



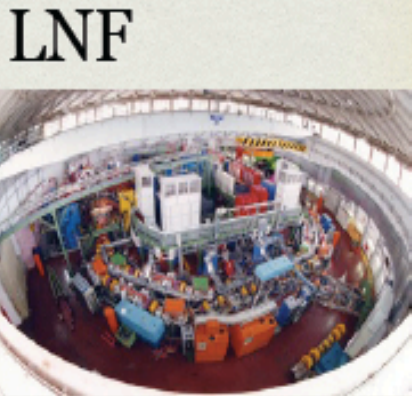
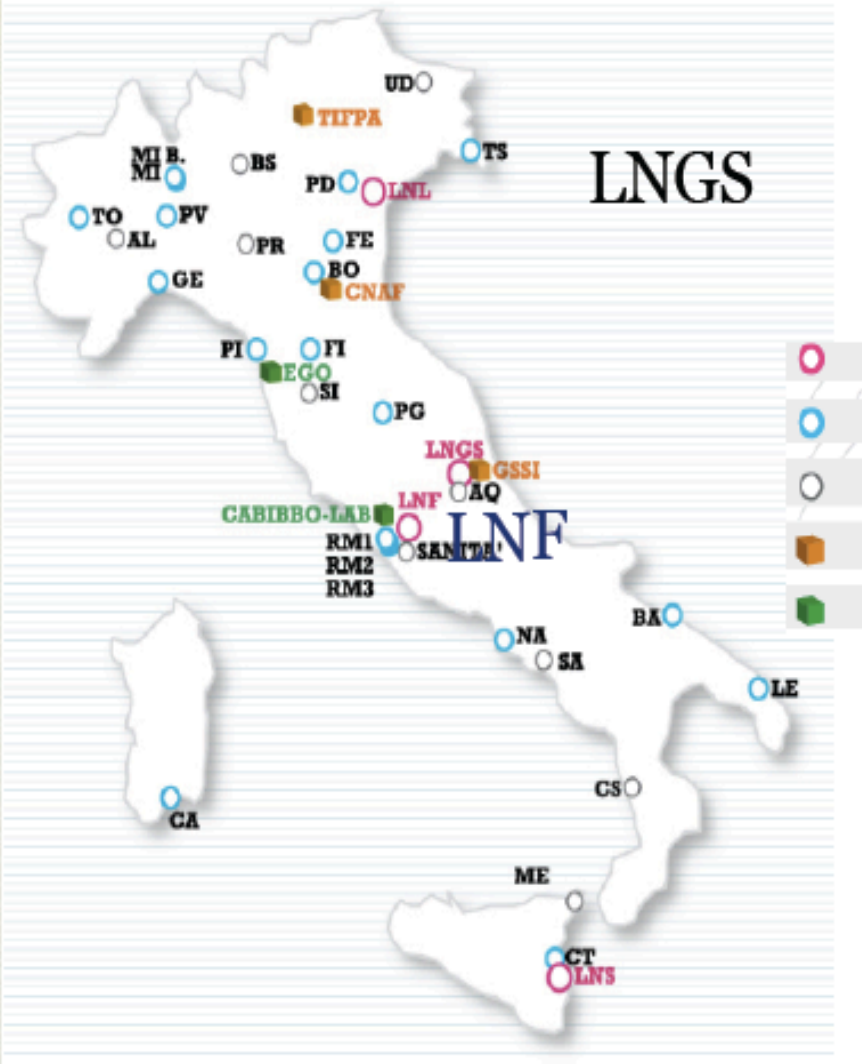
Scientific Report on the **INFN ACTIVITIES**

Antonio Masiero

INFN & Univ. of Padua

JINR – INFN Meeting, Pisa, Oct. 12-13, 2015

INFN: all over Italy in symbiosis with the University



the INFN Personnel

DG

Researcher

Engineers

Tech

Administration

Post-Doc

Researcher (full time)

Engineers

Researcher (part time)

