Astroparticle Physics for Europe

Report on Low Energy Neutrinos and Proton Decay detectors

WG7

Conveners: Aldo Ianni (LNGS-INFN)

André Rubbia (ETHZ)

Amsterdam, September 20th 2007

ASPERA

WG7 composition

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- Eugenio Coccia
- Antonio Ereditato
- Jan Kisiel
- Vitaly Kudryavtsev
- Fulvio Mauri
- Marcello Messina
- Luigi Mosca
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- Juha Peltonemi
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- Michael Wurm
- Alessandro Tonazzo
- Gianpaolo Bellini
- Kai Zuber
- Herve de Kerret
- Franz von Feilitzsch
- Lothar Oberaurer
- Thomas Patzak
- Agniezska Zalewska
- **Aldo Ianni**
- **André Rubbia**

+ ...

All large underground astroparticle physics experiments with European participation are represented

Projects discussed in WG7

- LVD
- BOREXINO / CTF
- ICARUS T600
- DOUBLE-CHOOZ
- SNO+
- MEMPHYS
- LENA
- GLACIER
- LAGUNA
- ModulAr
- (Eventually possibly also OPERA and T2K-EU ?)

→ *Convergence*

Astroparticle Physics for Europe

ASPERA

Broad and rich physics programme

- Direct evidence for Grand Unification (Proton decay)
- Low energy neutrino astronomy (SN, solar, geo, atm)
- Long baseline neutrino beam ($\not{C}P$)

Combine accelerator & non-accelerator physics

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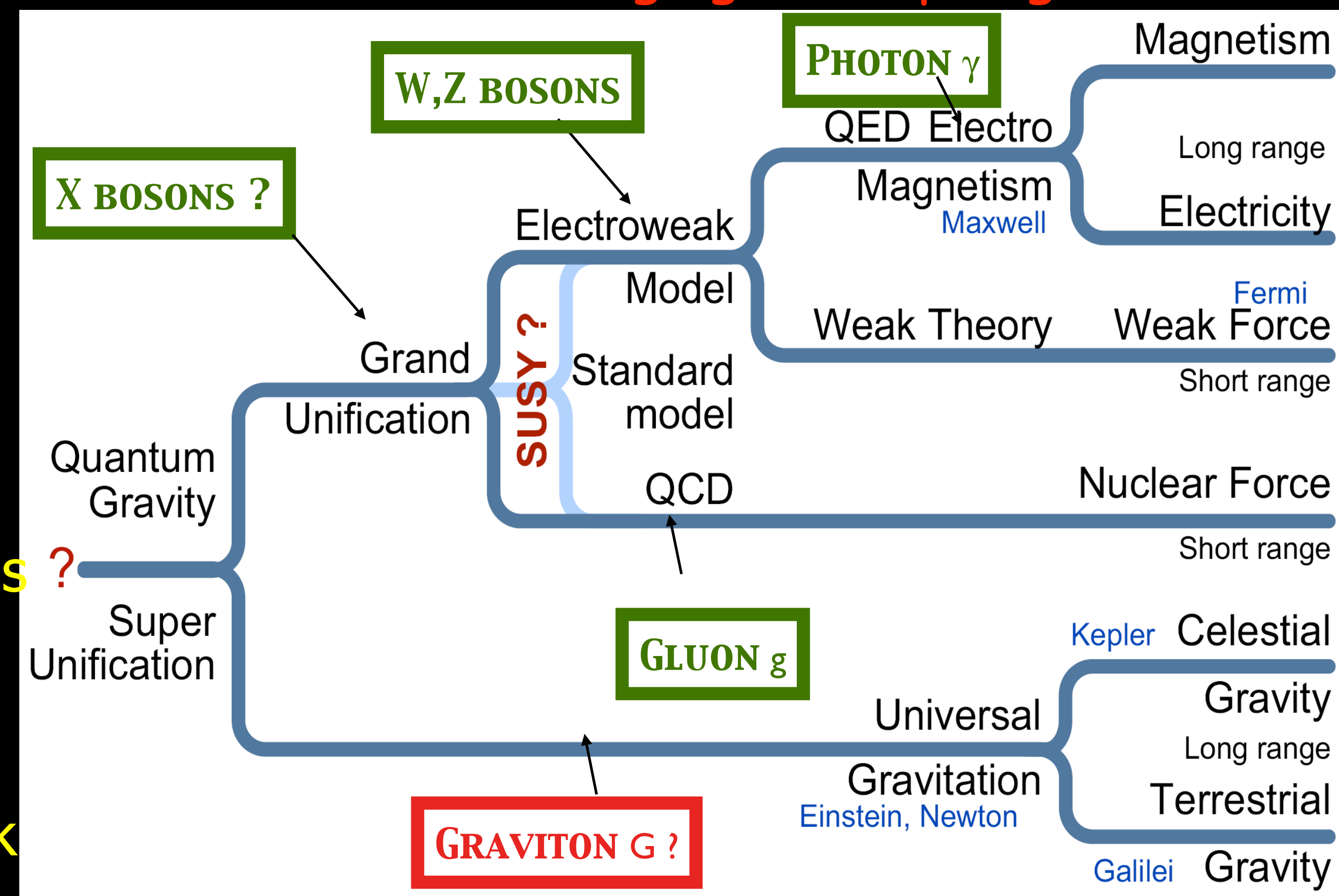
Combine accelerator & non-accelerator physics

(I) Grand Unification – proton decay

The understanding of the Grand Unification is one of the most challenging still-open goal of particle physics!



1. Grand-Unification:

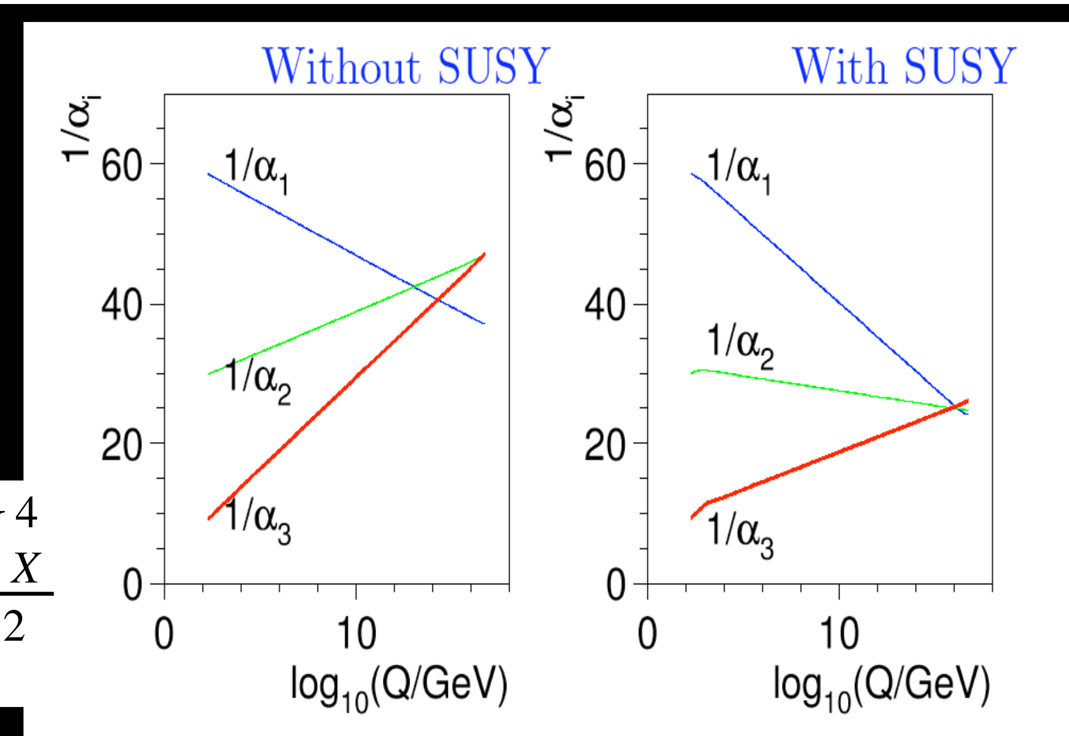
- Fundamental symmetry between quarks & leptons, transmutation between quarks and leptons: proton unstable
- Explain electric charges of elementary fermions ?
- Help simple models of fermion masses and mixing
- Motivates SUSY and SUSY predicts LSP as dark matter
- Motivates see-saw (N_R) and explains tiny neutrino masses

2. Proton decay

- Rate driven by dim-5 & 6 operators and wildly depends on model
- What are the branching fractions? $p \to e^+\pi^0$, νK^+, other decay modes? $\nu\pi^+$, $e\gamma$, $\mu\gamma$, …

Dim-6:

$$\tau_p \propto \frac{M_X^4}{\alpha^2}$$



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

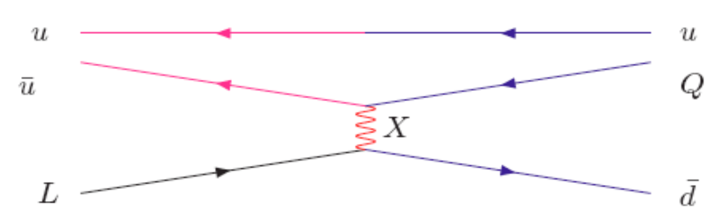


Figure 1. X boson exchange diagram giving the dimension 6 four fermion operator for proton and neutron decay.

