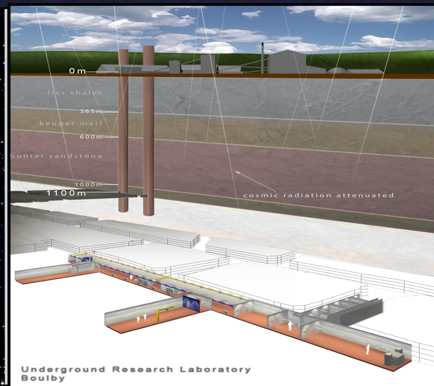
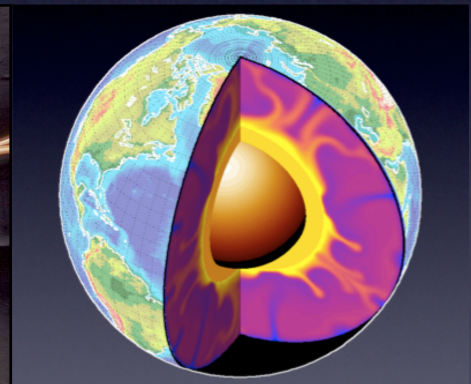
LAGUNA

Design of a pan-European infrastructure for Large Apparatus for Grand Unification and Neutrino Astrophysics





André Rubbia (ETH-Zürich)

CHIPP Plenary meeting
September 8-9th, 2008

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

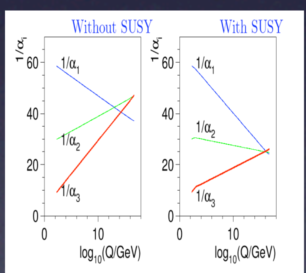
Address fundamental questions

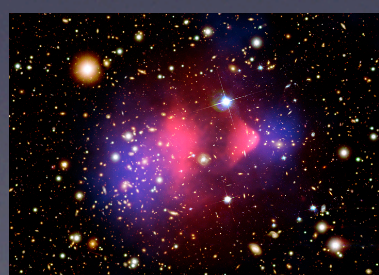
Particle physics

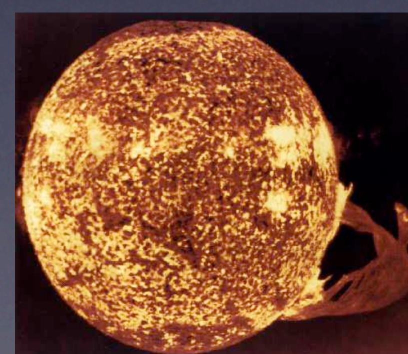
Proton decay
CPV in neutrinos
(combination atmospheric, reactors and beam neutrinos)

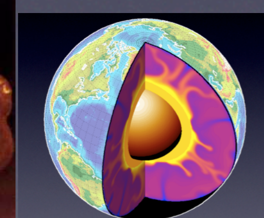
Neutrino astronomy

Supernova neutrinos
Diffuse SN neutrinos
Solar neutrinos
Dark matter annihilation
Geo-neutrinos



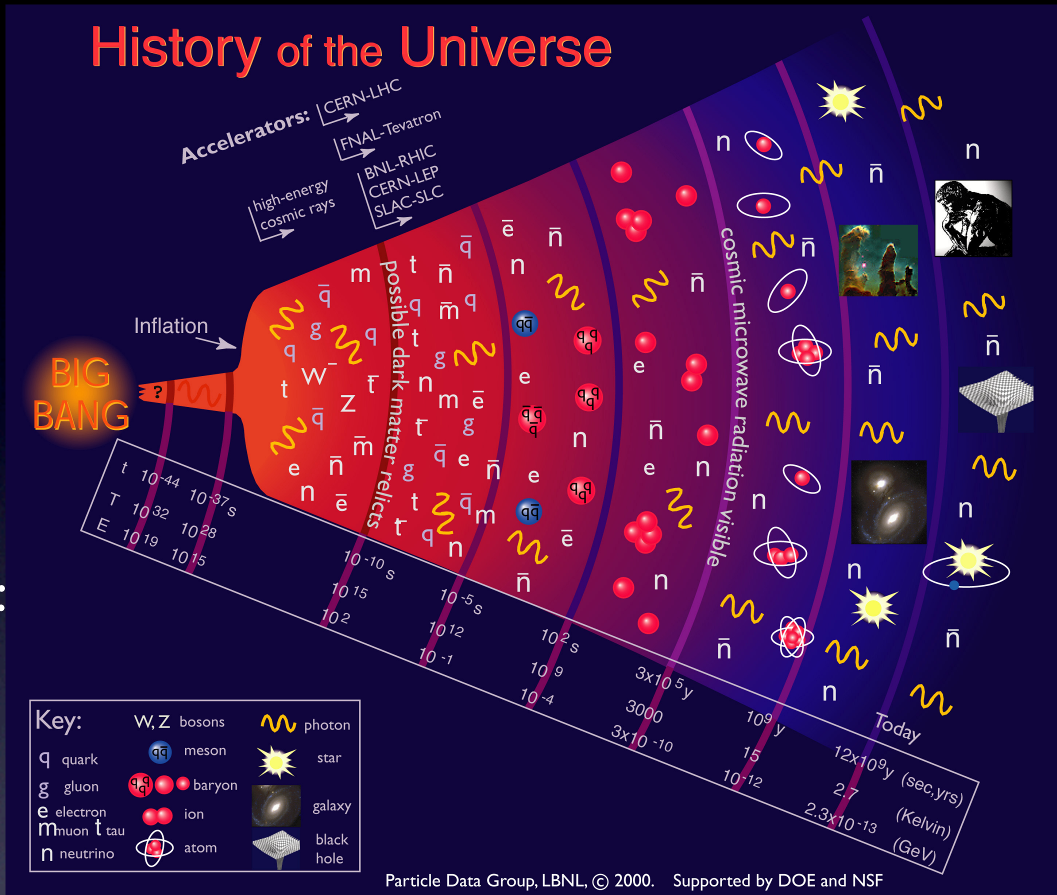






The Matter Dominated Universe

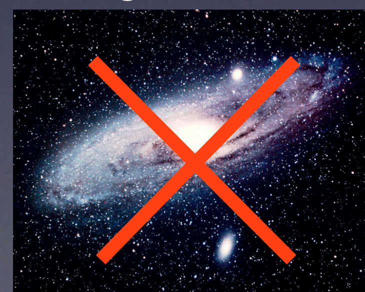
The Big Bang origin of the Universe requires matter and antimatter to be equally abundant at the very hot beginning.



But today there is a large dominance of matter in our Universe !

Galaxies are made of matter

No anti-galaxies around!



Asymmetry parameter:

$$\eta = \frac{n_b - n_{\bar{b}}}{n_\gamma} \approx 10^{-10}$$

What is at the origin of the observed matter dominance ?

Baryogenesis = generating baryons

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- What created this tiny excess of matter versus antimatter in the early Universe?

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- **Sakharov's conditions (1967)**

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2. CPV
3. Out of thermal equilibrium

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The (only) experimental evidence for baryogenesis is our existence in the Universe...

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- ★ Need baryon number violation
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  - reachable lifetime prediction within Grand Unified Theories

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- New type of CPV to explain amount of baryons in Universe ?
- What about leptonic sector ?

Consequence of Baryogenesis

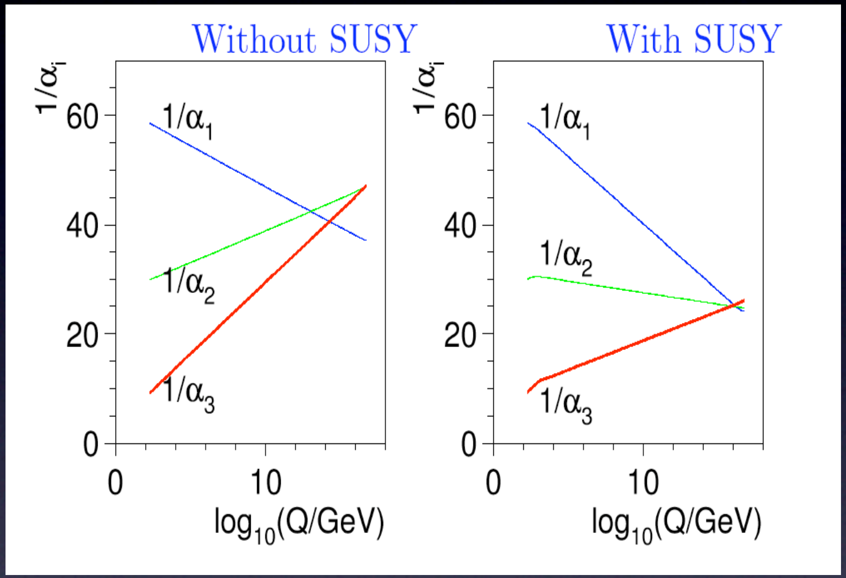
★ **Need baryon number violation**

- proton is unstable ("➠ proton decay")
- reachable lifetime prediction within Grand Unified Theories

