS	MARE-RD	NESSIE-RD	OPERA	T2K

Search for rare processes (mainly at LNGS)					
CTF-RD-DARK	CUORE	DAMA	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	FERMI	GAMMA400-RD	JEM-EUSO-RD	WIZARD	

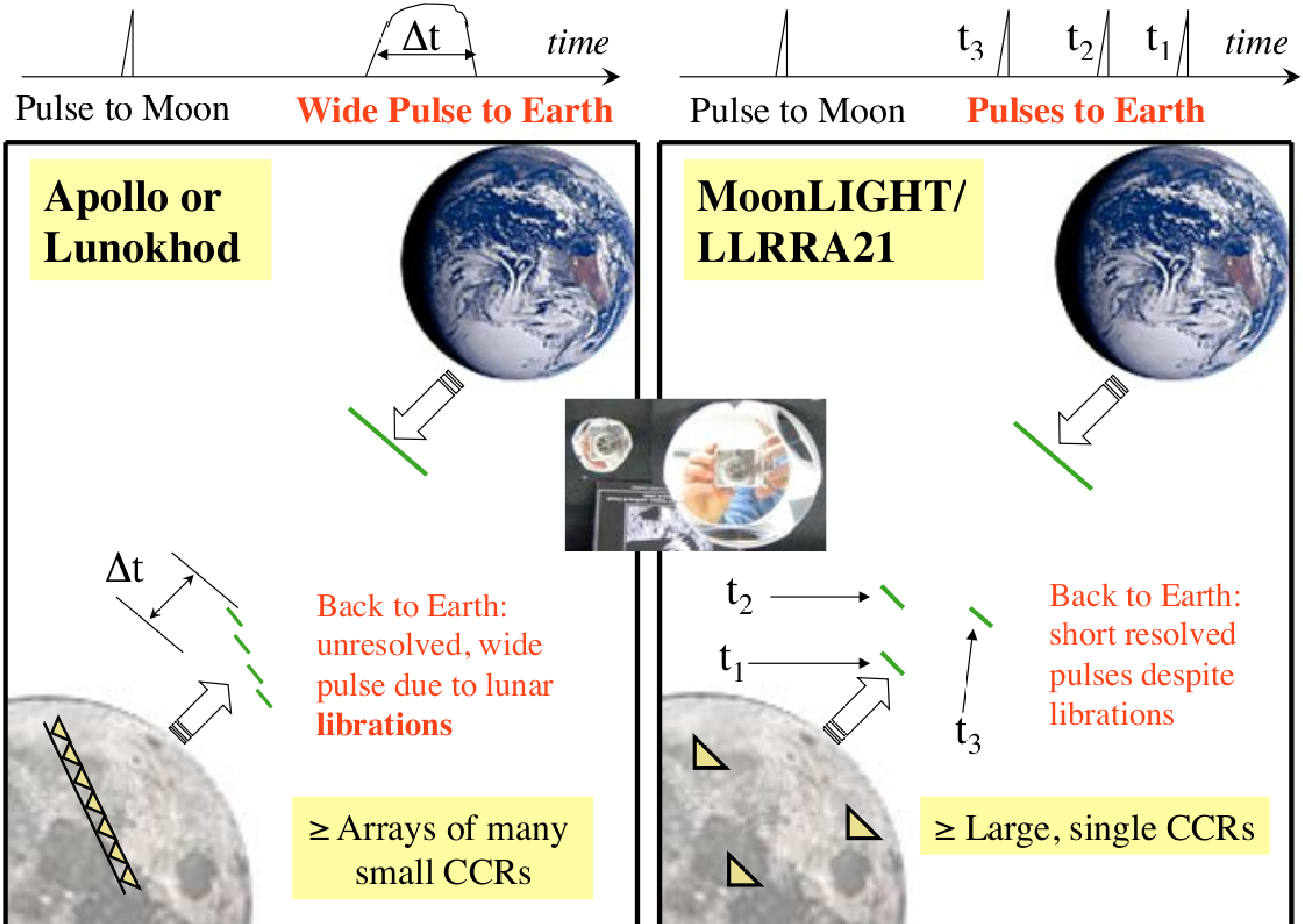
Search for gravitational waves					
AURIGA	LISA-PATHFINDER	RARENOISE-DTZ	ROG	VIRGO	VIRGO-ADV

General physics					
G-GRANSASSO-RD	GGG	HUMOR*	MAGIA	MICRA	MIR
MOONLIGHT2-DTZ*	PVLAS				

In total: 14 FTE (30 persons)

Moonlight2-DTZ

(lunar laser ranging)


Δt
time
Pulse to Moon
Wide Pulse to Earth
t3
t2
t1
time
Pulse to Moon
Pulses to Earth
Apollo or Lunokhod
MoonLIGHT/ LLRRA21
Δt
Back to Earth: unresolved, wide pulse due to lunar **librations**
≥ Arrays of many small CCRs
t2
t1
t3
Back to Earth: short resolved pulses despite librations
≥ Large, single CCRs

Tests of General Relativity with MoonLIGHT

Precision test of violation of General Relativity	Time scale	Apollo/Lunokhod few cm accuracy*	3 MoonLIGHTs 1 mm	3 MoonLIGHTs 0.1 mm
Parameterized Post-Newtonian (PPN) β	Few years	$\lvert\beta-1\rvert<1.1\times10^{-4}$	10^{-5}	10^{-6}
Weak Equivalence Principle (WEP)	Few years	$\lvert\Delta a/a\rvert<1.4\times10^{-13}$	10^{-14}	10^{-15}
Strong Equivalence Principle (SEP)	Few years	$\lvert\eta\rvert<4.4\times10^{-4}$	3×10^{-5}	3×10^{-6}
Time Variation of the Gravitational Constant (Gdot)	~5 years	$\lvert\dot{G}/G\rvert<9\times10^{-13}yr^{-1}$	5×10^{-14}	5×10^{-15}
Inverse Square Law (ISL)	~10 years	$\lvert\alpha\rvert<3\times10^{-11}$	10^{-12}	10^{-13}
Geodetic Precession (GP)	**Few years**	$\mathbf{\lvert K_{GP}\rvert<6.4\times10^{-3}}$	6.4×10^{-4}	6.4×10^{-5}

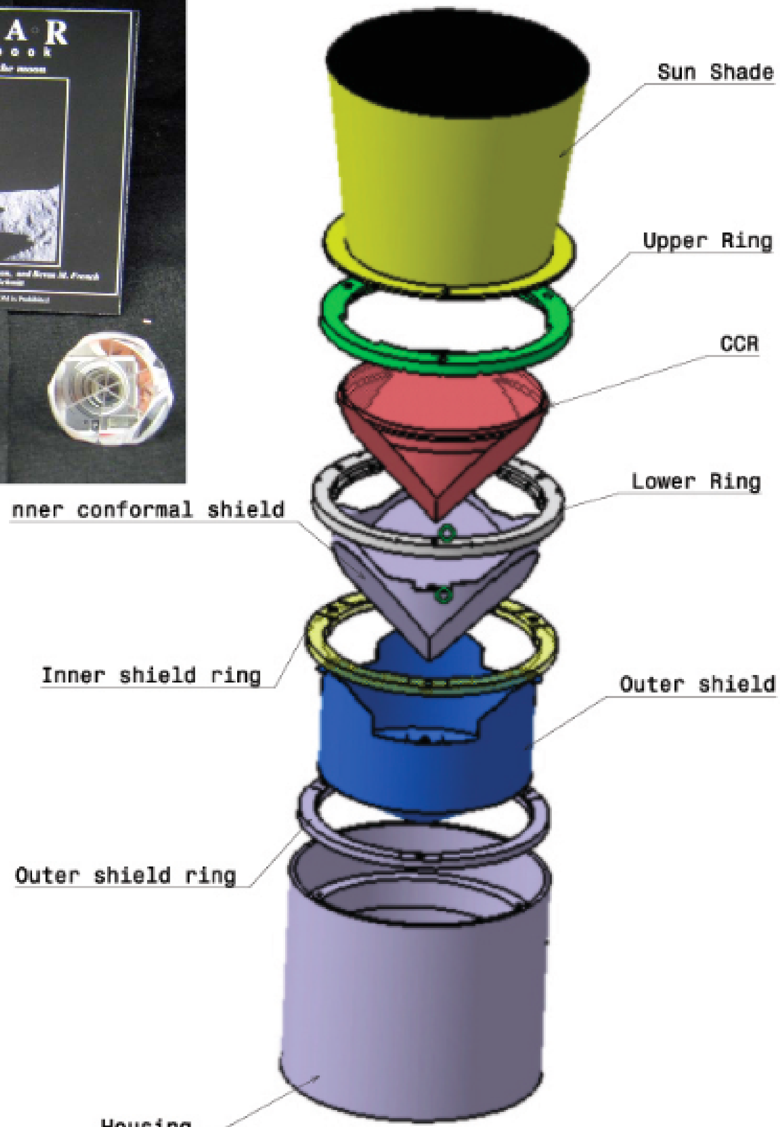
* J. G. Williams et al, PRL 93, 261101 (2004). Gravity Probe B final result on GP: $\lvert K_{GP}\rvert<2.8\times10^{-3}$

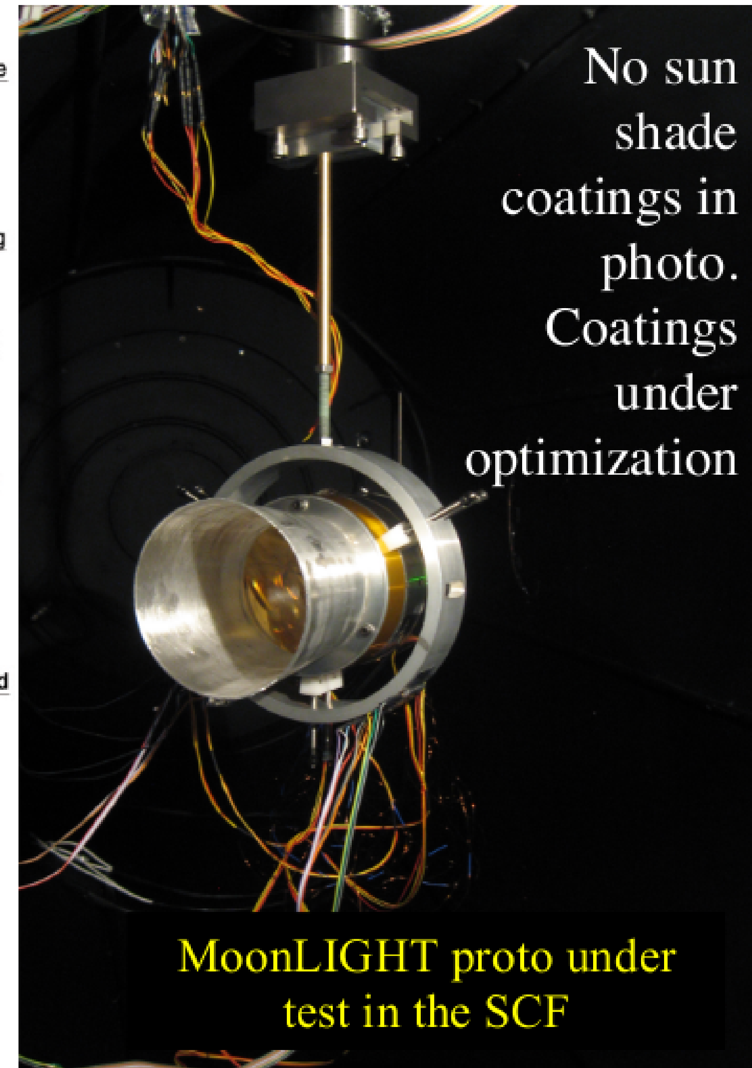
We are concentrating on Geodetic Precession and Apollo arrays
Our current accuracy, PEP and new APOLLO laser station: **1%**

Goal for 2014: Geodetic Precession @ **5×10^{-3} accuracy**

MoonLIGHT (10 cm reflector) SCF-Tested

1 MoonLIGHT equivalent to ~50 Apollo CCRs (38 mmm)





Mission opportunities [**P**ole/**E**quator/**L**imb site]

- **Commercial Launches** with SpaceX Falcon 9 missions (2 successful dockings to ISS); MoonLIGHT approved:
  - **Moon Express [E], 1st flight: end 2014**
  - **Astrobotic [E]: 2015**
  - **Moon Express, Commercial-ILN [P, E, L]: >2015**
- **Space Agency launches**:
  - SELENE-2 (JAXA), [P]; signed scientific agreement: 2017
  - Chandrayaan-2 Lunar Lander (ISRO) [P]; negotiating: 2015
  - LGN (NASA) [P1, P2, L or P, L1, L2]: 2018
- LunarCubeSats
  - Promoted by NASA-GSFC; transfer from GEO

Proposal to NASA's SSERVI (April 2013)

Network for Exploration and Space Science

Space Science Enabled by Exploration

Investigators

Principal Investigator:
Jack Burns, University of Colorado Boulder

Co-Investigators, Key Project Leads:
Joseph Lazio, JPL/Caltech, Deputy P.I.
Douglas Currie, University of Maryland
Douglas Duncan, University of Colorado, E/PO Lead
Justin Kasper, Smithsonian Astrophysical Observatory
Robert MacDowall, NASA GSFC

Co-Investigators:
Judd Bowman, Arizona State University
Richard Bradley, NRAO
Anthony Case, Smithsonian Astrophysical Observatory
Peter Chen, Catholic University & NASA GSFC
Pamela Clark, Catholic University & NASA GSFC
Steven Furlanetto, UCLA
Dayton Jones, JPL/Caltech
Abraham Loeb, Harvard University
Mark Looper, Aerospace Corporation
Joseph Mazur, Aerospace Corporation
Thomas Murphy, U. California, San Diego
Michael Reiner, Catholic University & NASA GSFC
William Sparks, Space Telescope Science Institute
Kenneth Stewart, NRL
Slava Turyshev, JPL/Caltech
Stephen Unwin, JPL/Caltech
James Williams, JPL/Caltech
Kris Zacny, Honeybee Robotics

Collaborators

Daniel Baker & Mihaly Horanyi, U. Colorado Boulder
Giuseppe Bianco, Centro di Geodesia Spaziale, Italy
Christopher Carilli, NRAO
Simone Dell'Agnello & Giovanni Delle Monache, INFN-LNF, Italy
Heino Falcke, Radbound University, Netherlands
William Farrell, NASA GSFC
Terry Fong, NASA Ames Research Center
Lincoln Greenhill, Harvard-Smithsonian CfA
Geraint Harker, University College London, UK
Joshua Hopkins & Scott Norris, Lockheed Martin Corp.
Telana Jackson, NASA GSFC
David Kring, Lunar & Planetary Institute
Melissa McGrath, NASA MSFC
Nicole Meyer-Vernet, Observatoire de Paris, France
Miguel Morales, U. Washington
Matt Mountain & Marc Postman, STScI
Issa Nesnas, JPL/Caltech
Hirotomo Noda, NAOJ, Japan
Nathan Schwadron, U. New Hampshire
David Smith, NASA GSFC
Gregory Taylor, U. New Mexico
Harley Thronson, NASA GSFC
Steven Tingay, Curtin U./ICRAR, Australia
Kurt Weiler, CPI
Michael Werner, JPL/Caltech
Maria Zuber, MIT

Fig. 17. LLRRA-21 Conceptual Design, especially addressing stepped sunshade, for SCF testing.

inputs and exchanges due to the solar radiation, the thermal radiation from the regolith and radiation to space. A range of material properties was considered for the materials and the thermal coatings to determine the strength of the return to the observatory on the Earth. In order to validate the simulations, components have been fabricated and tested in a unique facility developed by the NExSS international partners at INFN-LNF in Frascati, Italy. This has allowed us to define the properties that would be required for the LLRRA-21.

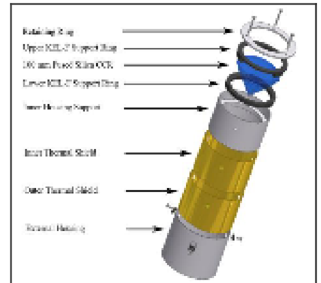


Fig. 18. Conceptual Design of LLRRA-21 as tested in INFN-LNF thermal-vacuum chamber.

