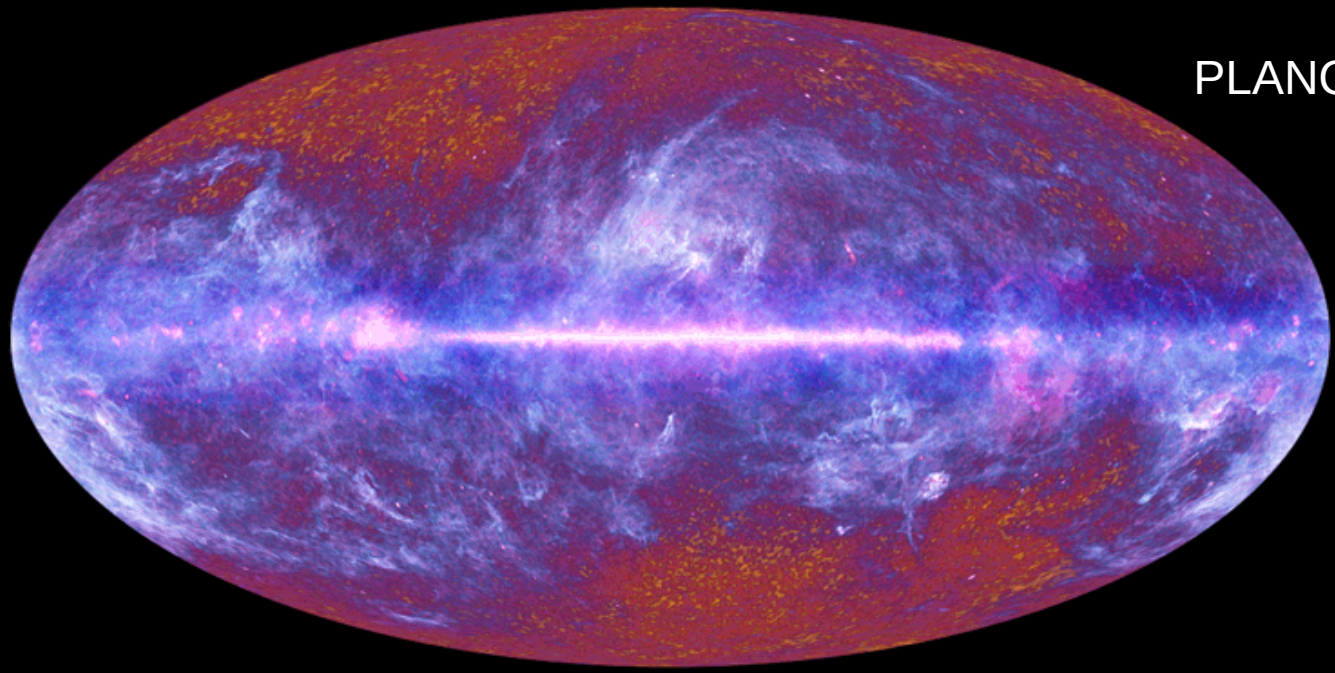


European Strategy on Astroparticle Physics

S. Katsanevas
IN2P3/CNRS, ApPEC/ASPERA
Zurich 9 July 2010

What is Astroparticle Physics ?

What is the role of high energy phenomena in the formation of cosmic structures?

Multi-messenger studies (γ,CR,ν, GW)

Detect dark matter, Limits of fundamental laws, Cosmological markers

What is the Universe made of?

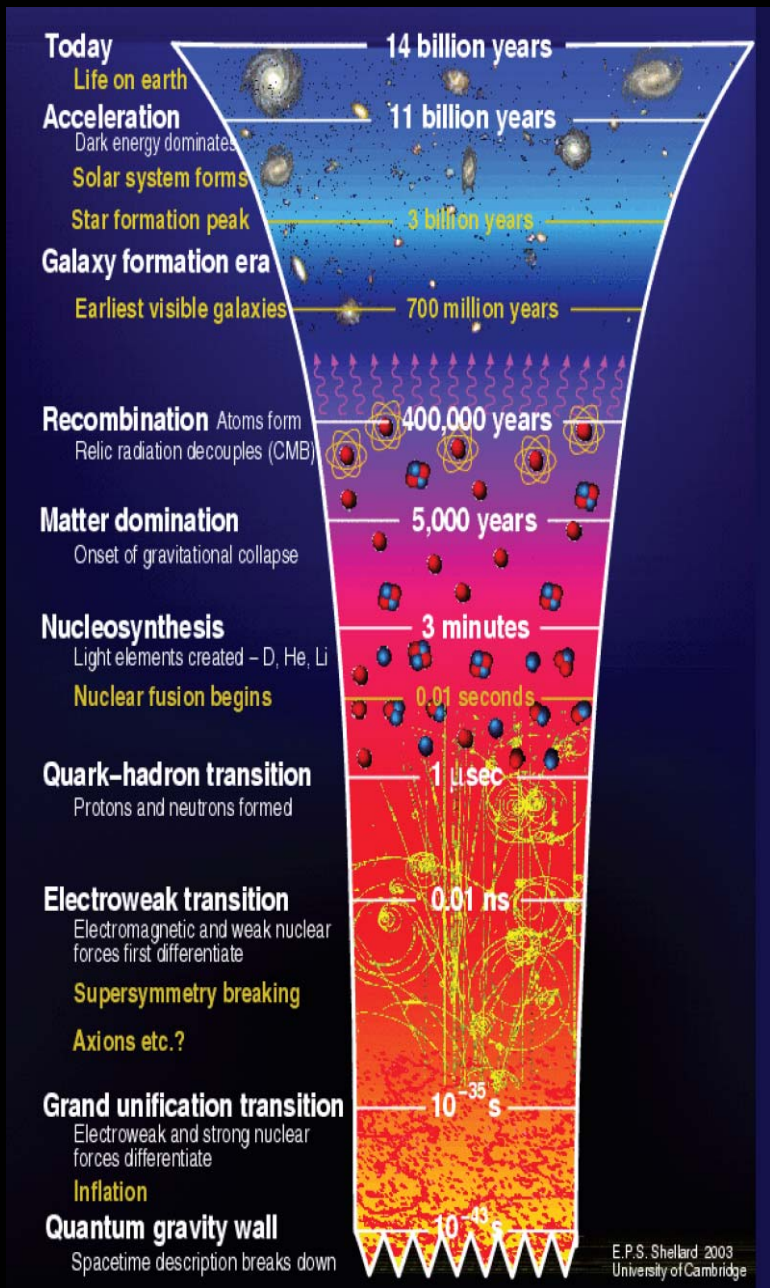
Nature of dark matter and energy

Probe EW scale, Gravitation

What is the form of matter and interactions at the smallest scales ?

Rare decays: proton lifetime , neutrino mass

Access GUT scales



What is the Astroparticle European Coordination? (ApPEC)

- **ApPEC is a consortium of 12 European agencies, created in 2001**
- **ApPEC aims to**
  - Promote and facilitate co-operation within the European Particle Astrophysics (PA) community
  - Develop long term strategies
  - Improving links and co-ordination between European PA and the scientific programmes of organisations such as CERN, ESA, and ESO
  - Express their collective views on in international for a (e.g. OECD)

- ApPEC operates
  - Strategically through its Steering Committee (chairman M. Bourquin)
  - Operationally through its Science Advisory Committee (chairman C. Spiering)
- ASPERA started as an ApPEC initiative

What is ASPERA ?

www.aspera-eu.org

“per aspera ad astra”

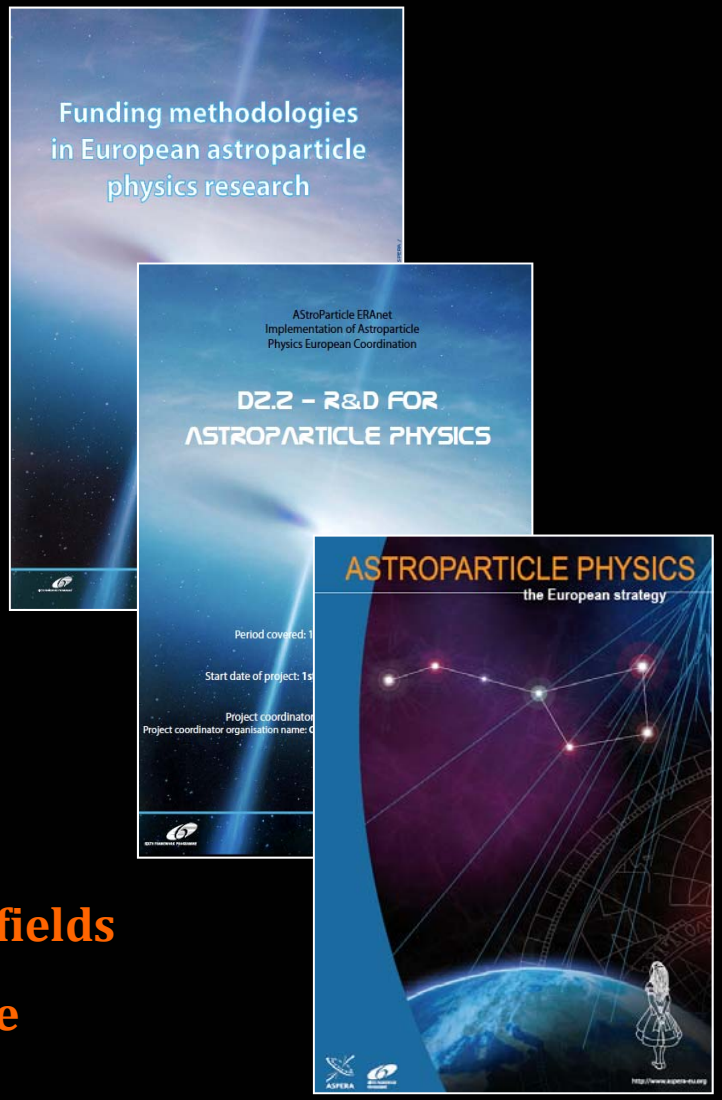
16 countries + CERN

- **ASPERA-I EU program FP6 (2006-2009)**
  - coordinator S. Katsanevas (CNRS)

  - Study APP personnel and funding in Europe
    - 2300 researchers and 70 M€/year
    - Organized 14 national days
  - Priority Roadmap for Infrastructures
    - and R&D
  - Linking of existing infrastructures
    - Underground laboratories
  - Issue a common call for R&D/Design studies
  - Common outreach, databases, portal, …

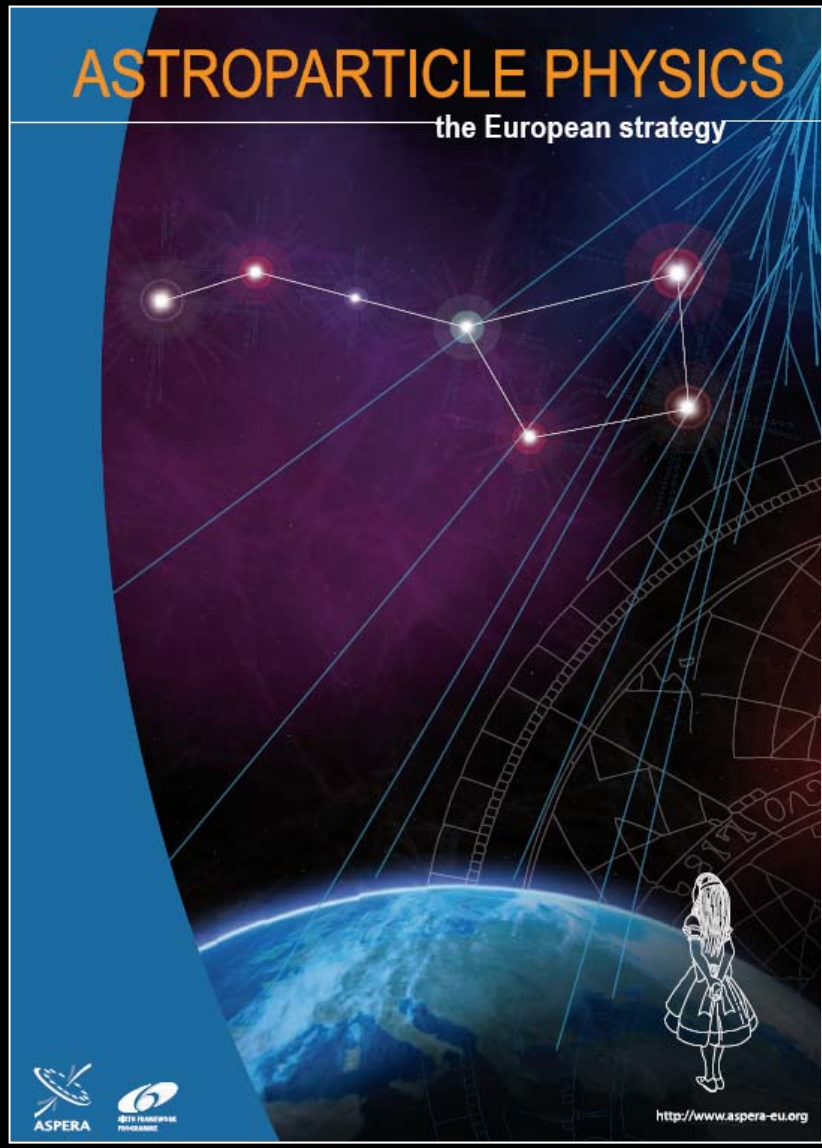
- **ASPERA-II EU program FP7 (2009-2012)**
  - Coordinator T. Berghoefer (BMBF)

  - **Update the roadmap**
  - **Accompany the realization of the roadmap**
  - **Coordinate with other continents**
  - **Knowledge transfer : industry, neighboring fields**
  - **Include the remaining European countries**
  - **ApPEC to a sustainable coordination scheme**



The Roadmap

- ✓Topical workshops organised by PRC since 2004
- ✓An inauguration workshop; Valence 2006
  - ✓Creation of 7 working groups
- ✓Science vision document, conference Amsterdam 2007
  - ✓ Workshops of the PRC
- ✓Action plan, conference Brussels 2008
  - ✓First discussions with non-european agencies
  - ✓Excellent convergence with ASTRONET/ESFRI
- ✓Many things happened since:
  - ✓International developments, realistic estimates, …
- ✓NEED to update the roadmap. Scientific Advisory Committee started working for an update by mid-2011



The European Roadmap priorities

1 ton dark matter

1 ton neutrino mass

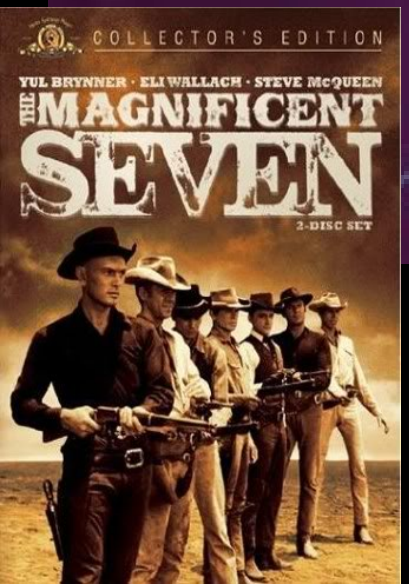
Megaton proton decay

Einstein telescope

CTA

AUGER -N

KM3NET



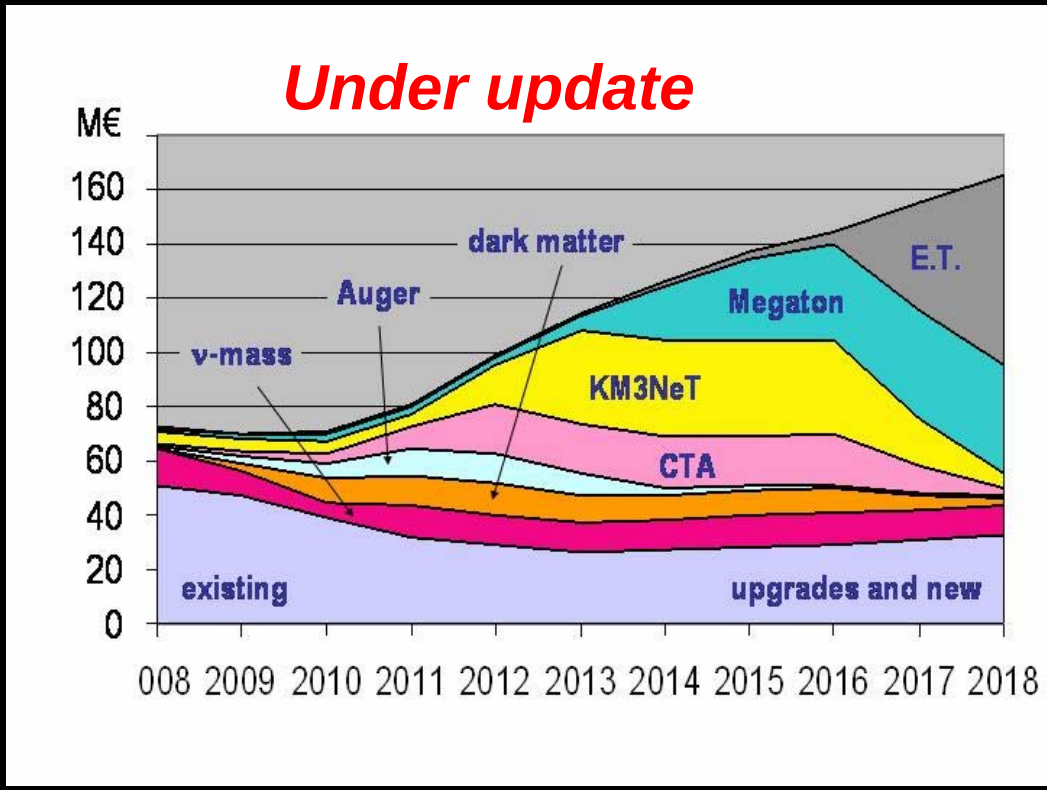
Did not cover in depth dark energy or space programs, since it concentrated in programs where the agencies participating were the major stakeholders. This will change in the update.