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

- 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

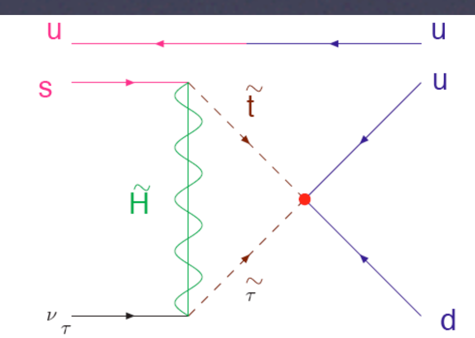
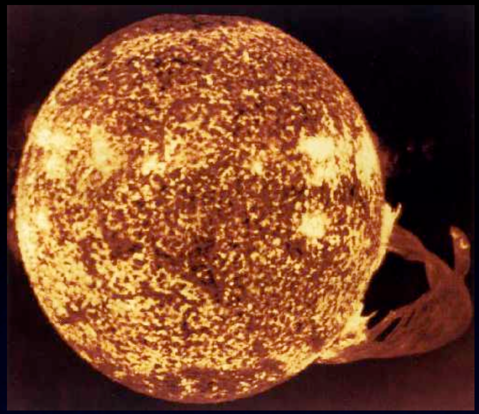


Figure 3. Higgsino and third generation stop - stau loop giving the dominant loop contribution to dimension 5 nucleon decay.

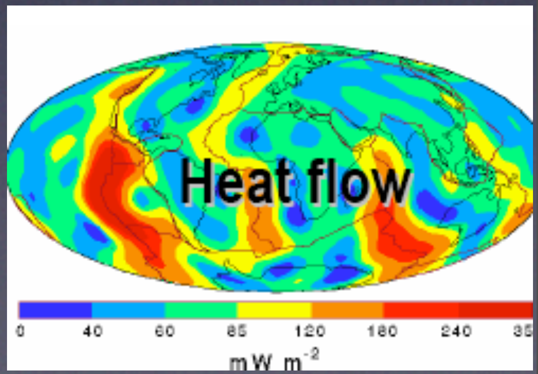
$$\tau(p \to K^+ + \bar{\nu}) < \left(\frac{1}{3} - 3\right) \times 10^{34} \left(\frac{0.015\,\mathrm{GeV}^3}{\beta_{lattice}}\right)^2 \text{ years.}$$

(2) MeV-GeV neutrino "astronomy"

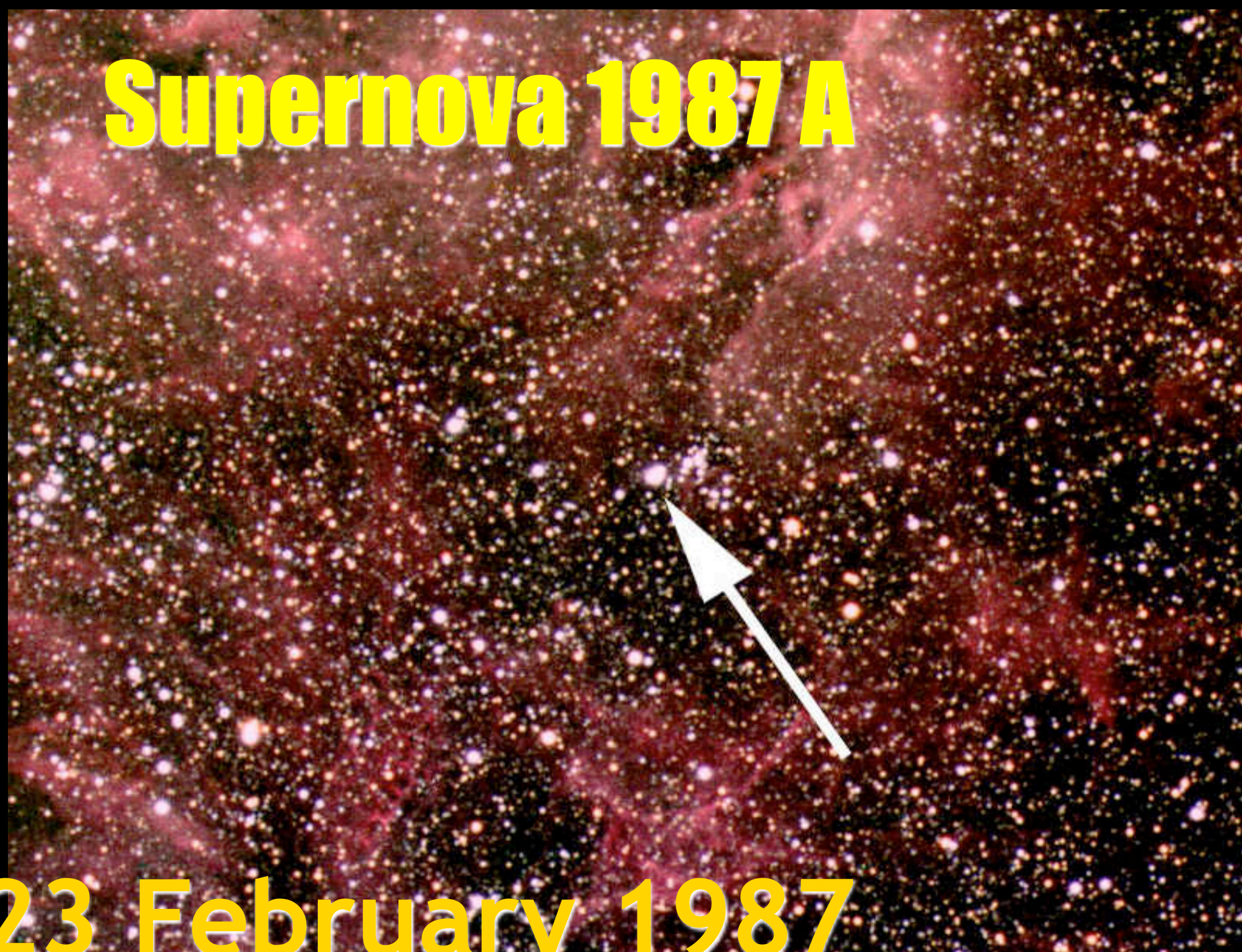
- Astrophysical origin:
  - ★Sun's interior (day&night)
  - ★Supernova core collapse
  - ★Diffuse supernova relic neutrinos
  - ★Dark Matter annihilation



- Terrestrial origin:
  - ★Atmospheric neutrinos
  - ★Geo-neutrinos (Earth natural radioactivity)
  - ★Nuclear reactor cores



SN core collapse



23 February 1987

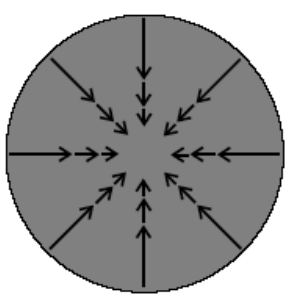
Energy of explosion shows up as
99% Neutrinos
1% Kinetic energy of explosion
(1% of this into cosmic rays)
0.01% Photons, outshine host galaxy

Neutrino luminosity

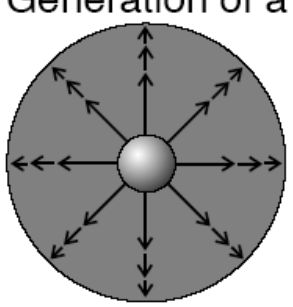
$L_\nu \approx 3 \times 10^{53}$ erg / 3 sec

$\approx 3 \times 10^{19}\ L_{SUN}$

- Gravitational core collapse

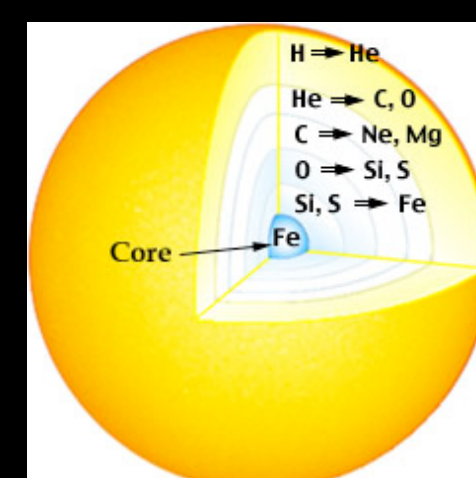


- Generation of a shock



- Neutronization burst:
  Shock wave breaks up the nuclei $\Rightarrow e^-$ capture enhanced
  ν_e emitted at the ν_e neutrinosphere.
  Duration: The first $\sim$ 10 ms
- Cooling through neutrino emission: $\nu_e, \bar{\nu}_e, \nu_\mu, \bar{\nu}_\mu, \nu_\tau, \bar{\nu}_\tau$
  Duration: About 10 sec
  Emission of 99% of the SN energy in neutrinos

The only known source of heavy elements from Iron to Uranium in the Universe



In our Galaxy: 1-3 per century!!!

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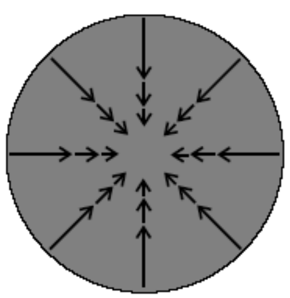

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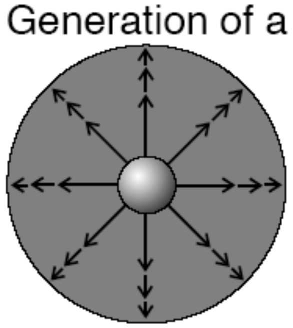

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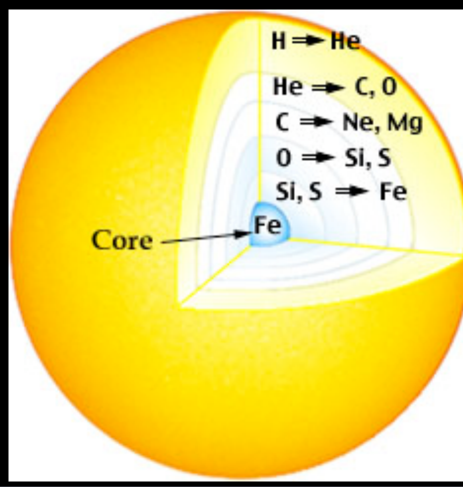


In our Galaxy: 1-3 per century!!!