•generically predict

$\tau/B(e\pi^0)=10^{34}\text{-}10^{36}y$

$\tau/B(\nu K) = 3\times10^{33}\text{-}3\times10^{34}y$



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★ **What about Leptogenesis ?**

- Undiscovered heavy neutrino mass partners or new source of CPV in neutrino sector create electron-antielectron asymmetry which imply baryogenesis (following electric charge conservation)

Theoretical predictions

An upper bound on proton lifetime:

Dorsner, Perez, Phys.Lett.B625:88-95,2005

$$\tau_p \leq 1.5^{+0.5}_{-0.3} \times 10^{39} \frac{(M_X/10^{16}\,\mathrm{GeV})^4}{\alpha^2_{GUT}} (0.003\,\mathrm{GeV}^3/\alpha)^2 \text{ years},$$

Majorana-ν

$$\tau_p \leq 7.1 \times 10^{36} \frac{(M_X/10^{16}\,\mathrm{GeV})^4}{\alpha^2_{GUT}} (0.003\,\mathrm{GeV}^3/\alpha)^2 \text{ years}.$$

Dirac-ν

Model independent upper bounds on total proton lifetime in the context of grand unified theories

α≡decay matrix element, poorly known!

- In 4D SUSY SU(5), SO(10) dimension 6 operators “Msusy independent” depend essentially on unification mass generically predict $\tau_p = 10^{34}$-10^{36}y

$$\tau(p \to \pi^0 + e^+) \approx 5 \times 10^{36} \left(\frac{M_X}{3 \times 10^{16}\,\mathrm{GeV}}\right)^4 \left(\frac{0.015\,\mathrm{GeV}^3}{\beta_{lattice}}\right)^2 \text{ years}.$$

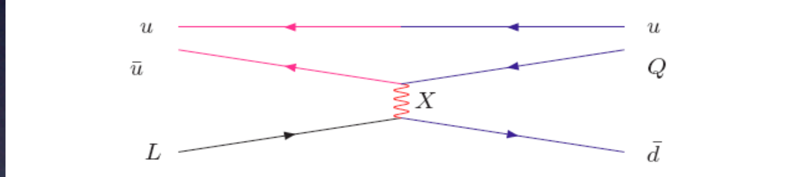


Figure 1. X boson exchange diagram giving the dimension 6 four fermion operator for proton and neutron decay.

- In 4D SUSY SU(5), SO(10) dimension 5 operators depend on sparticle spectrum (Msusy), family structure, triplet higgs mass generically predict τ_p= 3 x10^{33}- 3x10^{34}y

$$\tau(p \to K^+ + \bar{\nu}) < \left(\frac{1}{3} - 3\right) \times 10^{34} \left(\frac{0.015\,\mathrm{GeV}^3}{\beta_{lattice}}\right)^2 \text{ years}.$$

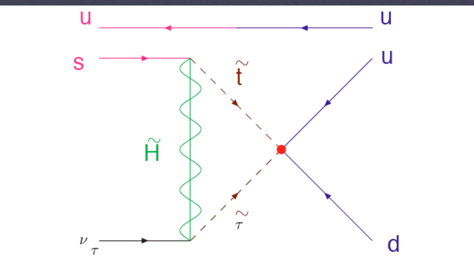


Figure 3. Higgsino and third generation stop - stau loop giving the dominant loop contribution to dimension 5 nucleon decay.

What will be the impact of LHC results ?

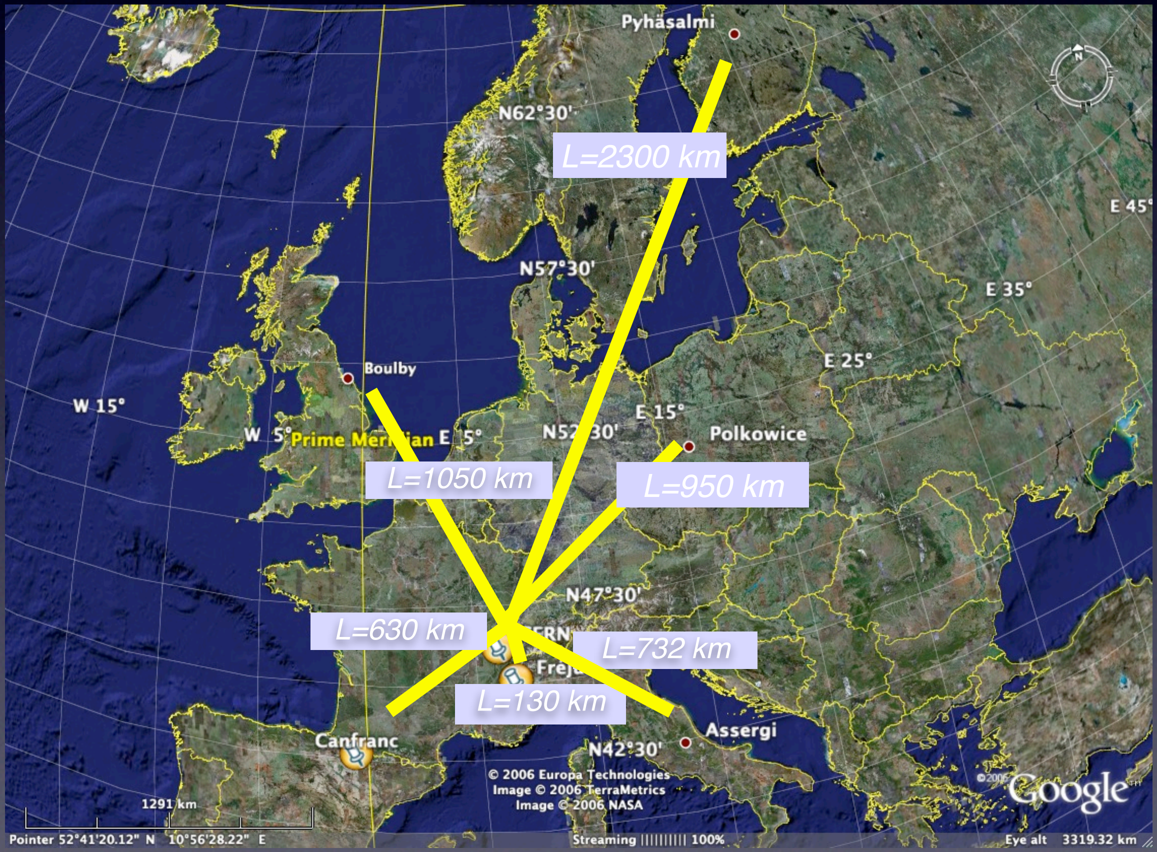
More on Leptogenesis

- Neutrinos have mass (1998-2002)
- Neutrinos, since electrically neutral, may be their own anti-particles (Majorana)
- They can transform matter to anti-matter and vice versa
- They might play a crucial role in baryogenesis!

➠ *Study CP-violation in neutrino sector !*

see e.g. S.Pascoli, S.T.Petcov and A.Riotto,"Leptogenesis and low energy CP violation in neutrino physics," Nucl. Phys. B 774 (2007) 1

Long baseline neutrino experiment to study CPV in leptonic sector



Progress beyond state-of-the-art

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- Several conceptual ideas for next-generation very-massive, multi-purpose underground detectors with target fiducial masses of scale of 50 to 500 kton have emerged in Europe over the last few years.