Ph. D. students, Post-Doc

INFN



1 Dirigente



610 Ricercatori



230 Tecnologi



692 Tecnici



301 Amministrativi



197 Associati Borsisti, Assegnisti

UNIVERSITÀ



843 Associazioni con incarico di ricerca



109 Associazioni con incarico di collaborazione tecnica

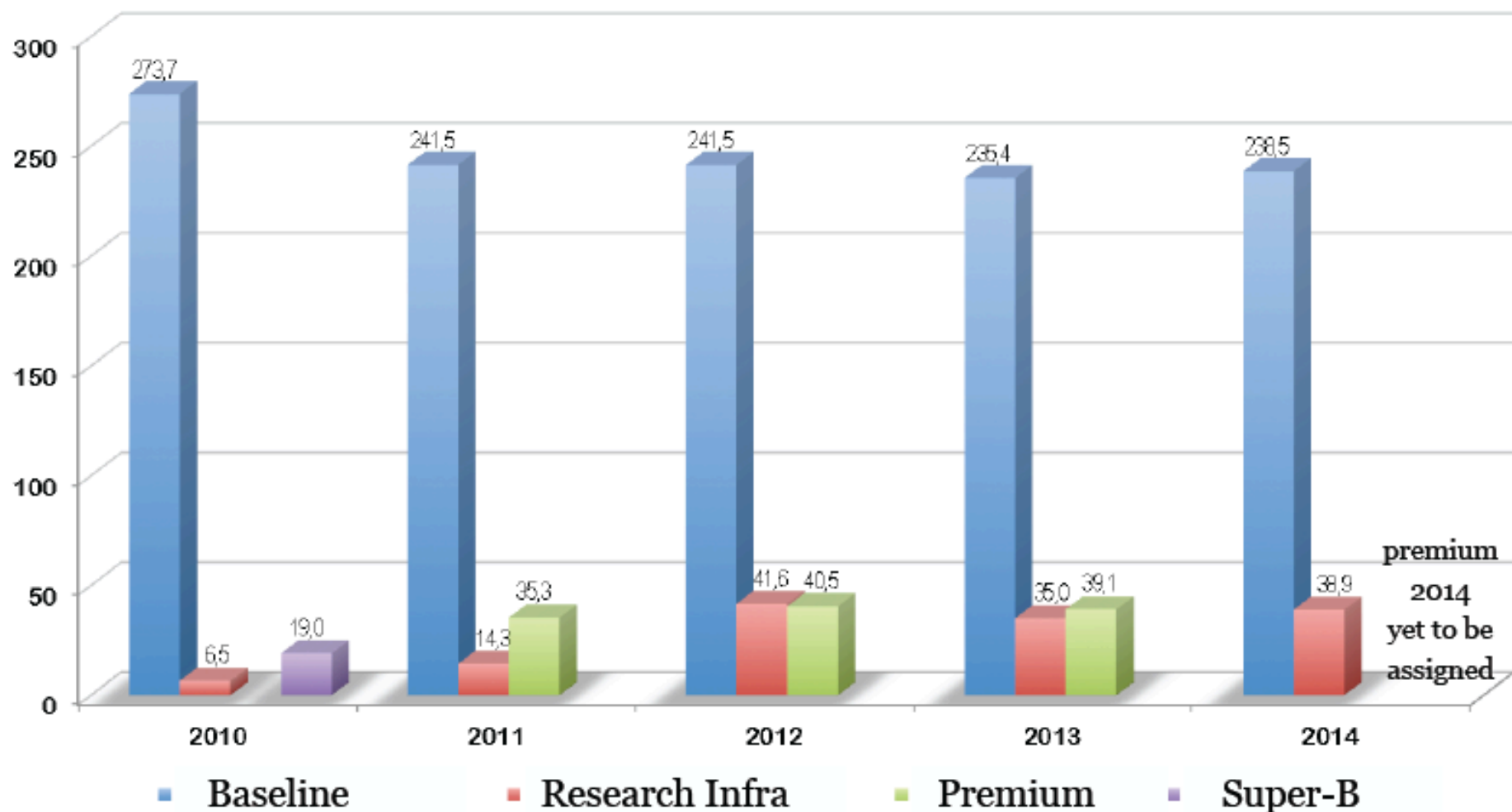


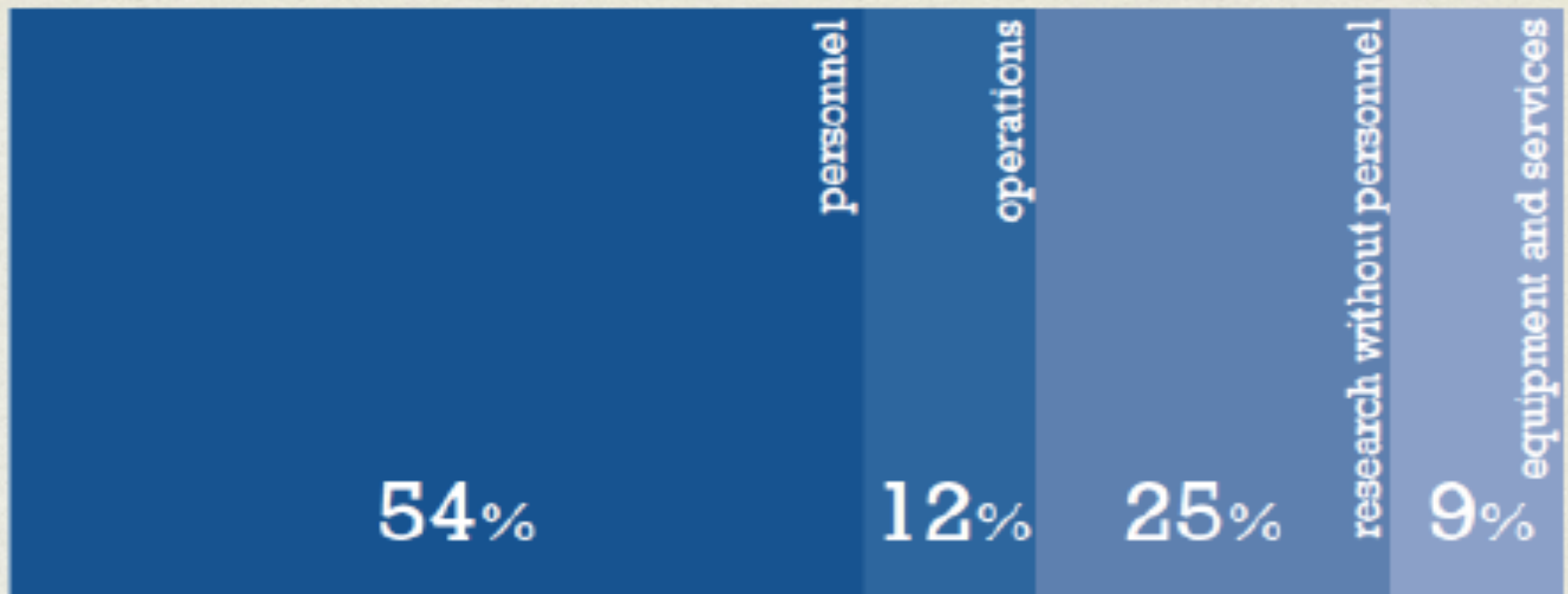
651 Associazioni scientifiche/tecnologiche/tecniche



1280 Laureandi, Dottorandi, Borsisti, Assegnisti

the INFN budget along the last years





Salaries ~ 135 ME **Infrastructures & operations** ~ 60 ME

Research direct costs ~ 50 ME

Extra funds labelled for specific projects (regional, national, EU projects, etc.) **acquire more and more relevance**

5 Research Lines with corresponding **5 Scientific**

Committees with **representatives of all the 20 divisions and 4 labs** and each followed by a **member of the Executive Board** (**bottom-up and top-down simultaneous approach**)

- Particle Physics **Nadia Pastrone** (with accelerators)
- Astroparticle Physics (includes all ν)
- Nuclear Physics (includes ALICE) **Pasquale Di Nezza**
- Theoretical Physics
- Research & Development (+Accelerators) **Nadia Pastrone**

SPECIAL PROJECTS

- IFMIF for ITER
- XFEL (Germany)
- Extreme Light Infrastructure (Magurele and Prague)
- European Spallation Source (Sweden)
- Gran Sasso Science Institute

WHERE TO GO: physics prospects

much depends on the next 5 years ...

- **LHC14** (high energy: ATLAS, CMS; flavor: LHCb; quark-hadron phase transition: ALICE)
- **Flavor**: NA62; upgraded MEG, Mu-e; BELLEII; EDMs; g-2
- **DM** 1-ton exps. $\rightarrow 10^{-10} - 10^{-11}$ pb
- **Neutrinoless double β** \rightarrow ν mass degenerate region; enter IH region
- **SBN** \rightarrow sterile ν ?
- **Gravitational waves** \rightarrow discovery
- **DE**: BOSS \rightarrow DESI; DES \rightarrow LSST
- **CMB**: final PLANCK; B-modes of the polariz.+ black-body spectrum : EU exps. QUBIC, LSPE, QIJOTE + many others on ground and balloons in US, Japan

if

- **Some signal** of physics beyond what the **Standard Models of Fundamental Interactions and Cosmology** predict → focus and converge on that “area” of New Physics
- **No signal** of BSM physics shows up whatsoever →
i) go on and move the frontier of the existing exploration paths → “**ballistic physics**”; ii) look for alternative, “**non-ballistic**” paths

WHY BSM

“OBSERVATIONAL” REASONS:

- Dark Matter ★ ★ ★
- Neutrino Masses ★ ★ ★
- Cosmic Matter-Antimatter Asymmetry ★ ★

(twofold problem: disappearance of primordial antimatter and extreme reduction of the number of baryons w.r.t the number of photons – initially \sim equal, today $n_{\text{baryons}}/n_{\text{photons}} \sim 10^{-9}$)

- Primordial Inflation ★
- Dark Energy ★

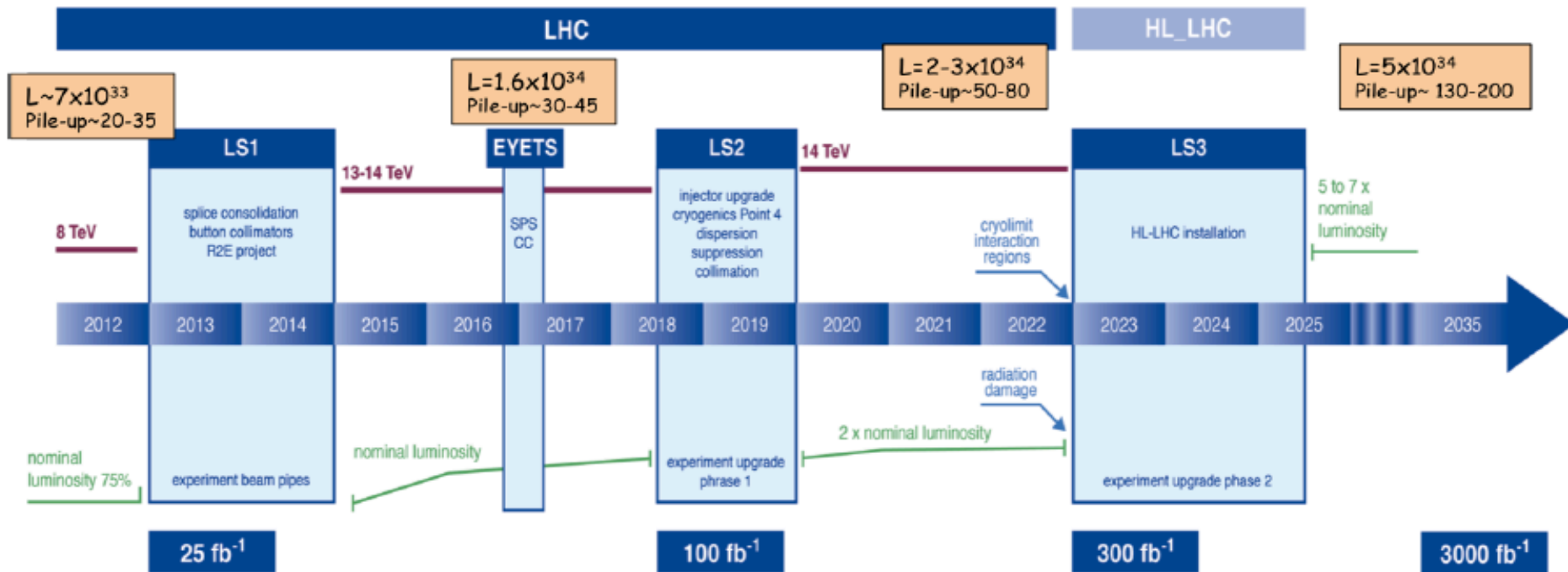
WHY BSM

Theoretical reasons (of dissatisfaction towards the SM as a “final” theory rather than actual problems for the SM)

- Lack of the theory of **Flavor** (why three fermion families, why hierarchical mass spectrum, why mixing angles so different)
- **CPV in strong interactions**, i.e. the θ -problem
- **Unification** of the fundamental interactions (running the SM gauge couplings \rightarrow clear trend for unification of the interactions, but “pure SM” fails
- **Gauge hierarchy** – twofold puzzle: why M_{GUT} or M_{planck} $\gg \gg M_W$; stabilization of the Higgs mass at M_W at any order in perturbation theory

most important example of “ballistic physics”

New LHC / HL-LHC Plan



We participate in all LHC experiments, about 800 FTE's. Very important responsibilities.