Thermal gradients within the CCR, caused by the input of solar heating and radiation to cold space, results in gradients in the index of refraction of the fused silica. This in turn causes a spreading of the return laser beam, greatly reducing the received signal (Currie 2011). In order to control the thermal issues, a number of new concepts must now be explored in the simulations. For example, while the sunshade in Fig. 17 and 18 (gold cylinder) blocks the solar radiation for low elevation angles of the Sun, near zenith, it ducts additional thermal energy into the CCR, which causes gradients that degrade the signal (Currie 2011). In simulation, the use of a unique "stepped" design reduced the solar ration reaching the CCR by 40%. In order to experimentally test this, we propose to use the Satellite/lunar laser ranging Characterization Facility (SCF) in Frascati, Italy (Fig. 19). This unique facility for testing retroreflector has been developed by the Laboratori Nazionali di Frascati (LNF) of the Laboratori dell'Istituto Nazionale di Fisica Nucleare (INFN) in collaboration with the University of Maryland (Dell'Agnello 2011a, b).

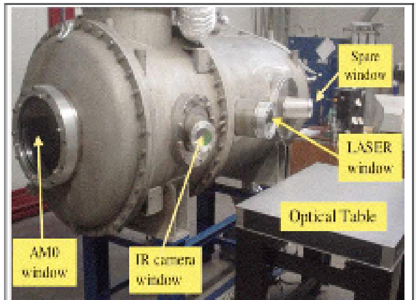


Fig. 19. SCF Facility at INFN-LNF in Frascati, Italy. This facility was used for previous tests. A new SCF facility will be made available to the NExSS team for testing a prototype LLRRA-21 (Dell'Agnello 2011).

3.3.2.2 Continued Ranging from the APOLLO and MLRO

In order to obtain improved accuracy, Co-I Murphy has developed the Apache Point Observatory Lunar Laser-ranging Operation (APOLLO) station (Murphy et al. 2008) as seen in Fig. 20. By operating on a 3.5 m astronomical telescope, we are able to collect many thousands of return photons in a session, and thereby determine the range with millimeter precision. The raw precision allows tests of systematic error sources, such as atmospheric delay, crustal loading, etc. One recent success was ranging to the "lost" Lunokhod 1 rover/reflector and, thus, adding an important new reflector to

SCF_Lab Team

INFN-LNF

S. Dell'Agnello, Resp.
G. Delle Monache, Dep.
R. Vittori,
C. Cantone,
A. Boni, C. Lops,
M. Maiello, S. Berardi,
G. Patrizi, M. Martini
G. Bellettini, R. Tauraso
R. March,
N. Intaglietta, M. Tibuzzi,
E. Ciocci, S. Contessa
L. Salvatori, L. Palandara
M. Lobello, A. Stecchi,
E. Bernieri

Students:
F. Piergentili, G. Capotorto,
M. Marra, N. Castel-Branco

International Collaborations

Univ. of Maryland at College Park - D. Currie
(LLRRA21: LLR Array for the 21 century)
Harvard-Smithsonian Center for Astrophysics (CfA),
J. Chandler, I. Shapiro
Instituto Superior Tecnico (IST) Lisboa
O. Bertolami, J. Paramos
Univ. of California at San Diego, T. Murphy

International Collaborations

International Laser Ranging Service (ILRS)
International Lunar Network (ILN)
Commercial ILN (C-ILN)

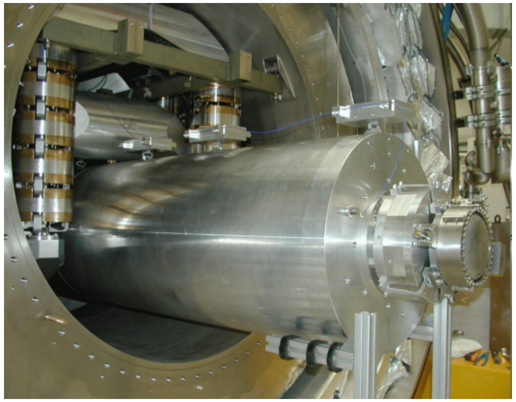
National Collaborations

ASI - Centro di Geodesia Spaziale, G. Bianco
Ministry of Defense, R. Vittori

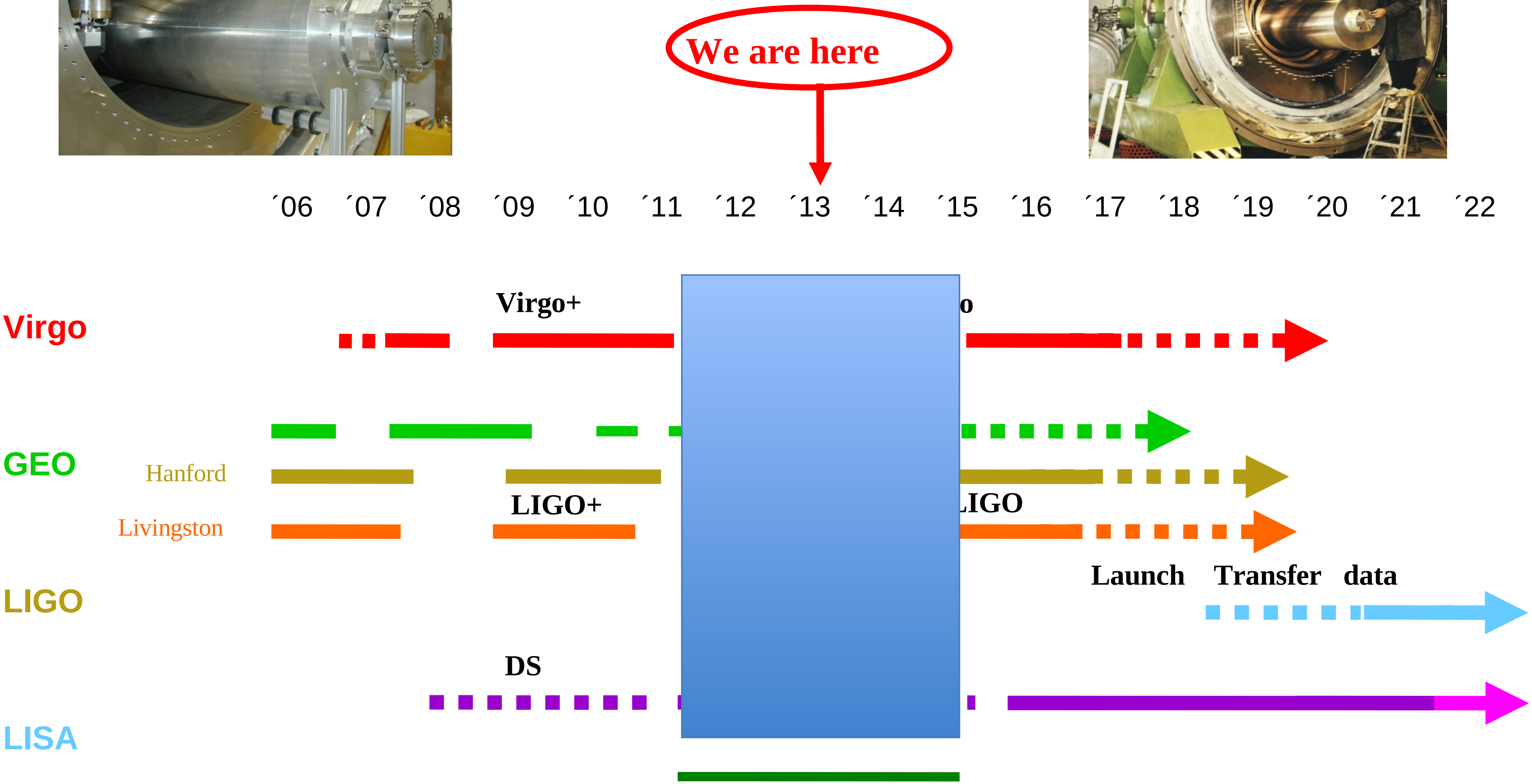
ROG (Nautilus)

(resonant bar gravitational wave detector)

AURIGA - LNL

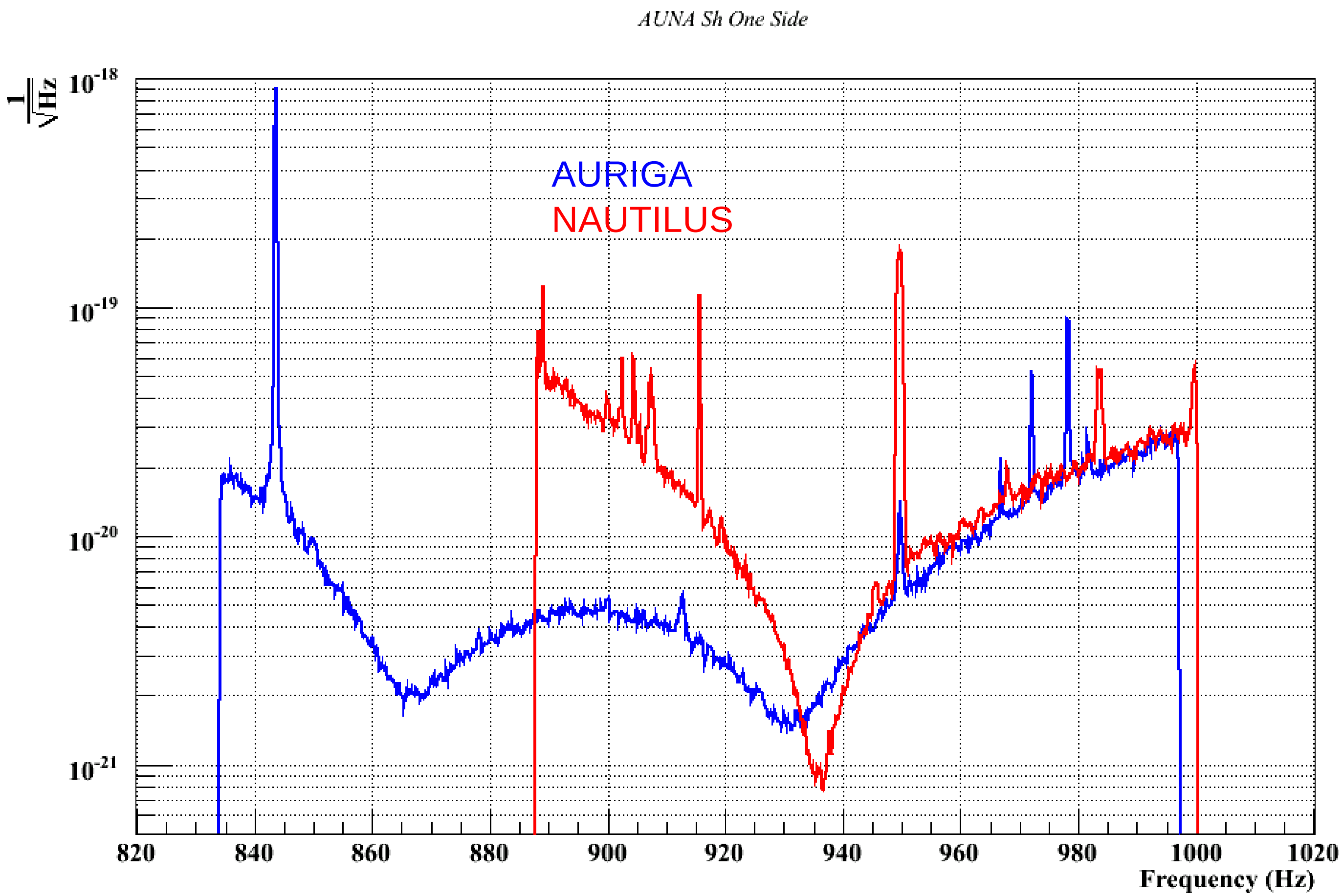


NAUTILUS - LNF



Window of opportunity
for AURIGA and NAUTILUS

AURIGA & NAUTILUS continously on the air ~ 90% (combined) with noise close to Gaussian (~ 20 outliers/day at SNR>6) until LIGO/Virgo resume operation



burst sensitivity hrss **~ 10-20 Hz-1/2 or** hburst **~ 2x10-19**

AUNA: "astrowatch" of AURIGA & NAUTILUS under triggers from SN neutrinos, giant X-rays flares, etc
CLIO, GEO-HF welcome to join

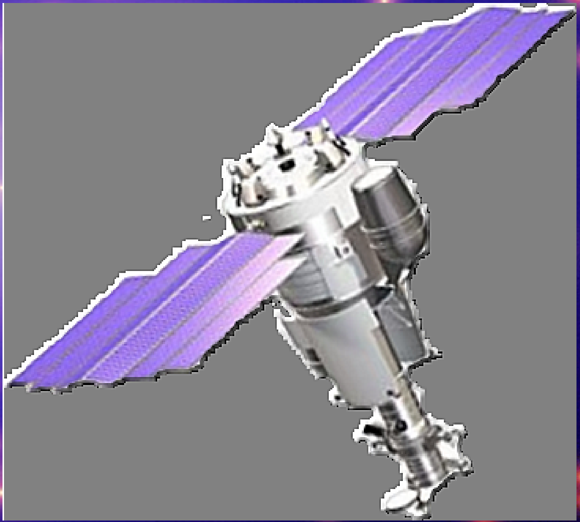
Bar Al 5056 M = 2270 kg

L = 2.91 m Ø = 0.6 m

νA=935Hz @ T = 3 K

Cosmic ray detector

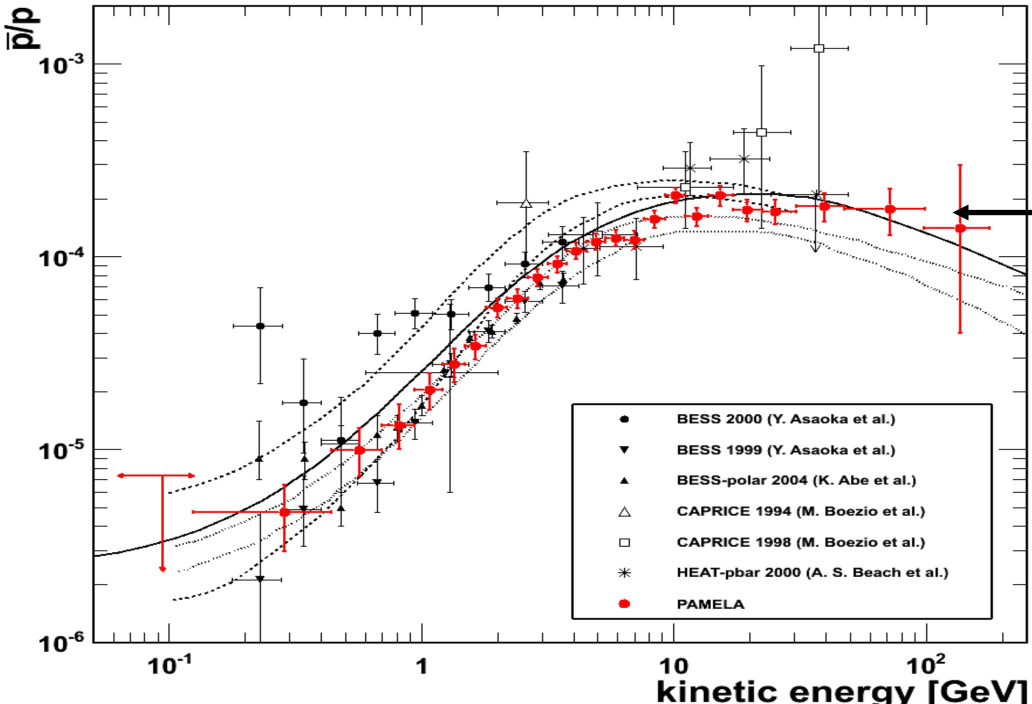
LNF ROG group:
2.2 FTE (5 persons)