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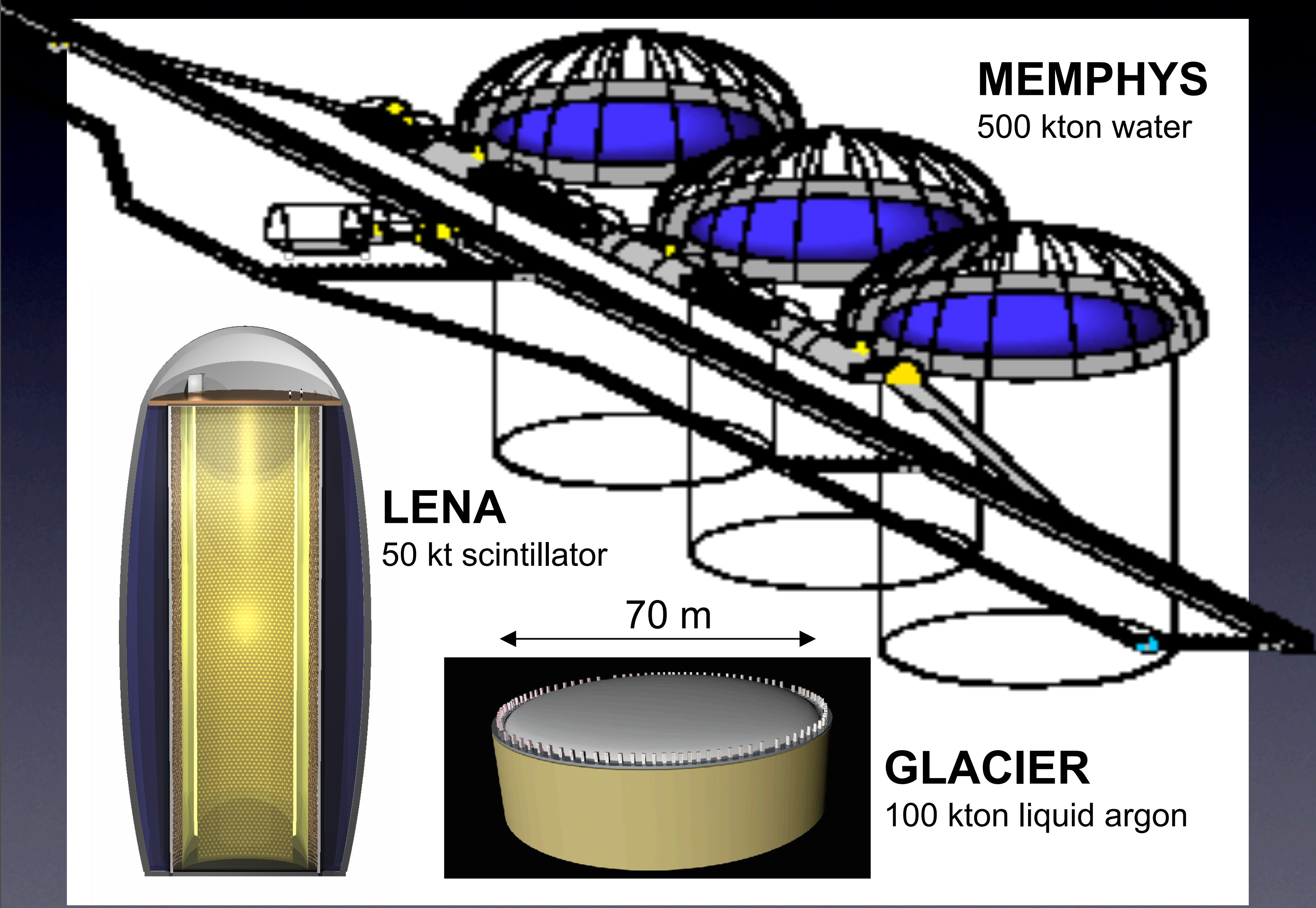
- The liquid simultaneously acts as the target and the detecting medium.
- Three liquids are considered:
  - water
  - liquid scintillator
  - liquid argon

New large Underground Detectors

- Three experiments proposed (approx. drawn to scale)



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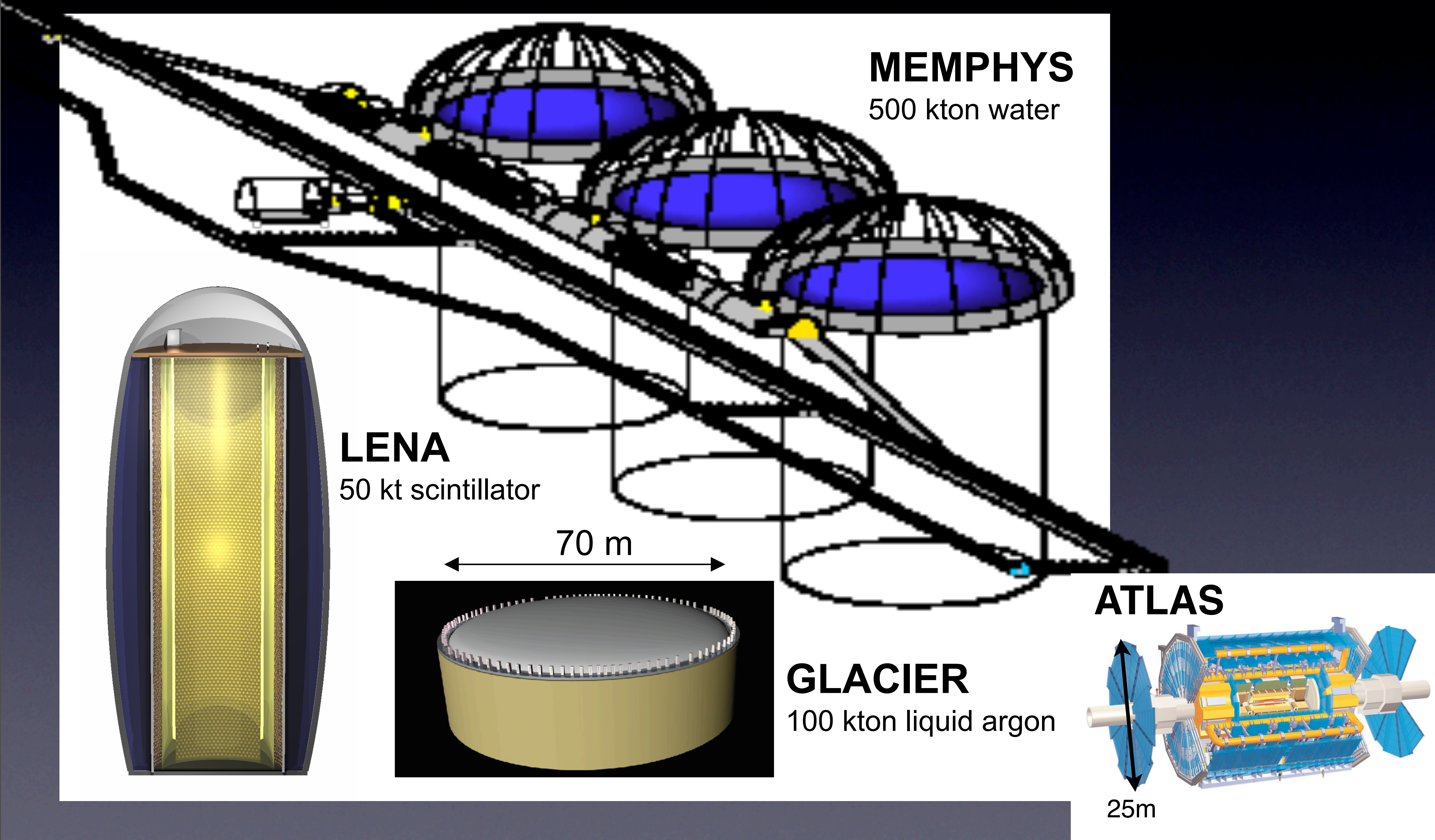


Recent publication:

JCAP 0711:011,2007

and references therein

Journal of Cosmology and Astroparticle Physics
An IOP and SISSA journal

Large underground, liquid based detectors for astro-particle physics in Europe: scientific case and prospects

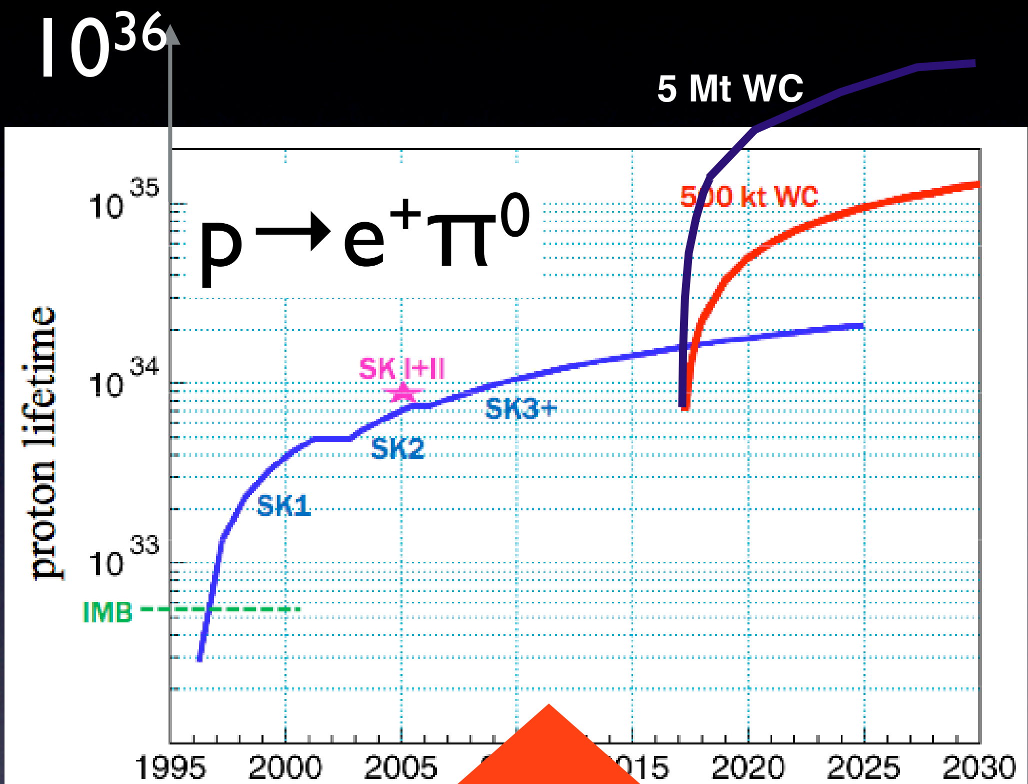
D Autiero[1], J Äystö[2], A Badertscher[3], L Bezrukov[4], J Bouchez[5], A Bueno[6], J Busto[7], J-E Campagne[8], Ch Cavata[9], L Chaussard[1], A de Bellefon[10], Y Déclais[1], J Dumarchez[11], J Ebert[12], T Enqvist[13], A Ereditato[14], F von Feilitzsch[15], P Fileviez Perez[16], M Göger-Neff[17], S Gninenko[4], W Gruber[3], C Hagner[12], M Hess[14], K A Hochmuth[17], J Kisiel[18], L Knecht[3], I Kreslo[14], V A Kudryavtsev[19], P Kuusiniemi[13], T Lachenmaier[15], M Laffranchi[3], B Lefievre[10], P K Lightfoot[19], M Lindner[20], J Maalampi[2], M Maltoni[21], A Marchionni[3], T Marrodán Undagoitia[15], J Marteau[1], A Meregaglia[3], M Messina[14], M Mezzetto[22], A Mirizzi[17,23], L Mosca[9], U Moser[14], A Müller[3], G Natterer[3], L Oberauer[15], P Otiougova[3], T Patzak[10], J Peltoniemi[13], W Potzel[15], C Pistillo[14], G G Raffelt[17], E Rondio[24], M Roos[25], B Rossi[14], A Rubbia[3], N Savvinov[14], T Schwetz[26], J Sobczyk[27], N J C Spooner[19], D Stefan[28], A Tonazzo[10], W Trzaska[2], J Ulbricht[3], C Volpe[29], J Winter[15], M Wurm[15], A Zalewska[28] and R Zimmermann[12]