The **ASTROPARTICLE** way to **NEW PHYSICS BEYOND** the SM

- **MULTI-MESSENGERS ASTRONOMY**
- **NEUTRINO PROPERTIES**
- **The DARK SIDE OF THE
UNIVERSE and the CMB**

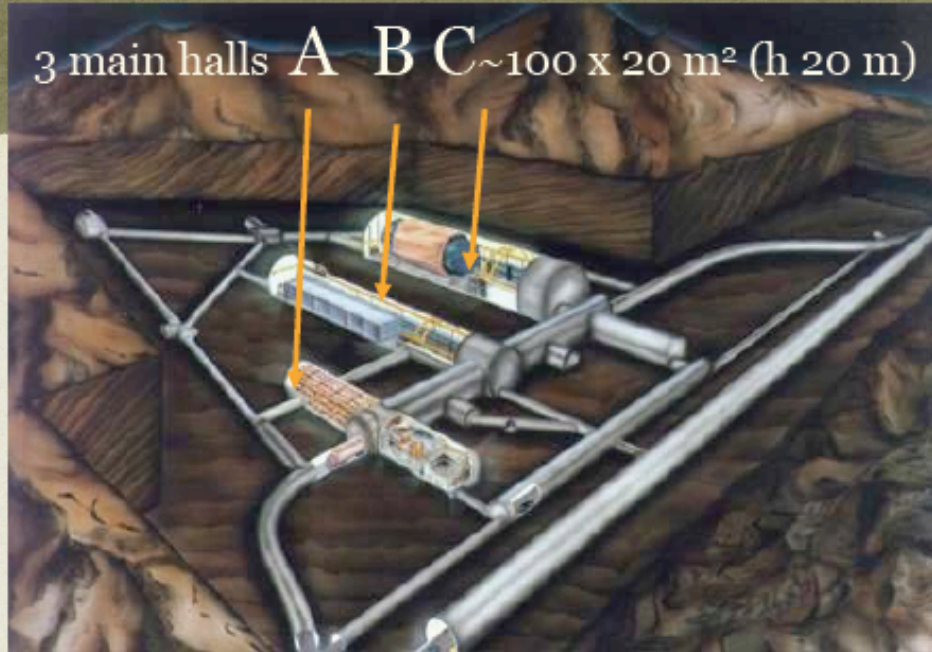
A) Multimessenger astronomy,

B) neutrino properties,

C) dark side of the Universe and CMB

- A) **Photon, cosmic ray, neutrino, gravitational** astronomies (some in their maturity, some in their youth, some just baby or even still to be born)
- B) **neutrino mass** and its relation to the global symmetry of the SM, **Lepton number** (Dirac vs. Majorana nature of the neutrinos); measuring the full neutrino mass parameters (neutrino mass hierarchy, CP violation)
- C) **Dark Matter; Dark Energy** and **their role in the evolution of the Universe** (primordial inflation, elw. Phase transition, quark-hadron phase transition, nucleosynthesis, matter-antimatter cosmic asymmetry)

LNGS: the GRAN SASSO LABORATORY



Muon Flux

$3.0 \cdot 10^{-4} \mu \text{m}^{-2} \text{s}^{-1}$

HORIZONTAL ACCESS

Depth: 1400 m (**3800 m w.e.**)

Surface: 17800 m²

Volume: **180000** m³

Rn in air: 20-80 Bq/m³

ISO 14001

Ventilation: 1 Lab volume/3 h

Electrical power: 1300 kW

LNGS RESEARCH ACTIVITIES

The inventory of Universe and
the dark matter

DAMA/LIBRA
CRESST
XENON IT
Dark Side

LBL - CNGS
OPERA

Icarus T600

Properties of neutrinos and their role in cosmic evolution

$2\beta 0\nu$

CUORE
GERDA
COBRA

Lucifer R&D

What about the interior of the
Sun and the Earth

BOREXINO
SOX
LUNA

LVD

What about the
supernova explosions

SEVERAL TECHNOLOGIES AT WORK IN LNGS

- Liquid Argon cryostat for hundreds of Tons
- Large Area counter detectors (RPC's)
- Liquid scintillators at highest purity
- Double phase liquid Xenon detectors
- Radiopure NaI scintillators
- Large volume Germanium detectors
- Large volume bolometers at few mK operation

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NEUTRINO PHYSICS

- PAST YEAR(S) : **BOREXINO, OPERA** CNGS ν_τ , ICARUS-CNGS, T2K θ_{13}
- NEXT YEAR(S) : **BOREXINO - SOX** (sterile), T2K, SHORT BASELINE@FNAL
- LONG TERM STRATEGY: **JUNO**, LONG BASELINE (CERN, US, JP)

LNGS the world largest underground lab to study

Neutrinoless double beta decay



$$\begin{array}{ccc} V_L^M & \xleftrightarrow{\text{CPT}} & V_R^M \\ & \text{Lorentz} & \end{array}$$

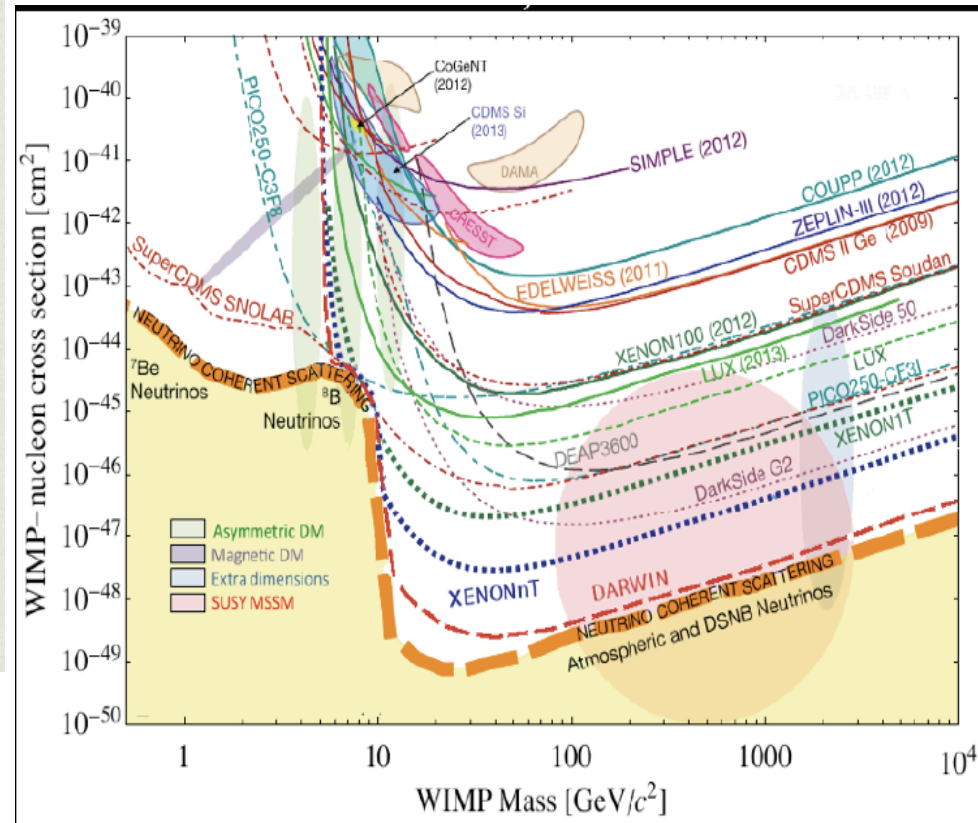
Majorana



$$\begin{array}{ccccc} & V_L^D & & V_R^D & \\ & \swarrow & \text{Lorentz} & \searrow & \\ \text{CPT} & & & & \text{CPT} \\ & \nwarrow & \text{Lorentz} & \nearrow & \\ & \bar{V}_R^D & & \bar{V}_L^D & \end{array}$$