Timeline and cost

- *Milestone 1 (2012) technology decisions for:*
  - *Ton scale dark matter and*
  - *Ton scale neutrino mass*

- *Milestone 2 (2013) start the construction of* :
  - *KM3net and CTA*
  - *Quid Auger North?*

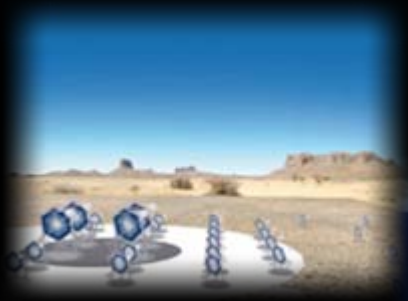
- Milestone 3 (> 2016) start the construction or participate in a worldwide collaboration for the construction of
  - *Megaton scale detector*
  - *Einstein Telescope*

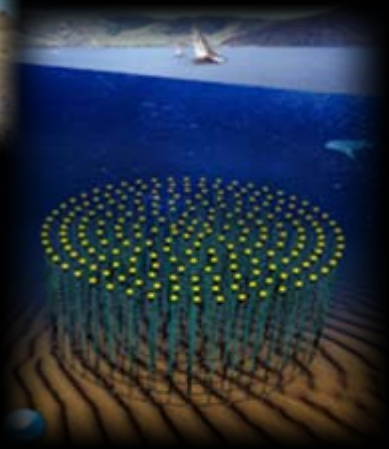


- The 2008 roadmap presented a scenario with 50% increase over traditional astroparticle budget (could not go below, due to multiplicity of funding sources)
- Help from regions? International sharing ? Sharing with other disciplines? Stretching factors ? Update of the roadmap by mid-2011, setting up agency committees

4 High Energy Universe infrastructures

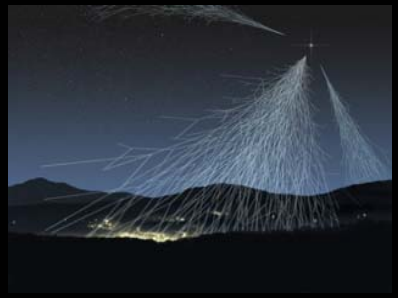
European context (DS,PP)
(ASPERA,ASTRONET, ESFRI)





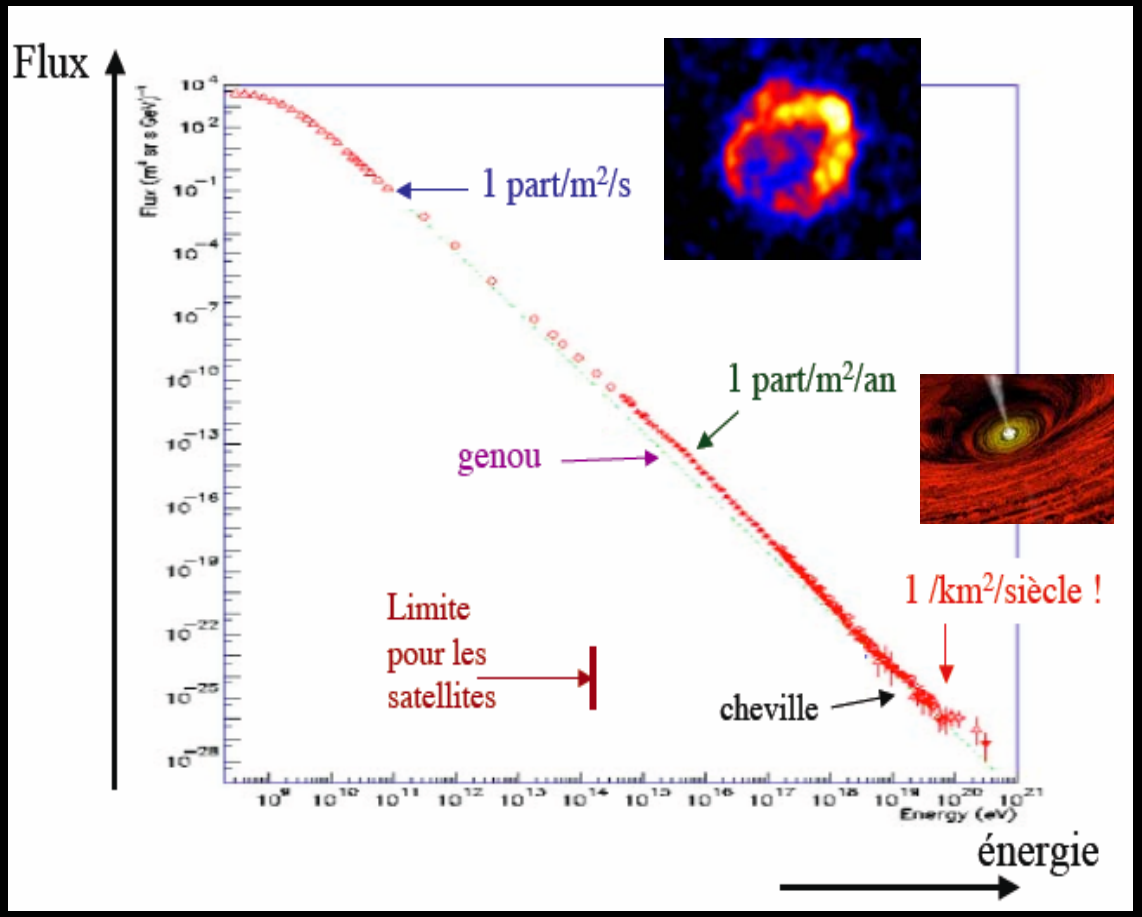
I. **Cherenkov Telescope Array (CTA)**
high energy γ
II. **Neutrino telescope (KM3)**
high energy ν

International context
(PASAG, US Decadal Survey, GWIC)



III. **Auger South Observatory and beyond**
ultra-high energy CR
IV. **Einstein Telescope (ET, DS)**
gravitational waves

The centennial puzzle of cosmic rays



Where are they accelerated?

Are the known laws of physics violated in the processes at their origin?

What happens during their propagation?

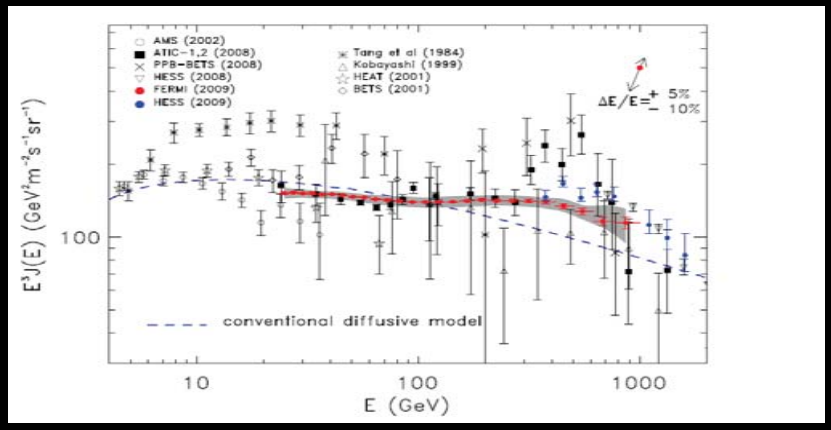
Are fundamental principles violated during this propagation?

What is their composition?

Are there dark matter decay or annihilation products among them?

Each of these questions (origin, propagation, composition) has both an astrophysical and a particle physics aspect which are closely entangled.

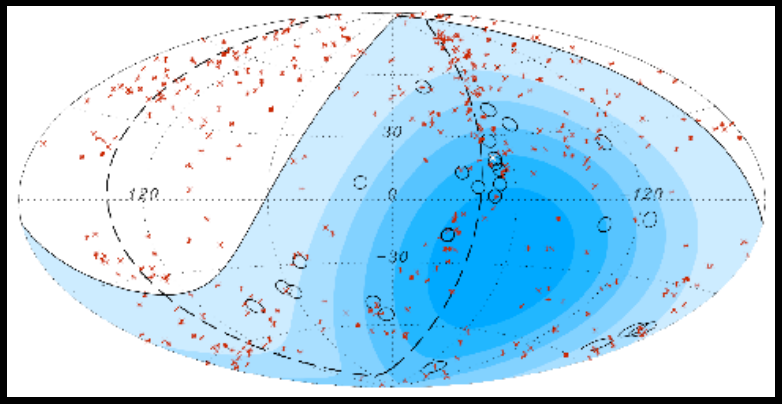
Cosmic rays in the last years : a rich harvest but still many uncertainties…



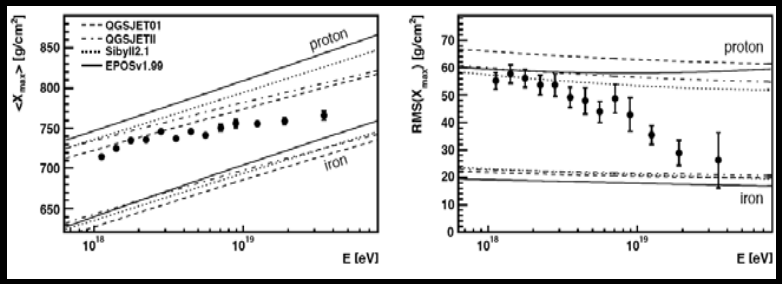
• Lower energies (PAMELA , ATTIC,FERMI, CREAM): Pulsars or dark matter ?

➔We must understand the galaxy to detect indirectly dark matter (remember the solar problem)

➔***AMS launch early 2011***



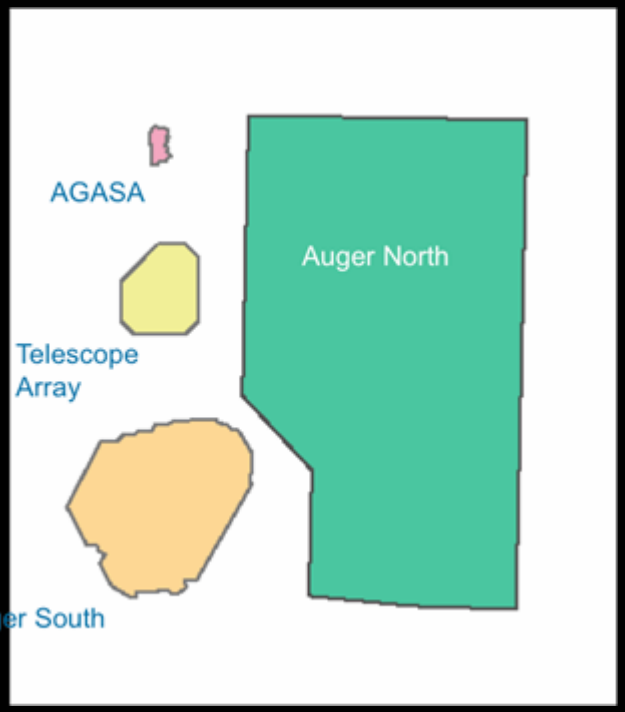
- UHECR , AUGER findings and ?
  - The GZK cutoff is there
  - No γ/ν (no top-down)
  - UHECR anisotropies. Correlations?
  - Protons or Iron?

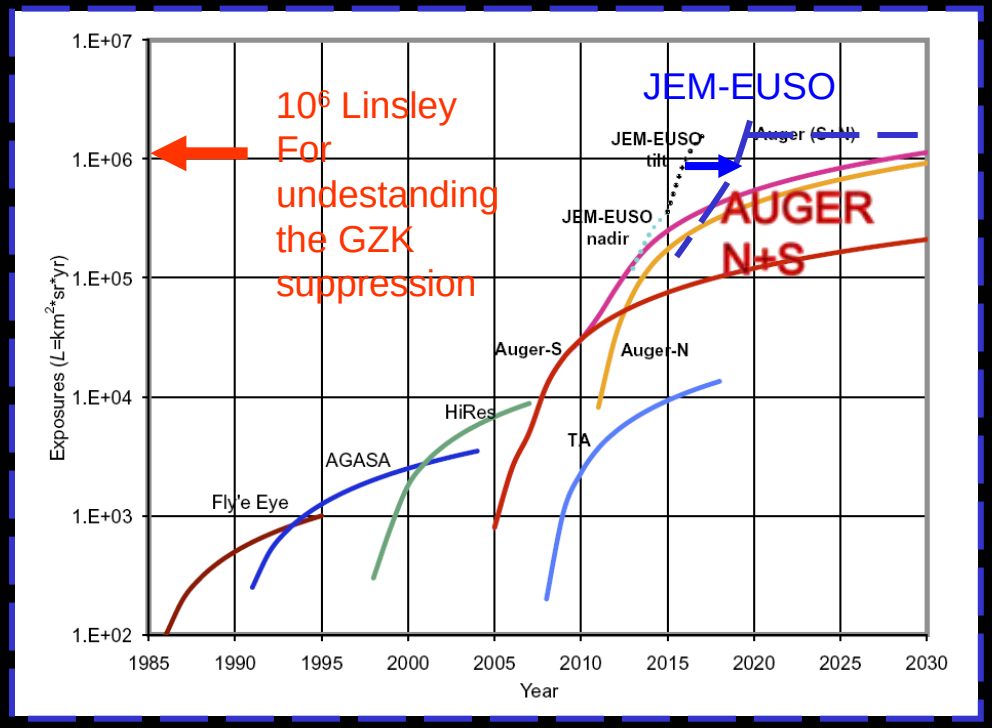


Which way beyond Auger South ?