[1] IPNL, Université Claude Bernard Lyon 1, CNRS/IN2P3, 69622 Villeurbanne, France
[2] Department of Physics, University of Jyväskylä, Finland
[3] Institut für Teilchenphysik, ETHZ, Zürich, Switzerland

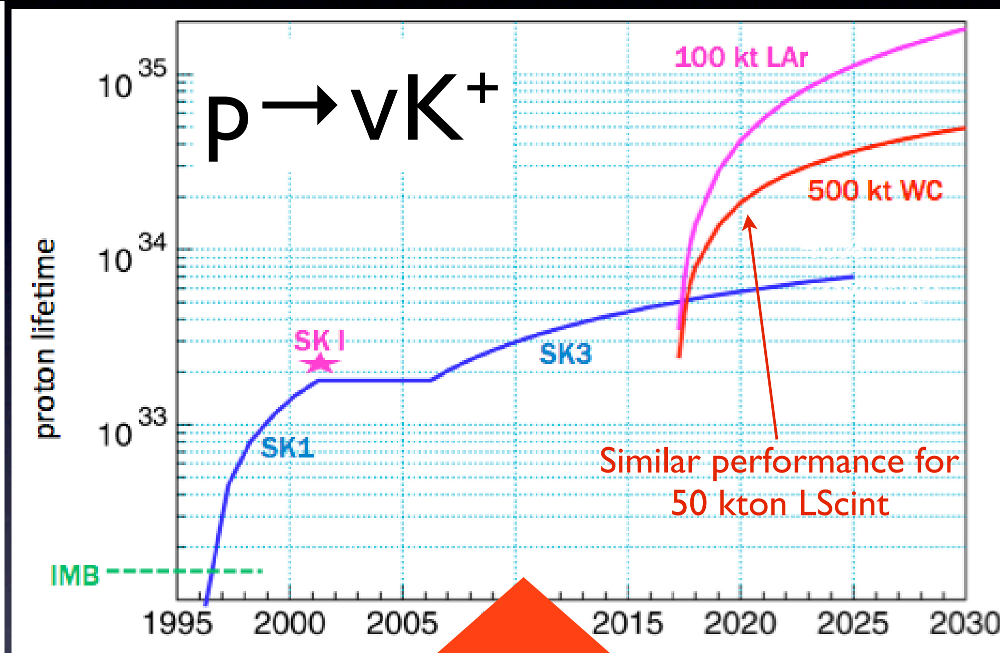
JCAP11(2007)011

Proton decay sensitivity curves

Consider two "typical" decay modes (more should be explored):



Curves adapted from E. Kearns, NP08



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Dorsner and Perez, Phys. Lett. B625 (2005) 88

Outstanding physics goals

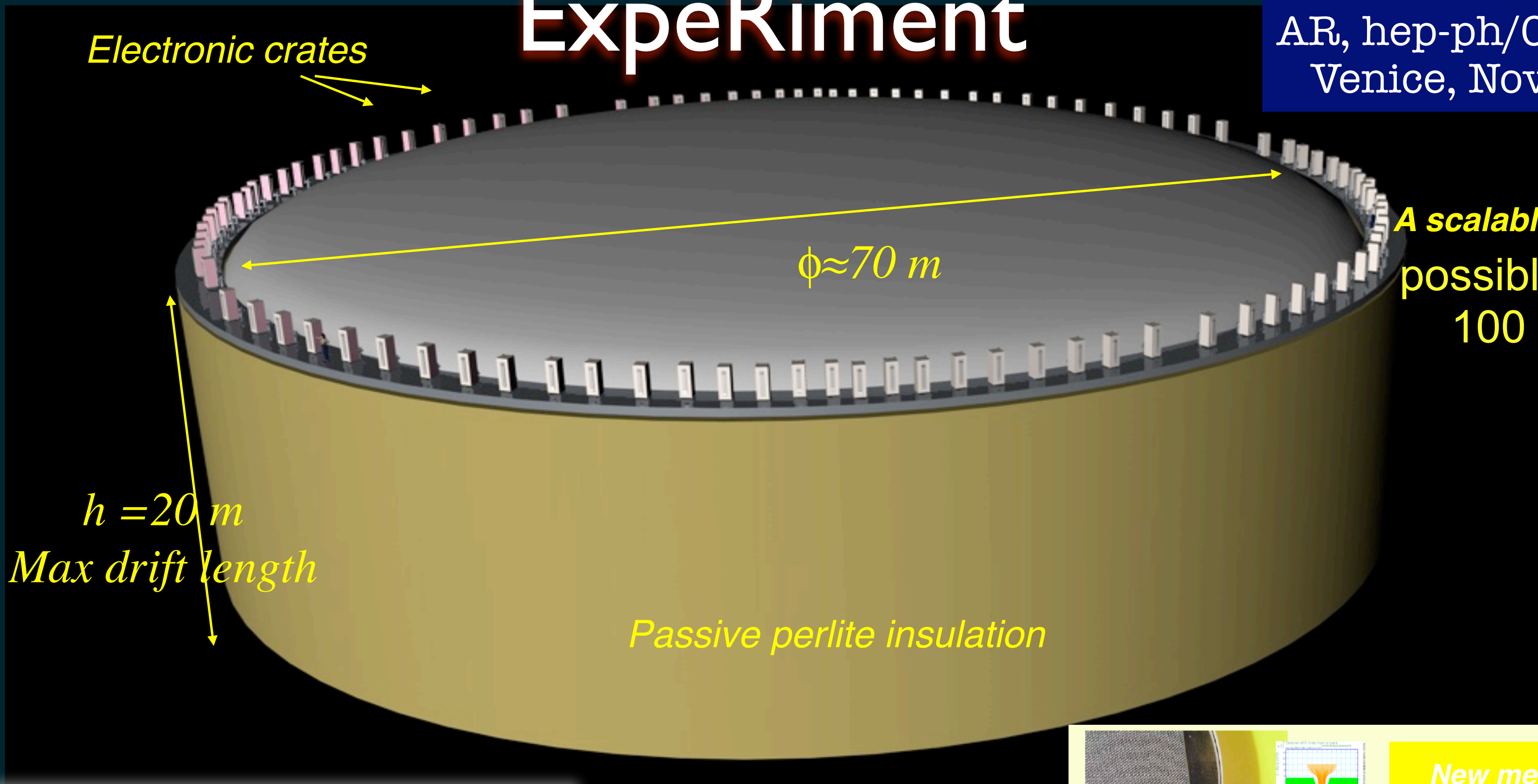
Comparison among liquids: which combination provides maximal physics output?