Dirac

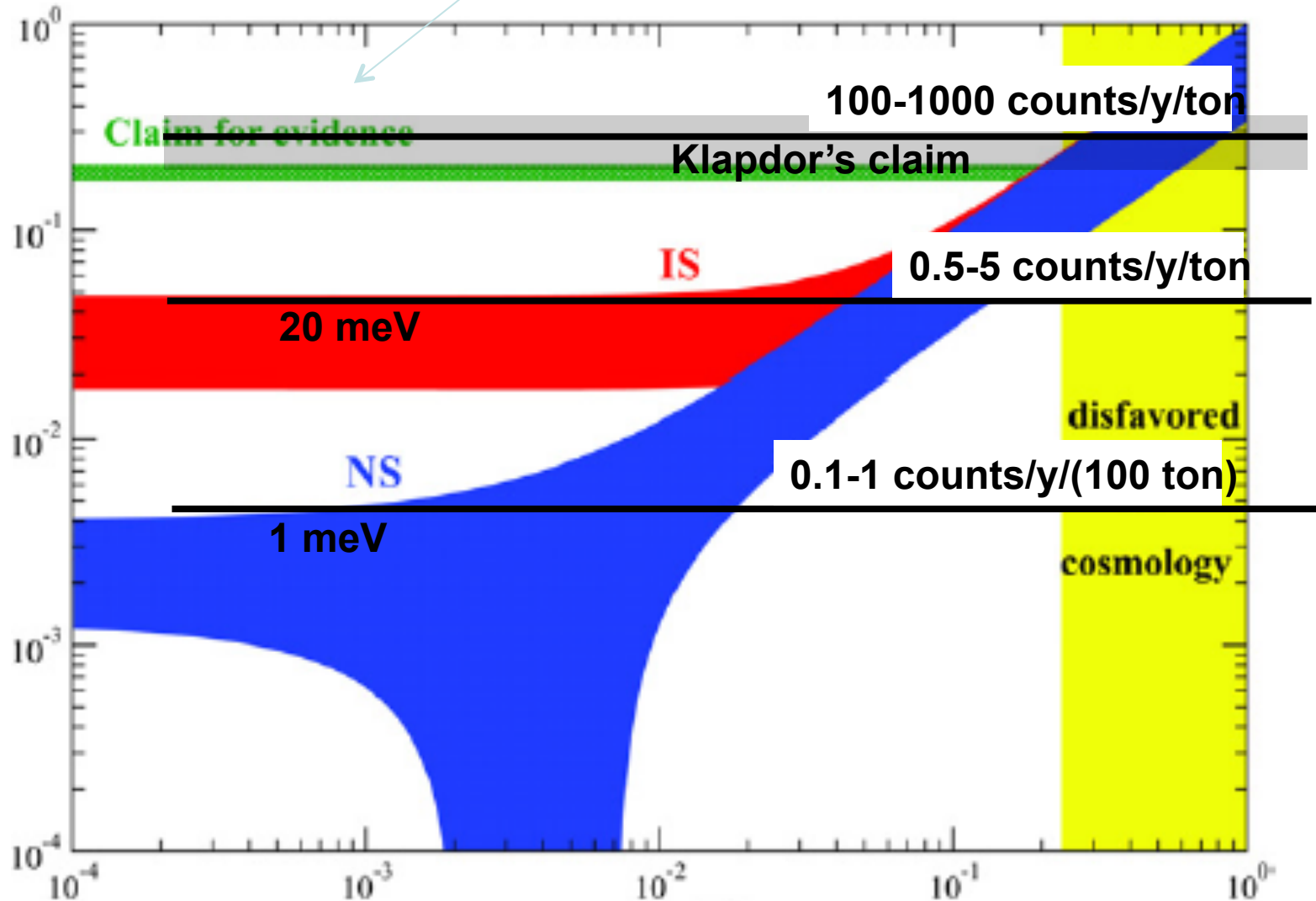
DARK MATTER



Three challenges for 0ν -DBD search

$\langle M_{\beta\beta} \rangle$ [eV]

Klapdor Krivosheina Modern Physics Letters A 21, No. 20 (2006) 1547



RARE PROCESSES at the LNGS

Dark Matter, Neutrino-less Double Beta Decay

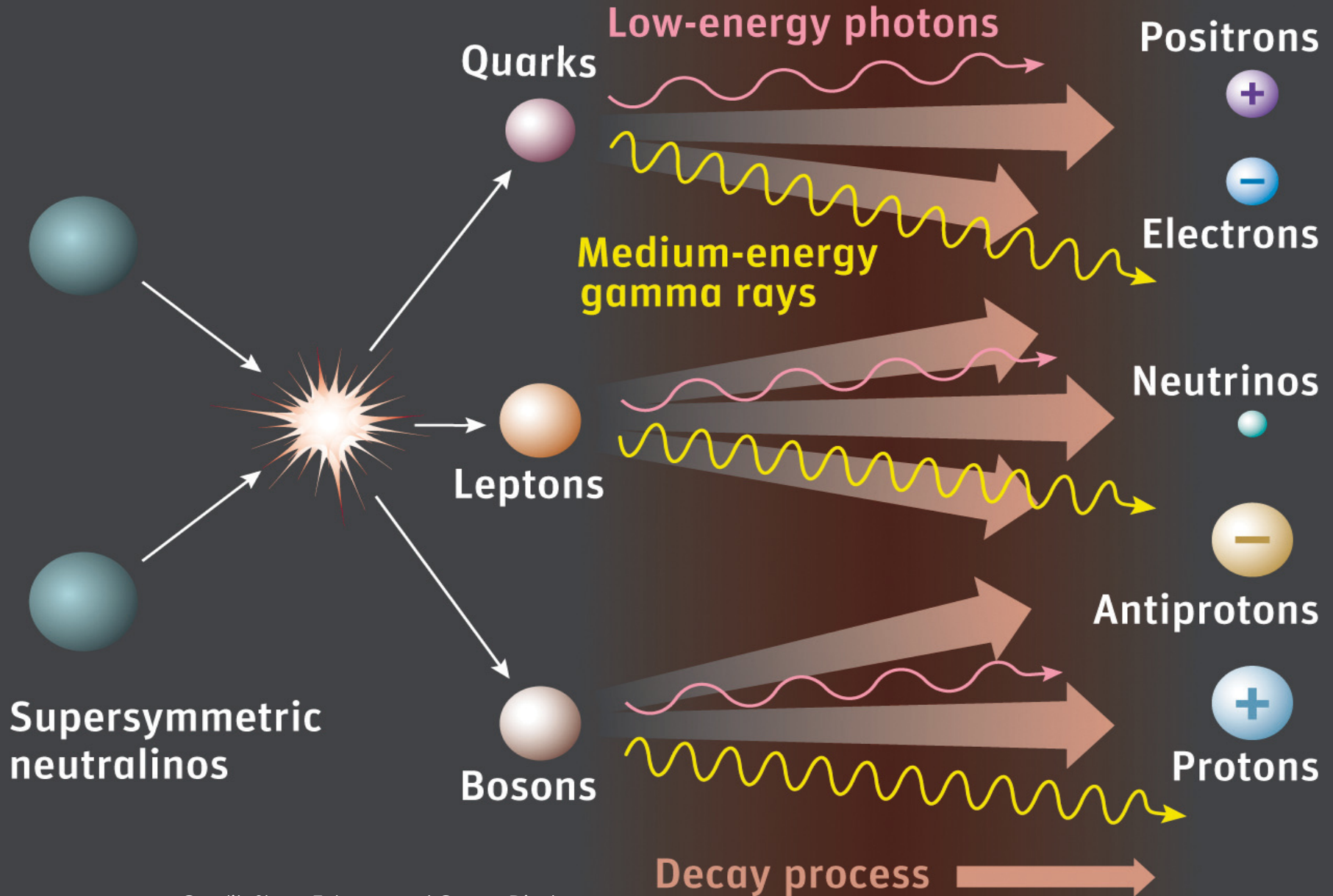
- **PAST YEAR(S) :**
 - DAMA-LIBRA, XENON-100, CRESST
 - **GERDA**
- **NEXT YEAR(S) :**
 - DAMA-LIBRA, XENON-1T, DARK-SIDE, CRESST
 - **GERDA**, CUORE
- **LONG TERM STRATEGY:** CUORE+ (?), XENON+ (?), DARK-SIDE+ (?), CRYOGENIC CRYSTALS (?)

Challenges for next DM, $\beta\beta$ frontiers; Challenges for LNGS

- Attack and cover the IH region \rightarrow 1-ton neutrinoless $\beta\beta$
- WIMPS DM : Reach the neutrino background \rightarrow n-ton exps. $n > 10$

Potentiality for the LNGS: hosting a large ultra low-background facility?