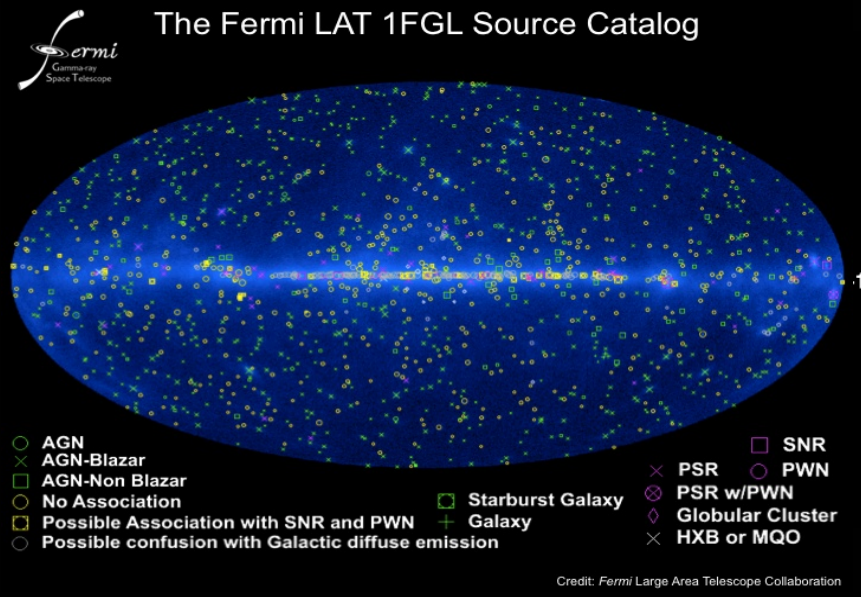
1) *Auger North x7 statistics @ GZK horizon*
2) *Increase the observables (separate muons from electrons in the shower) radiodetection?*
3) *Look down from space: JEM-EUSO*

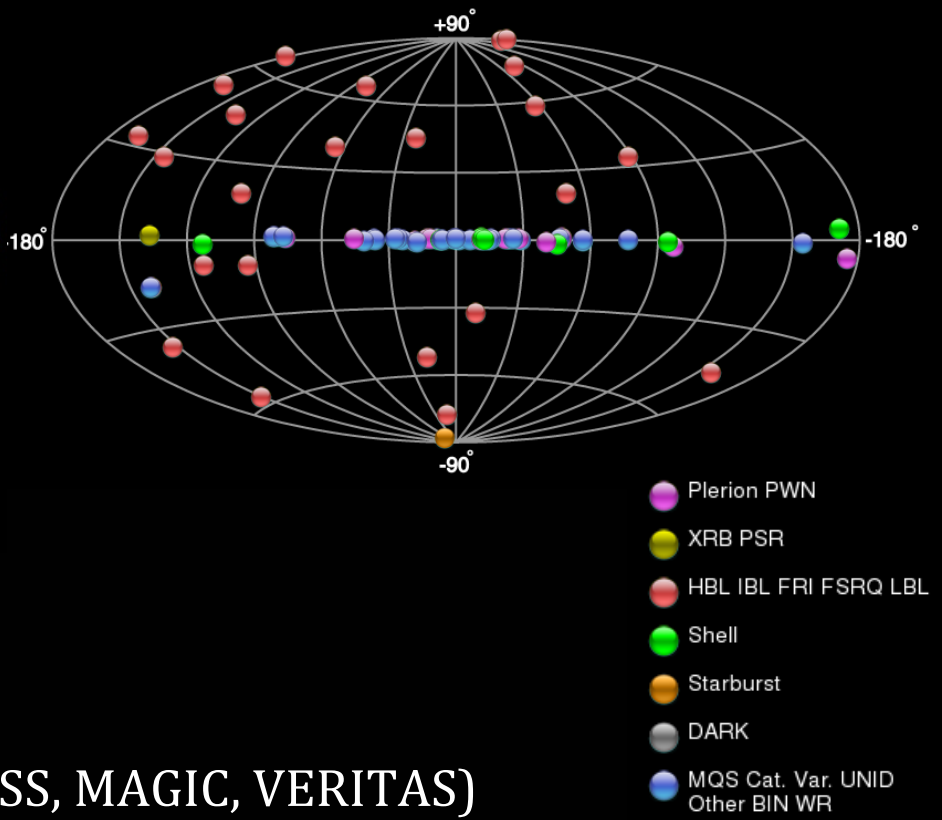
Wait for Astro2010, hopefully a mixture of 3





Golden age of HE gamma ray astronomy
In the last 5-10 years order of magnitude more sources discovered in the GeV and TeV sky





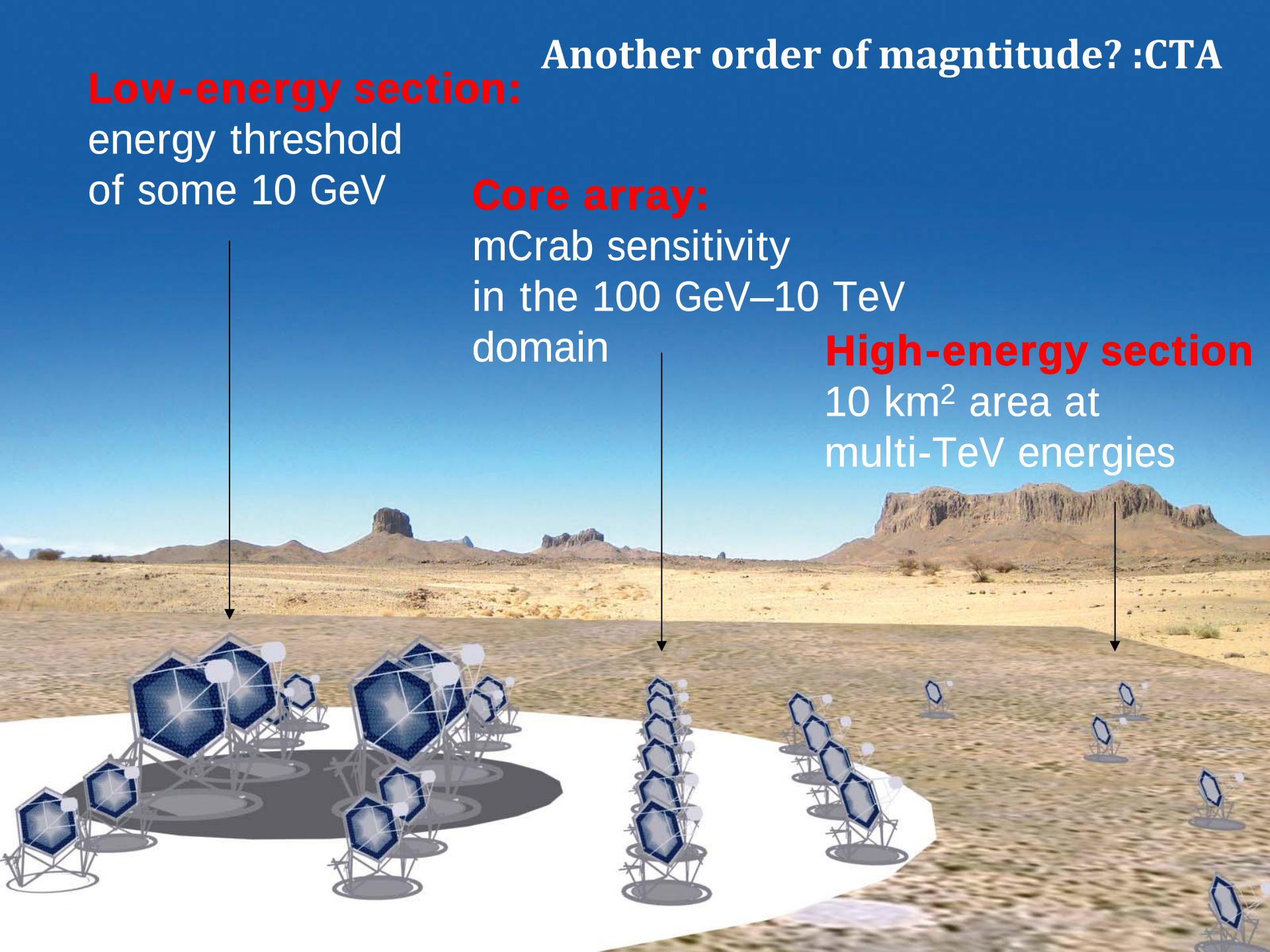
- 101 TeV sources discovered (HESS, MAGIC, VERITAS)
  - 12 in 2003
- 1451 GeV sources discovered (FERMI)
  - 350 in 2000

Another order of magntitude? :CTA

Low-energy section:
energy threshold
of some 10 GeV

Core array:
mCrab sensitivity
in the 100 GeV–10 TeV
domain

High-energy section
10 km^2 area at
multi-TeV energies



CTA

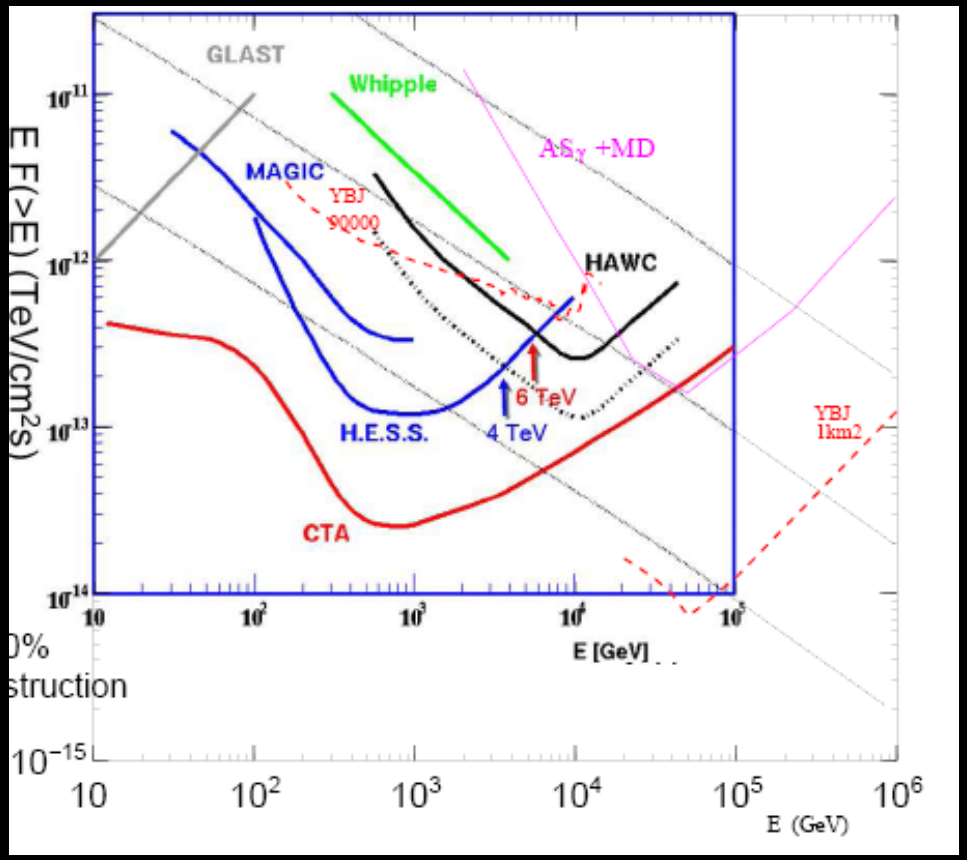
- ✓ **sensitivity x10**
- ✓ **angular resolution x2-3**
- ✓ **Field of view 2-3**

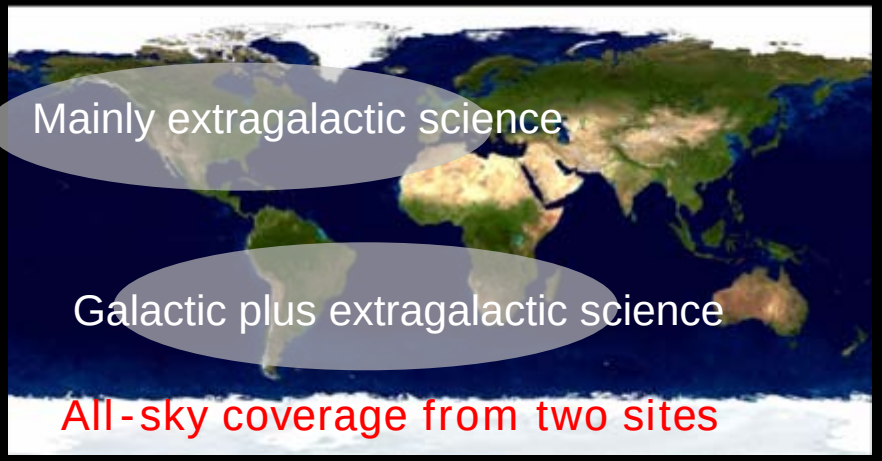
✓Collaboration: many European countries, plus other continents,
✓ AGIS(US), Japan joined CTA

✓Design study 2009-2012
✓(financed by APPEC/ASPERA)
✓Prep Phase under signature : 2010-2013
✓Start construction 2013-2014
✓End construction 2018
✓Superior to existing instruments 2015/16

✓Cost 150 M€ (2/3 south, 1/3 north)

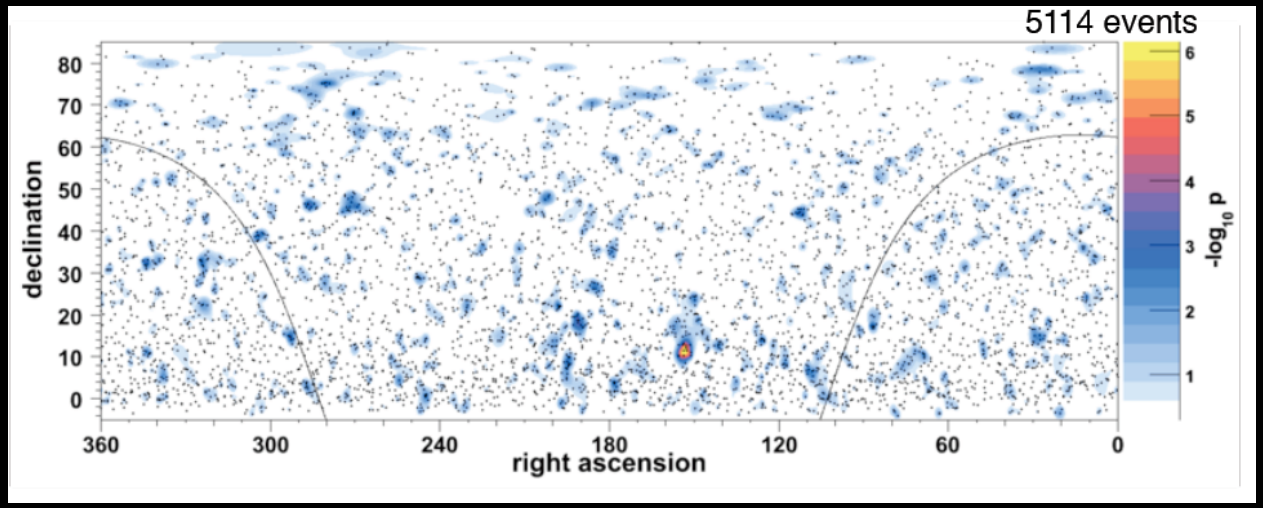
✓ World context:
✓Low energy MACE (India)
✓High energy LHAASO (China)





High Energy Neutrinos

Where are the sources ?

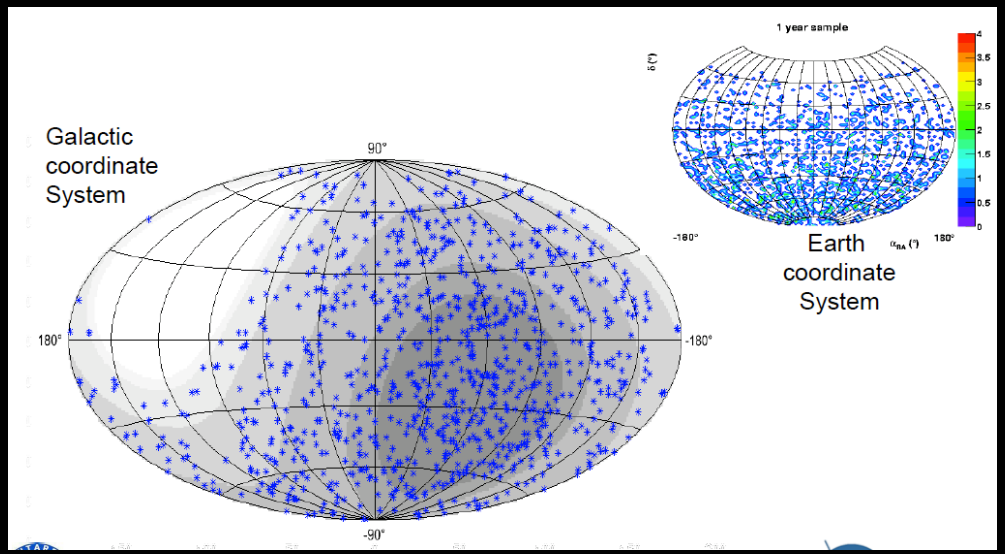


ICECUBE
Nearing completion
Only 1% fluctuations up to now

In the nothern hemisphere (looking down)