	Water Cerenkov	Liquid Argon TPC	Liquid Scintillator
Total mass	500 kton	100 kton	50 kton
$p \to e\,\pi^0$ in 10 years	$1.2\mathrm{x}10^{35}$ years ε= 17%, ≈ 1 BG event	$0.5\mathrm{x}10^{35}$ years ε= 45%, <1 BG event	?
$p \to \nu K$ in 10 years	$0.15\mathrm{x}10^{35}$ years ε= 8.6%, ≈ 30 BG events	$1.1\mathrm{x}10^{35}$ years ε= 97%, <1 BG event	$0.4\mathrm{x}10^{35}$ years ε= 65%, <1 BG event
SN cool off @ 10 kpc	194000 (mostly $\bar{\nu}_e p \to e^+ n$)	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	≈250 ν-e elastic scattering	380 ν_e CC (flavor sensitive)	≈30 events
SN relic	250(2500 when Gd-loaded)	50	20-40
Atmospheric neutrinos	56000 events/year	≈11000 events/year	5600/year
Solar neutrinos	91250000/year	324000 events/year	?
Geoneutrinos	0	0	≈3000 events/year

Clear complementarity between techniques !

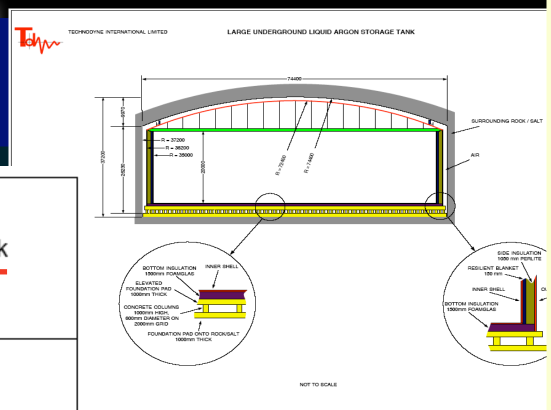
GLACIER: Giant Liquid Ar Charge Imaging ExpeRiment

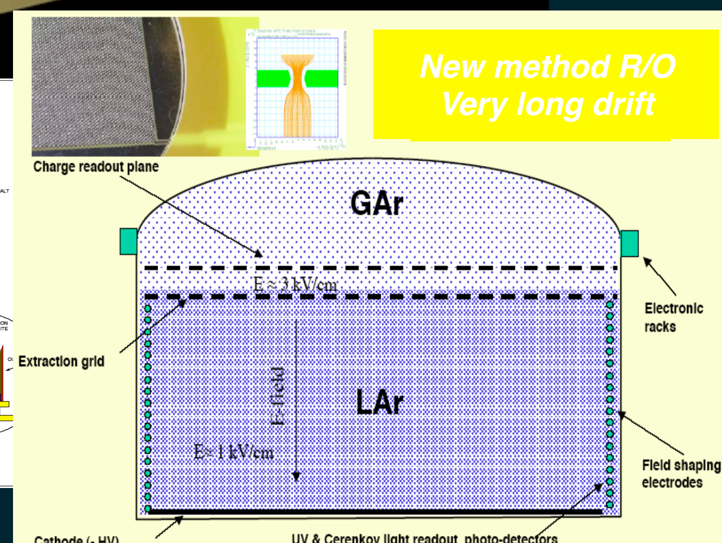
AR, hep-ph/0402110
Venice, Nov 2003



A scalable design
possibly up to 100 kton

Single module cryo-tanker based on industrial LNG technology



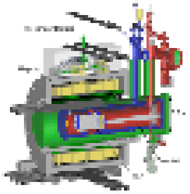


Project: Large Underground Argon Storage Tank

A feasibility study mandated to Technodyne Ltd (UK): Feb-Dec 2004

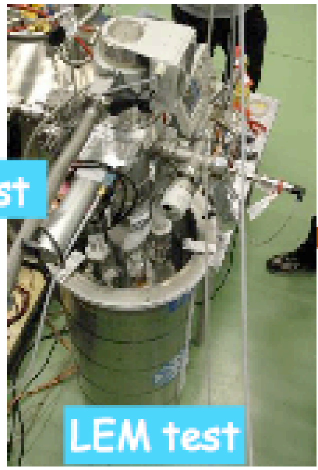
Steps towards GLACIER

Small prototypes ➡ ton-scale detectors ➡ 1 kton ➡ ?



B-field test

➡



LEM test

proof of principle double-phase LAr LEM-TPC on $0.1 \times 0.1\ m^2$ scale

➡

LEM readout on $1 \times 1\ m^2$ scale
UHV, cryogenic system at ton scale, cryogenic pump for recirculation, PMT operation in cold, light reflector and collection, very high-voltage systems, feed-throughs, industrial readout electronics, safety (in Collab. with CERN)

ArDM ton-scale

➡ **direct proof of long drift path up to 5 m**

we are here

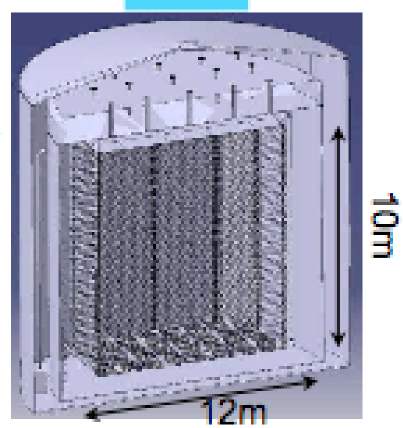
ArgonTube: long drift, ton-scale

➡ **Application of LAr LEM TPC to neutrino physics:** particle identification (200-1000 MeV electrons), optimization of readout and electronics, cold ASIC electronics, possibility of neutrino beam exposure

Test beam
1 to 10 ton-scale

➡ **full engineering demonstrator for larger detectors,** acting as near detector for neutrino fluxes and cross-sections measurements, ...

1 kton



Why LAGUNA ?

- The proposed large detectors require underground laboratories of adequate size and depth, naturally protected against cosmic rays
- The LAGUNA design study will focus on the feasibility and design of a new research infrastructure in Europe
  - considering three different detector technologies
  - in seven potential underground sites
  - in order to identify the scientifically and technically most appropriate and cost-effective strategy
  - fostering convergence into a "scientific proposal" around 2010

Six national underground science laboratories

IUS

Institute of Underground Science in Boulby mine, UK

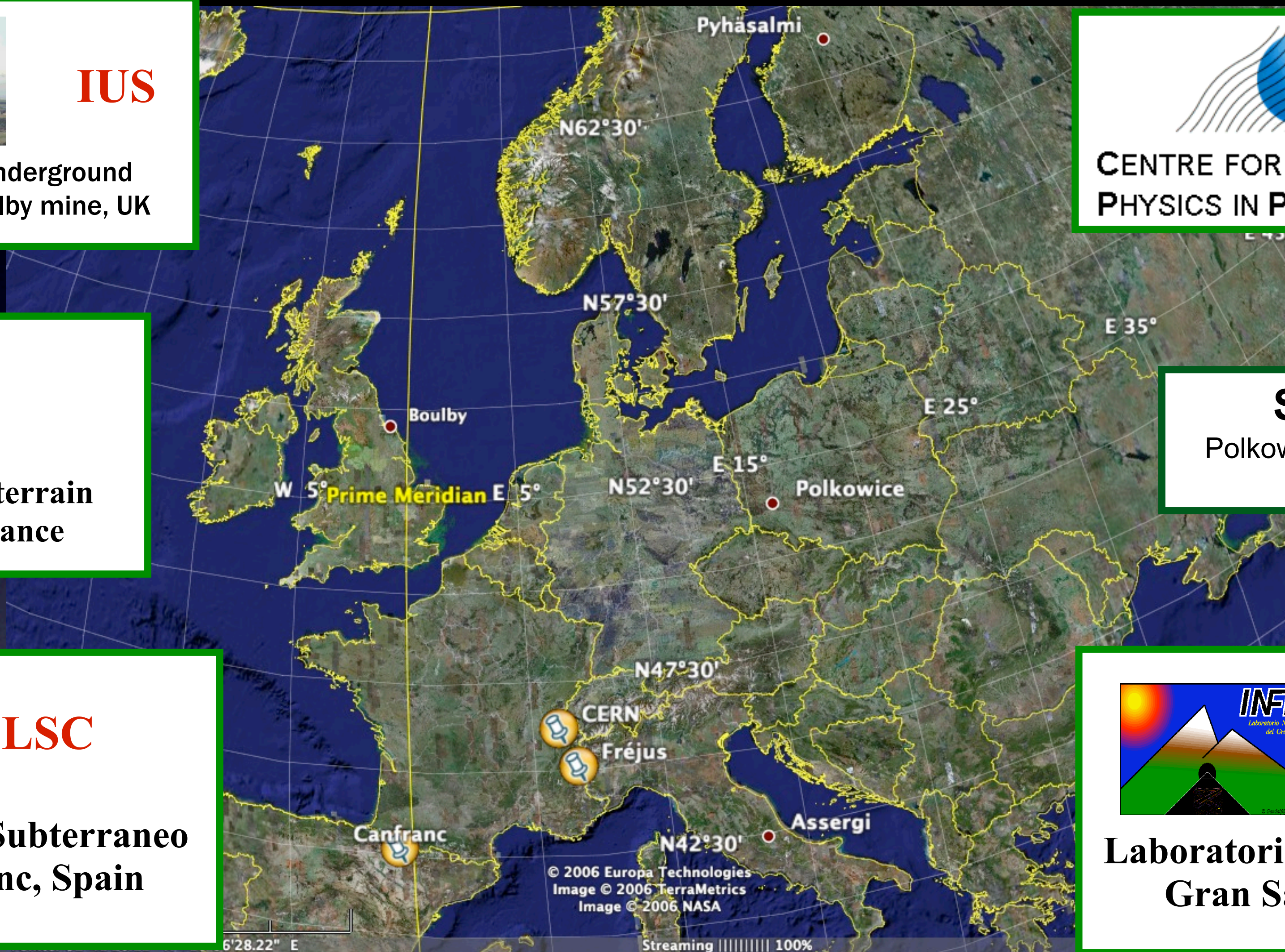
CENTRE FOR UNDERGROUND PHYSICS IN PYHÄSALMI MINE