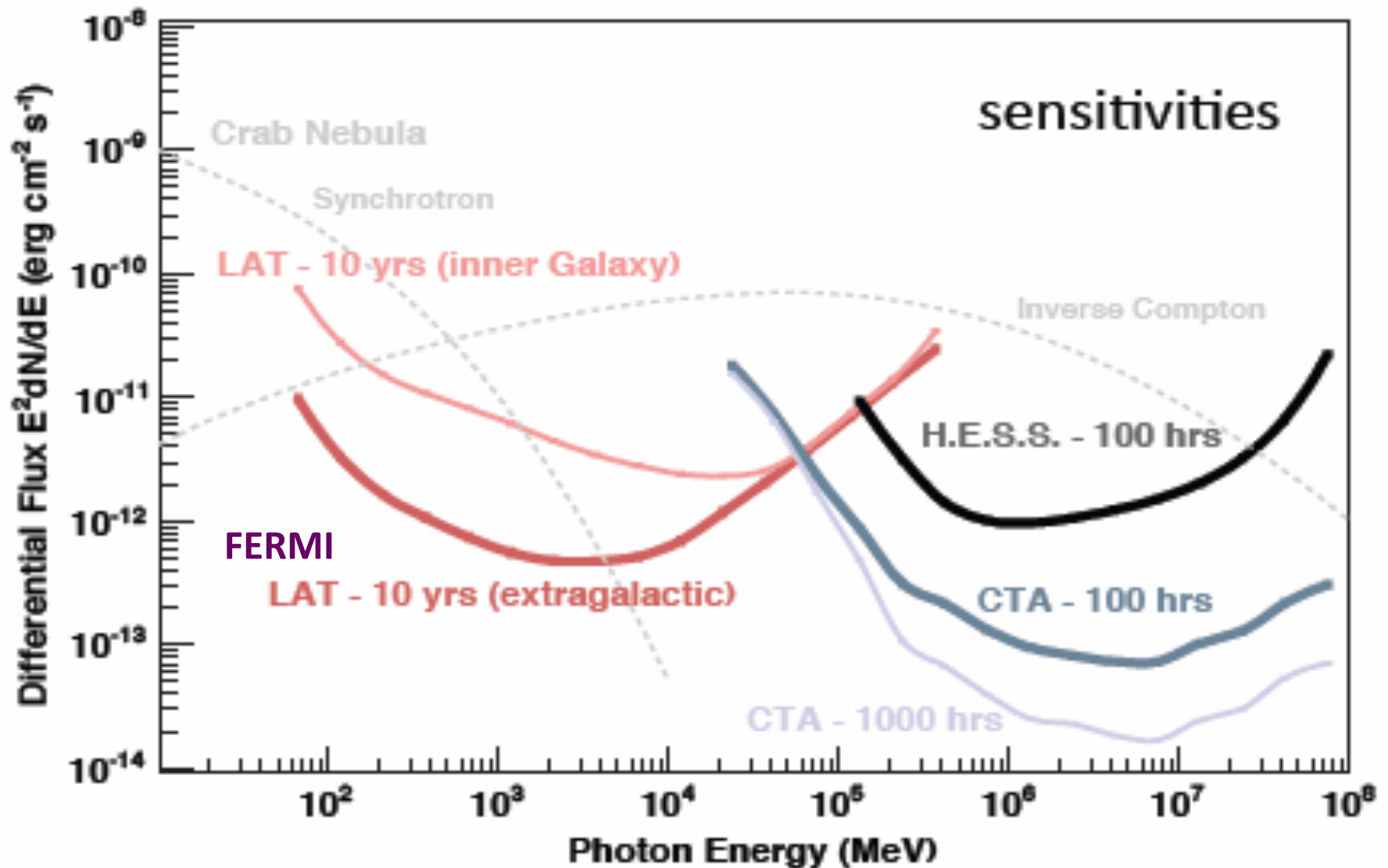
indirect search for dark matter



Cosmic Radiation from ground

- **PAST YEAR(S) :** ARGO, AUGER, MAGIC
ANTARES, KM3-NET
- **NEXT YEAR(S) :** AUGER, MAGIC, CTA, KM3-NET
- **LONG TERM STRATEGY:** AUGER, CTA, KM3-NET

GAMMA – ASTRONOMY FROM EARTH AND SPACE



Cosmic Radiation from space

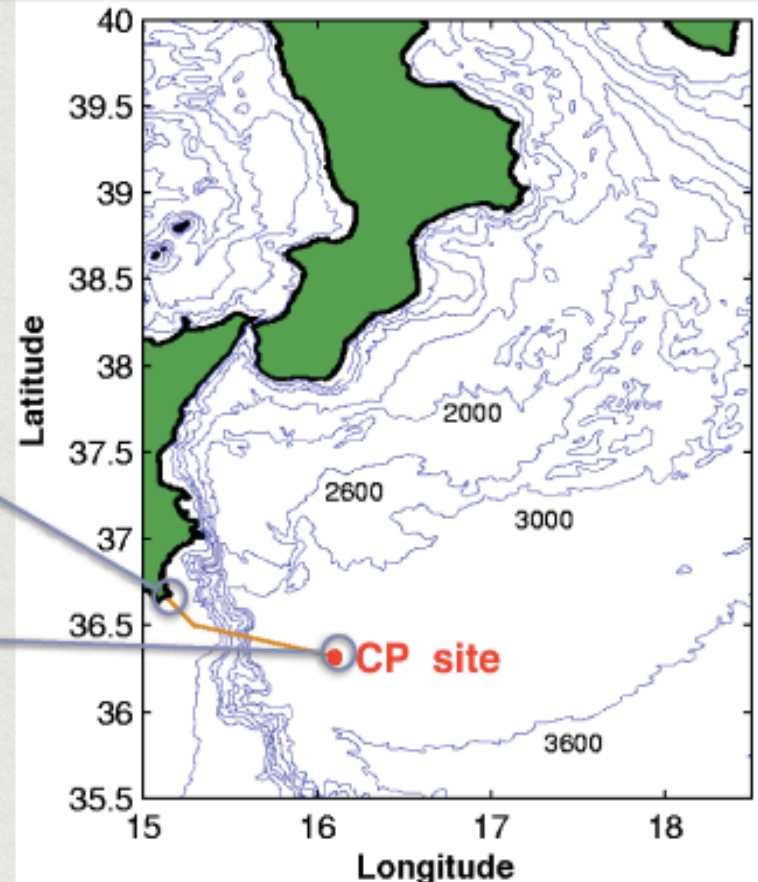
- **PAST YEAR(S)** : PAMELA, AGILE, FERMI, AMS-02
- **NEXT YEAR(S)** : FERMI, AMS-02, DAMPE
- **LONG TERM STRATEGY**: AMS-02, JEM-EUSO, HERD

KM3-NeT: Looking for **COSMIC NEUTRINOS** deep under the sea

Capo Passero is one of the candidate sites for the installation of KM3NeT
Deep sea site studied and fully characterized in the past 12 years
Already existing infrastructure with to be upgraded for KM3NeT-Italia



- Present infrastrucures
- Deep-sea 10 kW DC/DC converter
 - Main 100 km electro-optical cable
 - Power feeding system
 - Shore station
 - High bandwidth (1 Gbps) connection to LNS

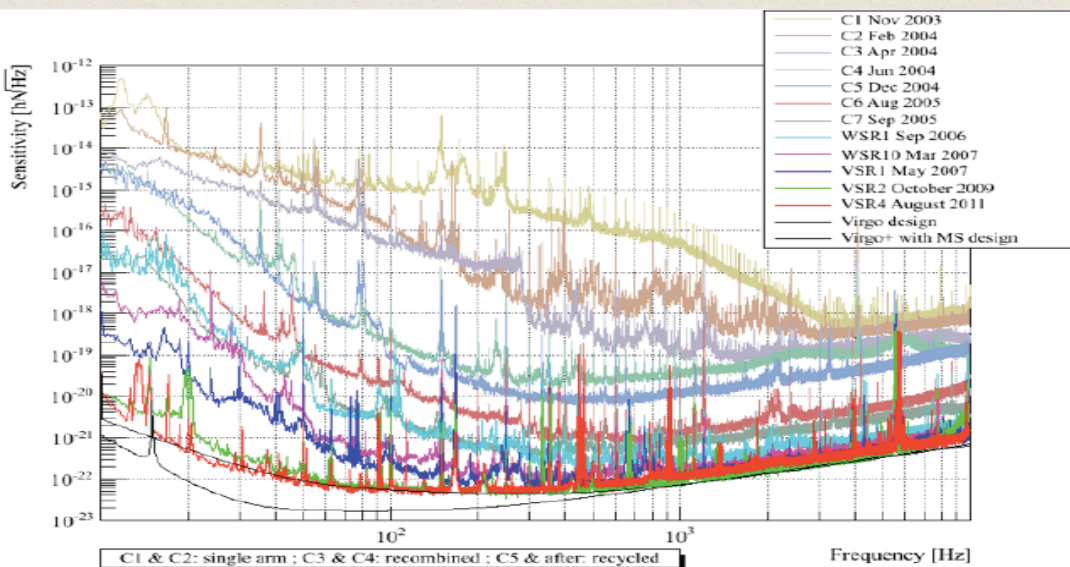


Gravitational Waves

- **PAST YEAR(S)** : 3 BARS (Explorer, Auriga, Nautilus), VIRGO, VIRGO+, LISA-PATHFINDER
- **NEXT YEAR(S)** : ADVANCED VIRGO, LISA-PATHFINDER
- **LONG TERM STRATEGY**: ADVANCED VIRGO, LISA/NGO, Einstein Telescope (ET) (?)