Core collapse neutrinos

⇒Access supernova and neutrino physics simultaneously

⇒Decouple supernova & neutrino properties via different neutrino detection channels

1. Supernova physics:

- Gravitational collapse mechanism
- Supernova evolution in time
- Burst detection
- Cooling of the proto-neutron star
- Shock wave propagation
- Black hole formation?

2. Neutrino properties

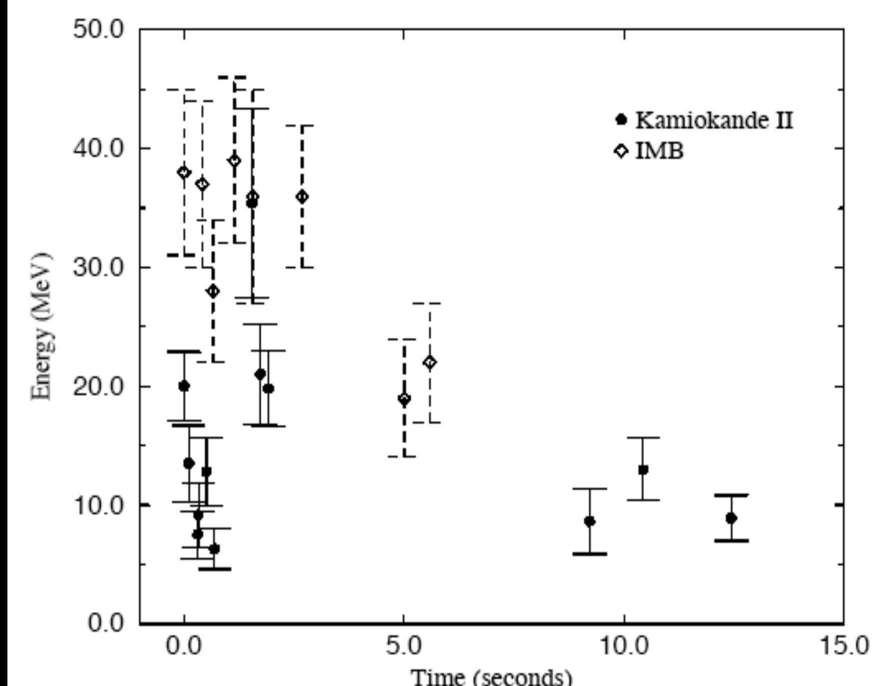
- Neutrino mass (time of flight delay)
- Oscillation parameters (flavor transformation in SN core and/or in Earth): Type of mass hierarchy and θ_{13} mixing angle

3. Early alert for astronomers

- Pointing to the supernova

SN1987A Type II in LMC (~55 kpc)

Water Cherenkov:	IMB	E_{th} ~ 29 MeV, 6 kton	8 events
	Kam II	E_{th} ~ 8.5 MeV, 2.4 kton	11 events
Liquid Scintillator:	Baksan	E_{th} ~ 10 MeV, 130 ton	3-5 events
	Mont Blanc	E_{th} ~ 7 MeV, 90 ton	5 events??



Confirmed baseline model... but still many questions

Must be ready for next one!

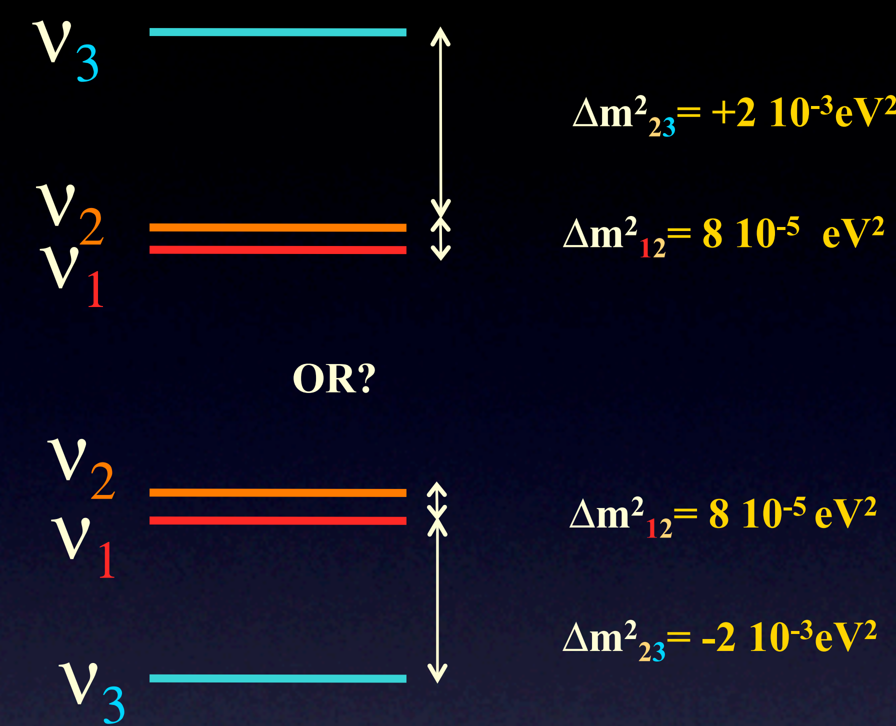
(3) Long baseline neutrino beams

- Study neutrino flavor oscillation at baseline L and neutrino energy E

Weak-eigenstates

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

Mass-eigenstates



$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$= \begin{pmatrix} \sim \frac{\sqrt{2}}{2} & \sim -\frac{\sqrt{2}}{2} & \sin\theta_{13}\, e^{i\delta} \\ \sim \frac{1}{2} & \sim \frac{1}{2} & \sim -\frac{\sqrt{2}}{2} \\ \sim \frac{1}{2} & \sim \frac{1}{2} & \sim \frac{\sqrt{2}}{2} \end{pmatrix}$$

$\sin^2 2\theta_{13} < 0.1$ (90%C.L.)
δ unknown

e.g. $P(\nu_\mu \rightarrow \nu_\mu) \approx 1 - \sin^2 2\theta_{23} \sin^2\left(\Delta m^2_{32} \frac{L}{4E}\right)$

- The goal of long baseline neutrino oscillation experiments is to precisely measure the mixing matrix and mass differences (squared) and answer to important questions such as:

✓Is θ_{23} mixing maximal? (present limit: $\sin^2(2\theta_{23})>0.92$ at 90% C.L)

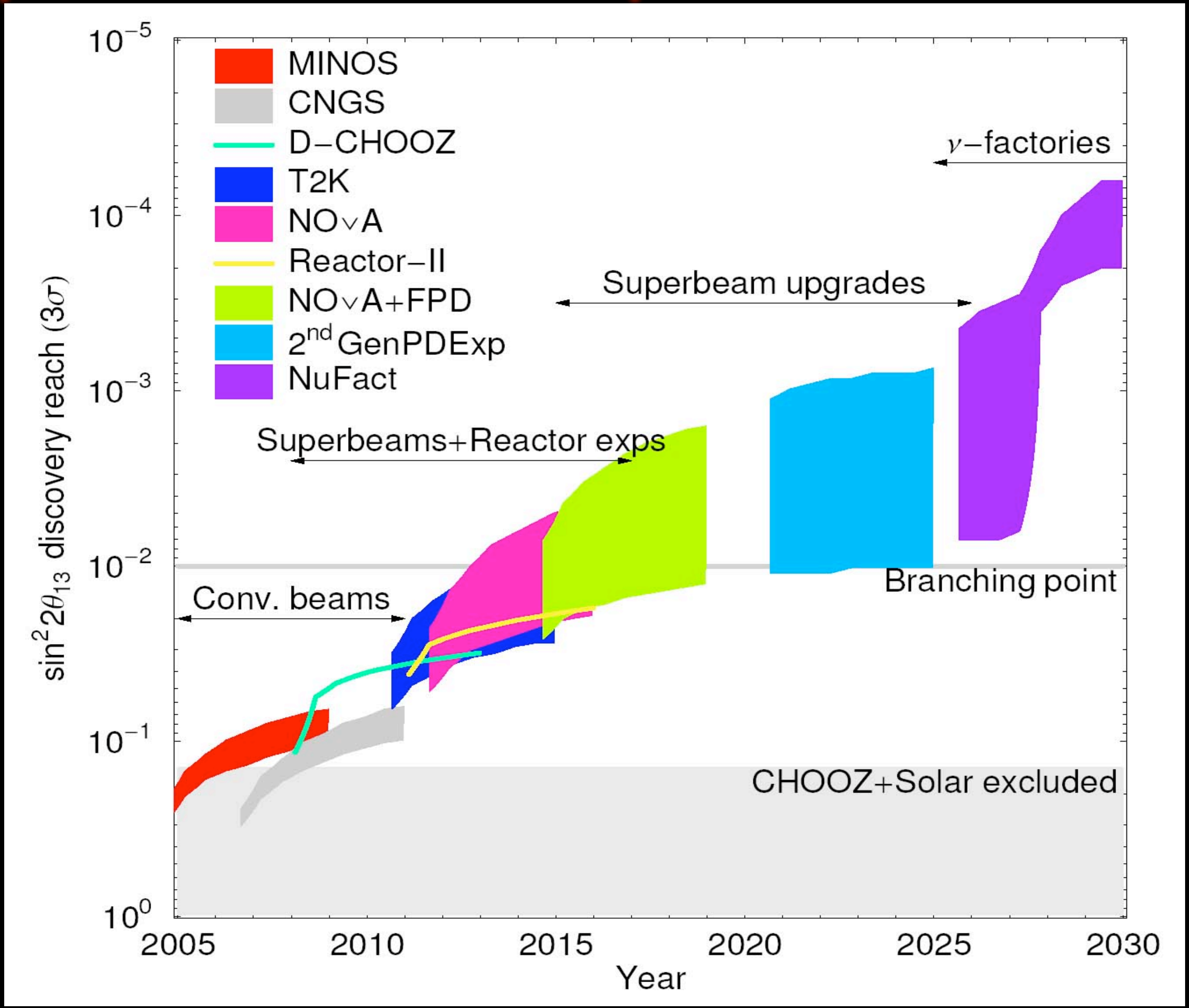
✓Is θ_{13} different from zero? (present limit: $\sin^2(2\theta_{13})<0.1$ at 90% C.L)

✓Is there CP violation in the leptonic sector? (i.e. is $\delta \neq 0$?)