Cosmic Ray Studies from Space

The PAMELA Experiment

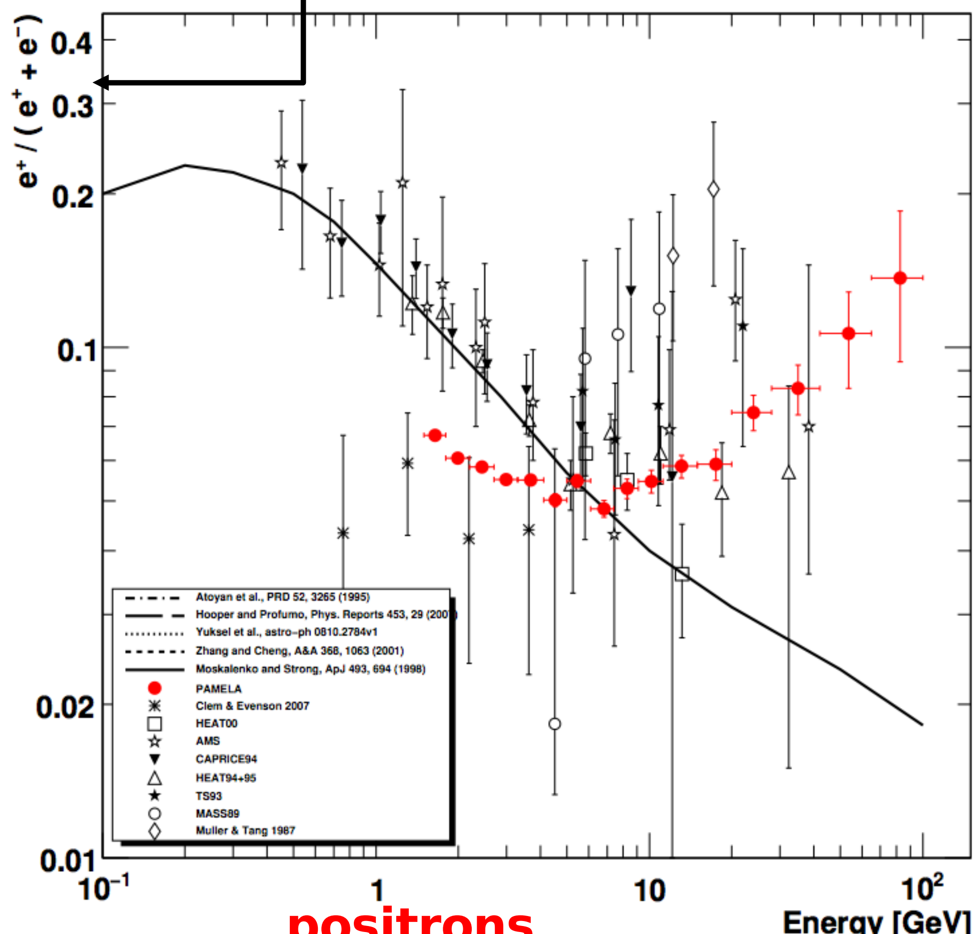
Antiparticle Results



antiprotons

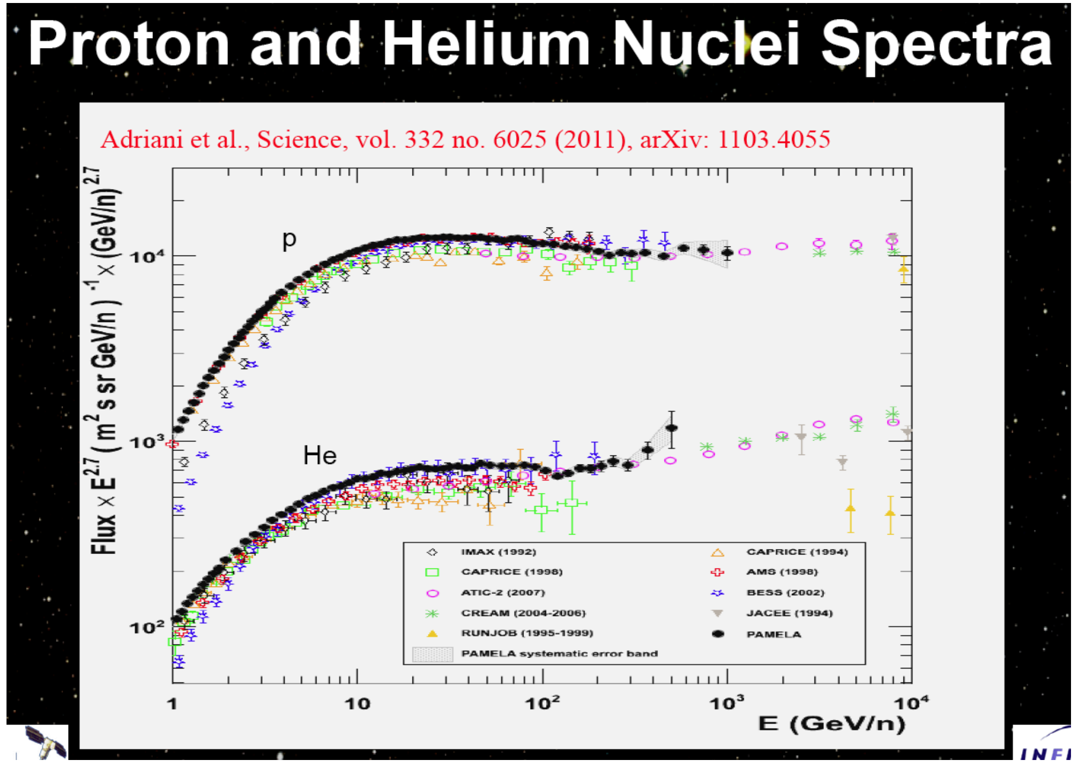
Adriani et al., PRL 102 (2009) 051101; PRL 105 (2010) 121101

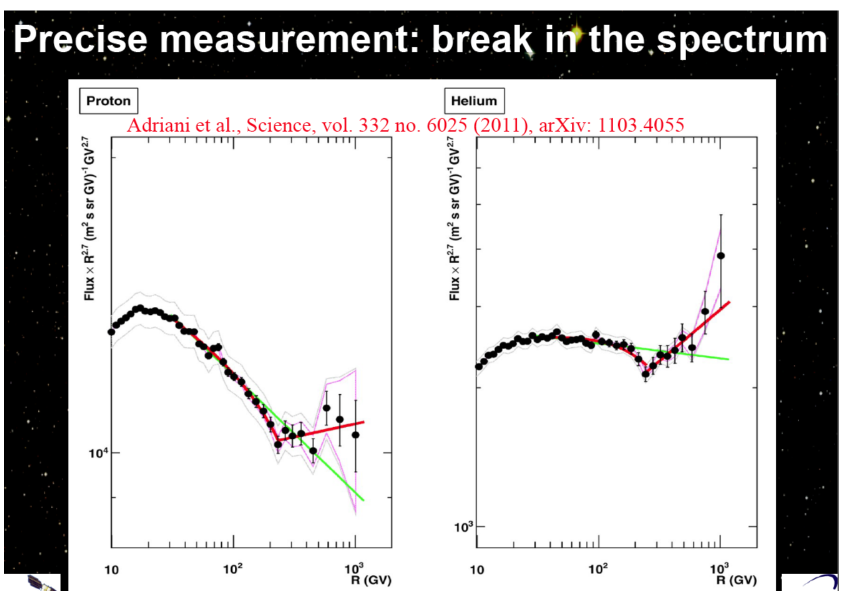
Secondary production calculations

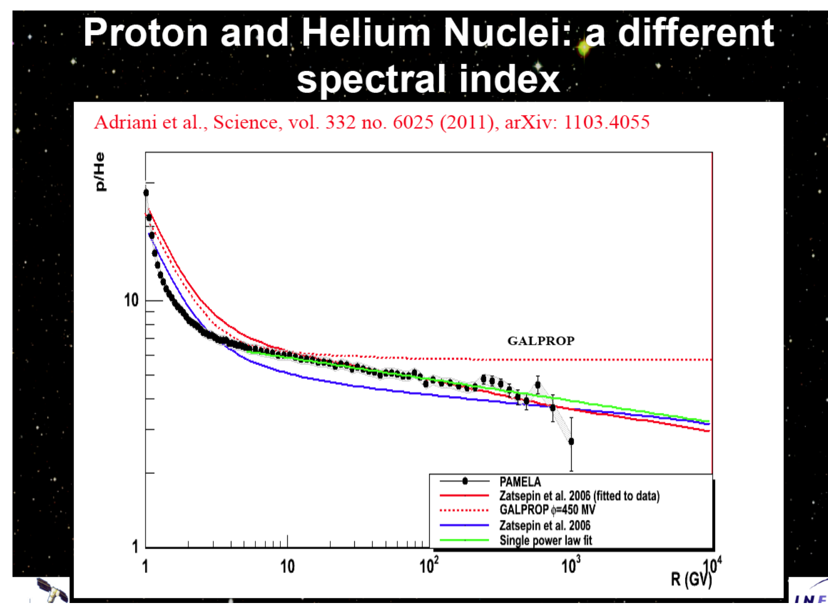


positrons

Adriani et al., Nature 458 (2009) 607; Astropart. Phys. 34 (2010) 1


Proton and Helium Nuclei Spectra
Adriani et al., Science, vol. 332 no. 6025 (2011), arXiv: 1103.4055
p
He
Flux × E^2.7 (m^2 s sr GeV/n)^-1 × (GeV/n)^2.7
E (GeV/n)
IMAX (1992)
CAPRICE (1994)
CAPRICE (1998)
AMS (1998)
ATIC-2 (2007)
BESS (2002)
CREAM (2004-2006)
JACEE (1994)
RUNJOB (1995-1999)
PAMELA
PAMELA systematic error band


Precise measurement: break in the spectrum
Proton
Helium
Adriani et al., Science, vol. 332 no. 6025 (2011), arXiv: 1103.4055
Flux × R^2.7 (m^2 s sr GV)^-1 GV^2.7
R (GV)


Proton and Helium Nuclei: a different spectral index
Adriani et al., Science, vol. 332 no. 6025 (2011), arXiv: 1103.4055
p/He
GALPROP
PAMELA
Zatsepin et al. 2006 (fitted to data)
GALPROP ϕ=450 MV
Zatsepin et al. 2006
Single power law fit
R (GV)

5/4/13

Summary

- PAMELA has been in orbit and studying cosmic rays for 6 and half years:
  > 109 triggers registered and 30 TB of data has been down-linked.
- Antiproton-to-proton flux ratio and antiproton energy spectrum (100 MeV- 200 GeV) show no significant deviations from secondary production expectations.
- High energy positron fraction (> 10 GeV) increases significantly (and unexpectedly!) with energy. Primary source? Dark Matter sign?
- The e^- spectrum up to 600 GeV shows spectral features that may point to additional components.
- The proton and Helium nuclei spectra have been measured up to 1.2 TeV. The observations challenge the current paradigm of cosmic ray acceleration and propagation.
- Analysis ongoing to finalize the antiparticle measurements (positron flux, positron fraction); continuous study of solar modulation effects at low energy.
- Solar Physics (flares, impulsive events, Forbush decrease etc.): more than half a solar cycle in orbit.


JEM-EUSO
The Extreme Universe Space Observatory
onboard the Japanese Experiment Module of the International Space Station

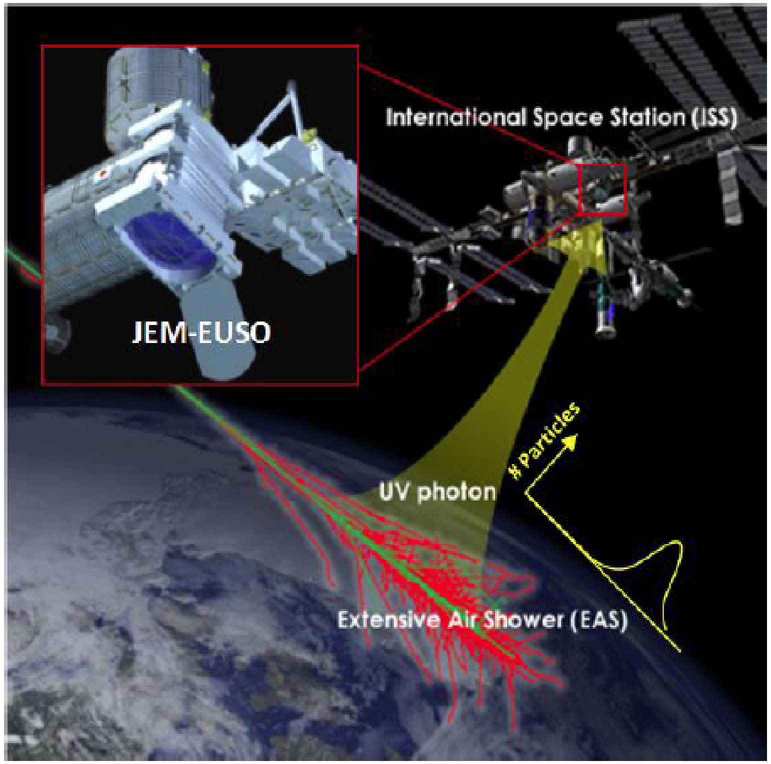
JEM-EUSO main features

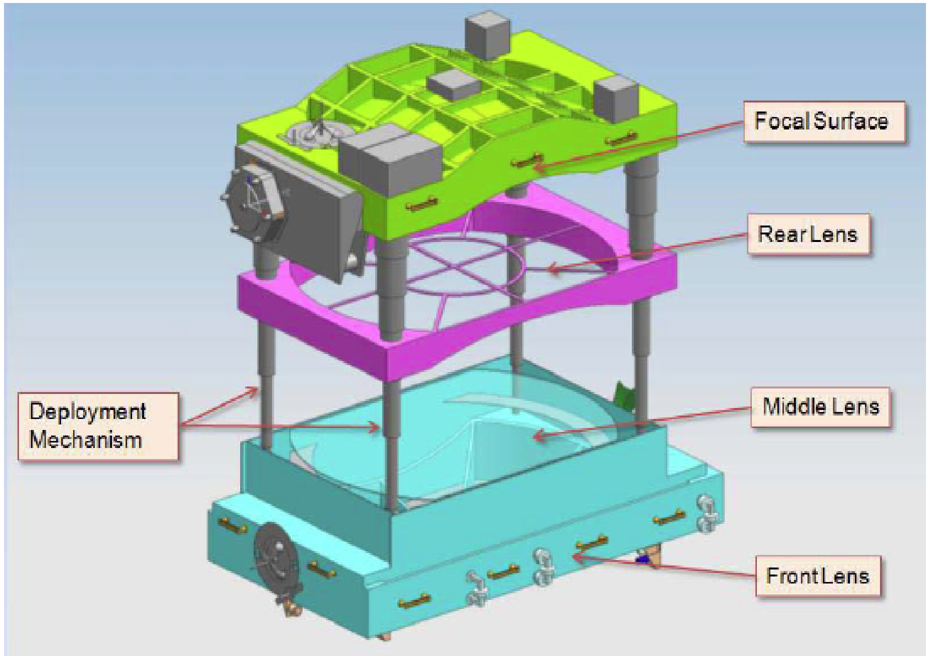
Method: fluorescence (full calorimetric)

Large field of view: ± 30° thanks to double sided spherical Fresnel lenses

At 400 km (ISS): 2 10^5 km^2 (nadir mode) up to 10^6 km^2 (tilted mode)

No need for stereo: 400 km >> shower length (TPC with a drift velocity = c)





Main Physics Program

Main scientific objectives

- Measurement of Ultra-high energy Cosmic Rays

➔ Astronomy and Astrophysics through the particle channel

= Physics and Astrophysics at $E > 5.\times 10^{19}$eV

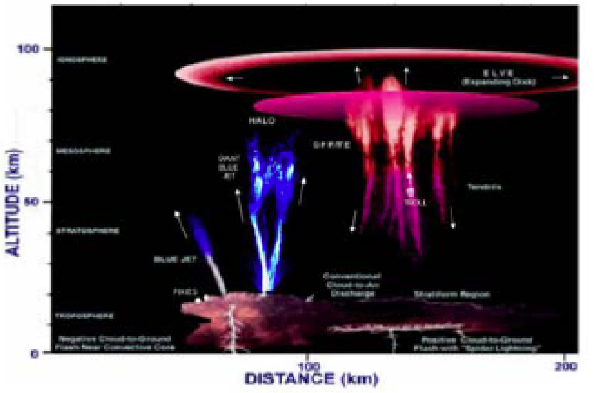
Exploratory scientific objectives

- Exploratory Objectives: new messengers
  - Discovery of UHE neutrinos
    discrimination and identification via X_0 and X_{max}
  - Discovery of UHE Gammas
    discrimination of X_{max} due to geomagnetic and LPM effect