EGO-VIRGO





2015-2020 the years of the
discovery; from '20 on the
years of GW astronomy →
ET, eLISA,...

Plausible LIGO-Virgo Observing

Aasi et al. 1304.0670

Epoch	Estimated Run Duration	BNS Range (Mpc)		Number of BNS Detections
		LIGO	Virgo	
2015	3 months	40 – 80	–	0.0004 – 3
2016–17	6 months	80 – 120	20 – 60	0.006 – 20
2017–18	9 months	120 – 170	60 – 85	0.04 – 100
2019+	(per year)	200	65 – 130	0.2 – 200
2022+ (India)	(per year)	200	130	0.4 – 400

Assumes NS-NS rate between $10^{-8} \text{ Mpc}^{-3} \text{ y}^{-1}$ and $10^{-5} \text{ Mpc}^{-3} \text{ y}^{-1}$.
Ranges double for $1.4 M_{\odot} - 10 M_{\odot}$ NS-BH binary.

The INFN center for advanced study and international PhD school *Gran Sasso Science Institute* has started its educational and scientific activities in October 2013, and is now entering his second year of life.



36 PhD students selected, divided into 4 courses:

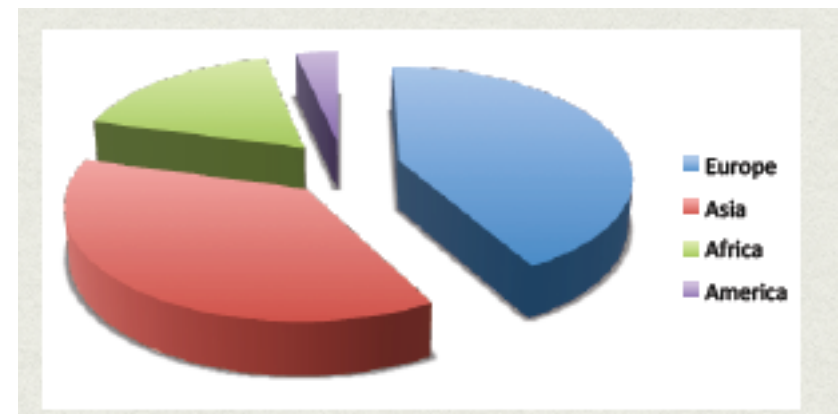
- *Astroparticle Physics* (10)
- *Mathematics in Natural, Social and Life Science* (6)
- *Computer Science* (8)
- *Urban Studies* (12)

Also appointed: 16 Post-docs with two-years research grants

811 applications
40 Students admitted



A TRULY INTERNATIONAL PHD SCHOOL



The GALILEO GALILEI INSTITUTE (GGI) for THEORETICAL PHYSICS in Florence

LONG-TERM WORKSHOPS

(and possibly a PhD program at the GGI)

- For the last 5 – 6 years the Galileo Galilei Institute located on the Arcetri hill overlooking the city of Florence has been offering a unique opportunity (in Europe) for **long-term topical workshops** (ranging from 2 to 4 months) with the participation of an average of ~50 researchers per workshop. The topics cover theoretical particle and astroparticle physics with some joint workshops together with the experimental community.

TIFPA

(TRENTO CENTER FOR PHYSICS AND APPLICATIONS)

INFN

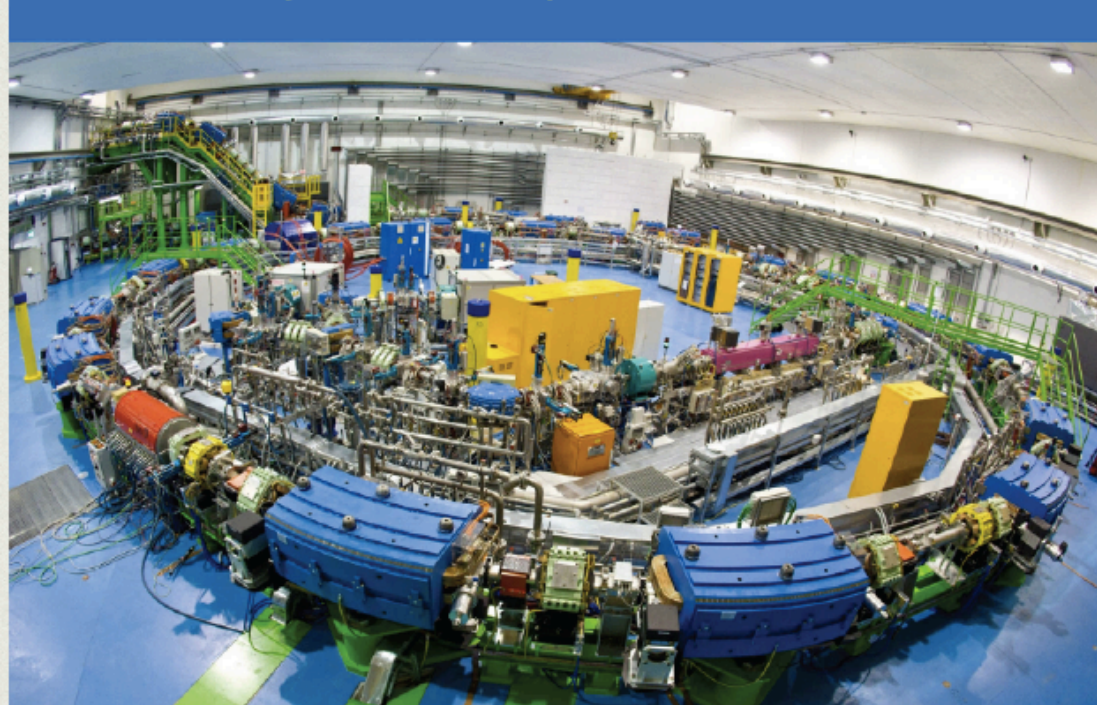
with

- University (physics, biology)
- Health care system (proton therapy cyclotron)
- FBK (applied physics, silicon detectors)
- ECT* (nuclear physics theory)

The brand new centre for
ION THERAPY in
TRENTO



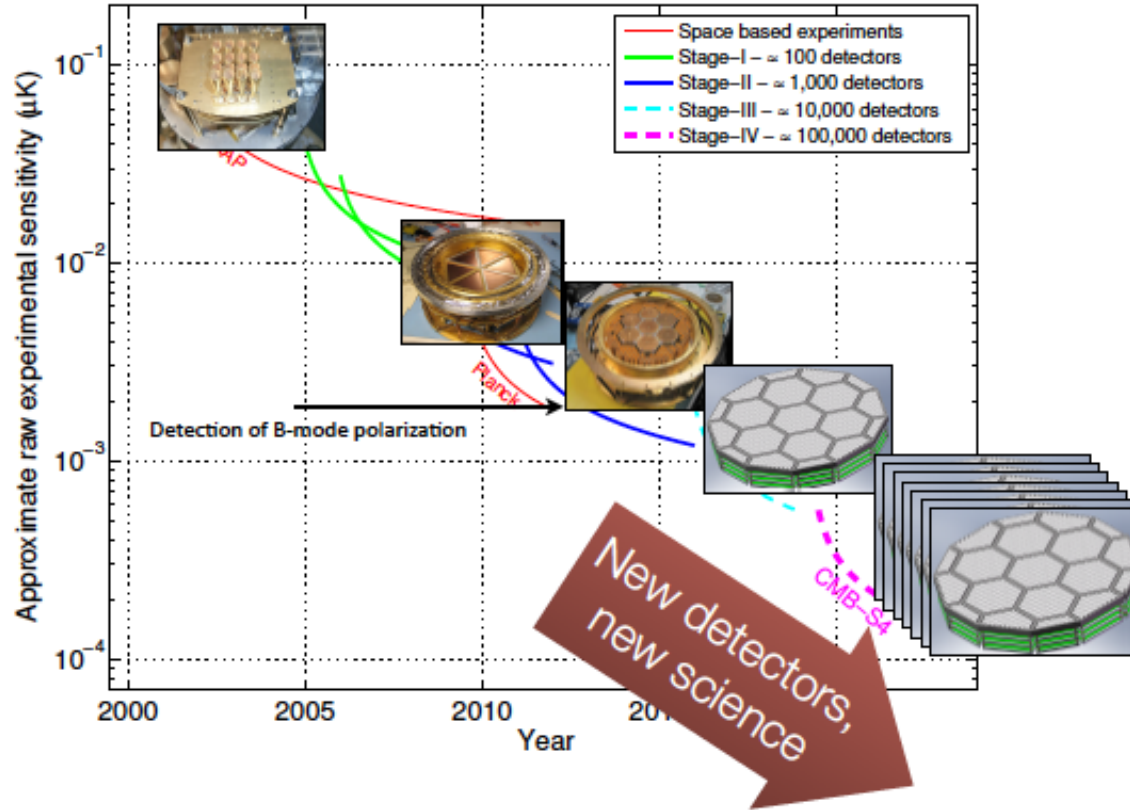
The synchrotron for protons and carbon ions