LSM

Laboratoire Souterrain de Modane, France

SUNLAB

Polkowice-Sieroszowice, Poland



LSC

Laboratorio Subterraneo de Canfranc, Spain

LNGS

Laboratori Nazionali del Gran Sasso, Italy

None of these laboratories can host next generation very large volume observatories. Extension are needed.

- What depth?
- What other synergies? (beamline distance from artificial sources at accelerators)
- What is the distance from reactors?

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A pan-European Infrastructure for very large volume underground observatories ?

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Worldwide context: very large volumes

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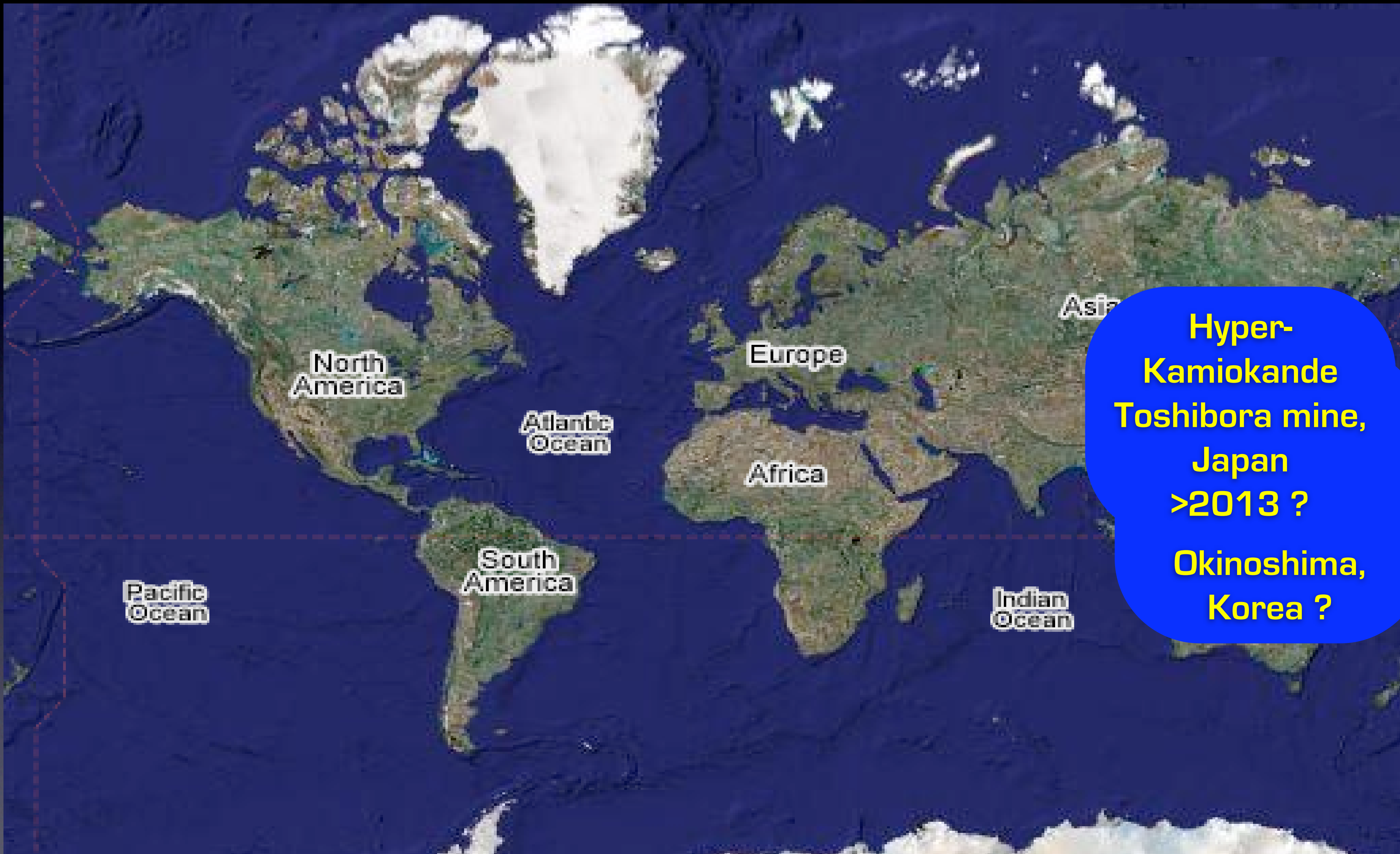

Hyper-Kamiokande
Toshibora mine, Japan
>2013 ?

Okinoshima, Korea ?

Worldwide context: very large volumes

Deep Underground Science and Engineering Laboratory (DUSEL) in USA:
Homestake site selected 2007