- Exploratory Objectives: magnetic fields

- Exploratory Objectives: Atmospheric science
  - Nightglow
  - Transient luminous events
  - Space-atmosphere interactions
  - climate change

  ← with the fast UV monitoring of the Atmosphere



(Elaboration of figure by Lyons et al. 2000)

Road Map to JEM EUSO

1) EUSO Balloon campaign

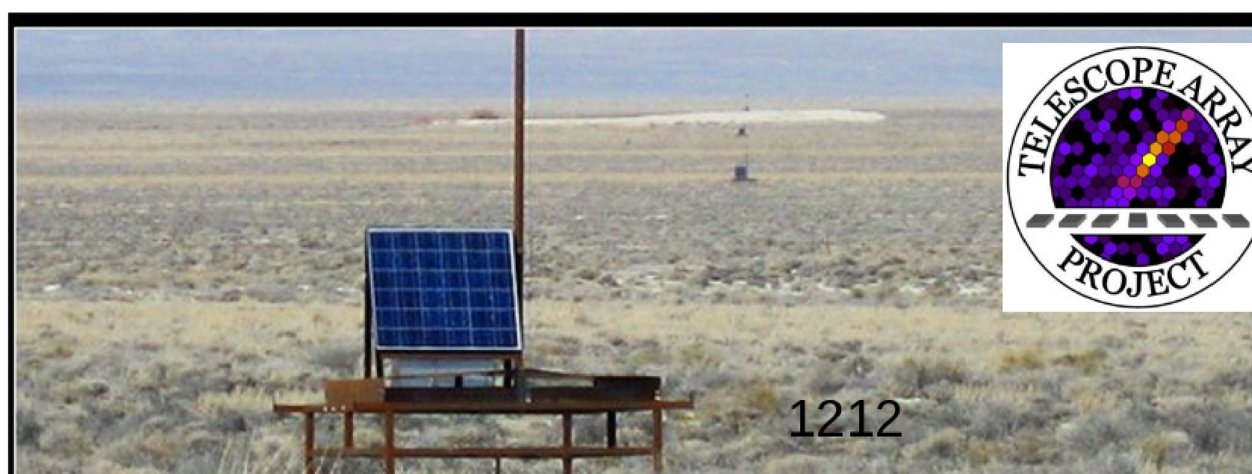
2011/6 Approved by CNES

2014 first of three launches

2) Cross-calibration tests at Telescope Array site, Utah

Collaboration with ICRR, Institute of Cosmic rays, Tokyo University, Kashiwa campus

Installation Winter 2012



The WIZARD (PAMELA) LNF group

1.8 FTE (4 persons)

The JEM-EUSO LNF group

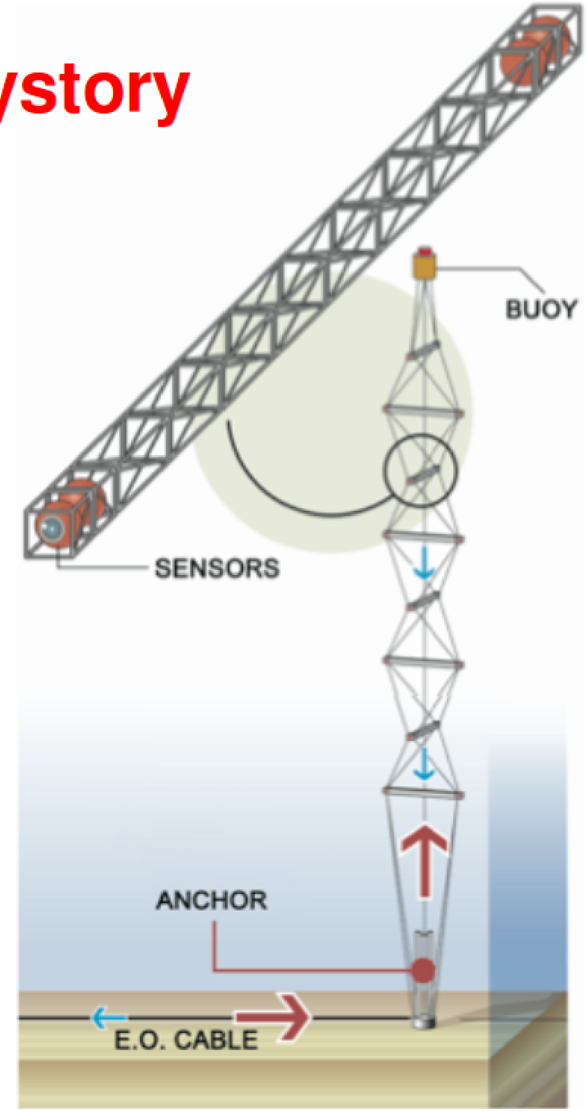
3.0 FTE (6 persons)

Activities:
PDM (Photo Detector Module) design (support by SPCM service)
Test on balloon

KM3

(astrophysical neutrino detector)

NEMO-Phase2 Tower deployment: short hystory



November 2012

- Teliri (MECMA) + INFN/INGV ROV: during a pre-inspection of the site, at 3500m depths, the ROV umbelical cable burned and the ROV was lost. Tower Deployment operation not even started.

23 March 2013

- Campaign with FUGRO vessel (Nautical Tide) +ROV: **successful NEMO-Phase2 Tower deployment, connection and start of data taking**

LNF group activity

PORFIDO

Physical Oceanography by RFID
Outlook

Use neutrino telescopes infrastructure
(power, communication)
for oceanographic measurements

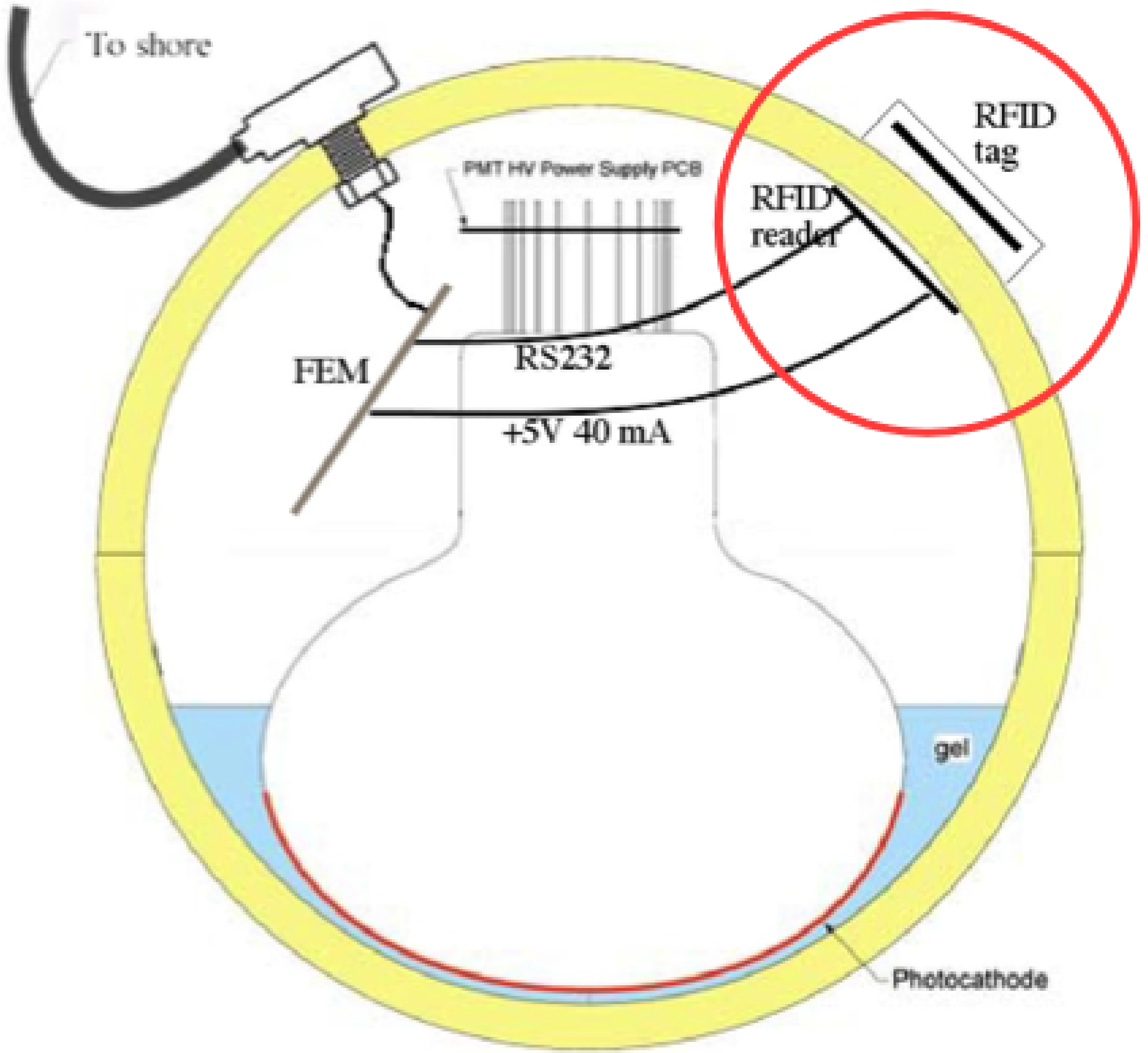
(Temperature, salinity, water mass movements)

Orlando Ciaffoni, Marco Cordelli, Roberto Habel, Agnese Martini, Luciano Trasatti

(2.0 FTE + 0.6 FTE tec)

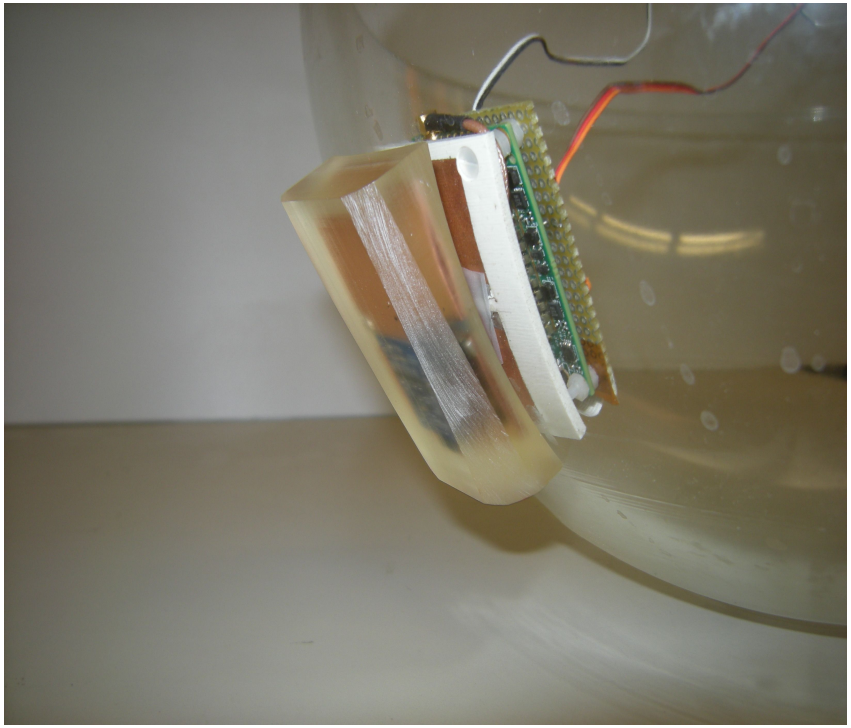
- RFID communication through OM glass without connectors
- Very little interference with detector
- Very little bandwidth to-from shore
- Very little power
- continuous data taking
- data rate controlled from shore

Optical Module with PORFIDO probe schematic



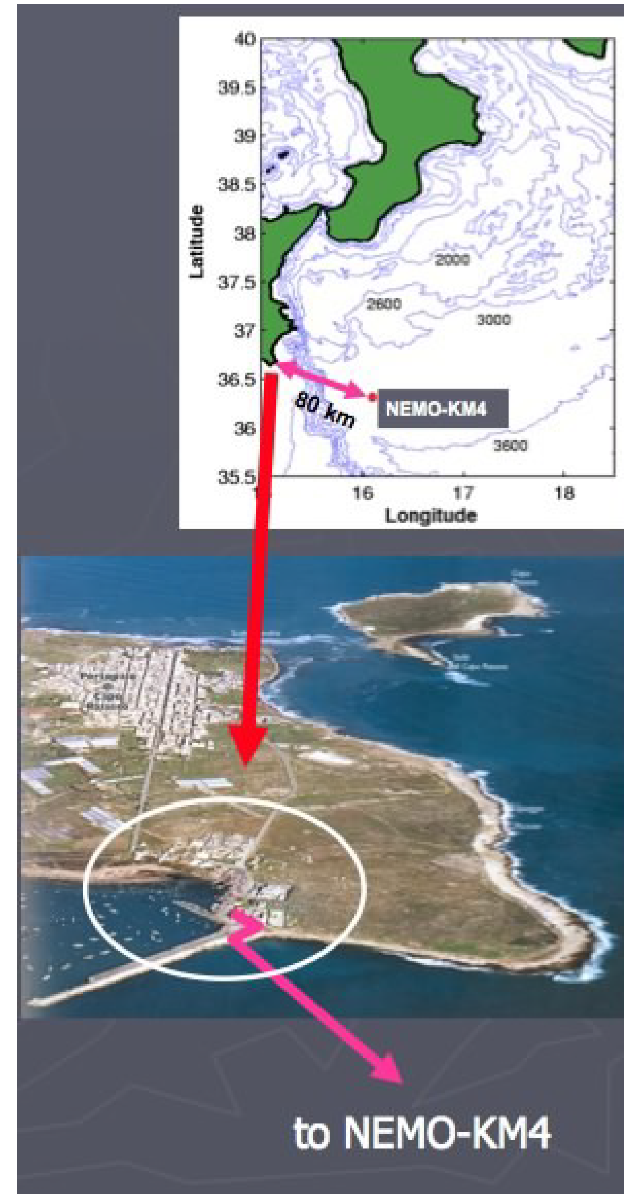
C

PORFIDO on the OM



4 PORFIDO probes on the Phase 2 tower

- Working at 3500 m depth!
- 12 more on Phase 3 (0.001 ˚C)



CUORE

(neutrino-less double beta decay)

CUORE: Experiment at LNGS for testing Majorana/Dirac nature of neutrinos in case of neutrino masses inverted hierarchy ...
Based on TeO_2 bolometer technique

LNF group is involved in the detector installation (technical support).