CNAO in PAVIA

The importance of Technology

Development of
TES and KIDS
technology



WHAT NEXT LNGS – Ambrosi et al

**THE PHOTODETECTORS CHALLENGE:
are SiPM the answer? ...**

The importance of being **SMALL**

My recommendation: beware the temptation of going ONLY for LARGE enterprises

The protective shield of large, Big Science: too big to fail!

Richness of small, “unorthodox” projects based more on clever ideas than on muscular, managerial strength!

WHAT NEXT

In view of the complex landscape we have to confront, INFN has recently started a process to identify the most important research themes that we should focus on amongst those that in this moment do not receive enough attention (people, funding). FERRONI

**HIGH ENERGY, HIGH-INTENSITY,
ASTROPARTICLE PHYSICS COMPLEMENTARY
ATTACK TO THE NEW PHYSICS FORTRESS**

7- 8 APRILE 2014

ANGELICUM

INFN
Istituto Nazionale
di Fisica Nucleare



**what
NEXT?**

Alla vigilia degli importanti input sperimentali che arriveranno da LHC a più alta energia e dai nuovi esperimenti sulla materia oscura, l'INFN si interroga sulle possibili strade da prendere per la ricerca di nuova fisica oltre il Modello Standard.

È aperto a tutta la nostra comunità INFN, per il tuo contributo iscriviti dal sito www.infn.it

Congress Centre - Aula Magna
Angelicum, 1 Roma

Informazioni
presid.infn.it - telefono 06 6840031



NON-BALLISTIC PHYSICS

A MINE OF OPPORTUNITIES

- CMB (a test balloon for validating the technology for a possible ESA mission on polarisation)
- Dark Energy (EUCLID science and some technology)
- Axions (an idea that might compete with ADMX together with INRIM)
- Cold atoms quantum simulator (in collaboration with the best of condensate matter in Italy- Florence LENS and Trento)

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WHERE and WHAT is the NEW PHYSICS beyond the Standard Model(s)

neutrino masses
dark matter
baryogenesis
inflation

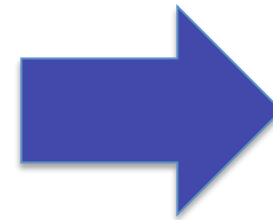


OBSERVATIONAL
REASONS

$M_{\text{HIGGS}} / M_{\text{PLANCK}} \sim 10^{-16}$

$E_{\text{VACUUM}} (\text{DE}) / M_{\text{HIGGS}} \sim 10^{-14}$

$\Theta_{\text{CPV in STRONG INTERAC.}} < 10^{-9}$



THEOR.
REASONS

INFN is going to hunt for it/them
through ballistic and non-ballistic paths

INFN-JINR Dubna: past, present, future

- **International collaboration is in the DNA of INFN:**
practically all the INFN research activity is carried out within international collaborations.
- **The collaboration between Dubna and INFN**
had a glorious past, *has* interesting points of contact and we have to exploit all synergies for a bright *future* between these two prestigious Institutions

BACK-UP SLIDES

A CULTURAL CHANGE

- Projects sometime require somebody doing something that he/she would not have done being in the old good times
- Projects require collaboration with other research institutions in Italy that was not seen as an opportunity in the past
- Chasing european/regional funds need a dedicated structure

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Moving from a feeling of self-sufficiency to a complex environment

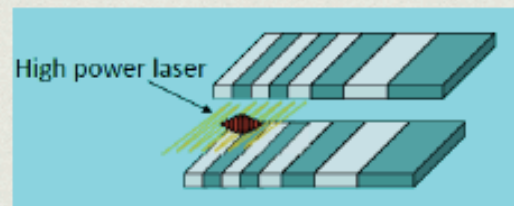
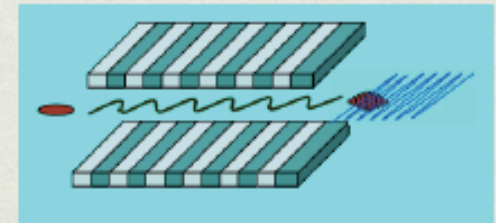
LNF

- the bigger laboratory in INFN, need to design a solid future
- Big machines cannot be done in this economic conditions
- Fully exploit the Beam Test Facility also connecting it to a more general Space Program Facility
- SPARC and Plasma Wakefield Acceleration the main future
- run Dafne with KLOE a bit longer, find a future in the study of accelerators
- a center for detector R&D and big construction

A NEW FRONTIER : MARRYING LASERS AND PARTICLE BEAMS

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Seeding a High Gain Free Electron Laser:
transfer coherence from the Laser to
the FEL radiation through the Electron
Beam



Inverse Free Electron Laser:
transfer energy from the Laser to the
Electron Beam through the FEL
radiation

THE FLAVOUR PROBLEMS

FERMION MASSES

What is the rationale hiding behind the spectrum of fermion masses and mixing angles (our “**Balmer lines**” problem)

→ LACK OF A FLAVOUR “THEORY”

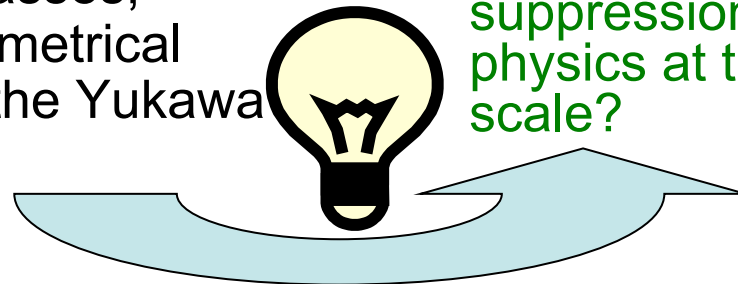
(new flavour – horizontal symmetry, radiatively induced lighter fermion masses, dynamical or geometrical determination of the Yukawa couplings, ...?)

FCNC

Flavour changing neutral current (FCNC) processes are suppressed.