Hyper-Kamiokande
Toshibora mine, Japan
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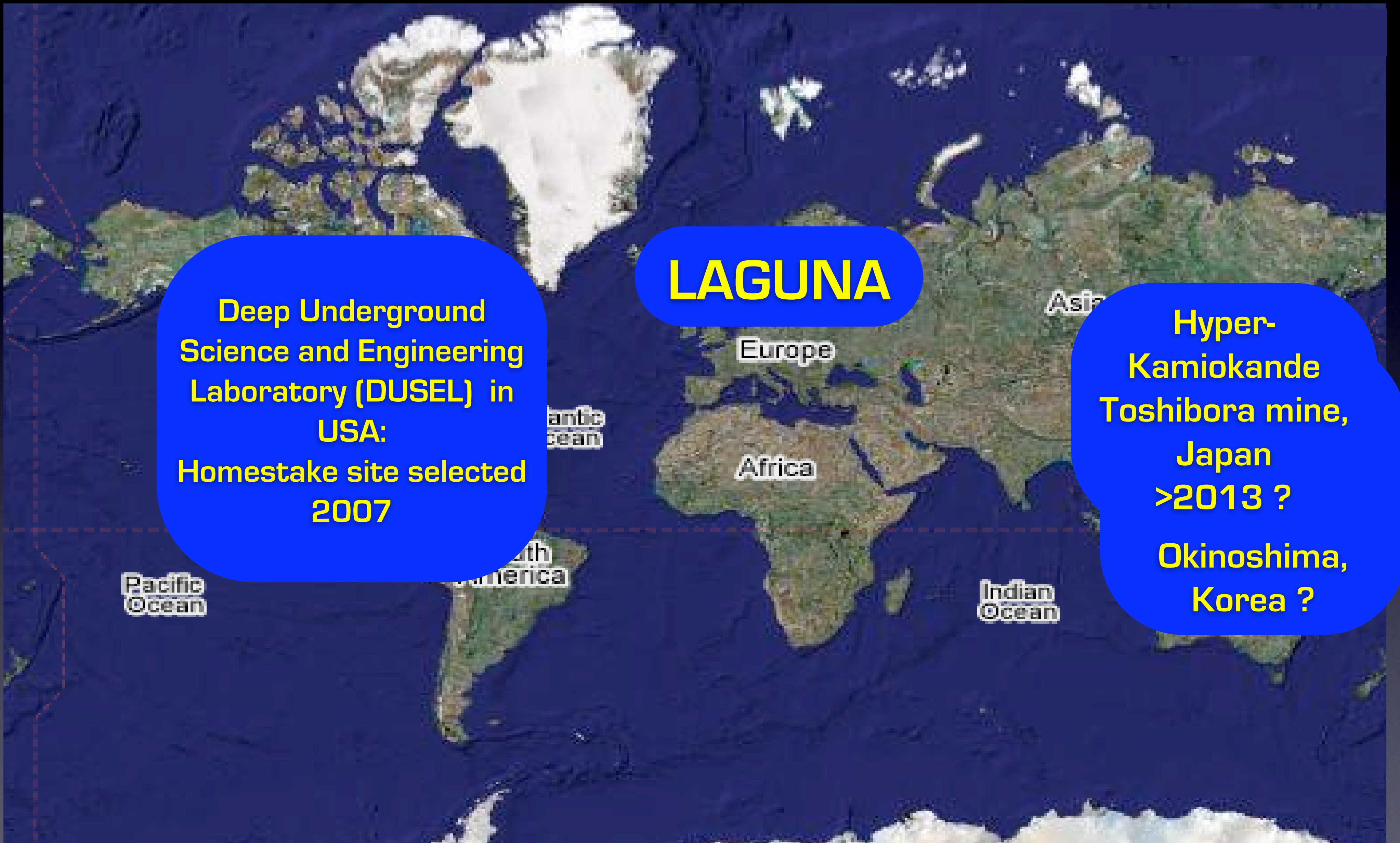
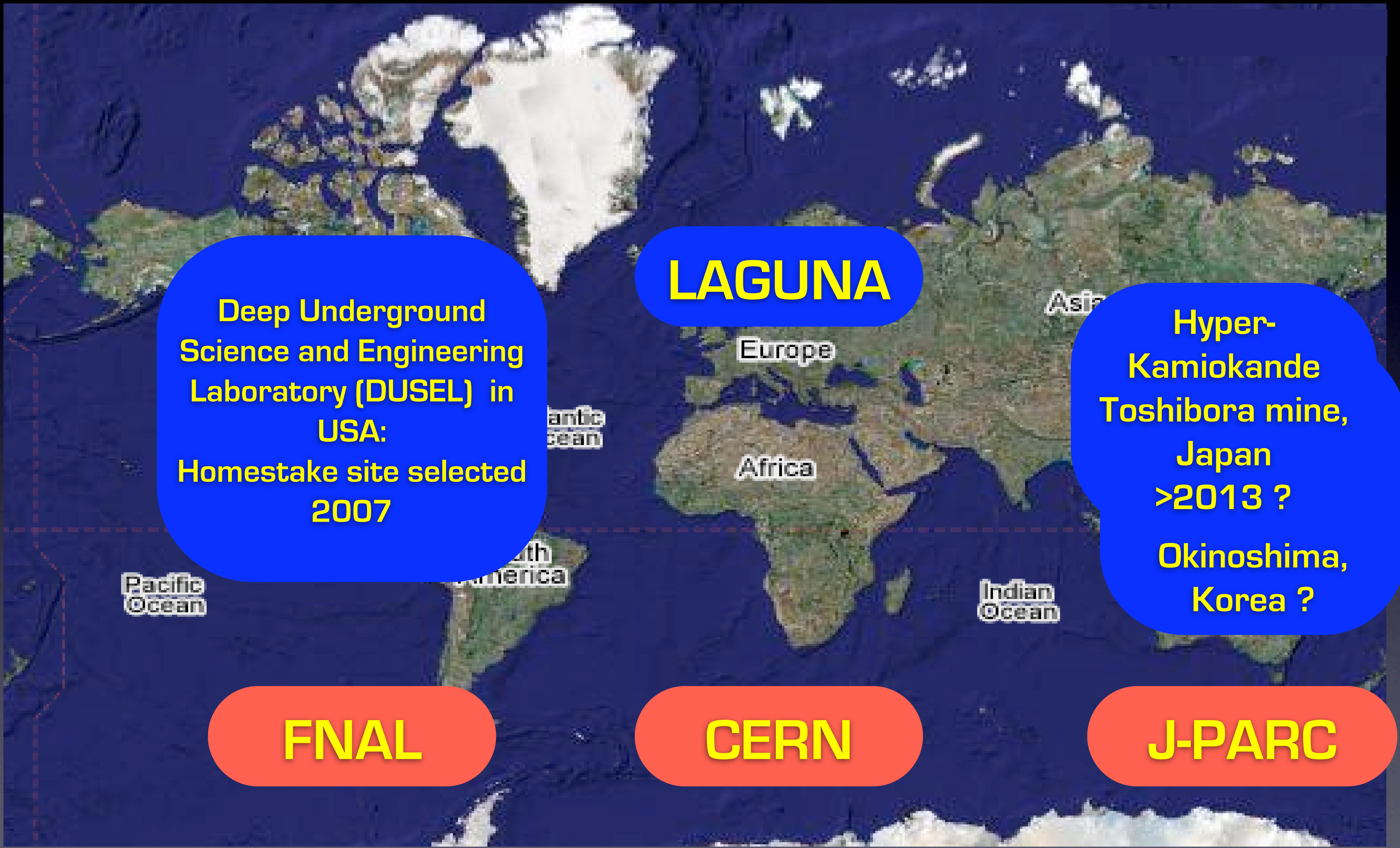
Okinoshima, Korea ?

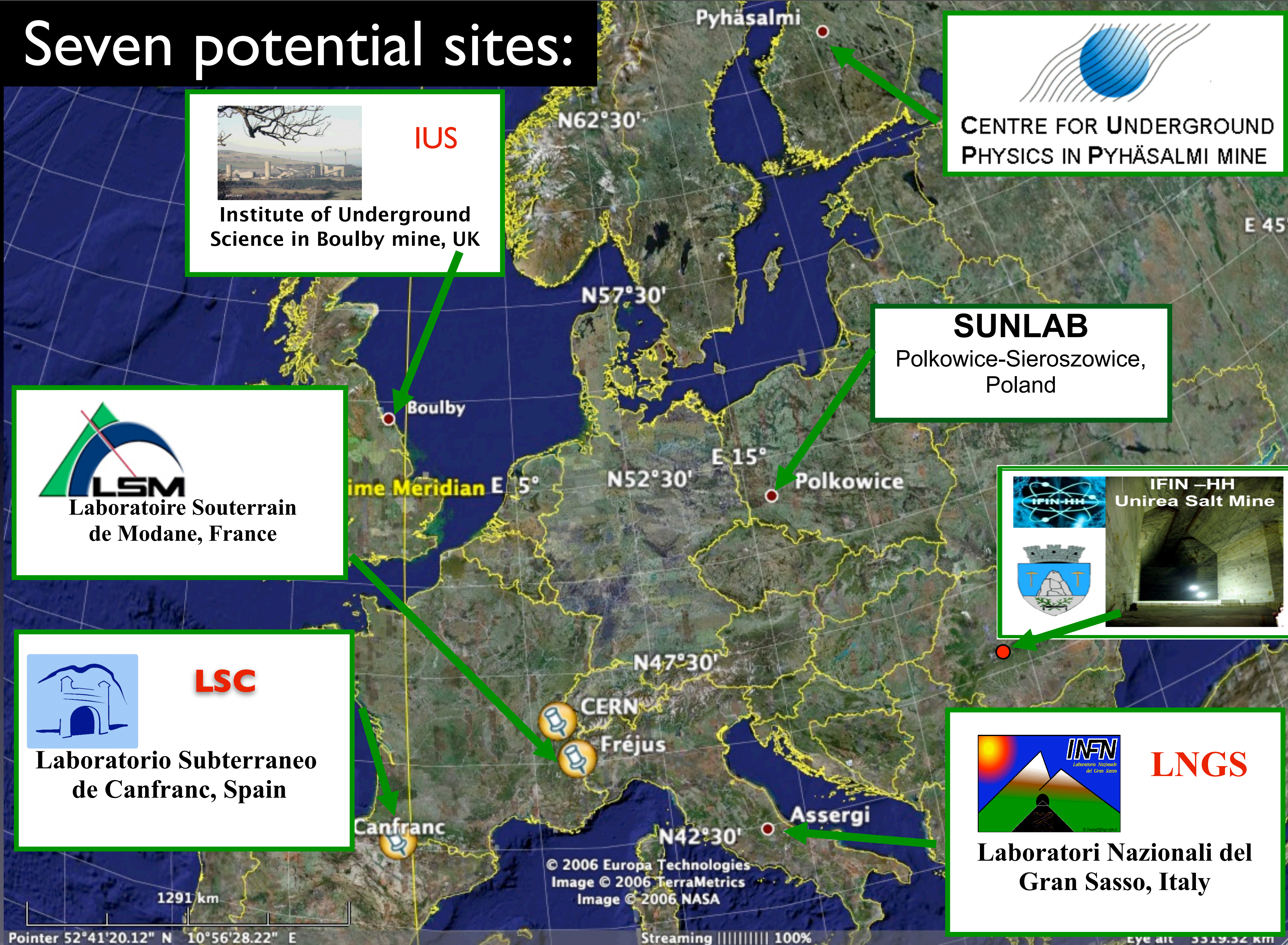
Worldwide context: very large volumes



Worldwide context: very large volumes



Seven potential sites:



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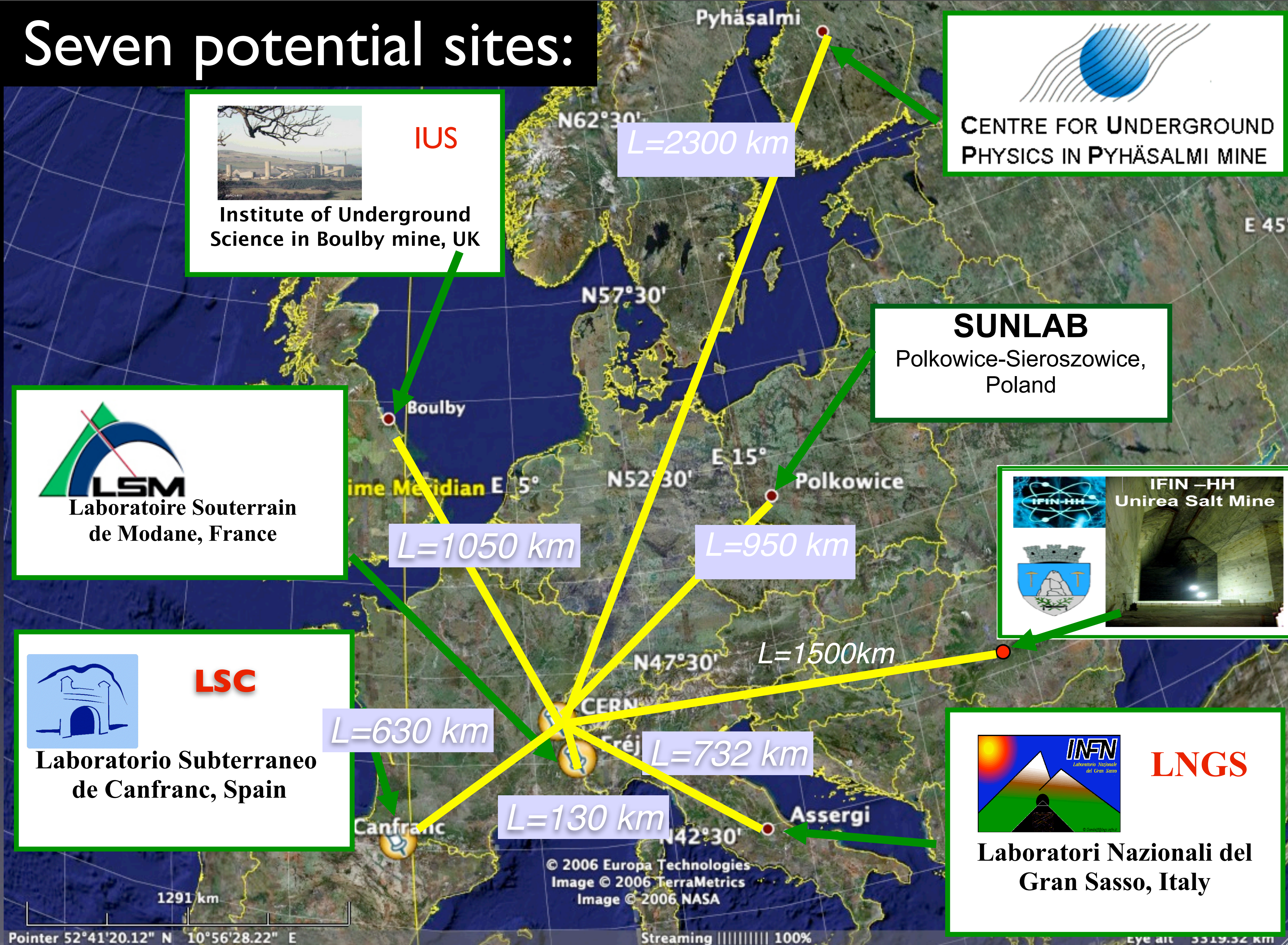

The main challenge of LAGUNA

- The technical and economical feasibility of an underground observatory of this magnitude, perhaps ultimate in size, requires a strong coordinate and coherent European strategy and will be heavily reliant on the possibility to contain costs compared to today's state-of-the-art by a careful optimization of all elements involved in the project:
  - ★ (1) the excavation and preparation of the underground space,
  - ★ (2) the design and construction of the tank,
  - ★ (3) the instrumentation and
  - ★ (4) the safety aspects.
- The LAGUNA DS will lead to a "conceptual design report" for a new infrastructure, to allow policy makers and their advisors to prepare the relevant strategic decisions for the development of a new research infrastructure in Europe.
- Submitted @ FP7 infrastructure call in May 2007

ApPEC recommendation (2007)

- *We recommend that a new large European infrastructure is put forward, as a future international multi-purpose facility on the 10^5-10^6 ton scale for improved studies of proton decay and of low-energy neutrinos from astrophysical origin. The three detection techniques being studied for such large detectors in Europe, Water-Cherenkov, Liquid Scintillator and Liquid Argon, should be evaluated in the context of* ***a common design study*** *which should also address the underground infrastructure and the possibility of an eventual detection of future accelerator neutrino beams. This design study should take into account worldwide efforts and converge, on a time scale of 2010, to a common proposal.*

Granted FP7 funding

The Design Study programme for the LAGUNA project has been approved as a whole by the European Commission (EC)

Official start date: July 1st 2008

EC contribution: 1.7 M€ to be mainly devoted to the sites infrastructure studies

National "matching" funds expected, in particular for the specific detector R&D

LAGUNA beneficiaries

- Consortium composed of 21 beneficiaries
  - 9 higher education entities (ETHZ, U-Bern, U-Jyväskylä, UOULU, TUM, UAM, UDUR, USFD, UA)
  - 8 research organizations (CEA, IN2P3, MPG, IPJ PAN, KGHM CUPRUM, GSMiE PAN, LSC, IFIN-HH)
  - 4 SMEs (Rockplan, Technodyne, AGT, Lombardi)
- Additional higher education participants (IPJ Warsaw, U-Silesia, U-Wroclaw, U-Granada)

EC experts evaluation

- Complementary to LHC and planned ILC goals
  - *"A major underground facility is a necessary complement to energy-frontier accelerators such as the LHC and ILC. Particle astrophysics can indirectly access energies approaching the Planck Scale, whereas terrestrial accelerators will be limited to the few TeV scale for the foreseeable future"*
- LHC: Higgs mechanism, SUSY, Rare decays
- LAGUNA: Proton decay, CP violation in leptons, neutrino astronomy

Astroparticle Physics Coordination in Europe (ApPEC)

Roadmap, January 2008

DM

LAGUNA

CTA

Auger N

KM3NeT

GW

Field/ Experiments	Cost scale (M€)	Desirable start of construction	Remarks
Dark Matter Search: Low background experiments with 1-ton mass	60-100 M€	2011-2013	2 experiments (different nuclei, different techniques), e.g. 1 bolometric, 1 noble liquid; more than 2 worldwide.

Proton decay and low energy neutrino astronomy: Large infrastructure for p-decay and ν astronomy on the 100kt-1Mton scale	400-800 M€	2011-2013	- multi-purpose
			- 3 different techniques; large synergy between them.
			- needs huge new excavation
			- expenditures likely also after 2015
			  - worldwide sharing
			  - possibly also accelerator neutrinos in long baseline experiments

The high energy universe: *Gamma rays:* Cherenkov Telescope Array CTA	100 M€ (South) 50 M€ (North)	first site in 2010	Physics potential well defined by rich physics from present gamma experiments
Charged Cosmic Rays: Auger North	85 M€	2009	Confirmation of physics potential from Auger South
Neutrinos: KM3NeT	300 M€		
Gravitational Waves: Third generation interferometer	250-300 M€		

Next ASPERA Roadmap Workshop : September 29th&30th 2008 Brussels

Submission to ESFRI ?

ApPEC roadmap (2008)

- The priority project in this field is a new giant underground observatory which has to be global in nature and has to follow worldwide coordination and cost sharing. A common FP7 design study, LAGUNA, is presently underway. It evaluates three detection techniques: water Cherenkov detectors, liquid scintillator detectors and liquid argon imaging detectors. The study will also address the costs of underground infrastructures in several potential locations in Europe. We recommend an additional coherent effort to complete the detector R&D programmes that could not be fully supported within the FP7 Design Study. The design study should provide, on a time scale of 2010, the key elements of the discovery potential for the different options and sites and then converge to a common proposal.

Kickoff meeting at ETH Zurich 3/4 July 2008:

7 general meetings in 24 months

Next meetings:

- Paris September 10th
- General meeting Bucharest November 5th-7th

Conclusions

- LAGUNA design study started in July 2008 for two years
- Physics programme addresses GUT, LE neutrino astrophysics and neutrino oscillations ➠ High discovery potential
- Site studies for 7 candidates and 3 technologies until 2010
- European <u>and</u> world-wide coordination is the only winning strategy to address projects of this scale. In addition, “accelerator-based” and “astrophysics” should be coordinated and considered as part of a single programme.
- The LAGUNA DS, if successful, will foster convergence towards a proposal for a new European infrastructure to address the next step in deep underground science. LAGUNA is European but open for world wide cooperation.