Preparazione/Ottimizzazione: estate → **inverno** 2012
Partenza: Novembre 2012 → **Febbraio 2013**

Assemblaggio torri

- Produzione parti: MIB, LNL
- Cleaning: LNL, MIB, LNF
- Incollaggio NTD e riscaldatori: MIB, PD, BO
- Assemblaggio meccanico: RM
- Bonding: MIB, PD

Partenza: fine Luglio 2012
Sviluppo: secondo piano

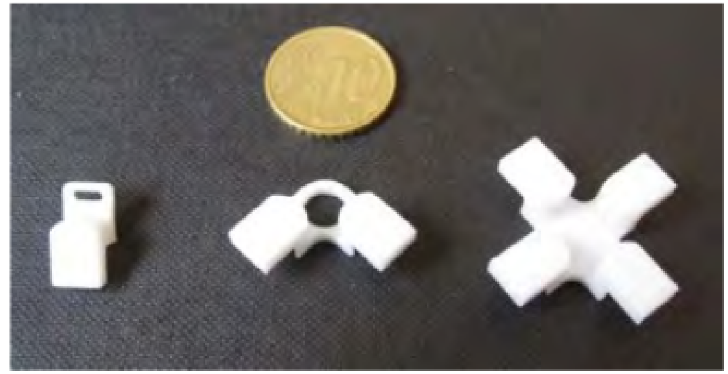
Installazione e test

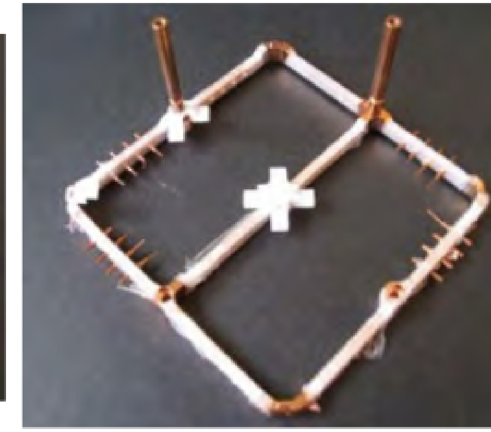
- Criostato: MIB
- Unità di raffreddamento: PD, MIB
- Sospensioni: GE
- Fili di lettura: LNF
- Sistemi di sollevamento: BO

LNF group:
1.6 FTE (3 persons)

e naturalmente il supporto continuo LNGS

Preparazione parti rivelatore

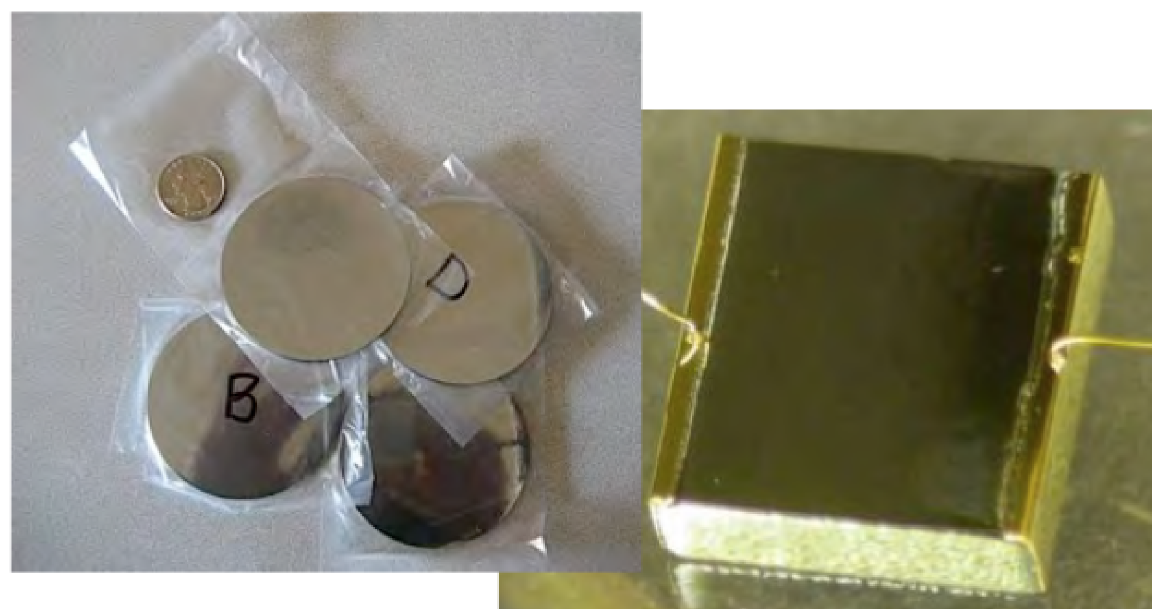




Crystals: delivered 1046 crystals. Preparing for refurbishing
NTD: prepared ~1000 thermistors. Preparing spares (250)
Teflon and Copper parts: almost completed. Copper cleaning underway

almost complete

TeO2 production @ SICCS close to completion



NTD's: 695 of 1250 already delivered

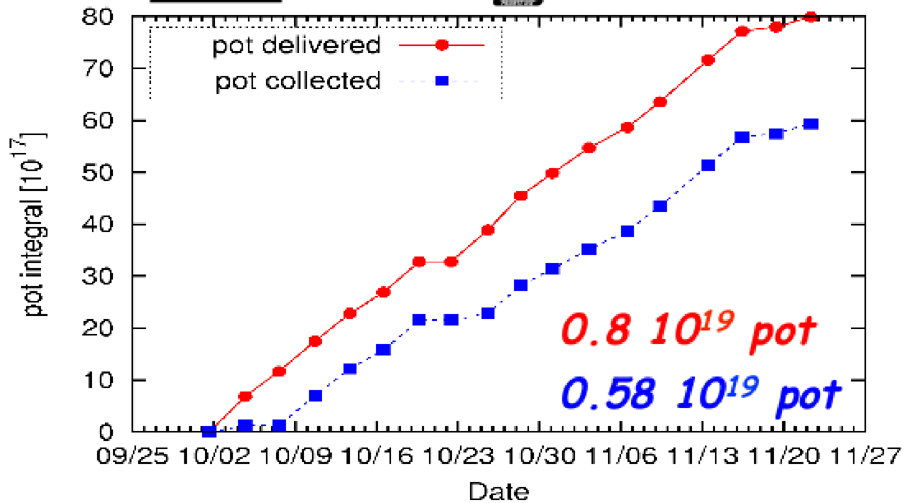
ICARUS

(neutrino oscillation)

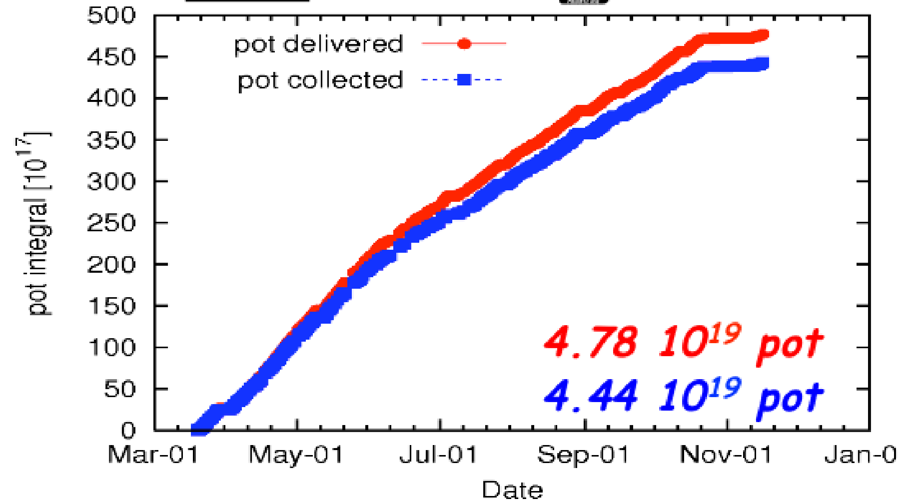
600 tonnes Liquid Argon detector at LNGS

- ICARUS T600 fully operational since Oct. 1st 2010

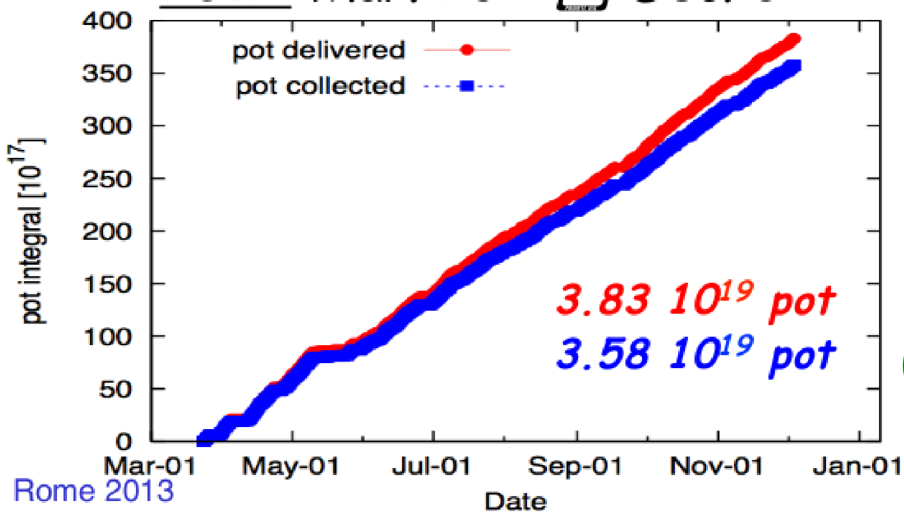
2010: Oct. 1st → Nov. 22nd



2011: Mar. 19th → Nov. 14th

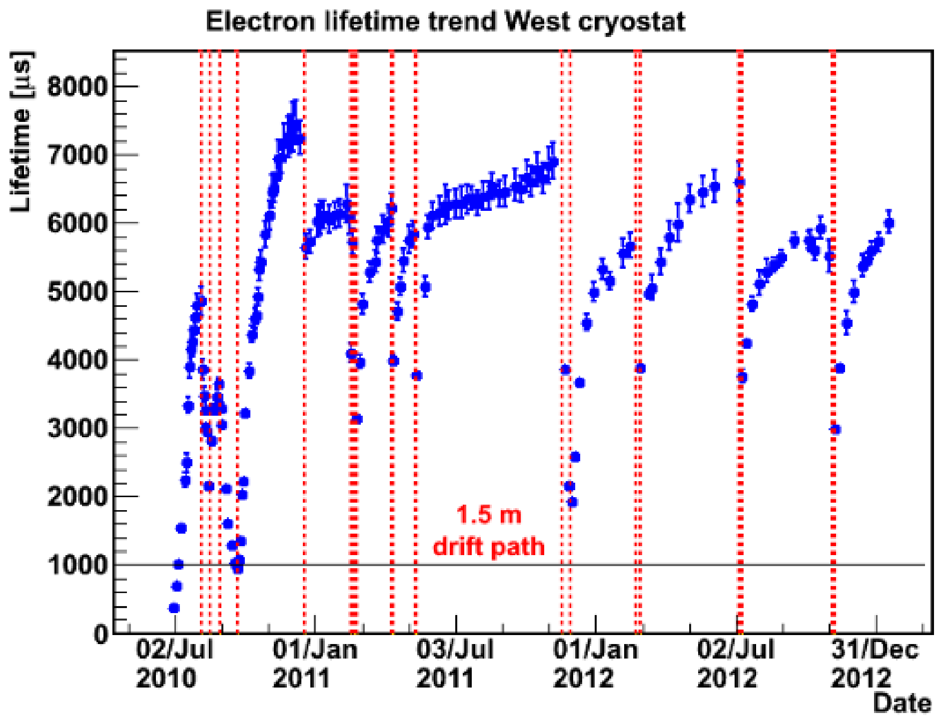


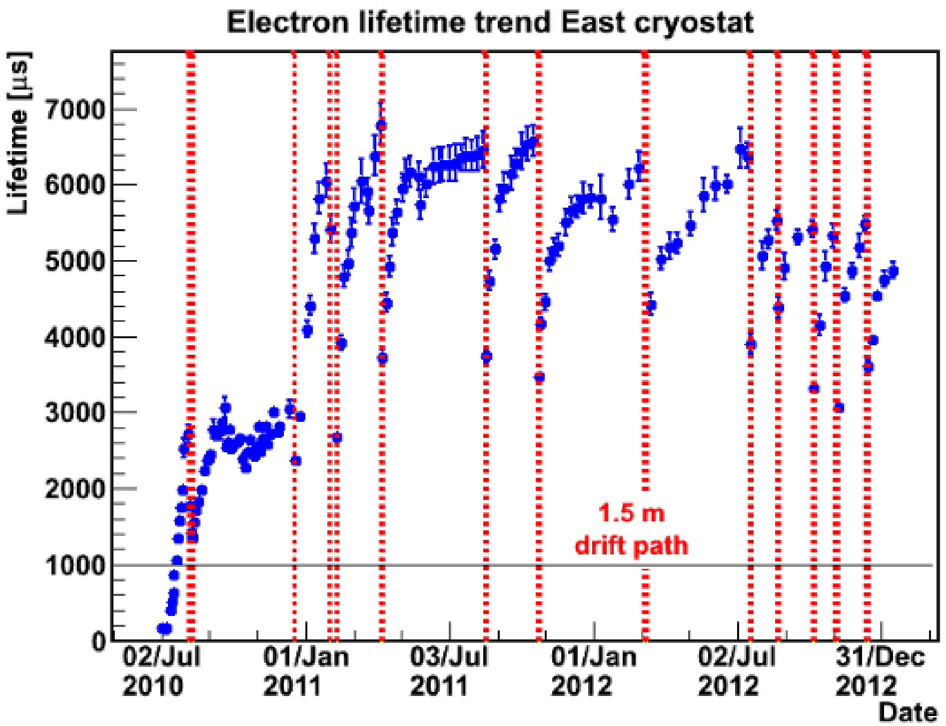
2012: Mar. 23rd → Dec. 3rd



- Detector live-time > 93% in 2011 and 2012
- Overall 8.6 10^{19} pot collected over 9.4 10^{19} pot delivered
- November 2011 and May 2012: ν t.o.f. measurement performed with bunched beam.

CNGS data not fully analyzed.
$\nu_\mu \Rightarrow \nu_e$ oscillation analysis published.
Proposal to move the detector at CENF (CERN Neutrino Facility) to study sterile neutrinos.





Free electron life-time measured by charge attenuation on cosmic μ tracks.

τ_{ele} > 5ms (~60 ppt $[O_2]_{eq}$) corresponding to a max. charge attenuation of 17% at 1.5 m

These results allow operation at larger drift distances

The ICARUS LNF group

0.2 FTE (3 persons)
Activity: detector R&D

PROCEEDINGS OF SCIENCE

Resistive microstrip and microdot detectors: a novel approach in developing spark protected micropattern detectors

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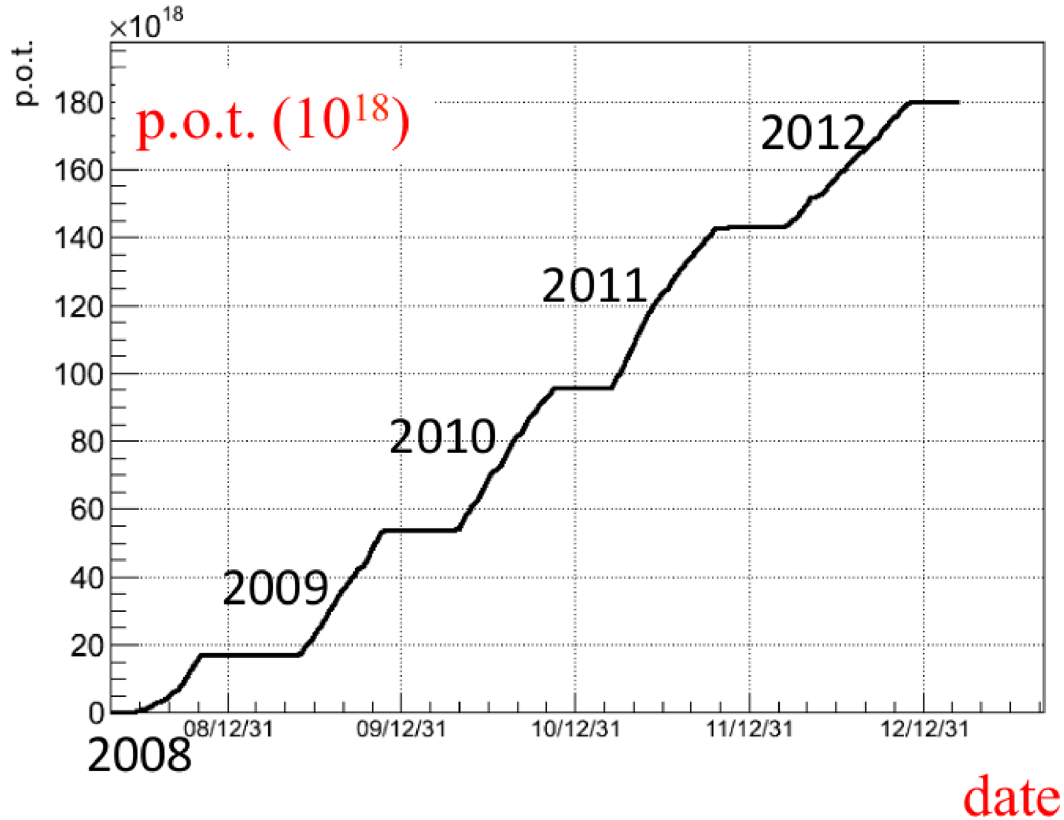
XI Workshop on Resistive Plate Chambers
and Related Detectors (LNF, February 2012)