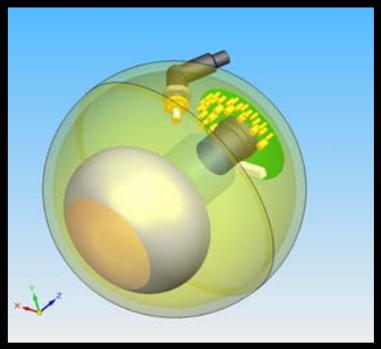
ANTARES

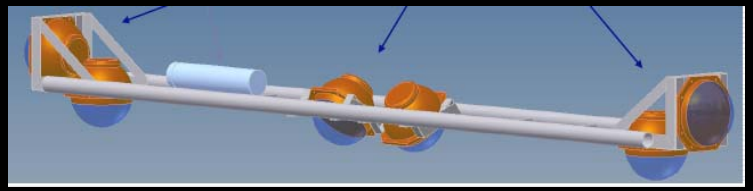
+R&D NEMO/NESTOR

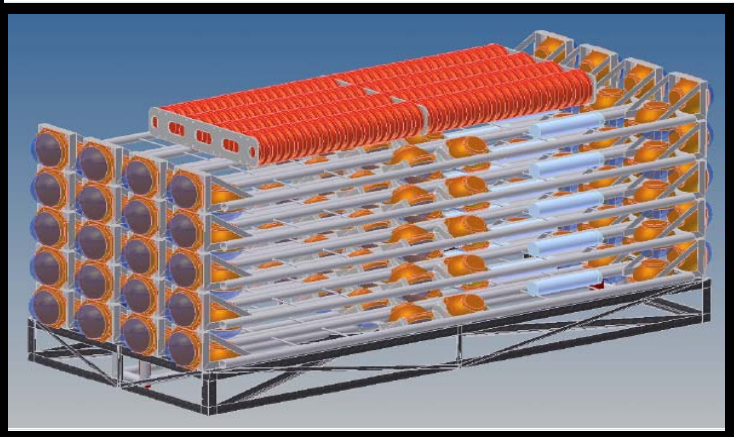


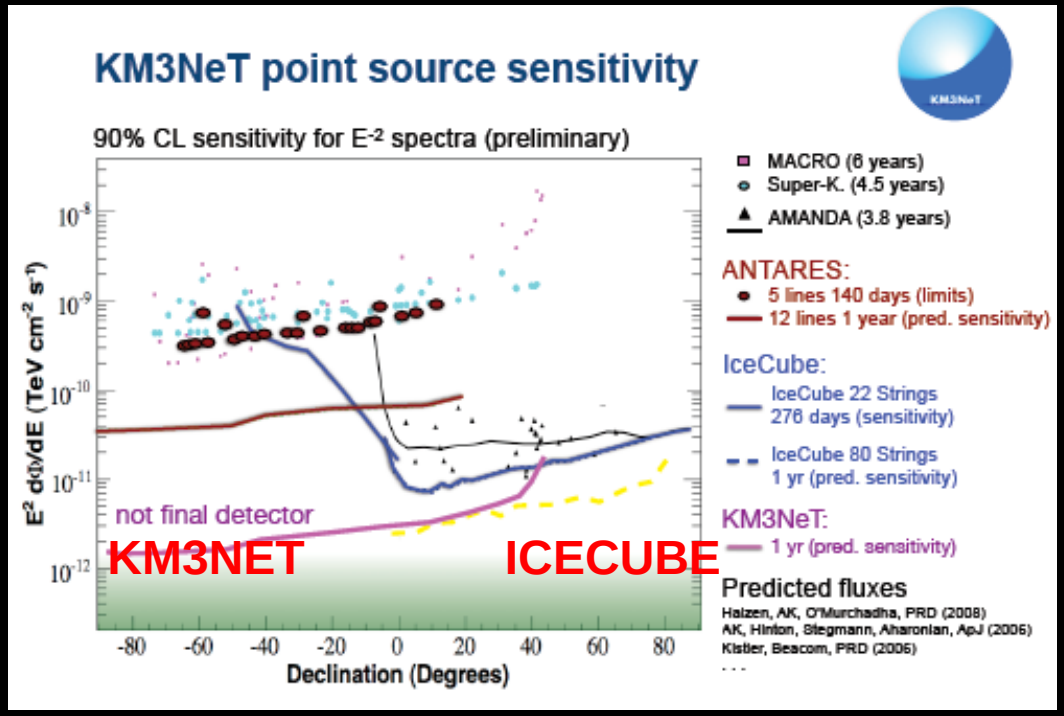
KM3Net

✓**Points to the Southern hemisphere and GC**
✓**X5 times ICECUBE sensitivity**



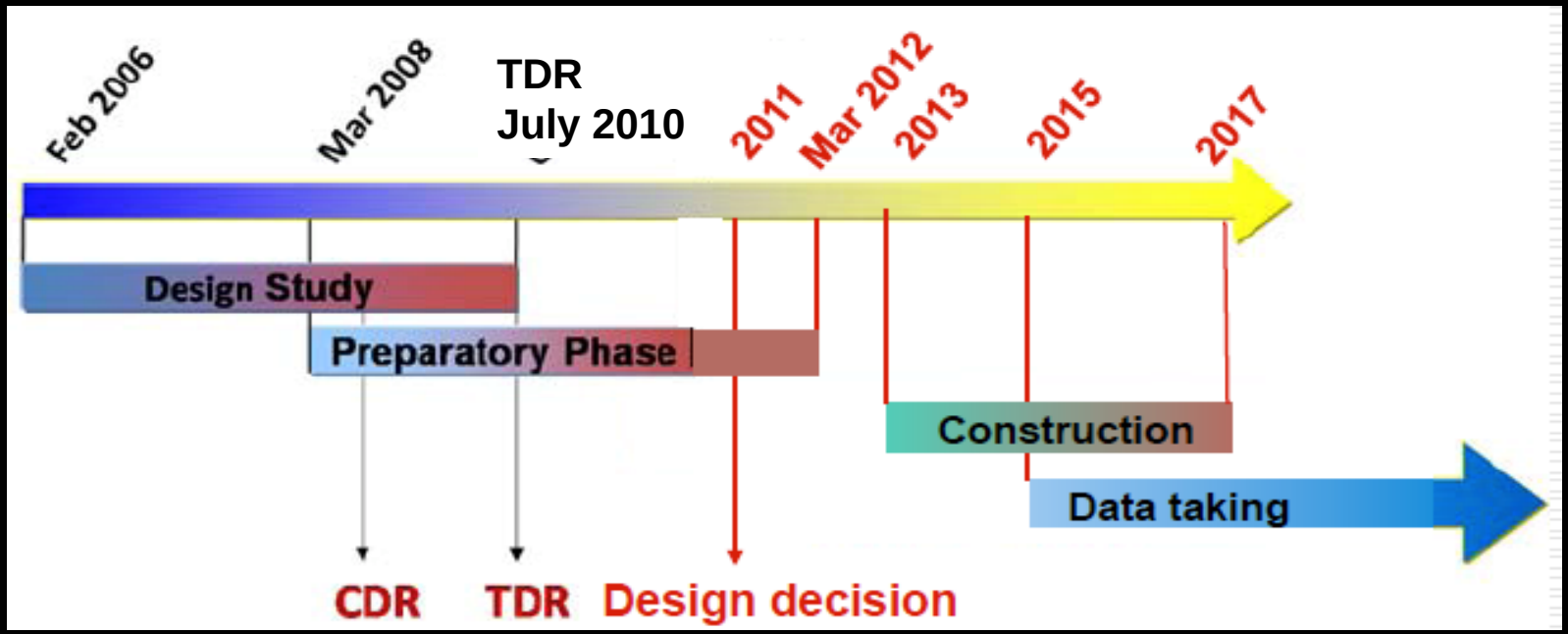


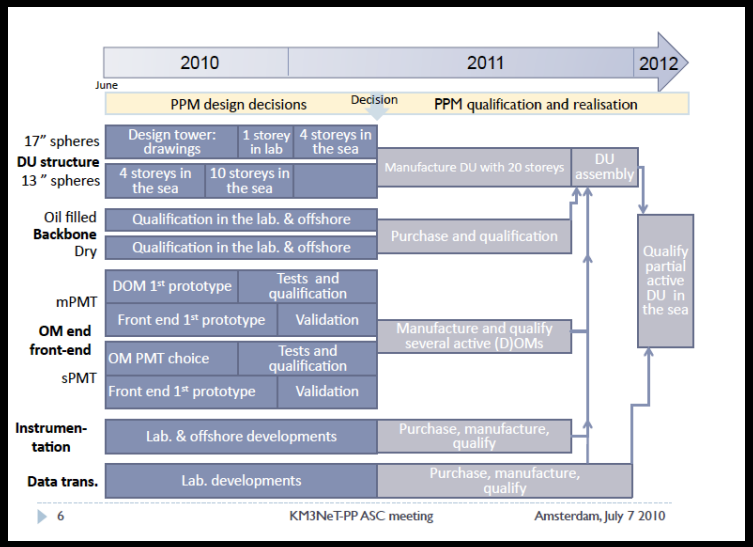




Parallelism with GW antennas:
Current phase is the phase of increase f the sensitivity till the first detection

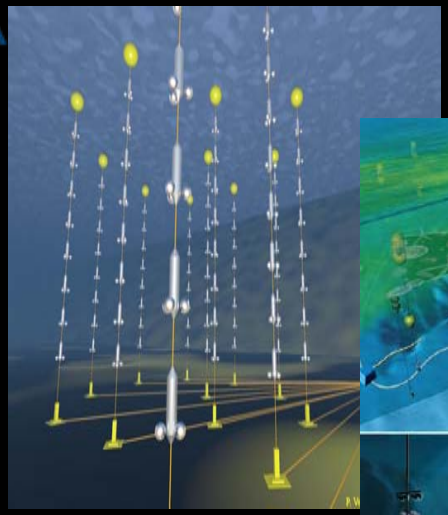
Timeline and cost

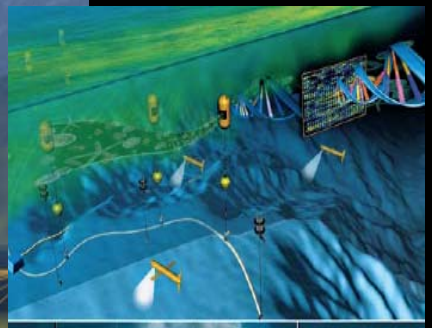




Technological convergence in progress
Tests of different options till mid-2011
In-situ qualification of final detection unit by 2012
Ready for construction by 2013
Regular meetings of an Agency Steering Committee
Establishment of Scientific Steering Committee
Towards a more flexible program of deployment ?

Synergies with geosciences and environment (new aspera theme)





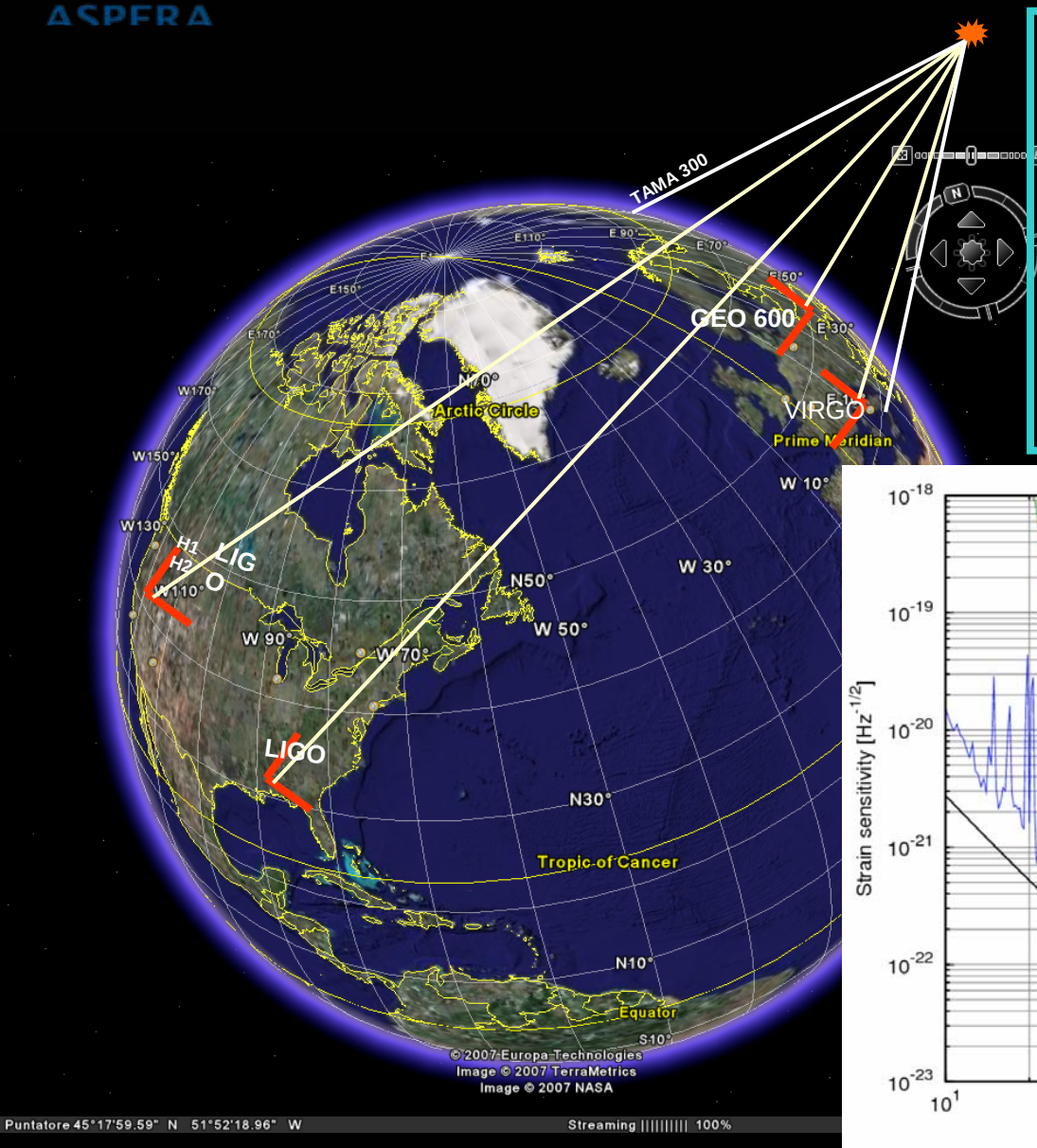
Astroparticle physics networks exhibit a natural synergy with climate and risk monitoring studies or geoscience observation networks. Since:

- ✓The atmosphere, the ocean and earth are both the target and detecting medium
- ✓Need to deploy large variable geometry networks of autonomous "smart" sensors in hostile environments

- ➢Neutrino telescopes as continuous ocean floor observatories;
  - ➢Oceanography (currents temperature variations)
  - ➢ Biodiversity (whales, bioluminescence,…)
  - ➢Seismology
  - ➢Environmetal studies
  - ➢….

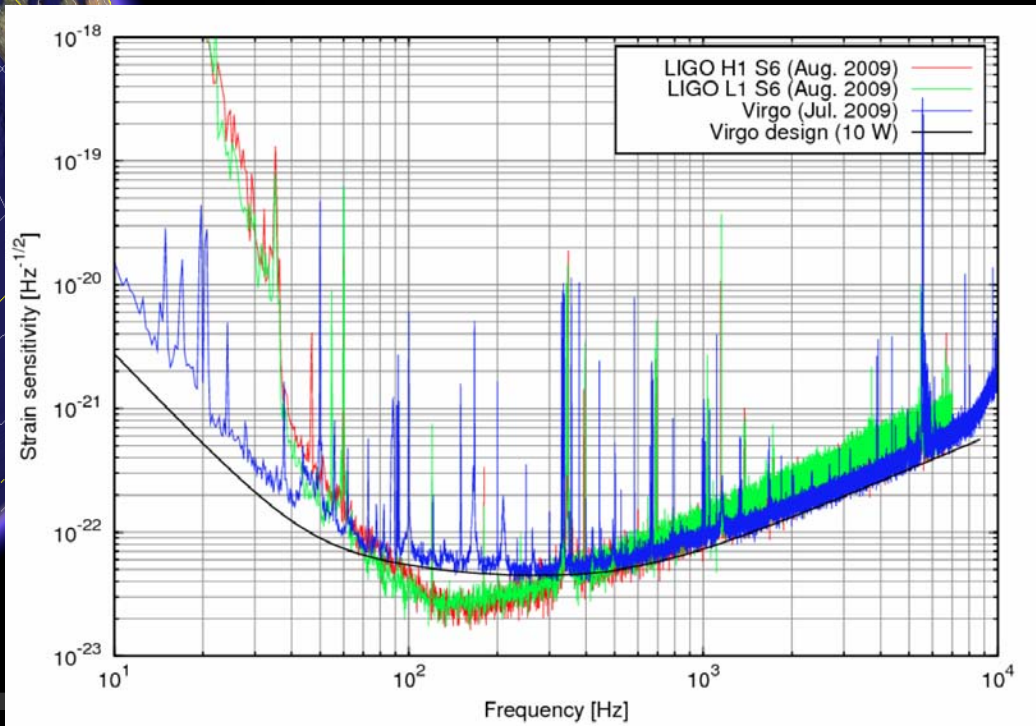
✓ There is now a clear demand by these disciplines for the technology developed in this context (EMSO, NEPTUNE, …)