✓Is there normal or inverted hierarchy? (i.e. which is the sign of Δm^2_{32}?).

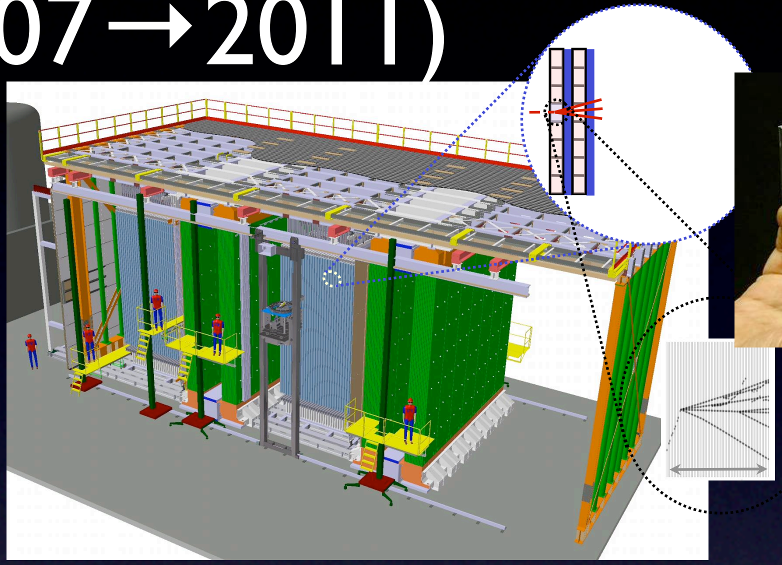
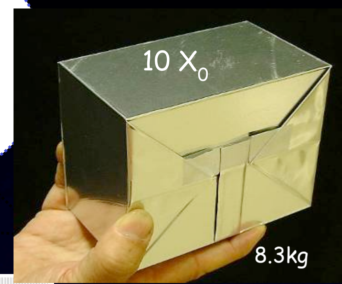
A possible roadmap to discover θ_{13}

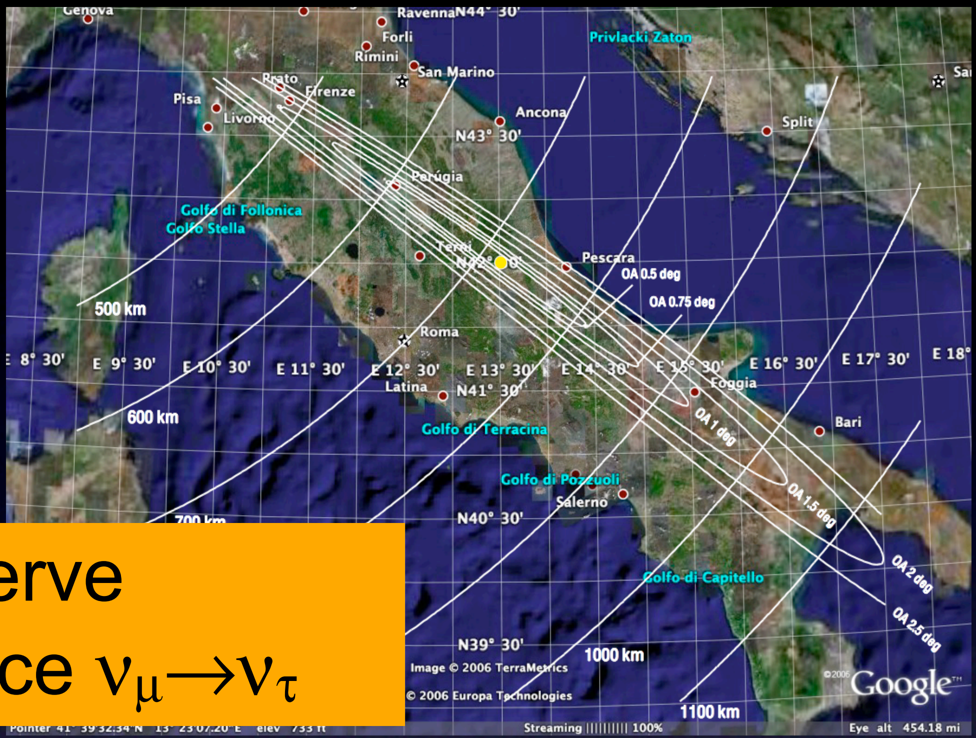
Sensitivity increases



On-going long baseline experiments

CERN-Gran Sasso → OPERA (2007→2011)

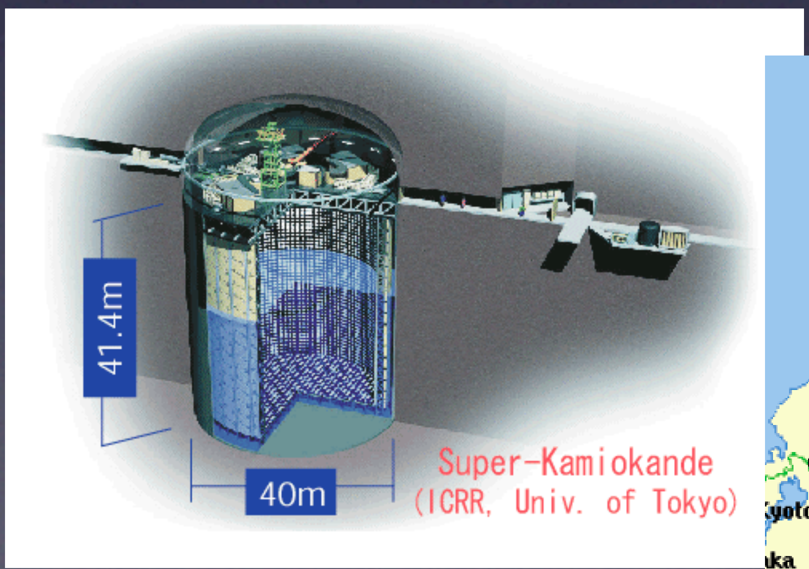





Goal observe appearance $\nu_\mu \rightarrow \nu_\tau$

T2K (2009→)

Currently 28/62 European institutes, ~170/370 European names



Far detector : Super Kamiokande

Goals:

$\delta(\sin^2 2\theta_{23}) \sim 0.01$

$\delta(\Delta m_{23}{}^2) \sim < 1\times10^{-4}$

$\sin^2 2\theta_{13} < 0.01$

MINOS @ Soudan NOvA (2011→)

Next generation ν-beams in Europe?

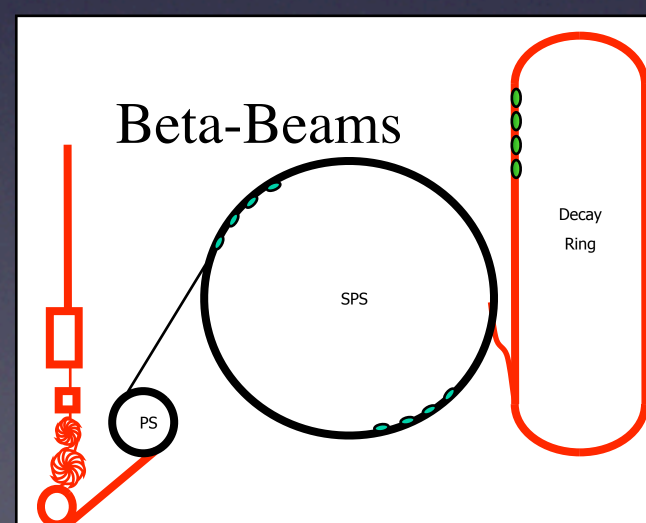
- On-going R&D for next generation neutrino beams (CERN involved)

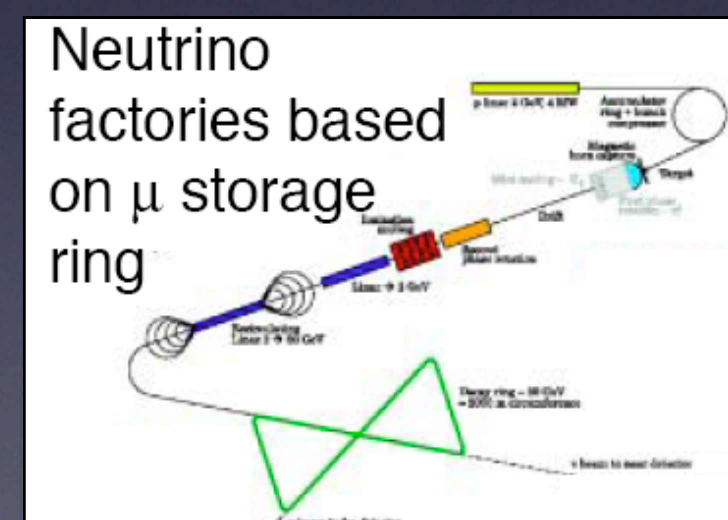
High intensity low energy conventional neutrino sources

“superbeams” ? MW power >2016

2/4 GeV p ? 50 GeV p ? 400 GeV ?