OPERA

(neutrino oscillation)

Final performances of the CNGS beam after five years (2008 ÷ 2012) of data taking

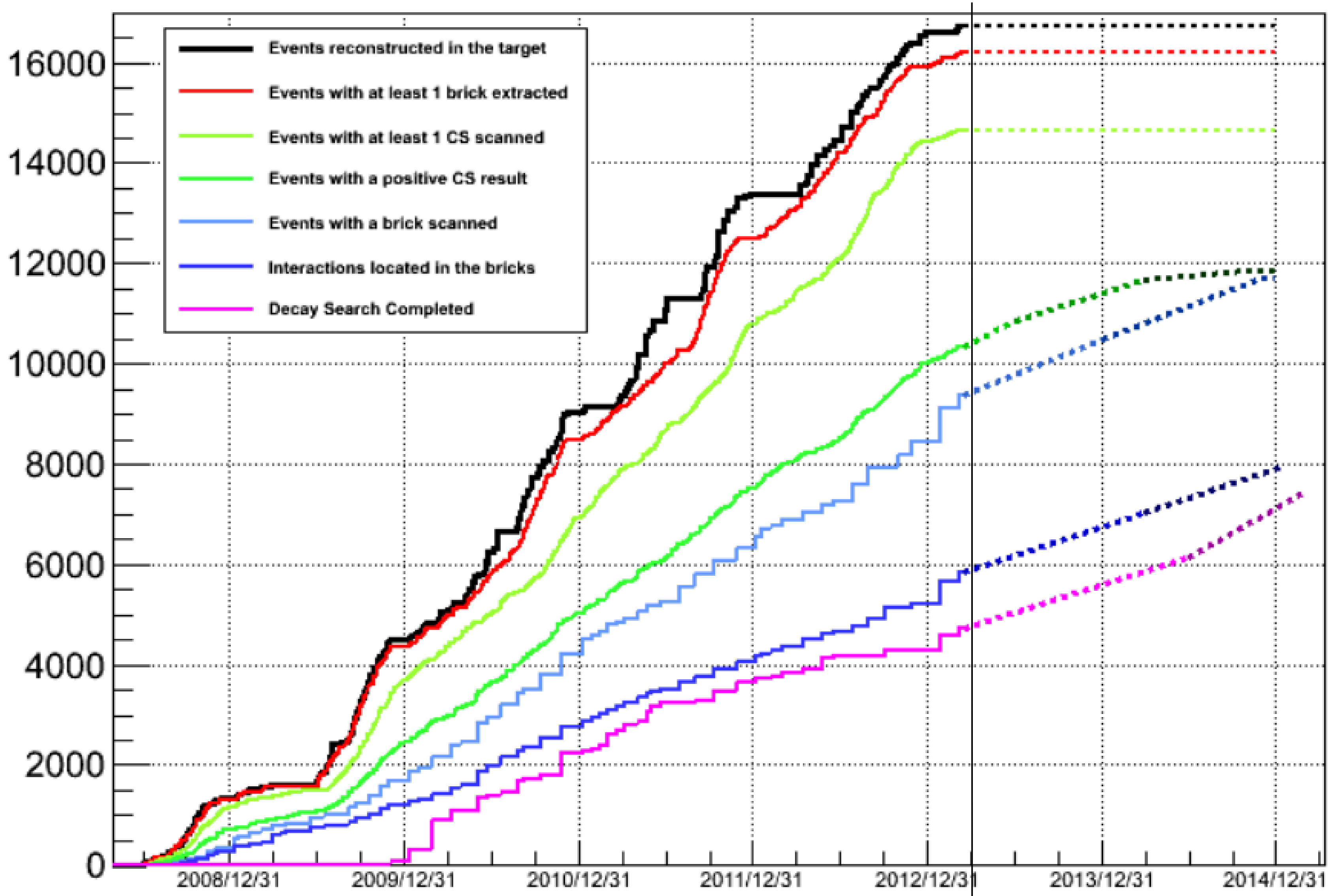
Year	Beam days	P.O.T. (10^{19})
2008	123	1.74
2009	155	3.53
2010	187	4.09
2011	243	4.75
2012	257	3.86
Total	**965**	**17.97**



Record performances in 2011

Overall 20% less than the proposal value (22.5)

Performance plot + educated guess for the future



End of March 2013: about 6000 events located
About two years needed to complete the analysis

ν_τ appearance analysis strategy

2008-2009 sample: unbiased analysis

First tau candidate observed and reported on 2010

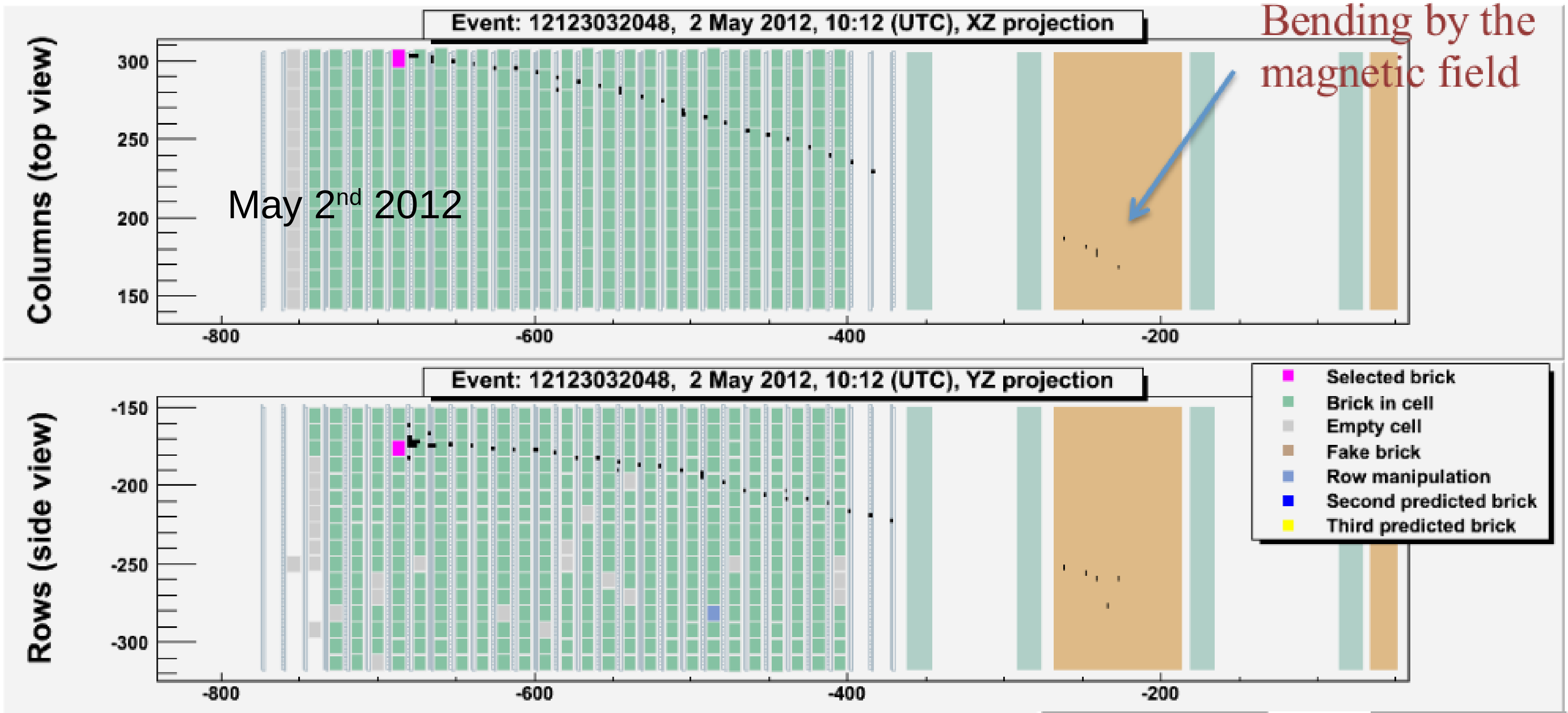
2010-2012 sample:

- Kinematic selection: muon momentum lower than 15 GeV
- Priority given to highest probable brick for brick-finding
- Priority for events without muons

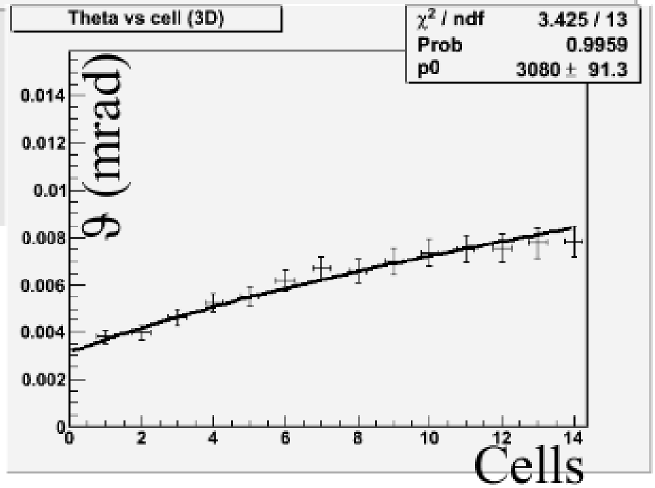
Second tau candidate reported at Neutrino 2012 conference (Kyoto)

After 2012 summer conferences: start of analysis of events with 1 muon

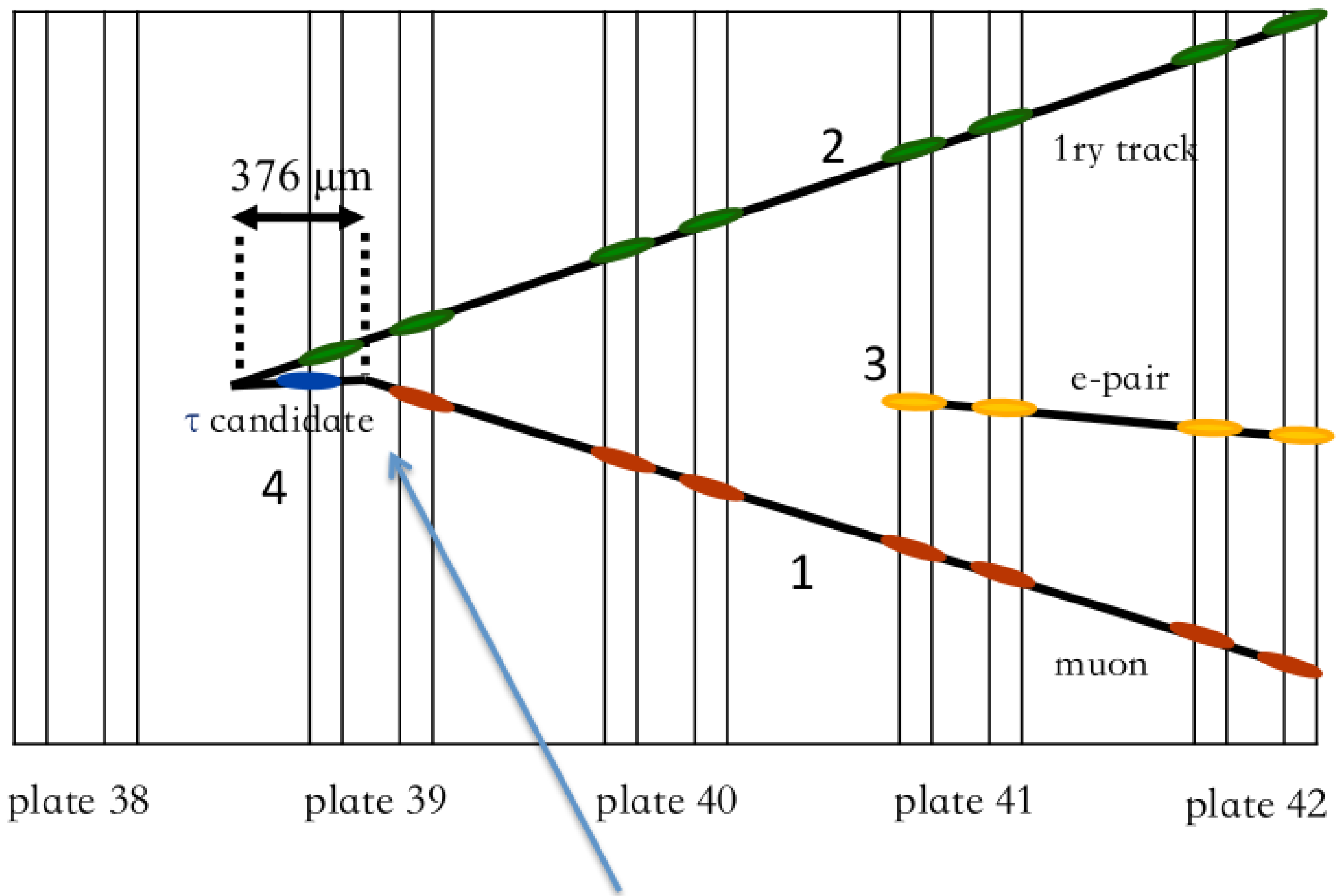
Third ν_τ candidate event



Muon momentum
by range in the electronic detector: 2.8±0.2 GeV/c
MCS in the brick consistent 3.1 [2.6,4.0] GeV/c



$\tau \rightarrow \mu$ candidate brick analysis and decay search



Decay in the plastic base

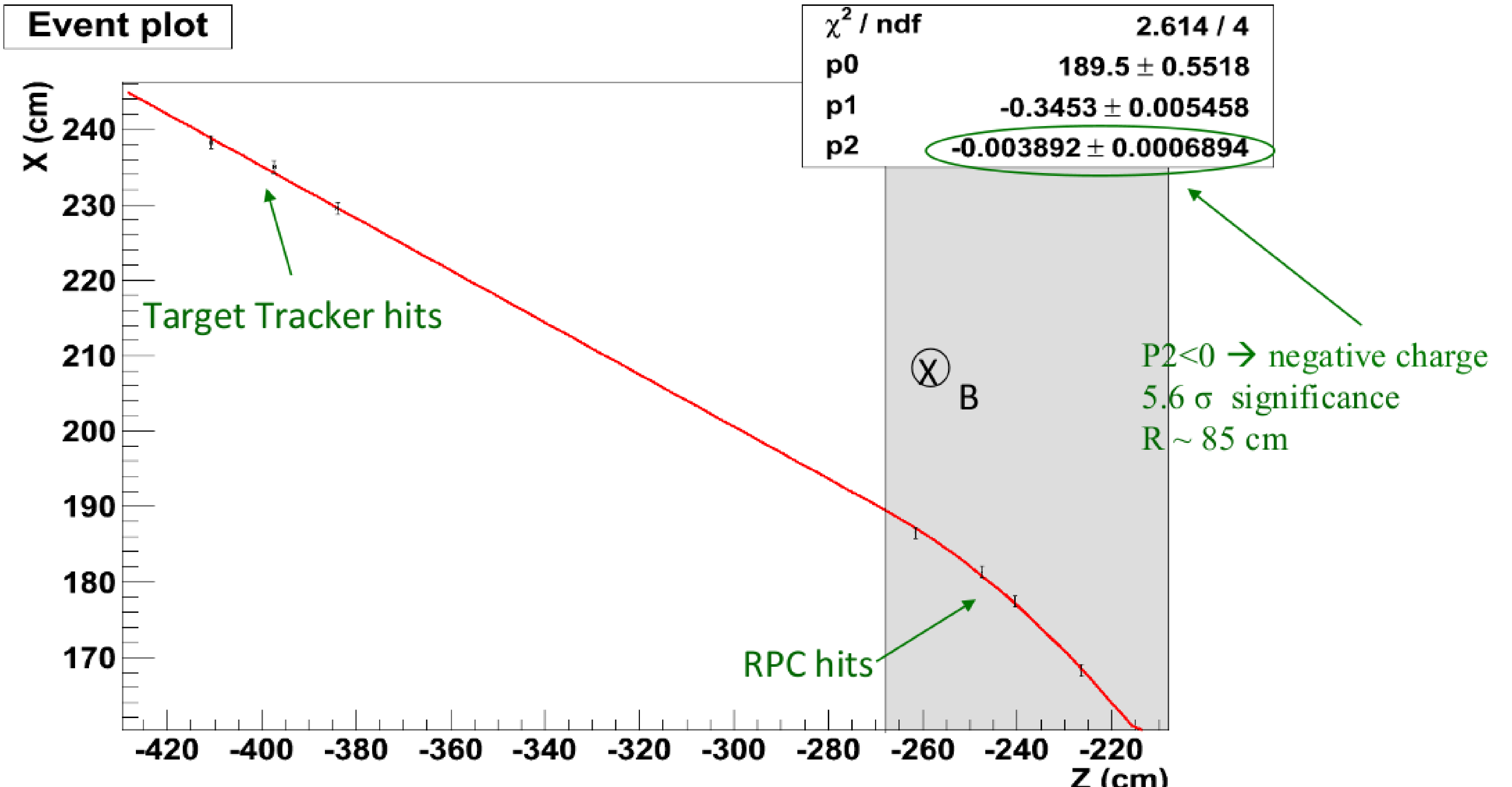
Charge determination of the muon

Charge measurement based on TT and RPC hits

Fit function:

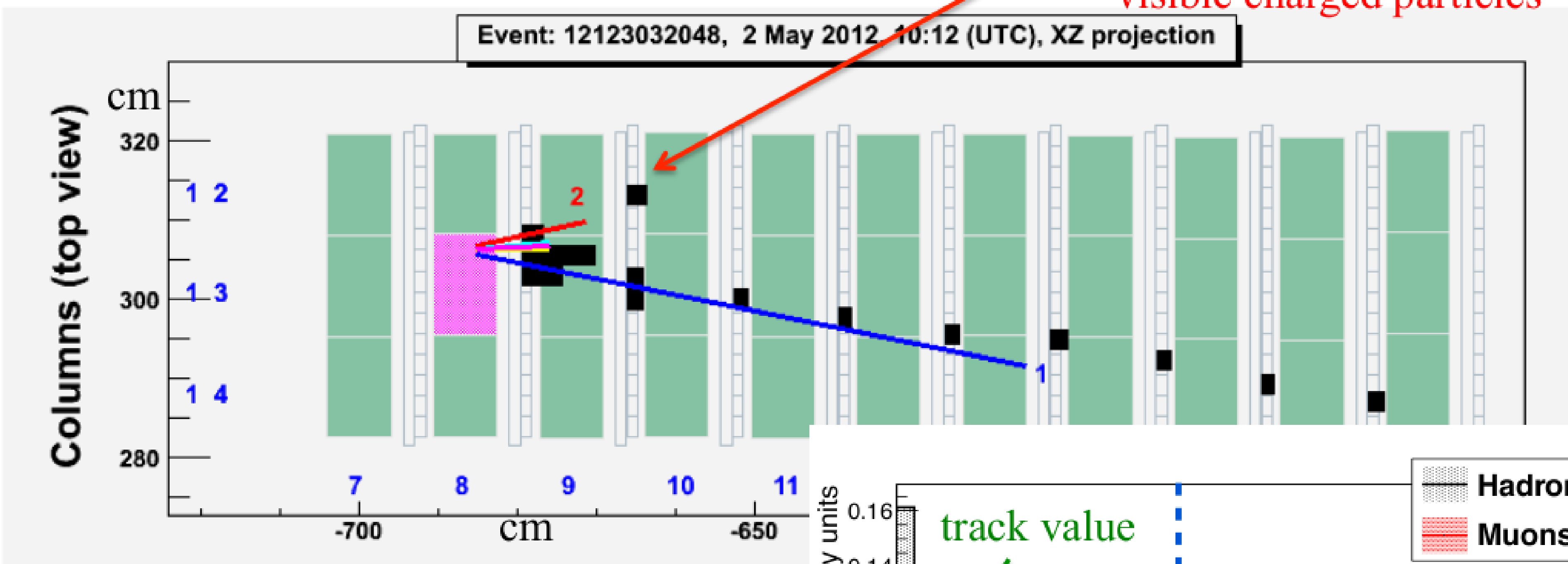
$$X(z) = p0 + p1 \times (z-z0) + p2 \times (z-z0)^2 \quad \text{for } z>z0\text{, start of magnetized region}$$

$$X(z) = p0 + p1 \times (z-z0) \quad \text{for } z<z0$$



P-value = 0.063% (probability to reconstruct a μ^+ stopping in the 7th iron layer with p2 < -0.00389 cm^{-1})

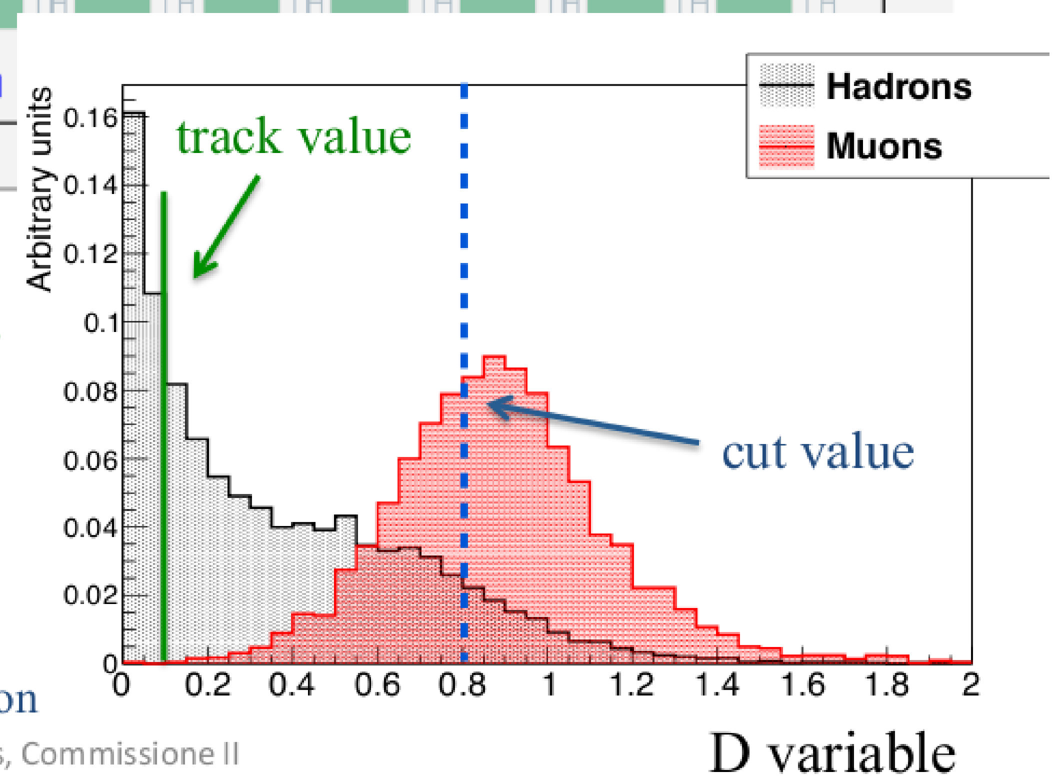
Track follow down to assess the nature of track 2



Momentum/range inconsistent with μ hypothesis
0.9 GeV/4 cm Lead

$$D = \frac{L}{R_{lead}(p)} \frac{\rho_{lead}}{\rho_{average}}$$

L = track length
R_{lead} = μ range
$\rho_{average}$ = average density
ρ_{lead} = lead density
p = momentum in emulsion



Statistical considerations

Extended sample

	Signal	Background	Charm	μ scattering	had int
$\tau \rightarrow h$	0.66	0.045	0.029		0.016
$\tau \rightarrow 3h$	0.61	0.090	0.087		0.003
$\tau \rightarrow \mu$	0.56	0.026	0.0084	0.018	
$\tau \rightarrow e$	0.49	0.065	0.065		
total	2.32	**0.226**	0.19	0.018	0.019

3 observed events in the $\tau \rightarrow h$ and $\tau \rightarrow 3h$ and $\tau \rightarrow \mu$ channels
Probability to be explained as a background = 7×10^{-4}
This corresponds to 3.2 σ significance of non-null observation

Likelihood-based analysis: 3.5 σ significance
4 σ within reach

OPERA LNF group

Composition: 2.7 FTE (6 people) + 2.5 tech. FTE

Activities:

- A. Paoloni technical coordinator
- Maintenance of the general structure of the detector (~0.3 FTE requested to LNF SSE service)
- Support to brick extraction (removal of blocked bricks), handling (X-ray marking facilities), development (automation of thermal control), scanning (one laboratory at LNF)
- 2012 re-measurement of neutrino velocity with an additional LNF-designed set-up
- A. Longhin editor of second tau candidate paper
- Analysis of the muon in the third candidate event (charge determination and large angle scattering studies)
- Further possible interests on OPERA data: neutrino NSI, technical paper on RPCs, ν_μ disappearance ?, sterile neutrino search ?

NESSIE-RD

(neutrino oscillation)

Sterile neutrinos

- The possible presence of oscillations into sterile neutrinos was proposed by B. Pontecorvo, *(JETP, 53, 1717, 1967)*, but so far without conclusion.
- "Sterile" means "No Standard Model Interactions" (i.e think to anti-ν_R, light neutrinos which can oscillate with "active" neutrinos)
- Smoking Gun: Neutral Current Deficit
- Counterchecked Smoking Gun: NC/CC ratios

- Two distinct classes of anomalies have been analyzed, namely
  - the apparent ***disappearance signal*** in the anti-ν_e events detected from (1) near-by nuclear reactors and (2) the from Mega-Curie k-capture calibration sources in the Gallium experiments to detect solar ν_e
  - observation for ***excess signals*** of anti-ν_e electrons from neutrinos from particle accelerators (LNSD/MiniBooNE)

- At least a fourth non-standard neutrino state can oscillate at small distances, $\Delta m^2_{new} \approx 1$ eV^2 (→ **SHORT BASELINE projects**)

3+1 SBL oscillations

appearance

$$P_{\mu e} = \sin^2 2\theta_{\mu e} \sin^2 \frac{\Delta m^2_{41} L}{4E} \qquad \sin^2 2\theta_{\mu e} = 4|U_{e4}|^2 |U_{\mu 4}|^2$$

disappearance ($\alpha = e, \mu$)

$$P_{\alpha\alpha} = 1 - \sin^2 2\theta_{\alpha\alpha} \sin^2 \frac{\Delta m^2_{41} L}{4E} \qquad \sin^2 2\theta_{\alpha\alpha} = 4|U_{\alpha 4}|^2 (1 - |U_{\alpha 4}|^2)$$

$$\boxed{\sin^2 2\theta_{\mu e} \approx \frac{1}{4} \sin^2 2\theta_{ee} \sin^2 2\theta_{\mu\mu}}$$

$\nu_\mu \to \nu_e$ app. signal requires also signal in both, ν_e and ν_μ disappearance (appearance mixing angle quadratically suppressed)

Fitting all together?

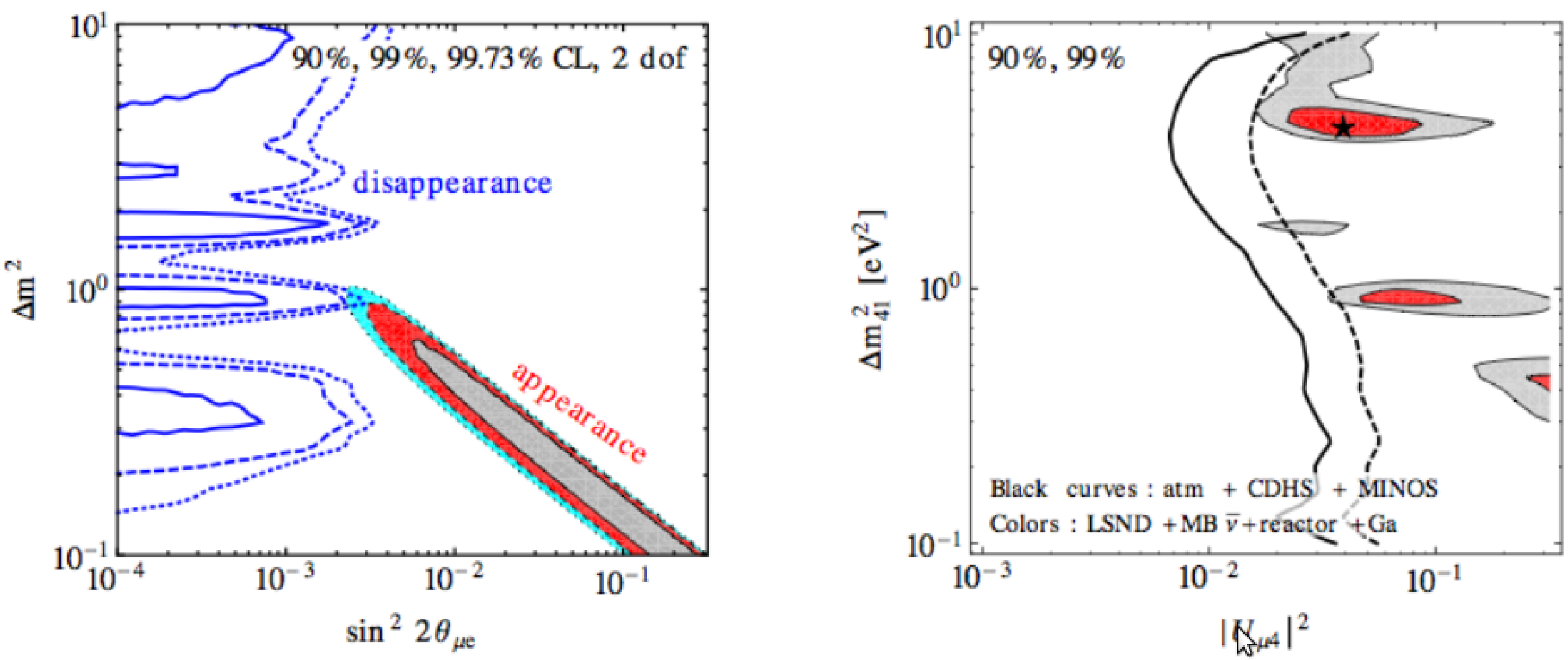
there are three classes of data:

$\nu_e \rightarrow \nu_e$ disappearance $\quad \sin^2 2\theta_{ee}$

$\nu_\mu \rightarrow \nu_\mu$ disappearance $\quad \sin^2 2\theta_{\mu\mu}$

$\nu_\mu \rightarrow \nu_e$ appearance $\quad \sin^2 2\theta_{\mu e}$

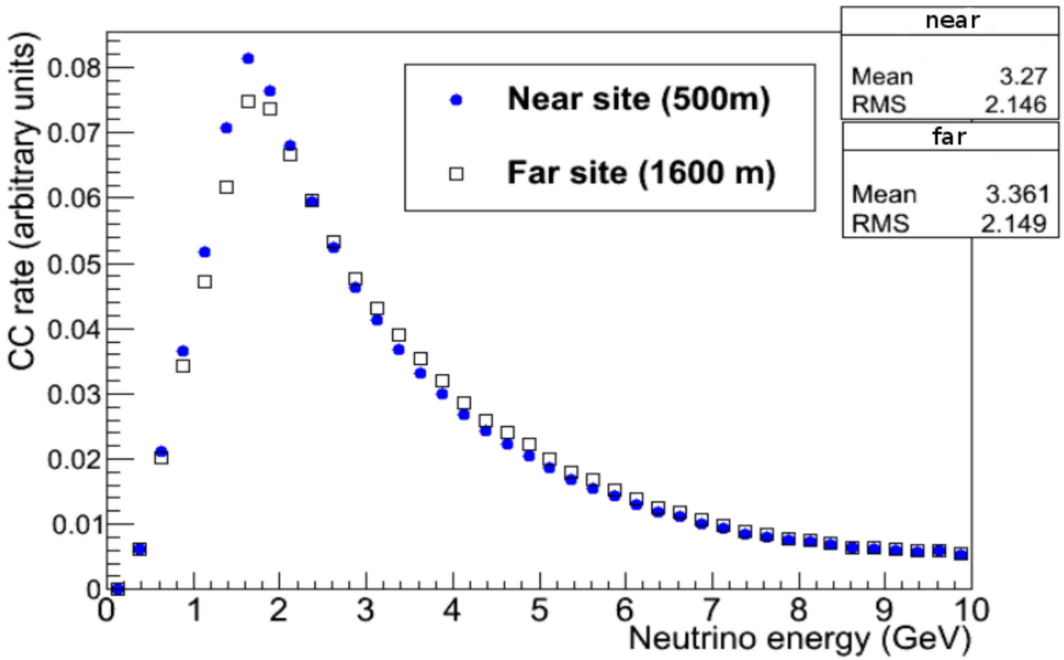
$$\sin^2 2\theta_{\mu e} \approx \frac{1}{4} \sin^2 2\theta_{ee} \sin^2 2\theta_{\mu\mu}$$