Gravitational waves: AdvLIGO-advVIRGO common runs

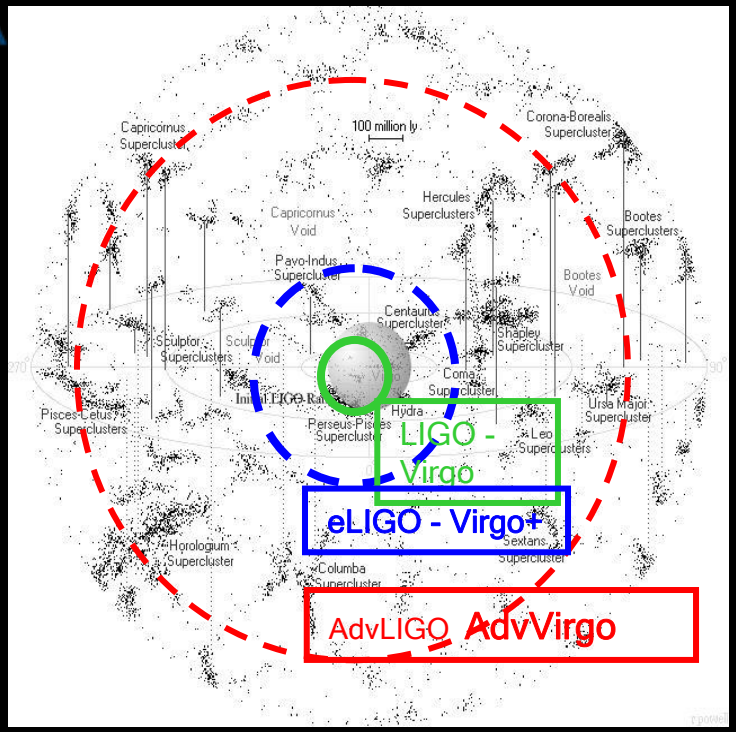


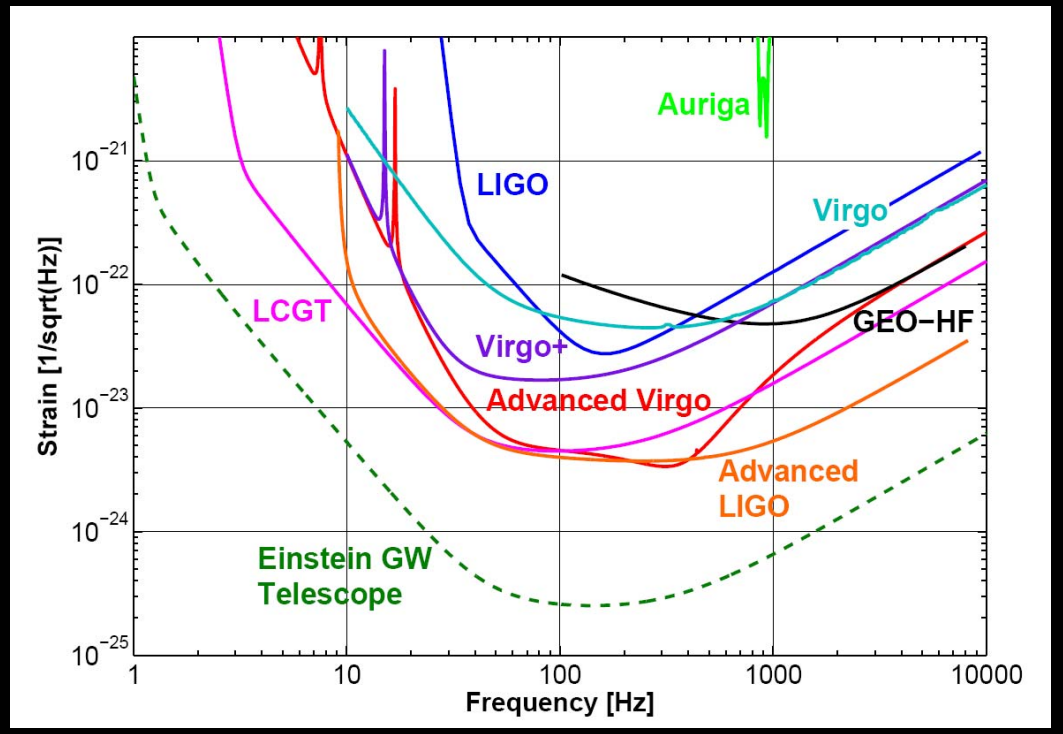
An inspiring example: World network of gravitational wave antennas:

- ✓ **Sensitivity increase**
- ✓ **Source direction determination**
- ✓ **Polarizations measurement**

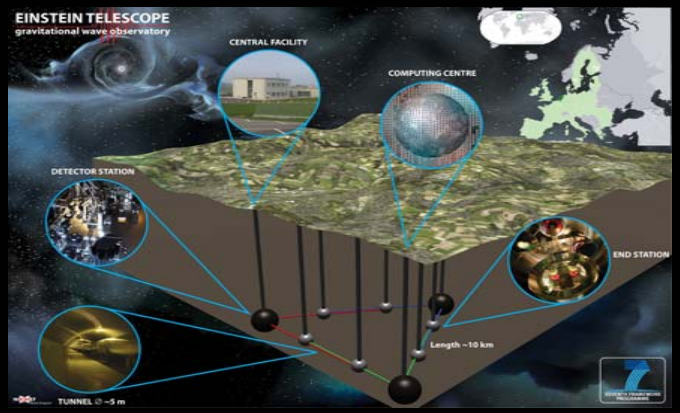


And beyond: Einstein Telescope (ET)





- ✓Adv-Virgo approved // timeline to adv-LIGO,
- ✓Expected 1-10 events/year by 2016-2018
- ✓If detection move to third generation
- ✓ EU funded Design Study: Einstein Telescope
- ✓Start construction by 2018-2019
- ✓Strong European support for LISA



3 infrastructures in underground laboratories

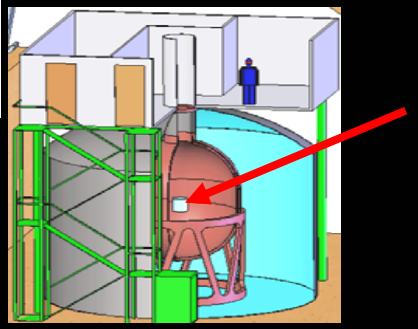
Addressing EW and GUT scale physics with very high cosmological impact

✓Dark Matter

Ton scale dark matter detectors

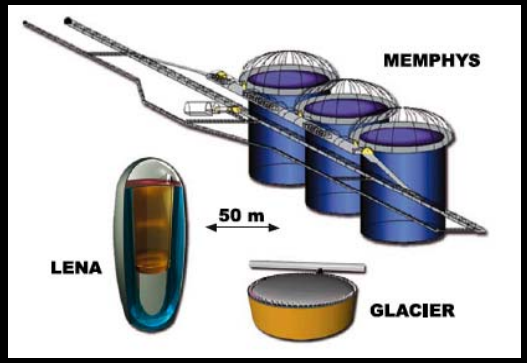
✓Neutrino mass

100Kg/ton neutrino mass detectors



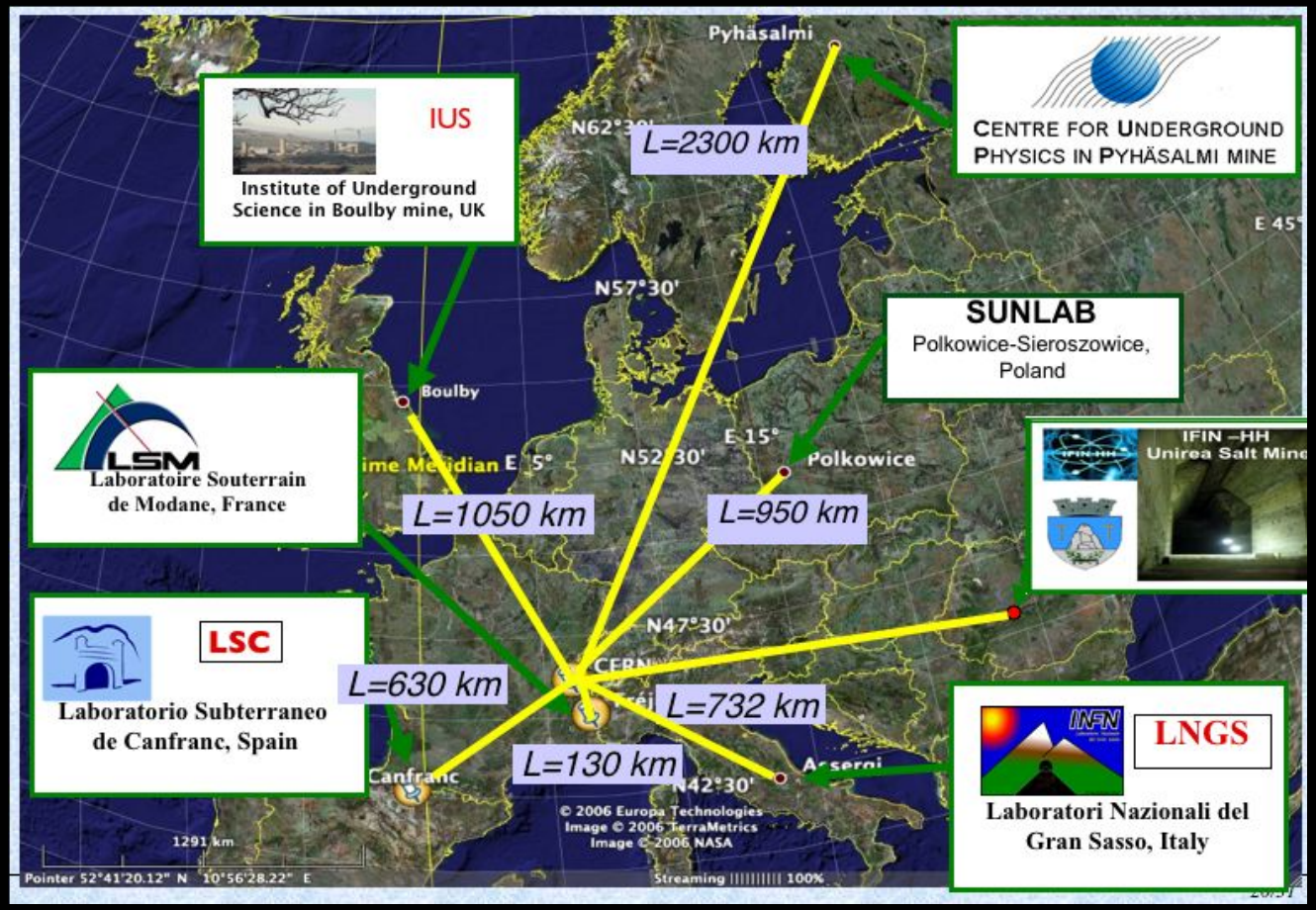
✓Proton decay, neutrino properties and low energy neutrino astrophysics

Megaton scale detectors

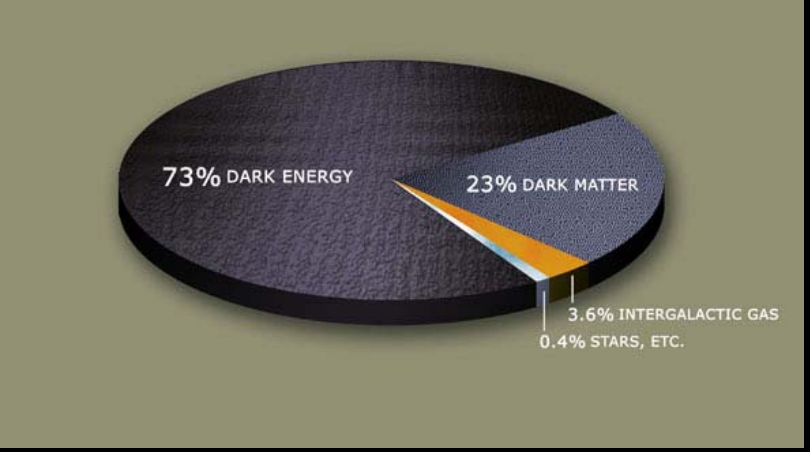


Underground laboratories

4 large laboratories + 3 smaller ones. Effort of coordination towards a distributed platform (Eulabs). Deliverable of ASPERA

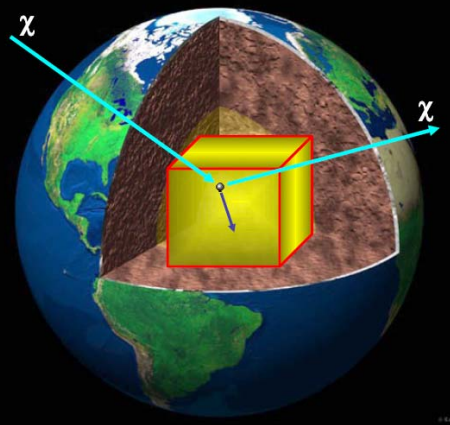


A common EU funded Design Study for cavity extensions (LAGUNA, results by september)



Direct Dark Matter searches

And axions of course…



PICASSO
SIMPLE

EDELWEISS

XENON, ZEPLIN_III
ArDM, WARP

ionisation
Q

scintillation
L

phonons
H

DAMA/LIBRA, ZEPLIN I
ANAIS

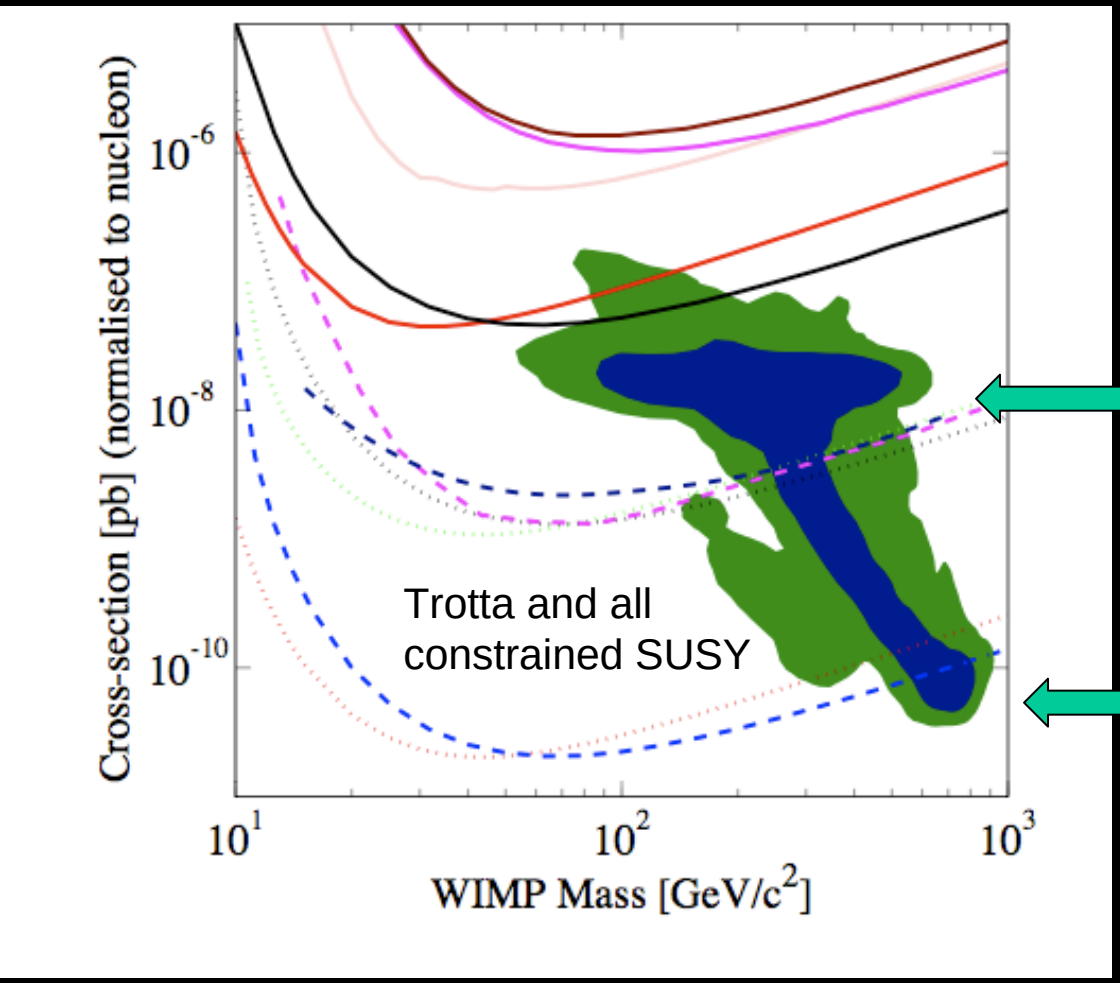
CRESST
ROSEBUD

Originally
by T. Sumner

Roadmap encourages large consortia of ton-scale and beyond

- EDELWEISS, CRESST =>EURECA
- XENON, ArDM => DARWIN
- Design studies financed by ASPERA