New neutrino production technology



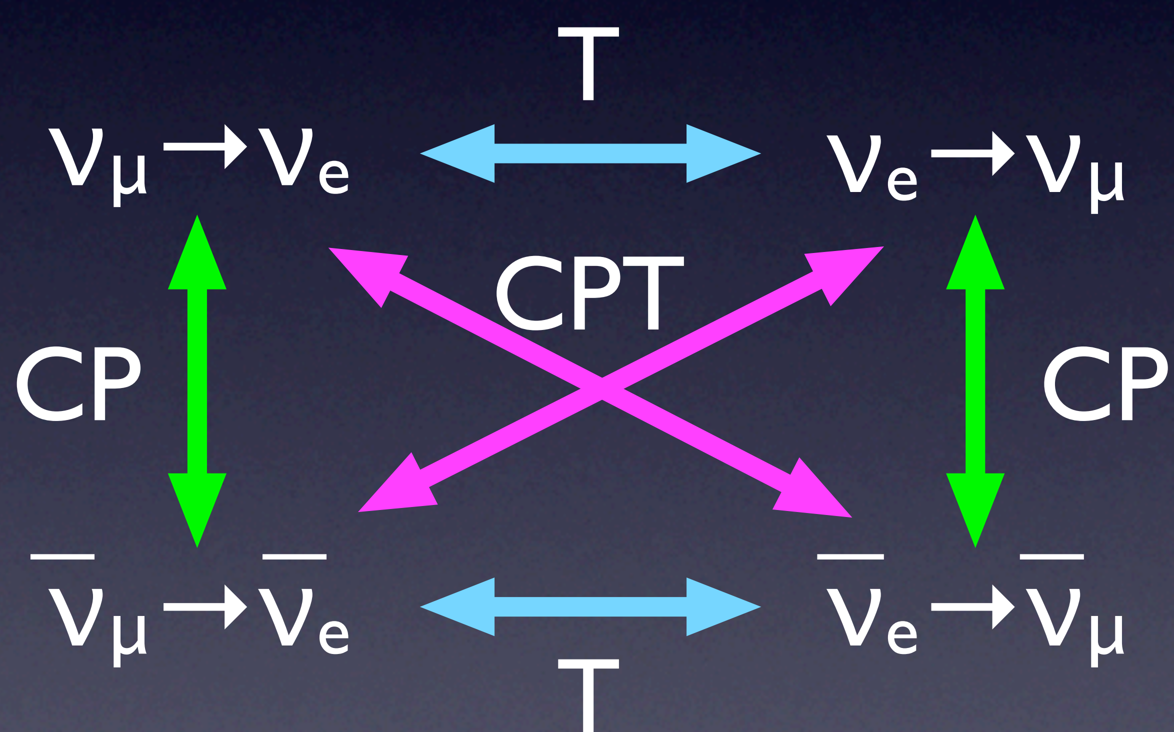


>2020 ?

Leptonic CP violation

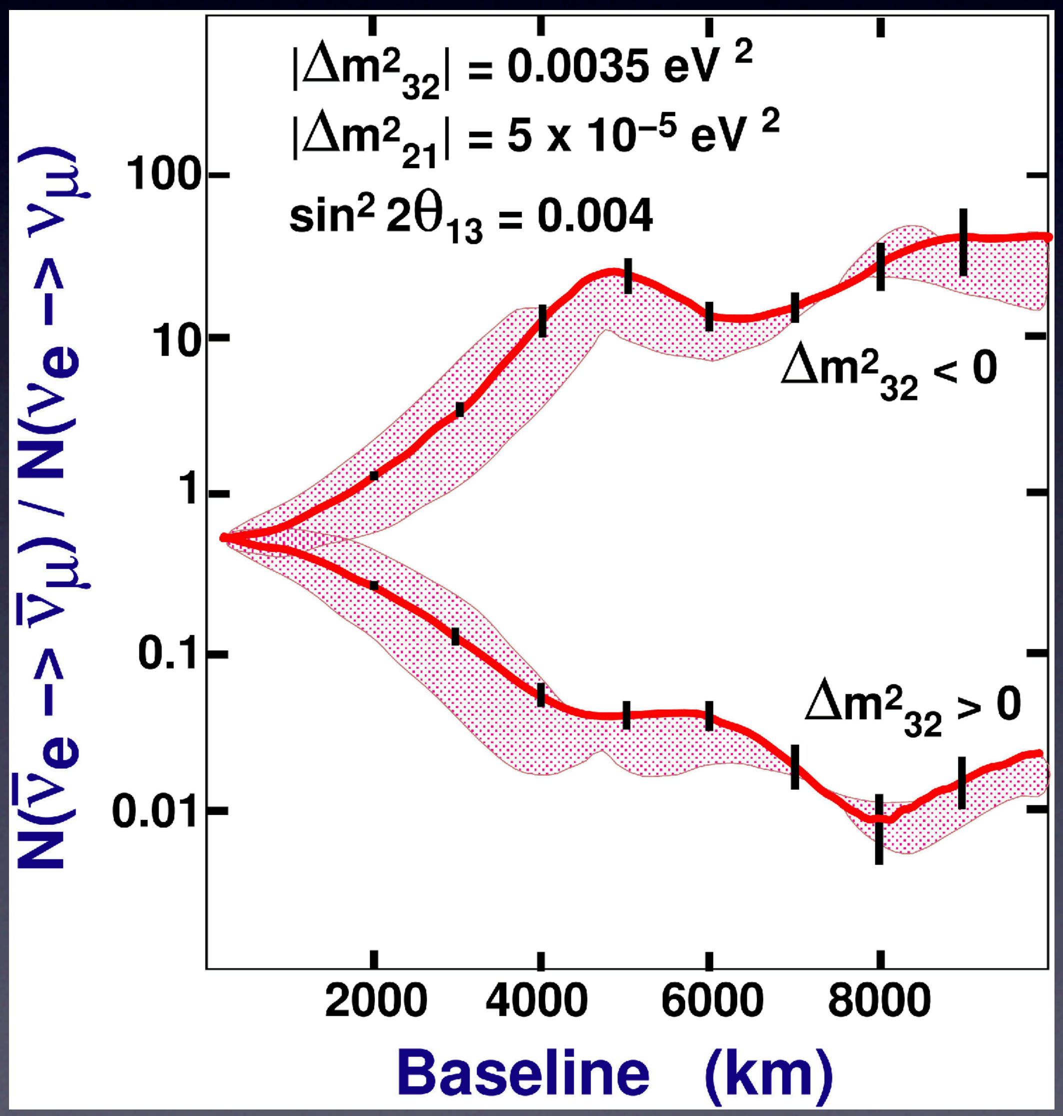
- Precision measurement of neutrino oscillations to determine all parameters of neutrino oscillation phenomenology and possibly discover CP-violation in the leptonic sector

T=time reversal
C=charge conjugation
P=parity (space inversion)



Measure various transitions to understand discrete symmetries
➠*Absolutely fundamental!*

Matter effects & mass hierarchy



Propagation through Earth...

The need for new generation experiments…

A broad particle and astroparticle physics program

• **Baryon number violation**	**Proton decay**
• **Astroparticle physics**	
• Gravitational collapse	**Supernova - ν**
• Early alert for astronomers	**Supernova -ν**
• Star formation in the early universe	**Relic SN -ν**
• Solar thermonuclear fusion processes	**Solar - ν**
• Indirect dark matter searches	**Muons, ν**
• **Neutrino properties**	**Supernova - ν,** **Atmospheric - ν,** **Long baseline - ν**
• **Geophysical models, Earth density profile**	**Atmospheric - ν** **Geo - ν**

> LVD @ LNGS

> Research goals

- LVD is planning an upgrade of the detector by filling one out of three existing towers with Liquid Scintillator loaded with Gd to increase the detection efficiency of inverse beta decay events from a core collapse galactic supernova.
- The target mass with Gd will be about 300 tons
- A publication with details is available

> Costs and funding

- Construction and commissioning for the upgrade: 410k€/3yr with 15 FTE
- Operations: 400k€/yr with 15 FTE
- European funding: 65% (INFN)

> Working Group contact

- Walter Fulgione (IFSI Torino)

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> CTF/Borexino @ LNGS

> Research goals

- CTF:
  - ultra low level radiopurity measurements using the shielding and sensitivity of the detector
  - study of metal loaded liquid scintillator properties for application in massive detectors
- Borexino:
  - real-time sub-MeV solar neutrinos
  - geo-neutrinos, reactor and supernova neutrinos
  - rare processes

> Costs and funding

- R&D and construction:
  - CTF: upgrade 480k€(2yr) and 6 FTE
  - Borexino: 1500k€ (upgrade of electronics and neutrino source) and 10 FTE
- Operations:
  - CTF: 40k€/yr 4 FTE
  - Borexino: 650k€/yr 15 FTE
- European funding: 55% (APC, INFN, Jag. Univ-Krakow, MPKI, TUM)

> Working group contact

- Gianpaolo Bellini (Milano University)

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Astroparticle Physics for Europe

> ICARUS T600 @ LNGS

> Research goals

- ICARUS-T600/CNGS-2 will provide a variety of different event types with and without the neutrino beam.
- Data taking is expected to last 5 more years at 4.5×10^{19} pots/yr during which ICARUS-T600 should collect about 6500 CNGS neutrino events to probe $\nu_\mu \rightarrow \nu_\tau$ neutrino oscillations (7 $\tau \rightarrow e\nu\nu$ events for $\Delta m^2 = 2.5 \times 10^{-3}$ eV^2 and maximal mixing and 48 ν_e CC background events).
- T600 is sensitive to galactic SN core collapses, solar and atmospheric neutrinos and to proton decay.
- Limited physics reach compared to other experiments (OPERA/CNGS-1, SuperK, etc.) but important milestone for a deep underground operation of LAr detectors