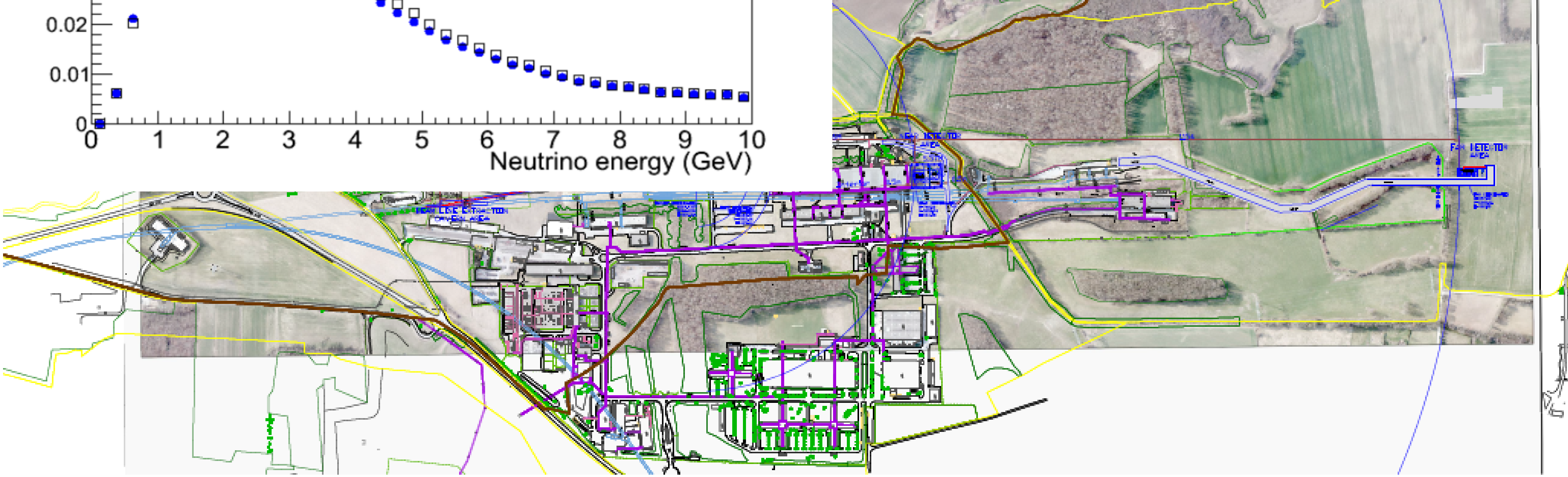


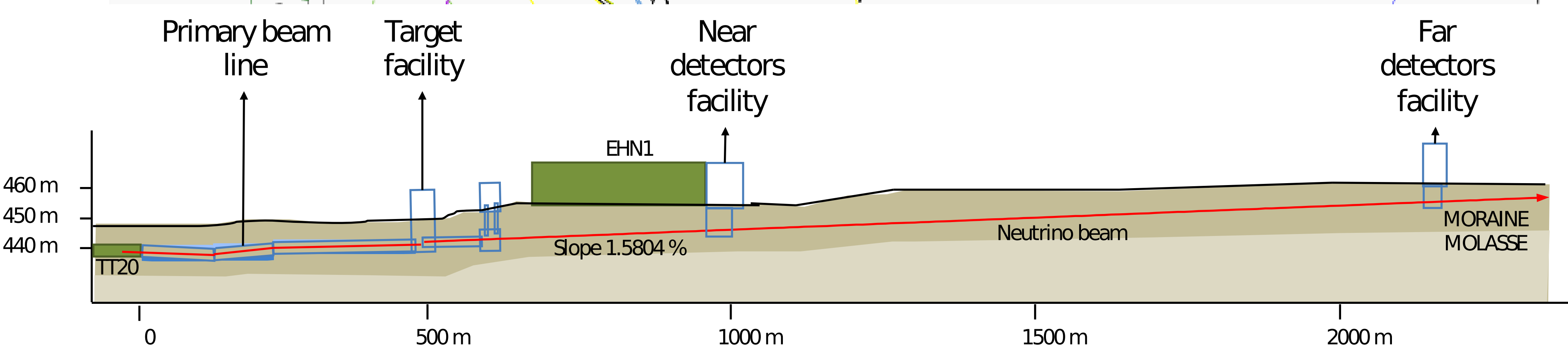
T. Schwetz©Kyoto 2012

TENSIONS...

CENF beam-line in NA







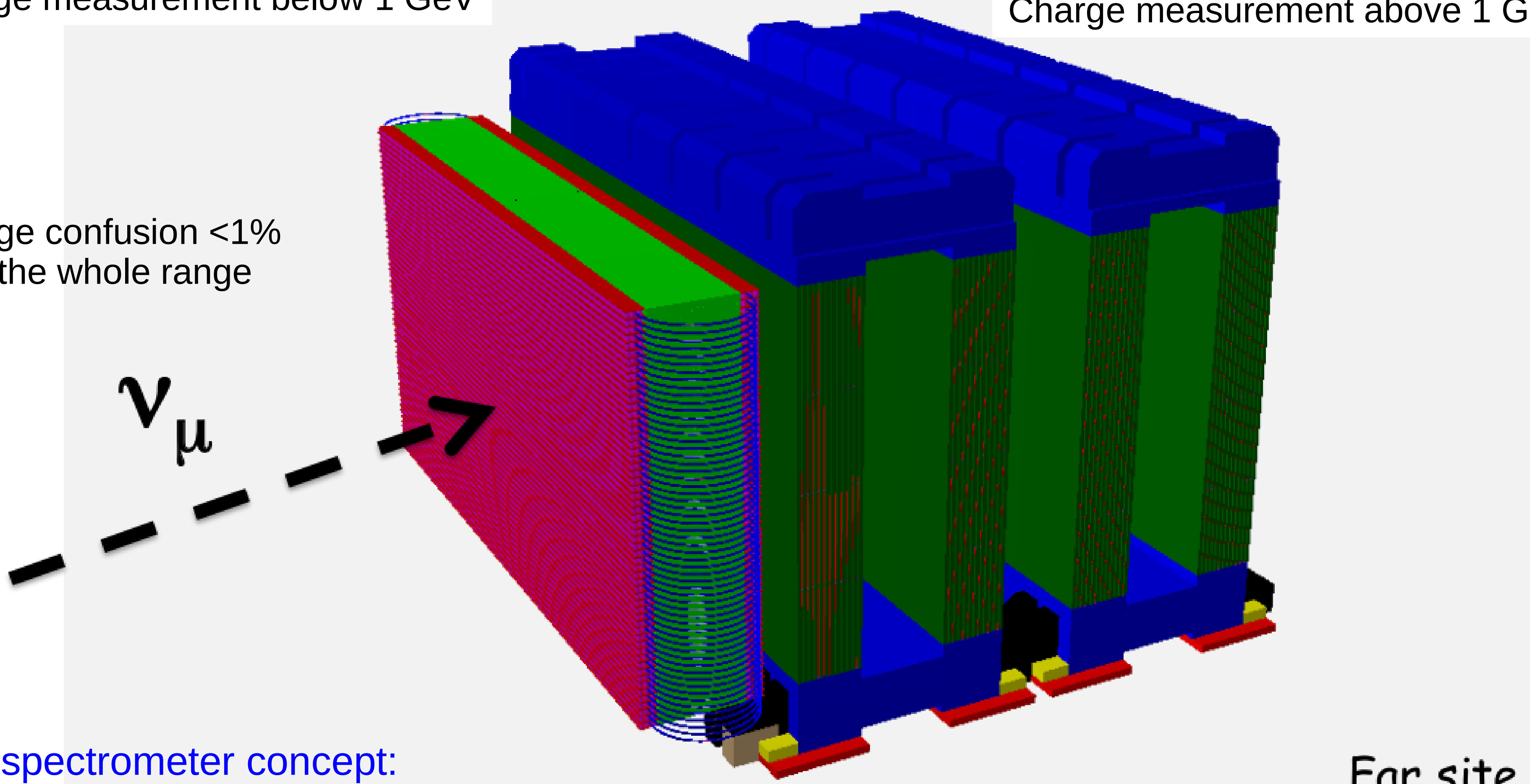
Nessie muon spectrometers:

1) Measure ν_μ disappearance (near + far site)
2) Constrain un-oscillated neutrino flux at high energy
3) Measure muon charge (important in anti-ν_μ run)

Air Core Magnet (ACM):
Charge measurement below 1 GeV

Iron Core Magnet (ICM) + RPCs:
Momentum measurement at 5% (range)
Charge measurement above 1 GeV

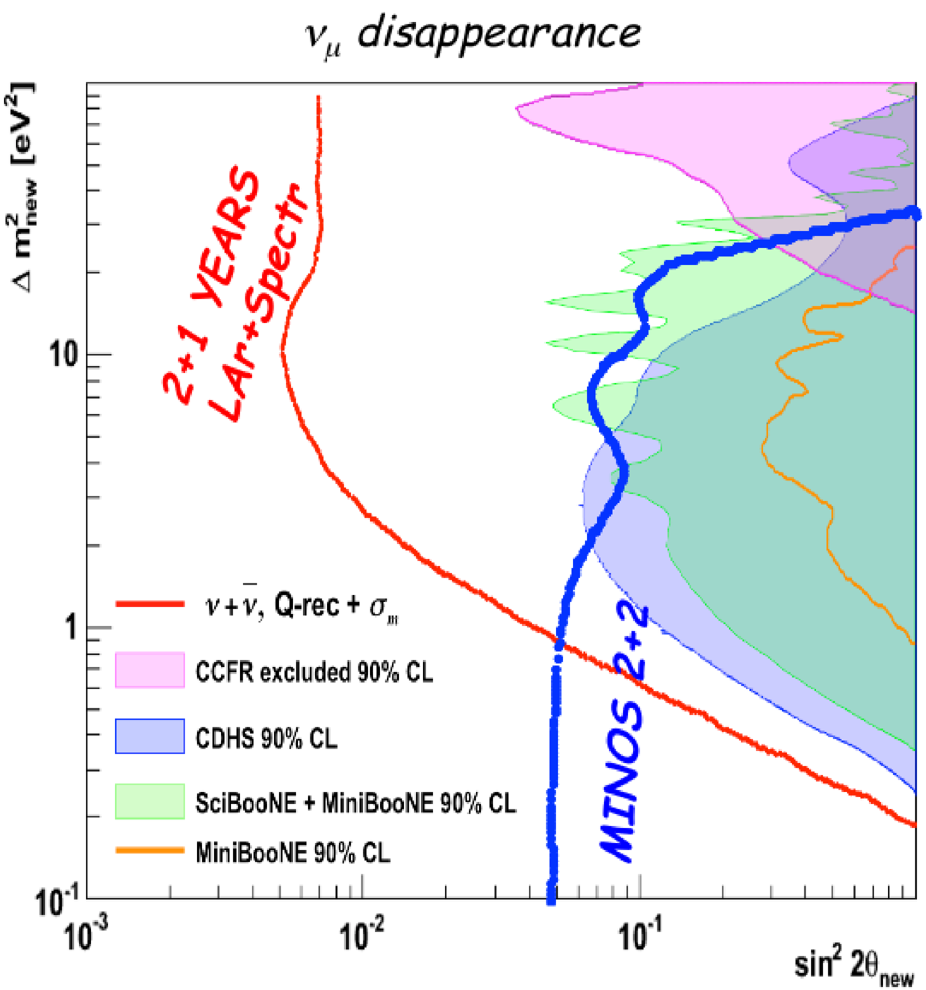
Charge confusion <1%
over the whole range

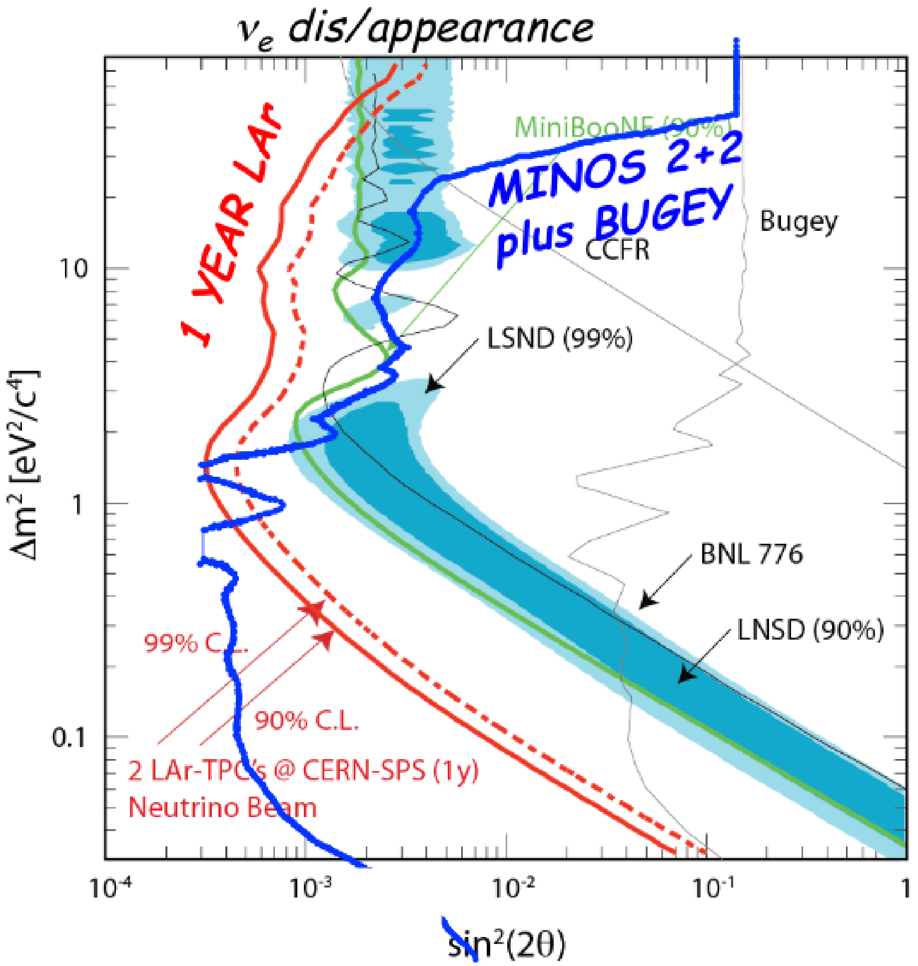


New spectrometer concept:
1) Two ICMs with OPERA top and bottom yokes
2) iron slabs as high as 4/7 (3/7) of OPERA slabs

Full recovery of OPERA iron. New production needed only for top and bottom yokes of near site.

ICARUS – Nessie combined performances





Nessie LNF group

Presently: 0.5 FTE (2 persons) – overlap with OPERA

In case of approval, 1 FTE required to SSE (involved also in OPERA decommissioning)

Group activities:
MC simulations for the optimization of the beam-line
Installation of Iron Core Magnets and Resistive Plate Chambers

Scientific approval by CSN2
Submitted to CTS (INFN Technical Scientific Committee)
CENF (CERN Neutrino Facility) approval by CERN ?
Nessie experiment approval by INFN ?
Critical to define common schedule with OPERA decommissioning.