Dark Matter Searches



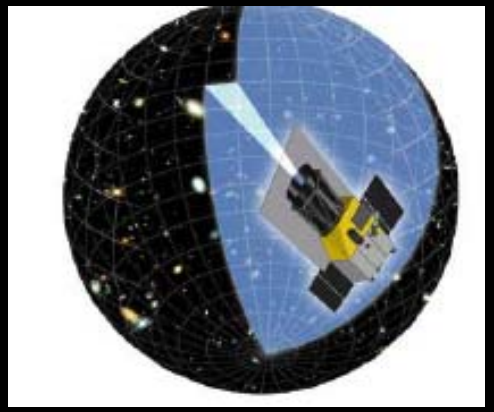
Present
1 event/ 100 kgdays

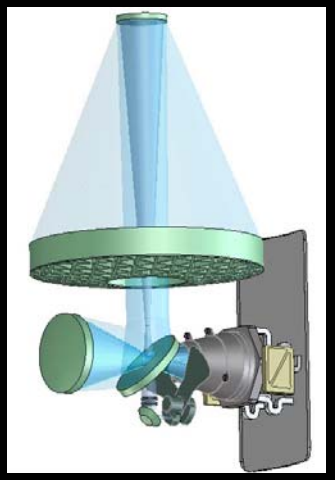
Next 3 years (2010-2012)
1 event/$10^{3\text{-}4}$ kgdays
XENON100/WARP140/
EDELWEISS-II/CDMS-II

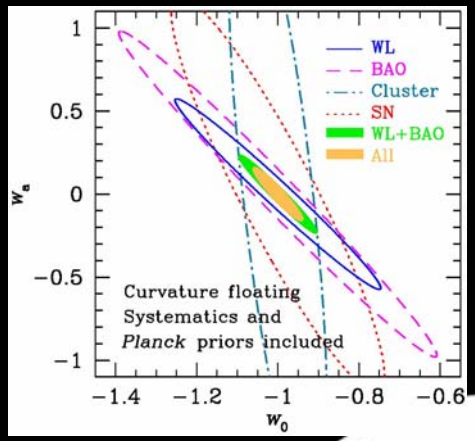
2013-2015
1 ton detector material
1-10 events/tonyear

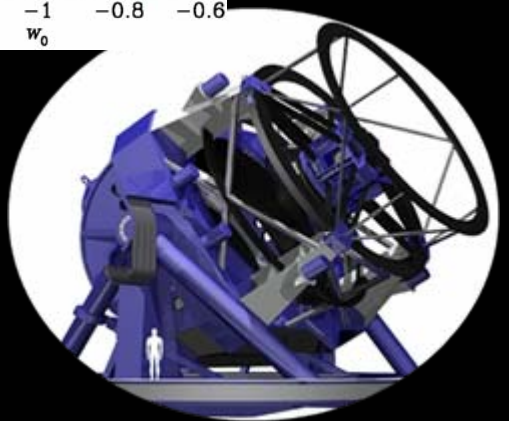
Dark Energy

- There are very visible contributions of the European astroparticle physics community to existing SNae program (SNFS, SNLS)
- For ground projects it supports participation to existing or future programs: (DES, BOSS, SuMire,..) but the emphasis is on LSST
- Space: Support for a common or complementary (EUCLIDE/JDEM) US-EU dark energy mission (all methods)
- The ESA mission EUCLIDE in 2 M missions enters phase A/B1 for a final selection in 2012 (launch 2018-2020).

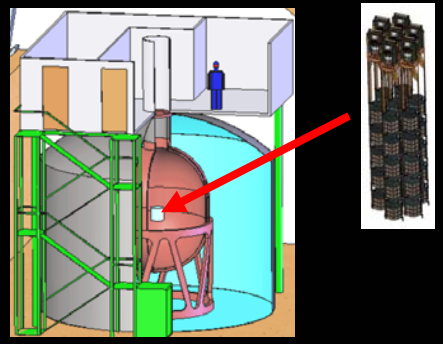








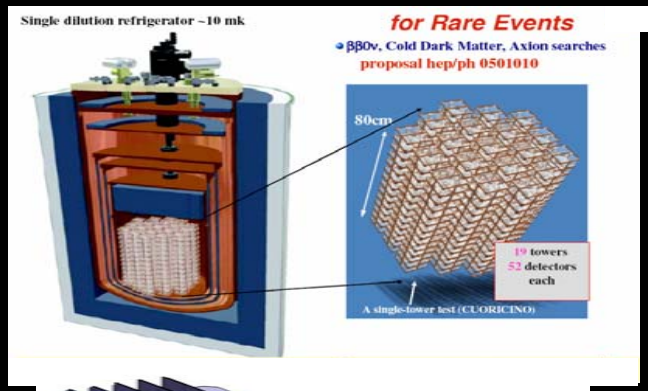
Neutrino mass searches



$0\nu\beta\beta$ decay: in operation CUORICINO, NEMO3

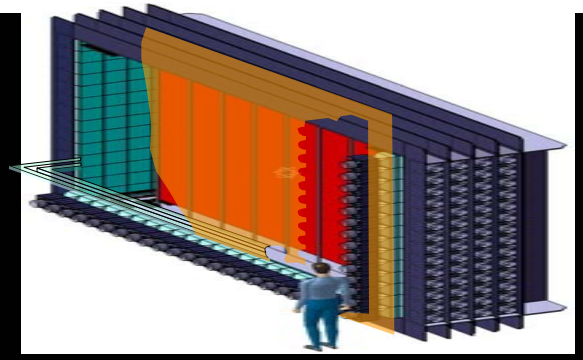
GERDA (I-II and III)

Ge diodes in liquid nitrogen
Implemented in phases (18,40,500 Kg)
Results phase I: 2011, phase II 2013



CUORE

Bolometer of TeO_2 (^{130}Te 203 kg)
Operation 2011, full detector in 2013



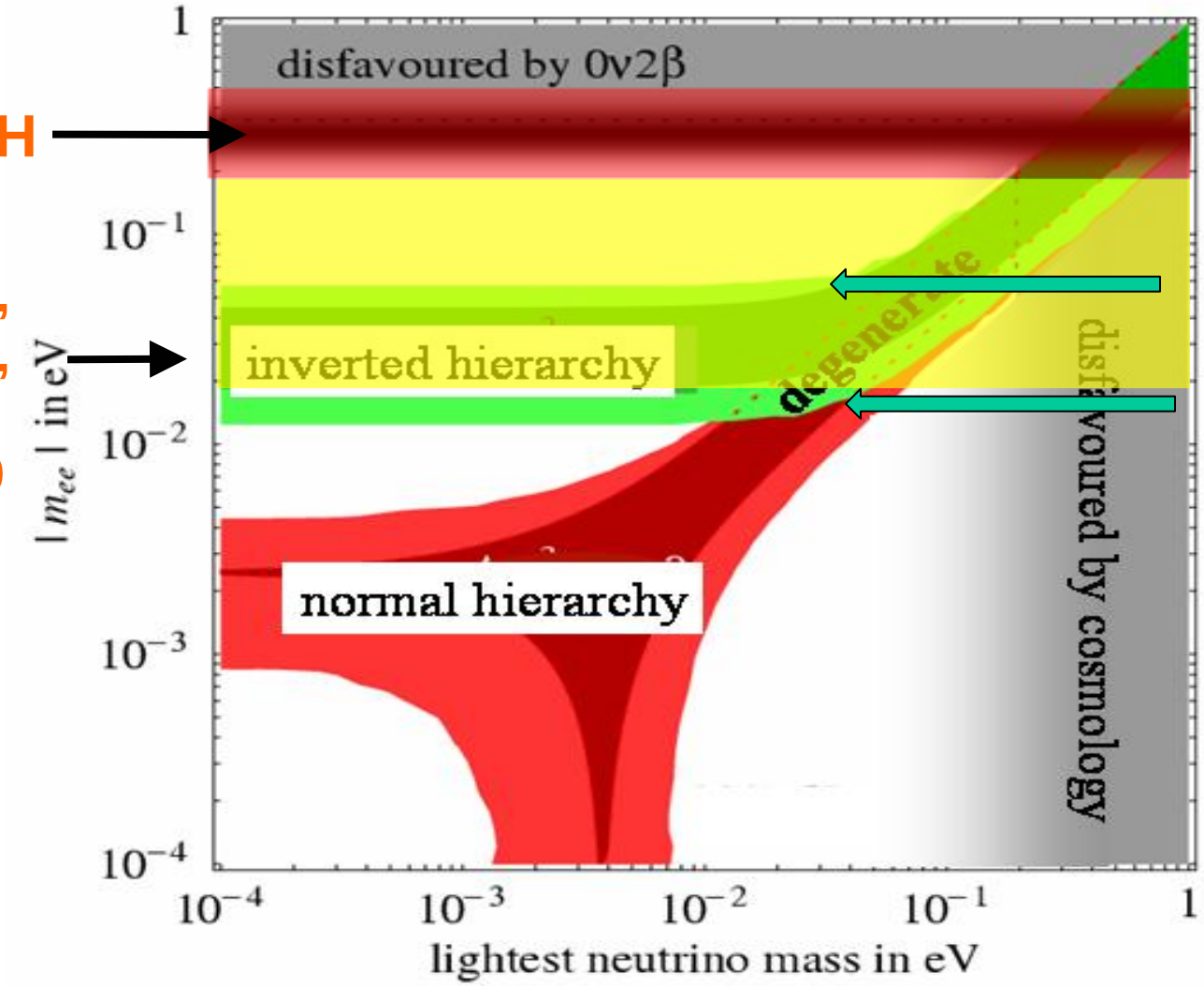
SuperNEMO

20 modules of a tracko-calo,
100 kg of ^{82}Se or ^{150}Nd

First module in 2012 (=GERDA I)

But also participation or R&D in EXO, Cobra, NEXT, Lucifer, …

Neutrino mass searches



KKGH

GERDA, CUORE, SNEMO EXO200

1-10 counts/year*ton

0,1-1 count/year*ton

LAGUNA Design Study

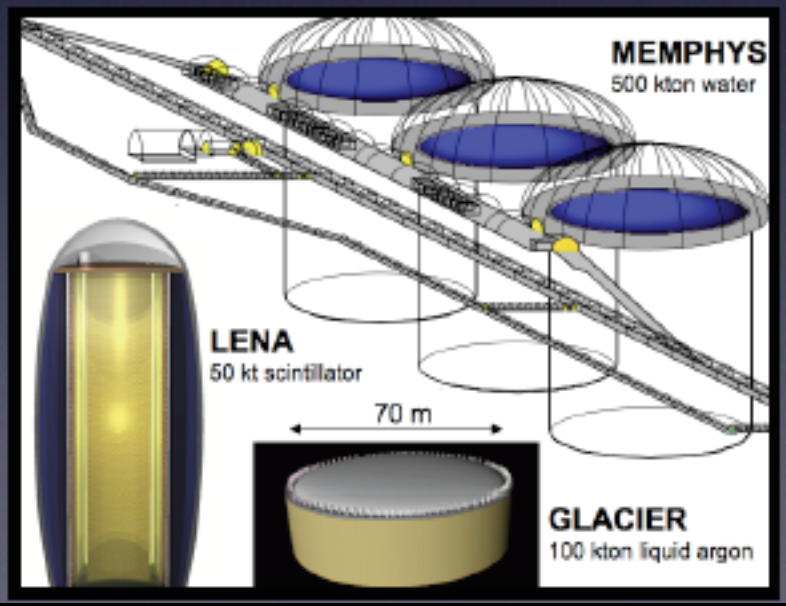
Large Apparatus for Grand Unification and Neutrino Astrophysics

- Objective: assess feasibility of a new far detector at a new site
  7 preselected sites and 3 detector concepts
- Participation (open): very interdisciplinary - most European physicists interested in massive detectors; geo-technical experts, geo-physicists; structural engineers; tank and mining engineers
- EU Funding and beneficiaries: €1.7M - 9 (+4) HE institutes; 8 research organizations; 4 companies

WP2: Underground Infrastructure and Engineering ↔

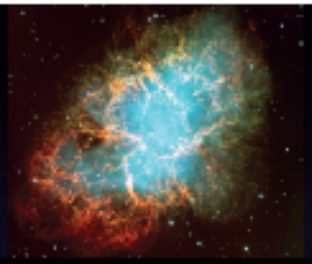
WP3: Safety, Environmental and Socio-Economic ↔

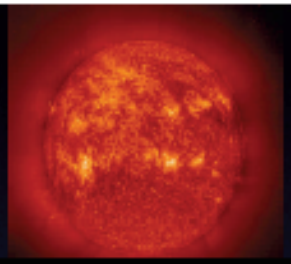
WP4: Science Impact and Outreach ↔

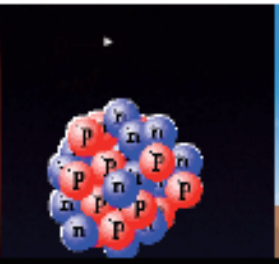


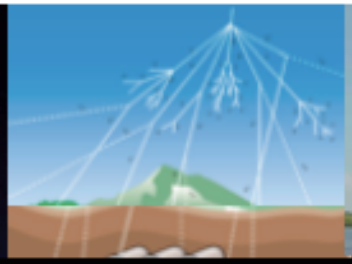
Science of LAGUNA

Particle Physics and Particle Astrophysics

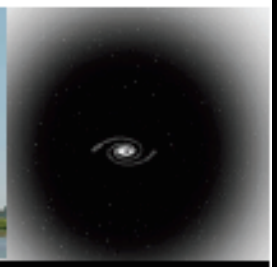

Supernova neutrinos


Solar neutrinos

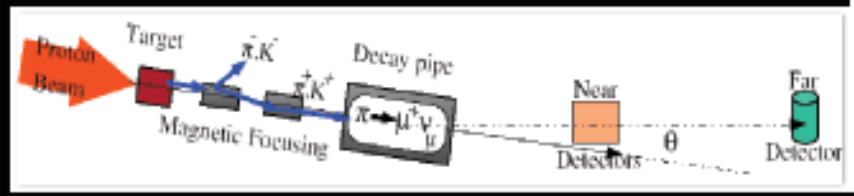

Proton decay


Atmospheric neutrinos

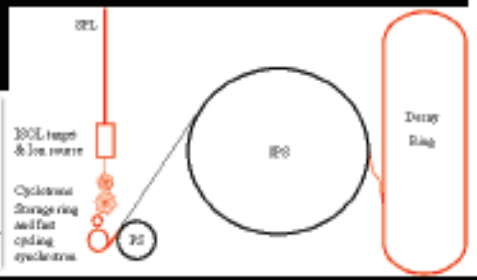

Reactor neutrinos


Dark matter

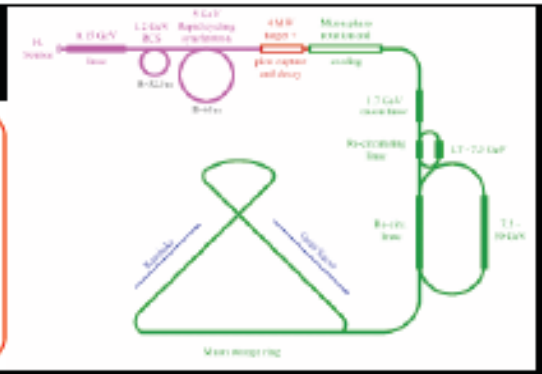
Neutrino Physics with accelerators



Superbeams



Betabeams


Neutrino factor

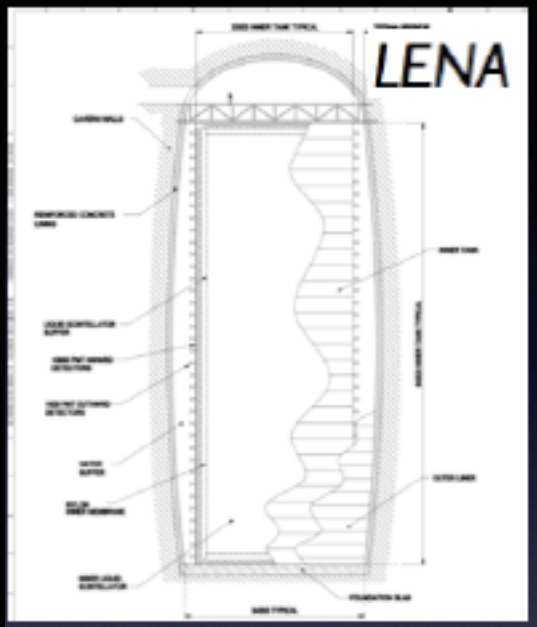
Science of LAGUNA

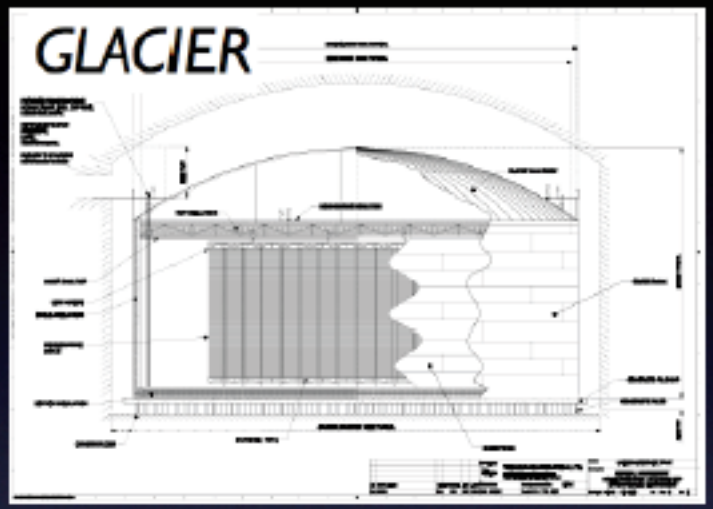
	Water Cerenkov	Liquid Argon TPC	Liquid Scintillator
Total mass	500 kton	100 kton	50 kton
$p \rightarrow e\,\pi^0$ in 10 years	$1.2\text{x}10^{35}$ years $\varepsilon = 17\%$, $\approx$ 1 BG event	$0.5\text{x}10^{35}$ years $\varepsilon = 45\%$, <1 BG event	?
$p \rightarrow \nu\,K$ in 10 years	$0.15\text{x}10^{35}$ years $\varepsilon = 8.6\%$, $\approx$ 30 BG events	$1.1\text{x}10^{35}$ years $\varepsilon = 97\%$, <1 BG event	$0.4\text{x}10^{35}$ years $\varepsilon = 65\%$, <1 BG event
SN cool off @ 10 kpc	194000 (mostly $\nu_e p \rightarrow e^+ n$)	38500 (all flavors) (64000 if NH-L mixing)	20000 (all flavors)
SN in Andromeda	40 events	7 (12 if NH-L mixing)	4 events
SN burst @ 10 kpc	$\approx$250 ν-e elastic scattering	380 ν_e CC (flavor sensitive)	$\approx$30 events
SN relic	250(2500 when Gd-loaded)	50	20-40
Atmospheric neutrinos	56000 events/year	$\approx$11000 events/year	5600/year
Solar neutrinos	91250000/year	324000 events/year	?
Geoneutrinos	0	0	$\approx$3000 events/year