> Costs and funding

- R&D and construction: 15 M€
- Funding: 97% (INFN, ETHZ, Granada, Polish groups)
- Est. cost operations: 1M€/yr and 40 FTE (INFN + Polish groups + UCLA)

> Working Group contact

- Alberto Guglielmi (INFN, Padova)

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> Double CHOOZ

> Research goals

- Search for electron neutrino disappearance effect using reactor antineutrinos tagged in a near and far detector at the CHOOZ site (France)
- Far detector under construction: start data taking in early 2009
- Near detector: data taking foreseen 1.5 years later
- Sensitivity to mixing angle down to $\sin^2 2\theta_{13} \approx 0.02\text{-}0.03$ until 2013
- Complementary measurement to T2K/NOvA (disappearance vs. appearance measurement, no dependence on CP δ-phase for Double CHOOZ)
- Double CHOOZ + T2K/NOvA results important milestone to help define the 3rd generation of long baseline neutrino experiments (CP-violation)

> Costs and funding

- Construction: 14M€ and 35 FTE
- Operations: 50k€/yr and 15 FTE
- European funding: 65% (CEA, CNRS, CIEMAT/CICYT, DFG, MPIK, PPARC)

> Working Group Contact

- Hervé De Kerret (CNRS/APC Paris), Thierry Lasserre (CEA Saclay), Alessandra Tonazzo (APC Paris)

> SNO+

> Research goals

- Follow-up of SNO replacing heavy water with high purity Liquid Scintillator (already identified).
- Main focus:
  - precision measurement of pep/CNO solar neutrinos
  - search for 0νββ search with Nd-150 loading
  - measurement of geo-, reactor and supernova neutrinos
- Main advantages:
  - existing SNO infrastructure and shielding → relative short-time startup time
  - large depth, very low cosmogenic backgrounds
  - large mass, good energy resolution (9000 PMTs)
  - fewer baselines than Kamioka for reactor neutrinos

> Costs and funding

- R&D and construction: 15M€ (EU contribution 100k€ with 5 FTE)
- Operations: EU contribution 40k€/yr with 5 FTE
- European participation at present limited to Sussex University and LIP-Lisbon. Growing interest foresees a larger participation.

> Working Group contact

- Kai Zuber (Sussex University)

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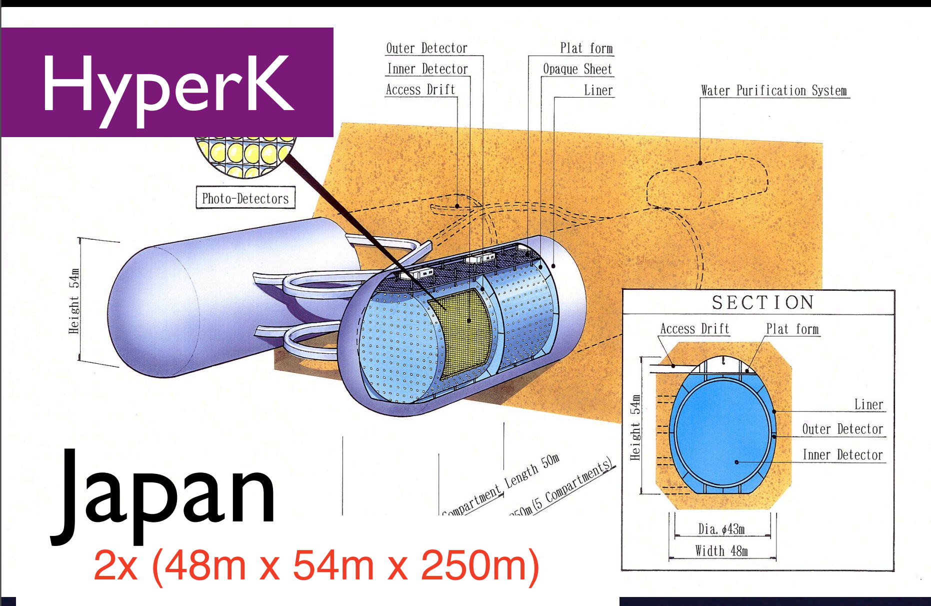
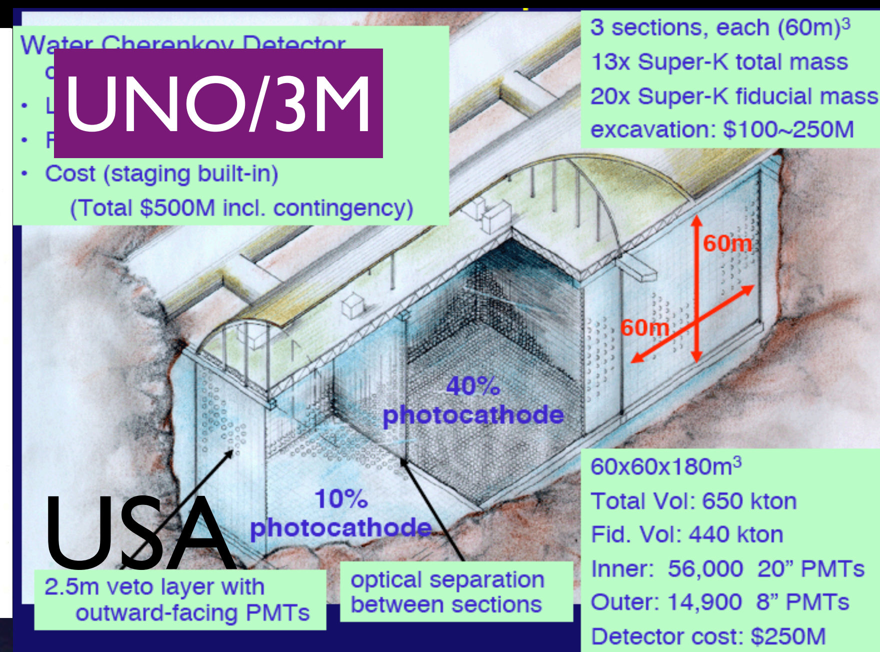
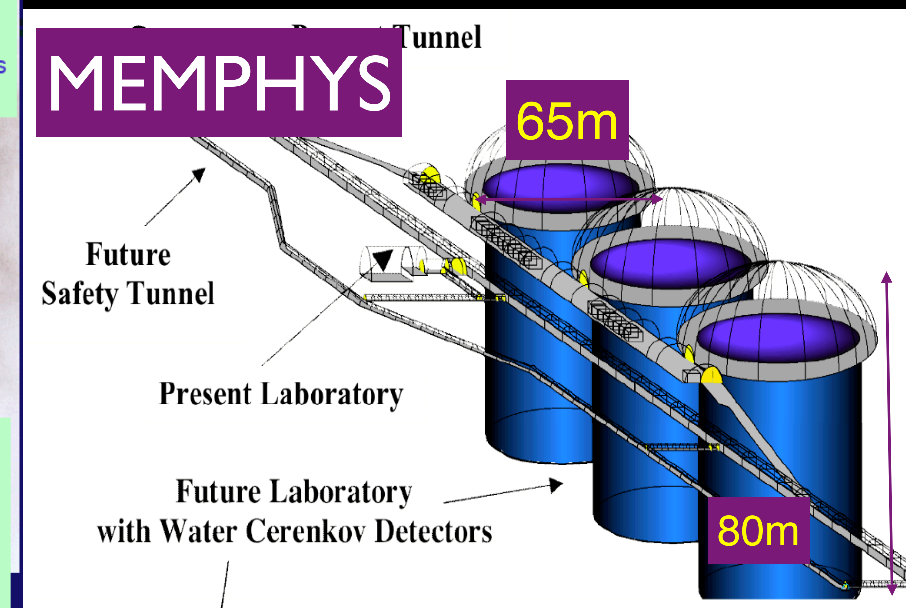
Some detectors presented at NNN Workshops