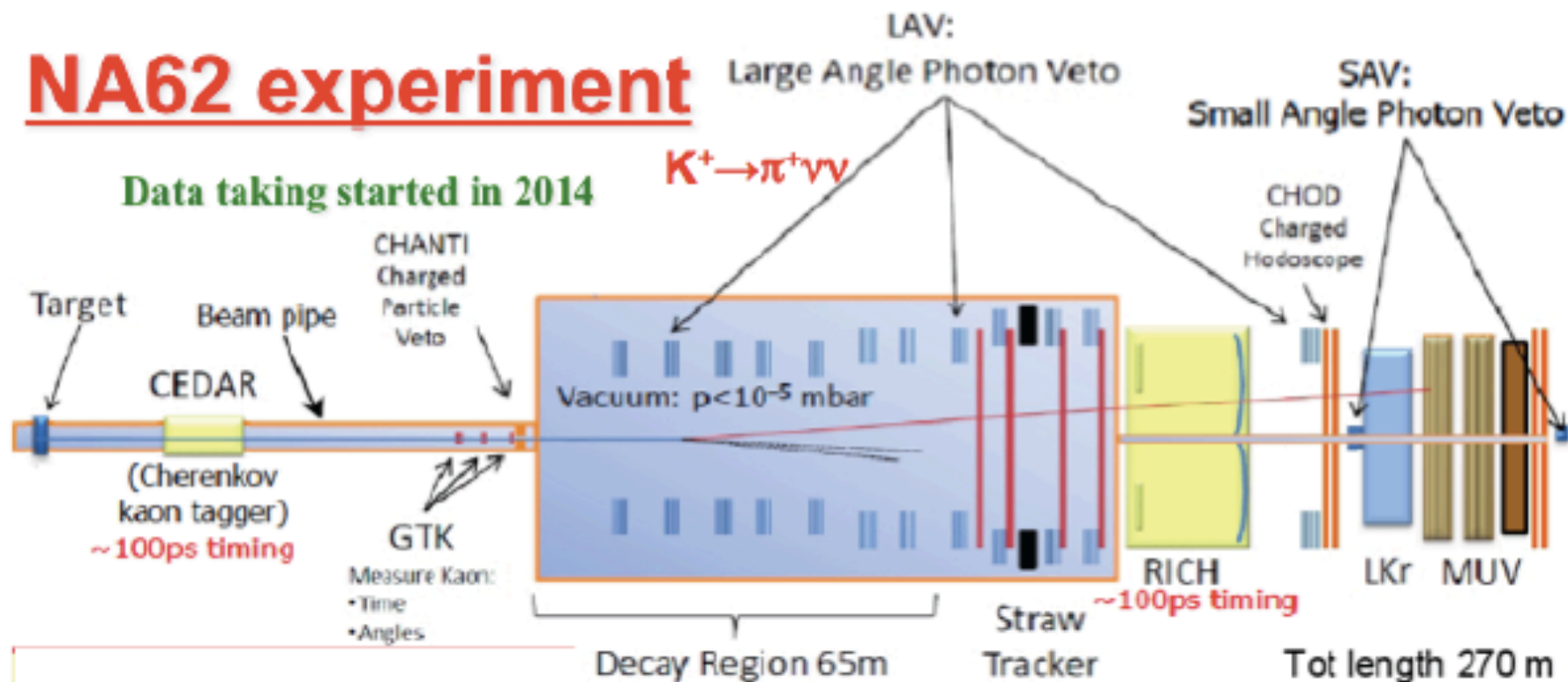
In the SM two nice mechanisms are at work: the **GIM mechanism** and the structure of the **CKM mixing matrix**.

How to cope with such delicate suppression if there is new physics at the electroweak scale?

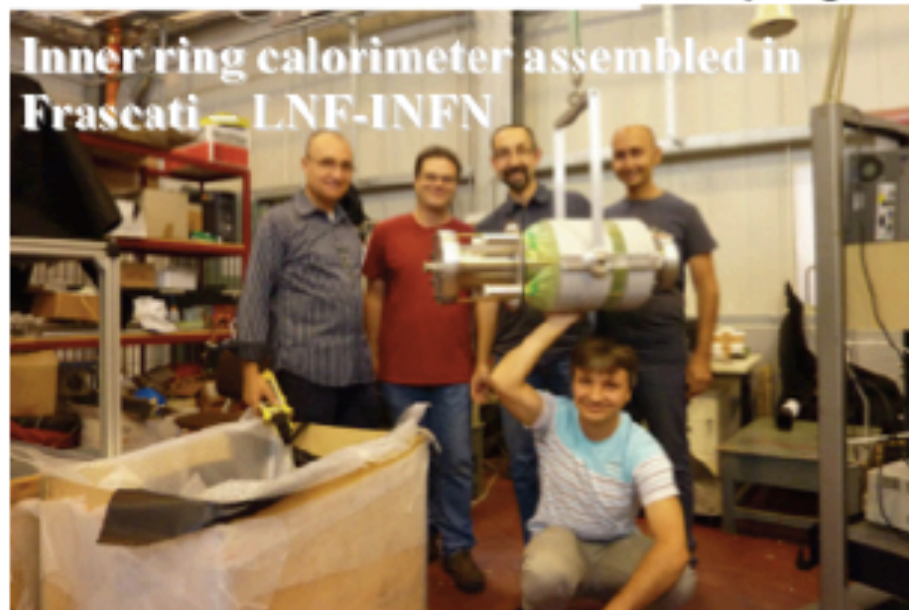


NA62 experiment

Data taking started in 2014



Inner ring calorimeter assembled in Frascati LNF-INFN



Installation in ECN3



- IRC design and mechanics produced by **University of Sofia** and **LTDP - BAS-BG**
- Design review and assembly at **LNF**
- SAC upgrade and PMT test at **LNF BTF**

Going beyond the SM: the NEUTRINO MASS

A. GIULIANI, SAC APPEC 2013

Cosmology, single and double β decay measure different combinations of the neutrino mass eigenvalues, constraining the **neutrino mass scale**

In a standard three active neutrino scenario:

$$\Sigma \equiv \sum_{i=1}^3 M_i$$

cosmology
simple sum
pure kinematical effect

$$\langle M_\beta \rangle \equiv \left(\sum_{i=1}^3 M_i^2 |U_{ei}|^2 \right)^{1/2}$$

β decay
incoherent sum
real neutrino

$$\langle M_{\beta\beta} \rangle \equiv \left| \sum_{i=1}^3 M_i |U_{ei}|^2 e^{i\alpha_i} \right|$$

double β decay
coherent sum
virtual neutrino
Majorana phases

KM3NeT

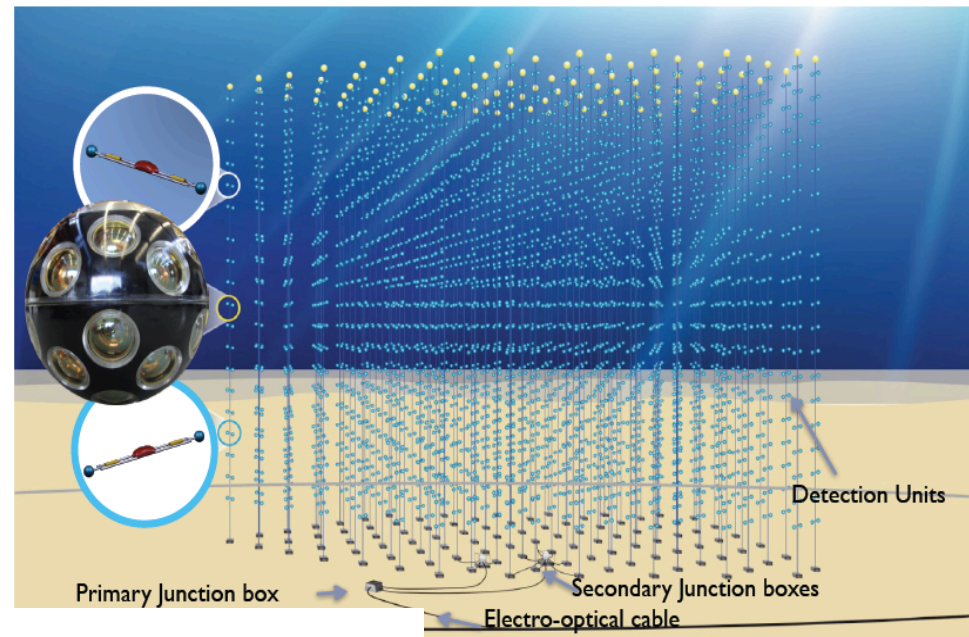
An artists impression of KM3NeT

KM3NeT

International consortium involving more than 300 scientists from 10 EU countries (CY, DE, ES, FR, GR, IE, IT, NL, RO, UK)

One objective: build the most sensitive high energy neutrino telescope

KM3NeT is on the ESFRI roadmap since 2006



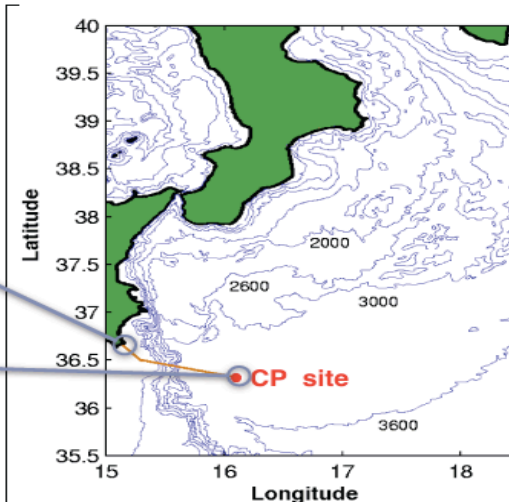
The Capo Passero site

Capo Passero is one of the candidate sites for the installation of KM3NeT
Deep sea site studied and fully characterized in the past 12 years
Already existing infrastructure with to be upgraded for KM3NeT-Italia



Present infrastructures

- Deep-sea 10 kW DC/DC converter
- Main 100 km electro-optical cable
- Power feeding system
- Shore station
- High bandwidth (1 Gbps) connection to LNS



**Revived interest
into HE cosmic
neutrino detection
after the discovery
of ~50 events in
ICECUBE**