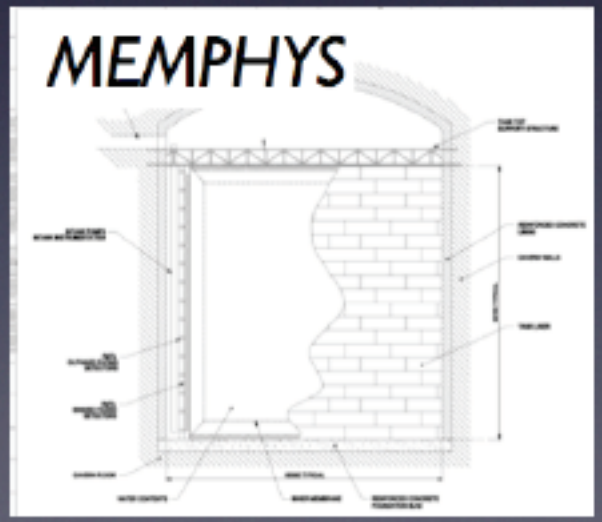
Superbeams Betabeams Neutrino factor

(1) Tank Concepts - Cavern Scale

Engineering of large tanks becoming well understood







- Collaboration with Technodyne Ltd.

	MEMPHYS	LENA	GLACIER
Overburden	>2000 mwe	>4000 mwe	>600 mwe
#tanks	3 to 5	1	1 preferred
Dimensions of tank	cylinder 65m Ø x 65m height	SS cylinder of 30m Ø x105 m height, inside a external tank of ~ cylindrical shape, of at least 34m Ø for water-buffer.	cylinder: 72,4m Ø x 26,5m height dome: 12,7m height x 144,8m Ø
Cavern	65m Ø x 70m height + dome	Egg-shaped to house external tank	cylinder: 75,1m Ø x 26,5m height + dome

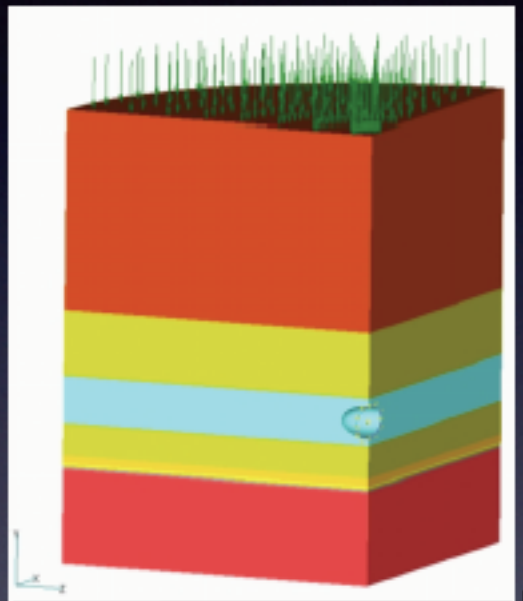
(2) Geo-mechanical Studies

Rock data gathered, rock tests and simulations by all sites

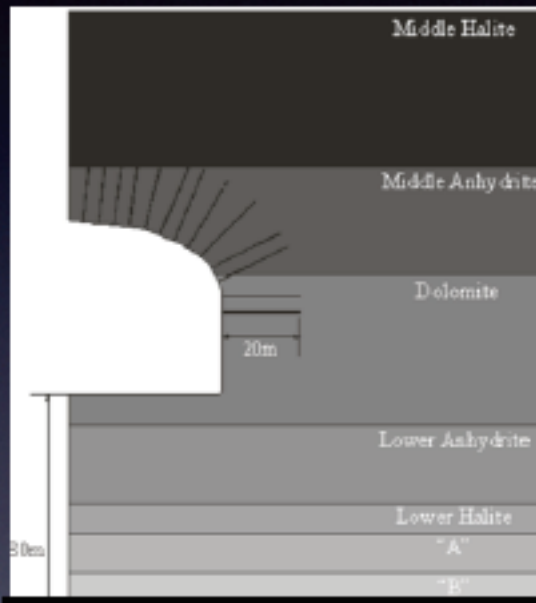
- Convergence
- Spalling
- Rock-bolting
- Mucking
- Multi-strata rock issues
- Cavern shapes

EXAMPLES

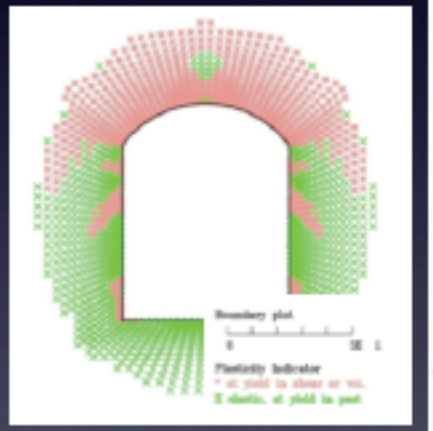
Sieroszowice



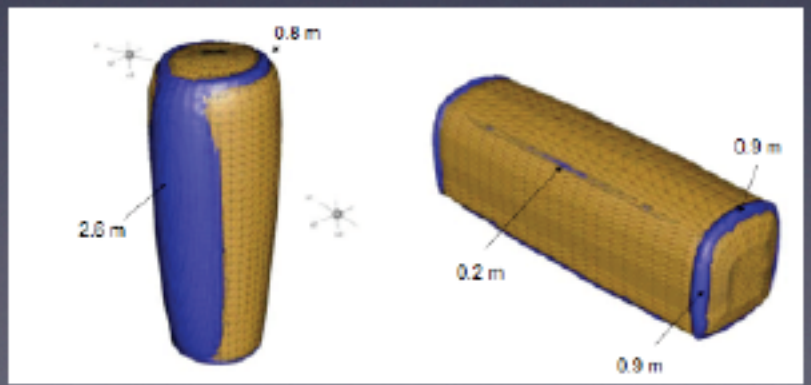
Boulby

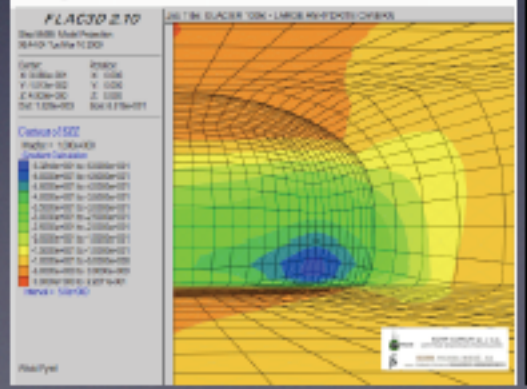


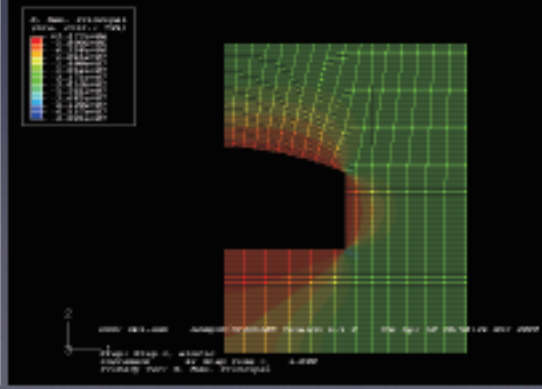
Frejus



Phyasalmi



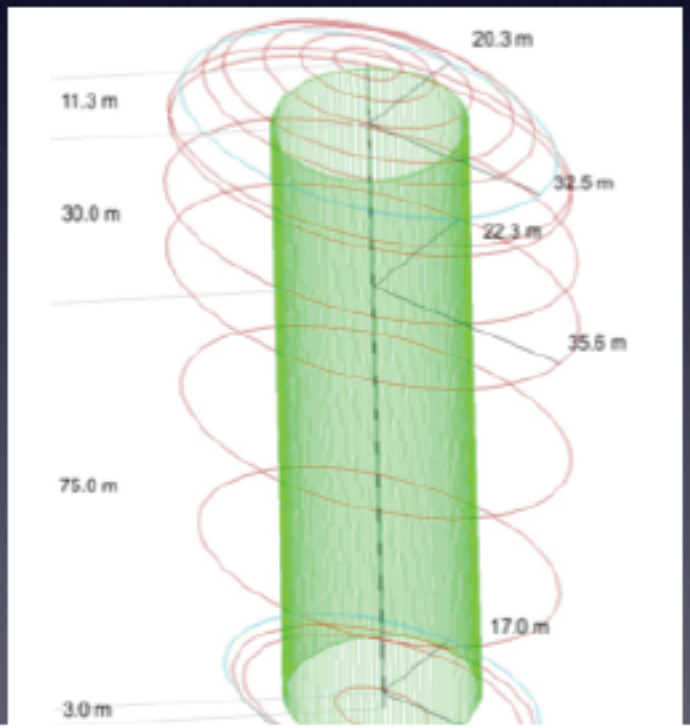




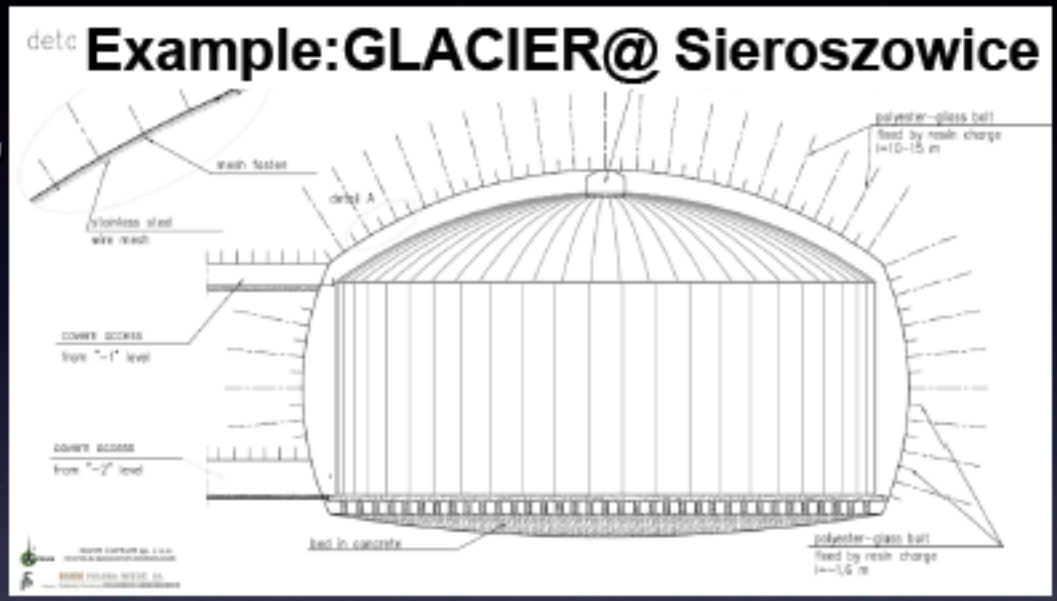
(3) Main Cavern Engineering

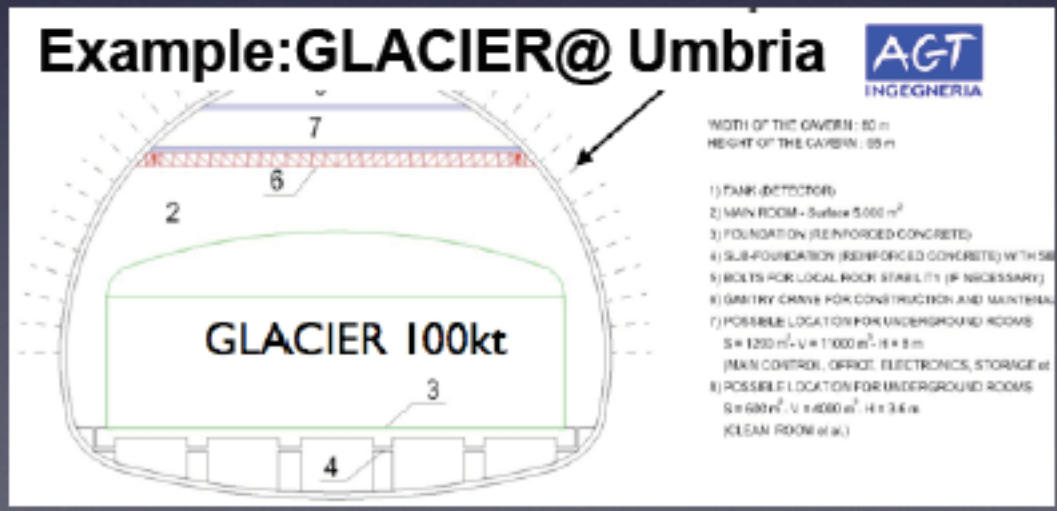
Focus on Main Detector Cavern (MDC) engineering

- Relationship between tank design and main cavern excavation
- Interaction between scientists, Technodyne Ltd. with Rockplan, Cuprun, CPL, AGT