Stony Brook 1999, ..., Aussois 05, Seattle 06, Hamamatsu Oct 07, Paris 08

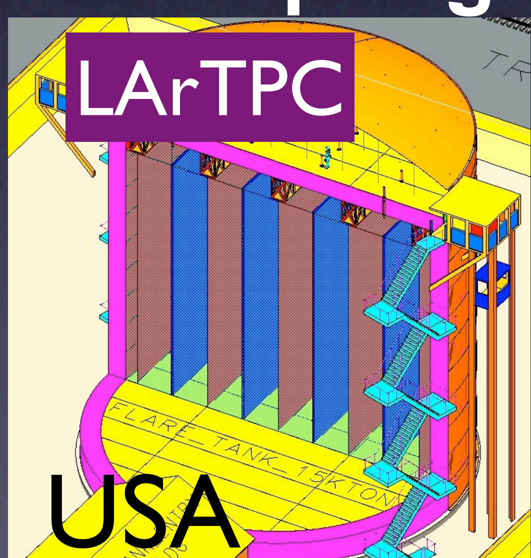
Water Čerenkov 500kt→1Mt

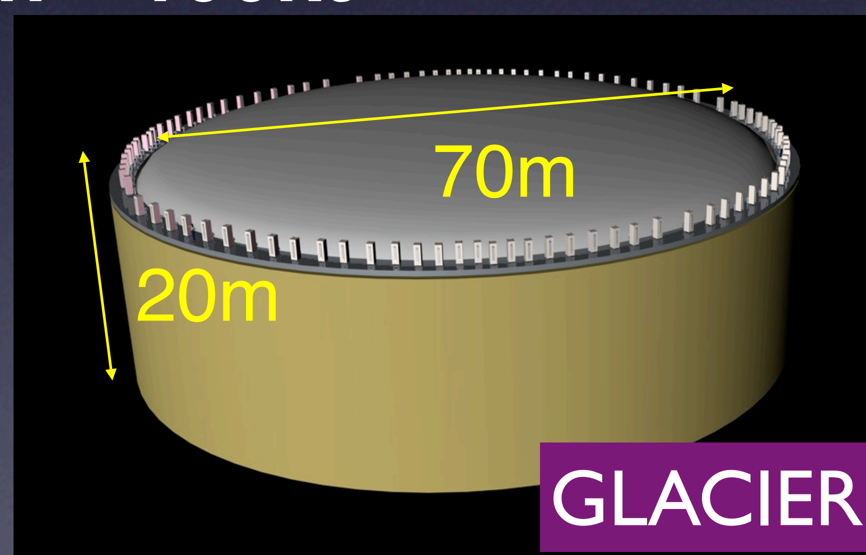


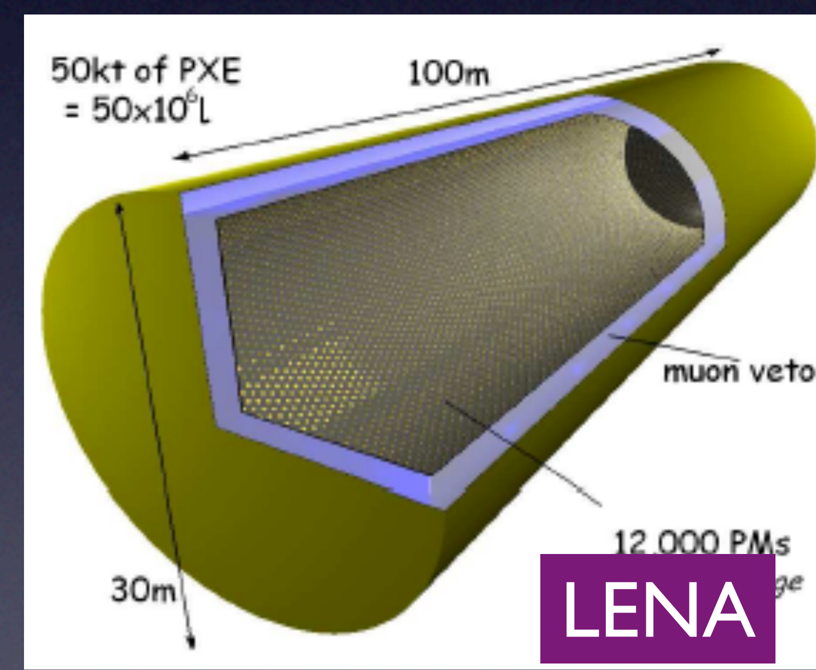




Liq. Argon→100kt







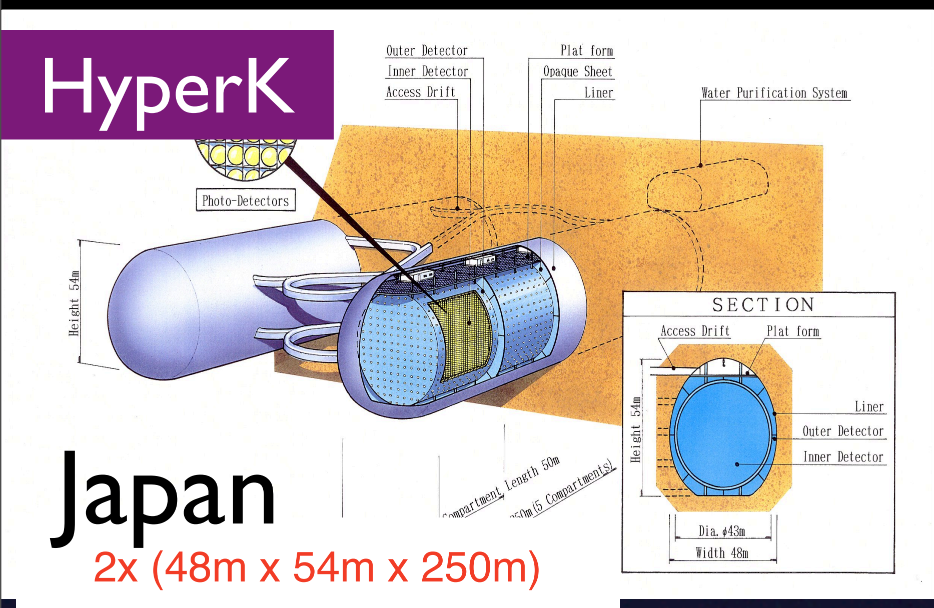
Liq. Scintillator→50kt

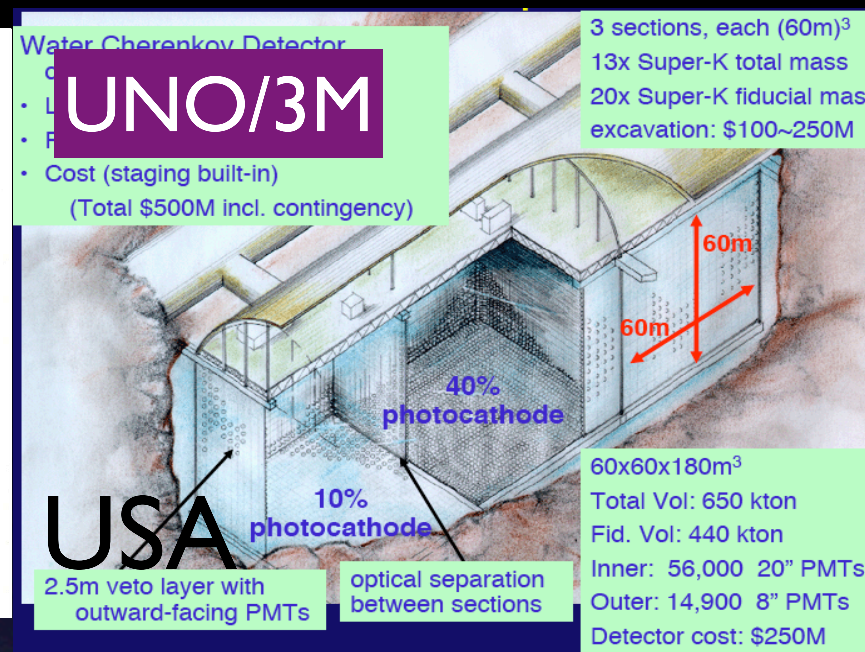
Large Apparatus for Grand Unification and Neutrino Astrophysics : LAGUNA

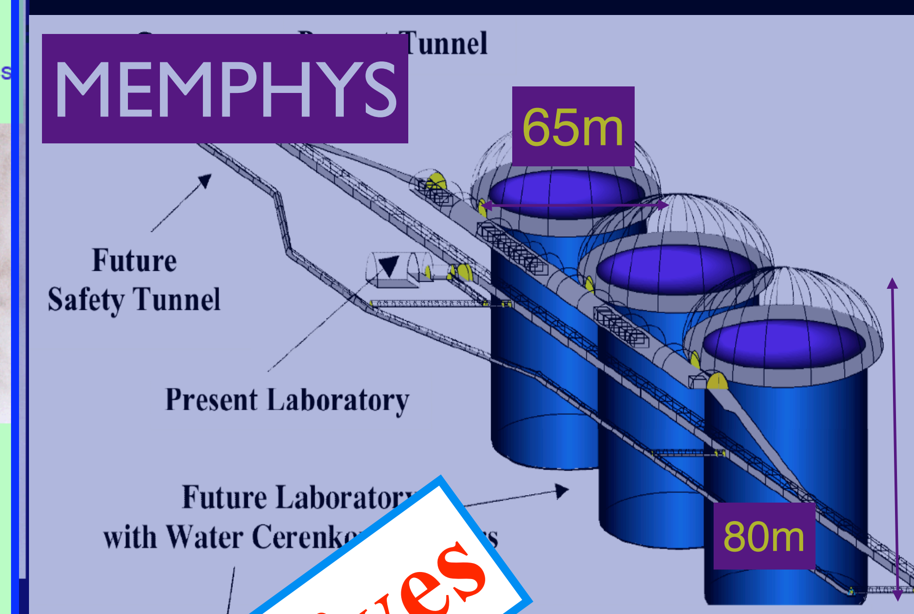
Some detectors presented at NNN Workshops