Example LENA@ Phyasalmi

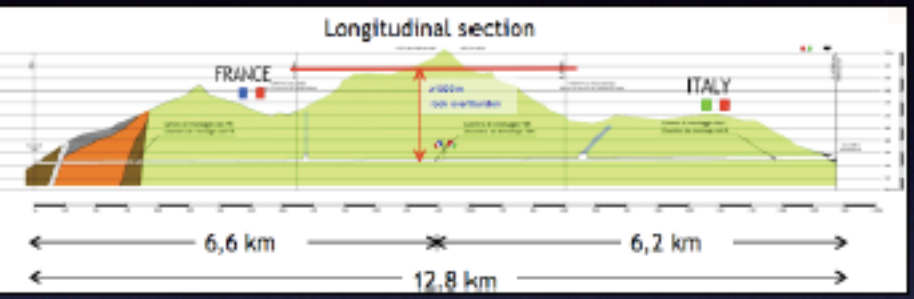


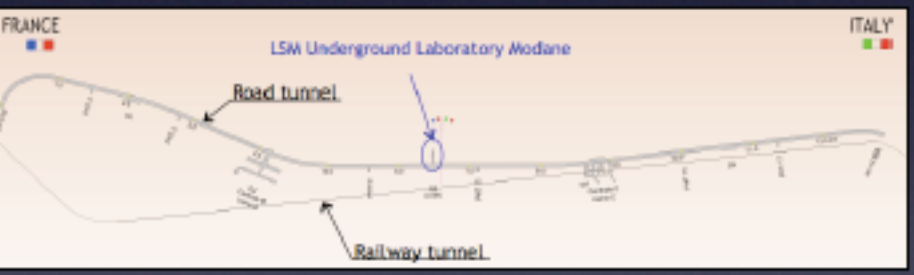


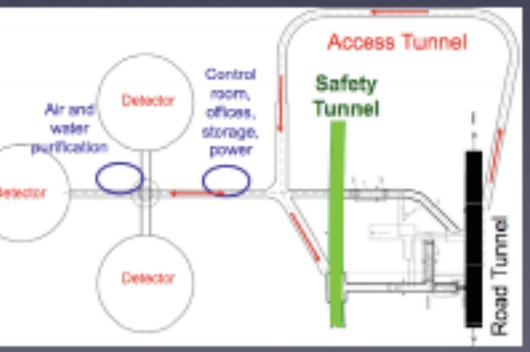
(4) Layout studies: Tunnel sites

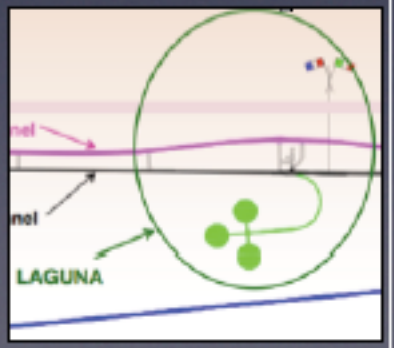
Frejus

- 130 km from CERN
- Deepest site (1700m)
- MEMPHYS design study



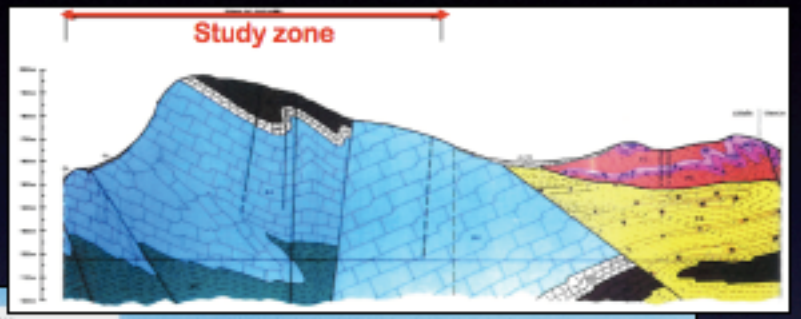


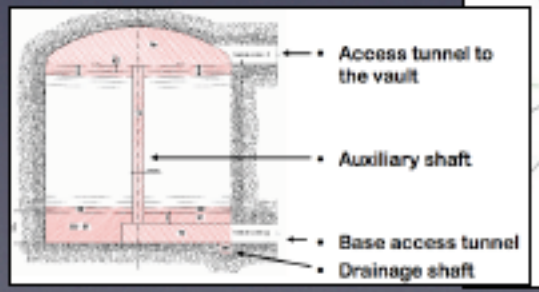


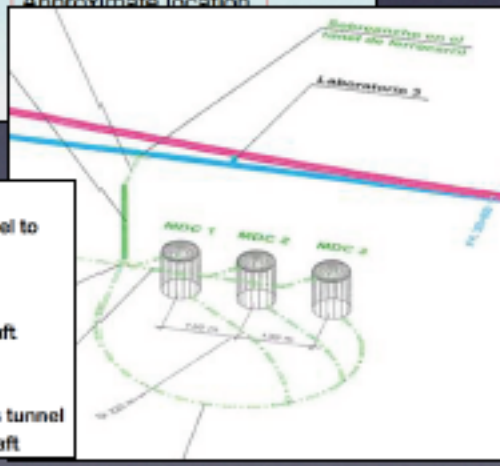


Canfranc

- 630 km from CERN
- Likely requires new tunnel + shaft (current depth 800m)







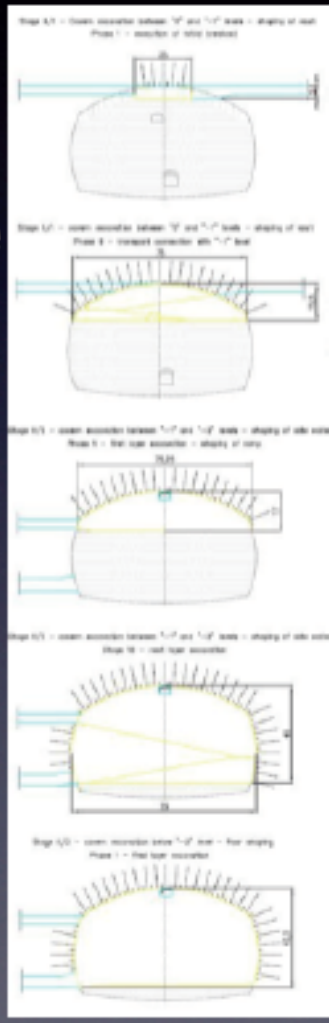
(5) Construction Sequences

Details of construction sequence also studied at all sites

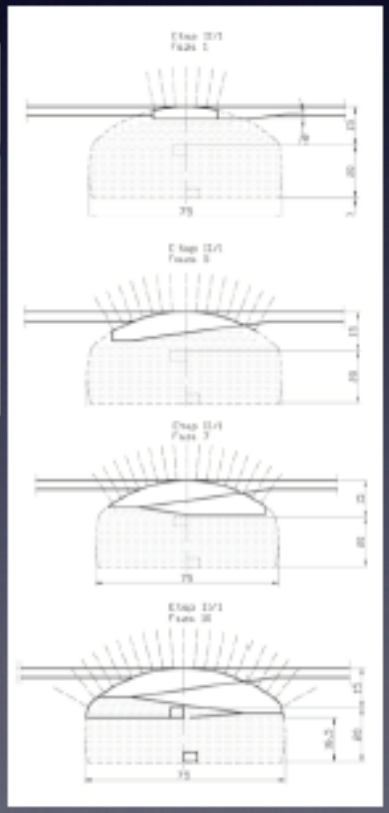
- Geotechnical stability and safety at each stage of excavation
- Requirements for rock removal and rock bolting
- Egress routes and evacuation safety

EXAMPLES

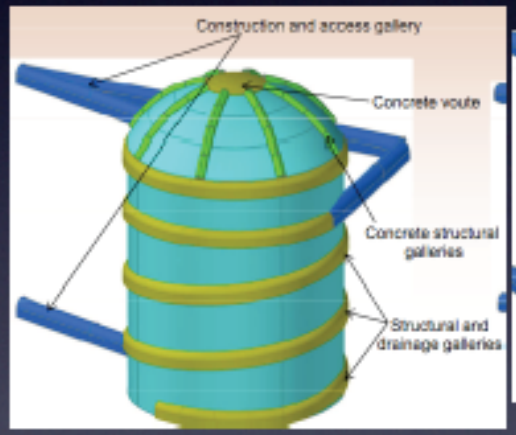
Umbria



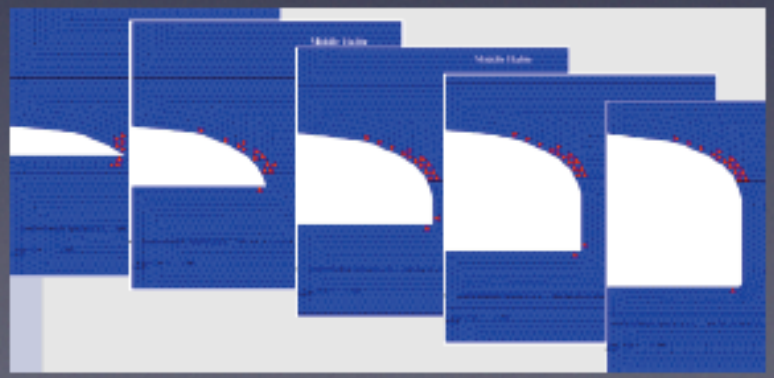
Sieroszowice



Frejus



Boulby



LAGUNA [redacted] Timeline

Paper Design Study (EU funded):	2008-2010
Prioritize the sites and down-select:	July 2010
Prioritize detectors and down-select LAGUNA-NEXT:	2011-2012
Detailed construction phase study:	2012-2015
LAGUNA construction	>2015

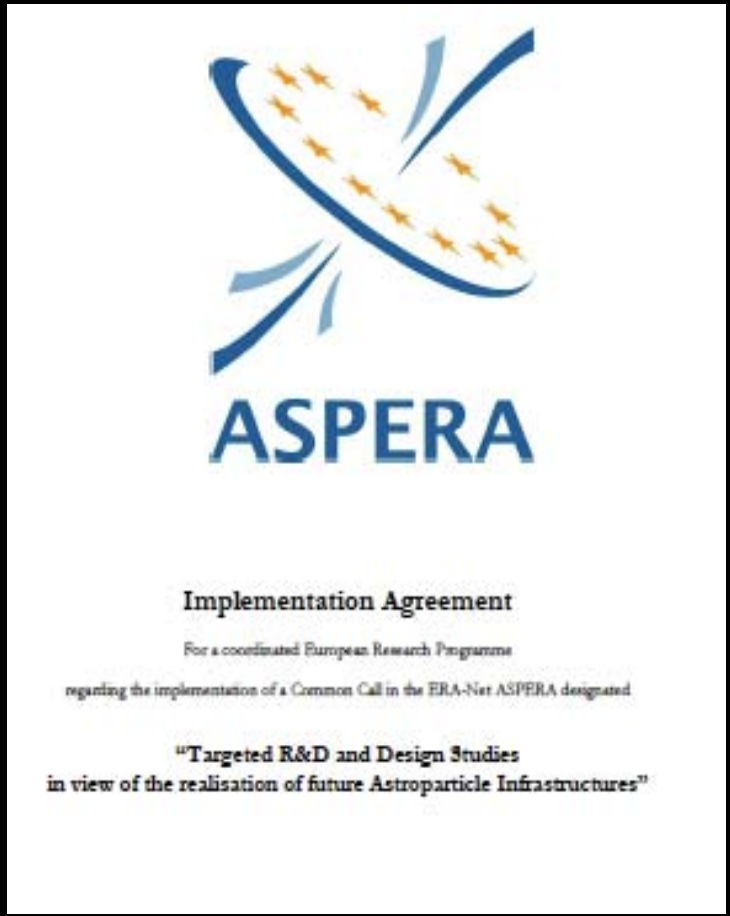
well matched to new CERN neutrino beam in 10 years?

Boulby (UK)
Canfranc (Spain)
Frejus (France)
Phyasalmi (Finland)
Sieroszowice (Poland)
Slanic (Romania)
Umbria (Italy)

Glacier (liquid argon)
Lena (liquid scintillator)
Memphys (liquid water)

ASPERA work in progress: Common calls for R&D

- ✓ **First call in ASPERA 2 themes:**
  - ✓ **CTA**
  - ✓ **Dark Matter**
  - ✓ **Grants awarded by end 2009**
- ✓ **Virtual pot of 3 M€ (9 agencies)**
- ✓ **Second call in preparation**
  - ✓ **High energy cosmic rays**
  - ✓ **Neutrino mass**
  - ✓ **Grants to be awarded by mid-2011**
- ✓ **Virtual pot of 3 M€ (9-10 agencies)**



ASPERA Workshops in preparation

- Computing in Astroparticle Physics
  - Lyon 7-8 October
- Technological challenges in Astroparticle physics : Photodetectors
  - Munich 21-22 October
- Interdisciplinary potential of Astroparticle Physics
  - Paris 2-3 December (Palais de la Découverte)
- Town meeting for the update of the roadmap
  - Spring 2011

OECD Global Science Forum on Astroparticle Physics

EU, US (DOE,NSF, NASA), Japan, China, Australia, Canada, Corea, Russia, CERN

- **Timeline : 2 years (2009-2010)**
  - **Started in Paris (spring 2009) , and will end at SLAC (4 Sep 2010)**
  - **Produced interim report (Oct 2009) well accepted by OECD GSF**
  - **The perimeter of the field was defined (8 themes: magnificent 7 +DE)**
  - **Four WG have been set and mapped the corresponding areas**
    - **"Cosmic rays" (CR, HE gamma and HE neutrino)**
    - **"Beyond accelerator Particle Physics" (underground lab science: dark matter, neutrino mass, proton decay)**
    - **Gravitational waves and Dark Energy**

From the report:

"The GSF Astroparticle Physics working group believes that the field has reached a high degree of autonomy, and that therefore an independent strategic vision for the field and its worldwide coordination should be developed"

Towards an ad-hoc group meeting on a yearly basis

Estimated

400 M$/year

4000 researchers

in Astroparticle physics

Worldwide

Budget and Personnel of Astroparticle Physics in Participating Countries

Annual Funding*	Lab Operation	Investment	Salaries	Other	Total
Europe	26	50.6	90.35	10	176.95
US	9.9	34.9	56.3	2.1	119.2
Canada	5	6	3	1.0	15
Argentina					
Russia (in Million $)	3.5	2.5	6.0	0.5	12.5
India					
China					
Japan					
Australia	0.3	0.3	1.4	0	2.0
TOTAL	44,4	94	157,05	13,6	335,65

*In Million Euros, Dollars or Okuyen, without exchange rate applied

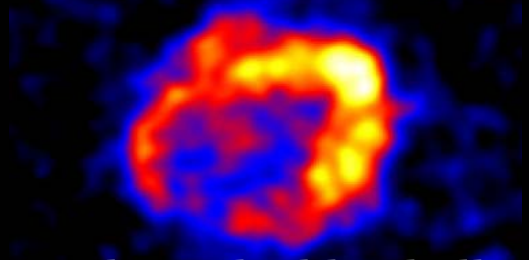
PERSONNEL (FTE)	Permanent*	Postdocs	Graduate Students	Other	TOTAL
Europe	1021	269	439	197	1926
US	269	135	220	68	692
Canada	46	35	63	55	199
Argentina					
Russia	500	60	50	100	710
India					
China					
Japan					
Australia	6	4	20	0	30
TOTAL	1836	503	792	420	3557

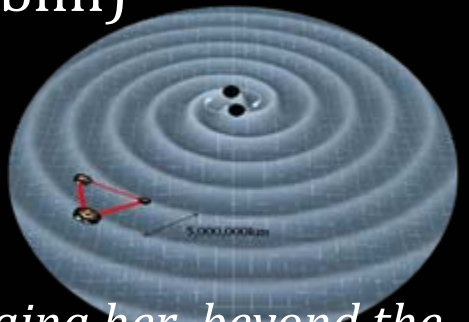
* Scientists and Engineers

Conclusions

- What did we gain ?
  - A sense of community for the scientists and the agencies
  - A better definition of the field
  - A sense of our "recent" history and a common plan for the future
  - A confidence for our plans imbedded in a global scale
- What are the challenges ?
  - Realistic planning
  - Find the proper forms for the implementation of these large infrastructures
  - A sustainable form of european coordination embedded in a global scale coordination

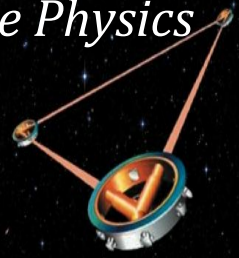
Who the h… is the first Astroparticle Theorist ?
(Coming back from a meeting in Dublin)

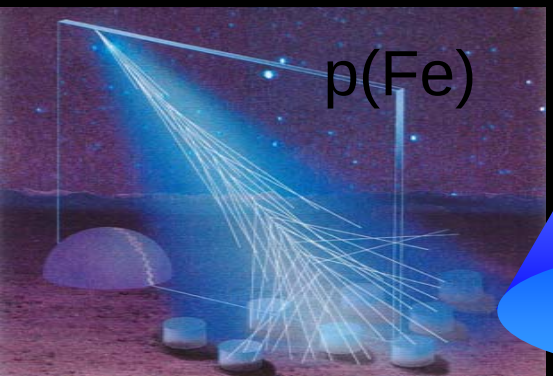


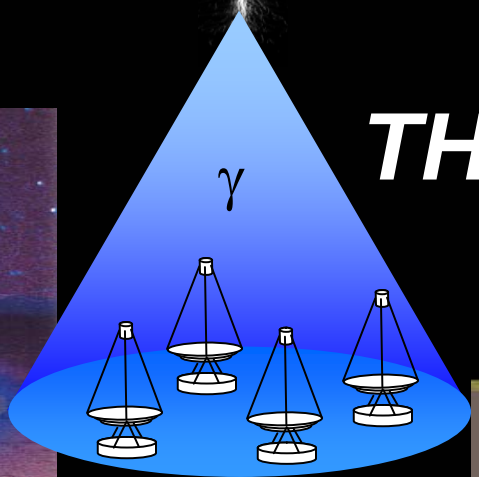


Now where the blue hell am I bringing her beyond the veil? Into the ineluctable modality of the ineluctable visuality. Ulysses . J. Joyce

One should add, the ineluctable modality of the invisible in order to have the full definition of Astroparticle Physics







THANKS