Stony Brook 1999, ..., Aussois 05, Seattle 06, Hamamatsu Oct 07, Paris 08

Water Čerenkov 500kt→1Mt

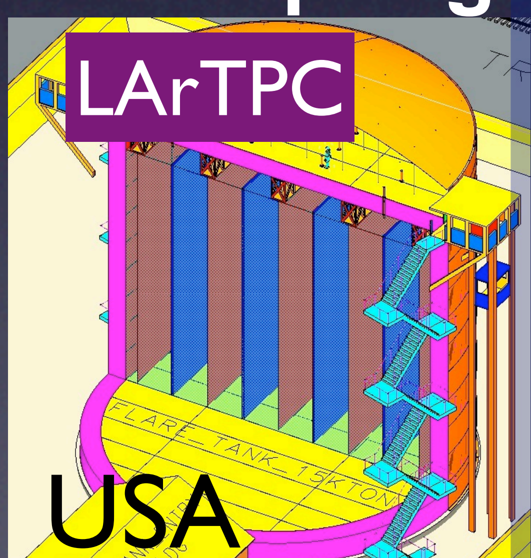


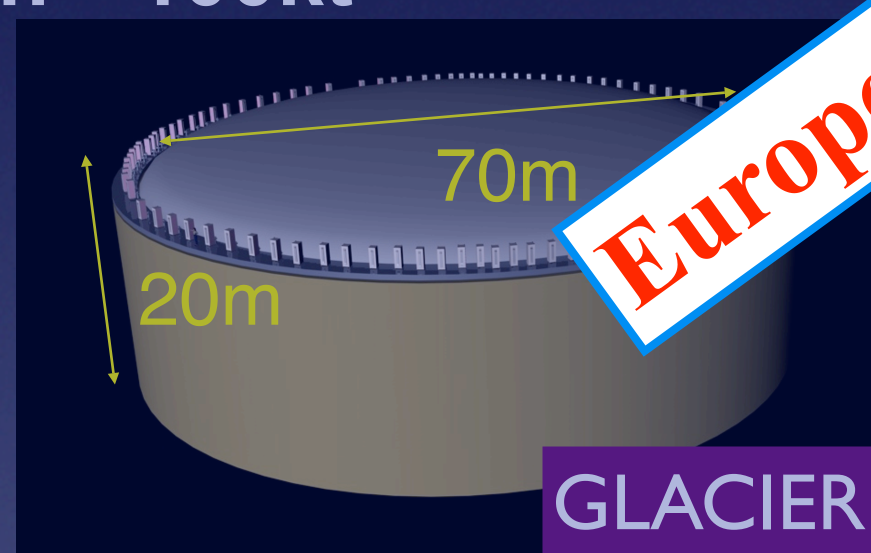


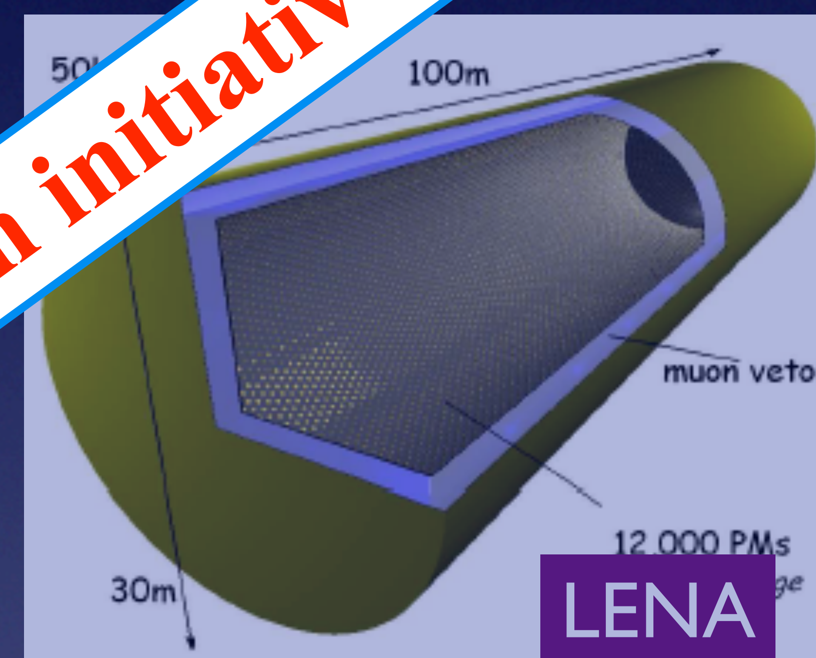


European initiatives

Liq. Argon→100kt







Liq. Scintillator→50kt

Large Apparatus for Grand Unification and Neutrino Astrophysics : LAGUNA

Outstanding non-accelerator 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	1.2×10^{35} years ε = 17%, ≈ 1 BG event	0.5×10^{35} years ε = 45%, <1 BG event	?
$p \to \nu K$ in 10 years	0.15×10^{35} years ε = 8.6%, ≈ 30 BG events	1.1×10^{35} years ε = 97%, <1 BG event	0.4×10^{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 !

> MEMPHYS 1000 kton

> Research goals

- **"Megaton-scale" Water Cerenkov detector (hep-ex/0607026)**
- Grand Unification: proton decay investigated in the 10^{35} yr range
- 3rd generation experiment for θ_{13} mixing angle and CP violation with CERN low-energy superbeam and/or betabeams (JHEP 0704:003,2007)
- Large sensitivity to solar/atmospheric neutrinos
- Study of SN core collapse and detection of relic SN neutrinos

> Physical and Technical R&D phase

- Study of siting under the Fréjus (extension of LSM). Further site studies within the LAGUNA FP7 DS.
- Funded R&D on large area photomultiplier production (IN2P3, ANR)
- Funded R&D on integrated photomultiplier electronics production (IN2P3, ANR)
- Smaller scale prototypes (e. g. MEMPHYNO) under investigation
- LOI for 1 kton WC in T2K beam submitted to JPARC PAC

> Estimated costs

- Final detector: 500 M€

> Working Group contact

- Jean-Eric Campagne (LAL) and Thomas Patzak (APC)

> GLACIER 100 kton

> Research goals

- **“Megaton-scale” liquid Argon detector (hep-ph/0402110)**
- Grand Unification: proton decay investigated in the 10^{35} yr range and study of atmospheric neutrinos (JHEP 0704:041,2007)
- SN core collapse, all neutrino flavors (JCAP 0408:001,2004)
- 3rd generation experiment for θ_{13} mixing angle, CP violation and mass hierarchy with upgraded CERN SPS neutrino beam (JHEP 0611:032,2006)
- Possible synergies with future betabeams and/or neutrino factory (Nucl.Phys.B631:239-284,2002)

> Physical and Technical R&D phase

- Funded R&D setups for charge & light readout, HV, feed-throughs, electronics, purification, long drift paths, ... (CH-SNF, ETHZ, IN2P3, Granada Univ, UniBe, UniZ)
- Magnetized TPC (NIM A555:294-309,2005)
- ArDM 1 ton detector (J.Phys.Conf.Ser.39:129-132,2006)
- ArgonTube 5 m drift full test: being installed
- ePiLAr in particle beams: under investigation, possibly magnetized TPC
- Detection of ≈1 GeV neutrino beam: under investigation
- LOI for 150 ton in T2K beam submitted to JPARC PAC
- European siting possibly at shallow depth to be studied within LAGUNA FP7 DS. Other sites, e.g. T2K/T2KK, being discussed

> Estimated costs

- Total(Detector only) = 390(200)M€ for 100kt, 87(50)M€ for 10kt, 21(13)M€ for 1kt

> Working Group contact

- André Rubbia (ETH Zurich)

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> LENA 50kt

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> Research goals

- **“Megaton-scale” liquid scintillator detector (up to 50 kton)**
- Grand Unification: p→νK$^+$ decay investigated in the 10^{35} yr range (Phys.Rev.D72:075014,2005)
- Large sensitivity to low energy astrophysical neutrinos (J.Phys.Conf.Ser. 39:287-290,2006)
- Study SN core collapse and SN diffuse relic neutrinos (Phys.Rev.D75:023007,2007)
- Detection of solar neutrinos with high statistics (Rate ^{7}Be=200/h!)
- Detection of geo-neutrinos (Earth Moon Planets 99:253-264,2006)

> Physical and Technical R&D phase

- R&D funded on a national scale in the “ Center for excellence : origin and structure of the universe” and the “Sonderforschungsbereich-Transregio TR27: neutrinos and beyond” both at the Technische Universität München.
- Study of siting in CUPP Pyhäsalmi Mine or Pylos (Nestor Institute). Further site studies within the LAGUNA FP7 DS.
- R&D on highly pure scintillator (PXE): material compatibility, transparency, ...

> Estimated costs

- 100-200 M€

> Working Group contact

- Lothar Oberaurer (TUM)

ASPERA

> MODULAr 20 kt

> Research goals

- Large sensitivity measurement of θ_{13} mixing angle, CP violation and mass hierarchy with off-axis ν_μ beam with 20kt LAr modular and shallow depth detector (arXiv:0704.1422, April 2007).
- Compete with NOvA/T2K thanks to better $\nu_\mu \rightarrow \nu_e$ event identification efficiency and background suppression (time scale?).
- Detection of solar/atmospheric neutrinos, SN explosions.
- Proton decay investigated in the 10^{34} yr range

> Physical and Technical R&D phase

- Proposed "next-step" after ICARUS T600
- Modular design with 4x5 kton modules
- Study of excavation LNGS-II nearby LNGS
- Slice detector with (another) 500 ton LAr to test the technique optimized for very large volumes and the expected powerful NC rejection of LAr, and a possibility of detection of sterile neutrino at CERN PS neutrino beam.

> Estimated costs

- *"Not applicable at the present stage to this framework"*

> Working Group contact

- Alberto Guglielmi (INFN Padova)

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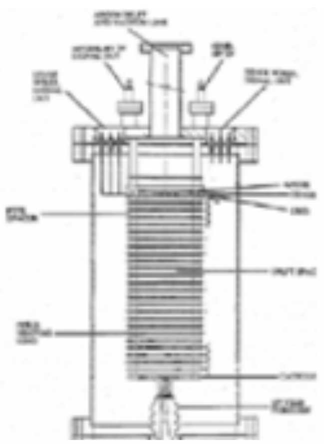
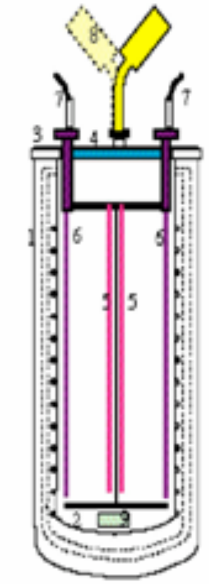
The pioneering project: ICARUS



24 cm drift wires chamber

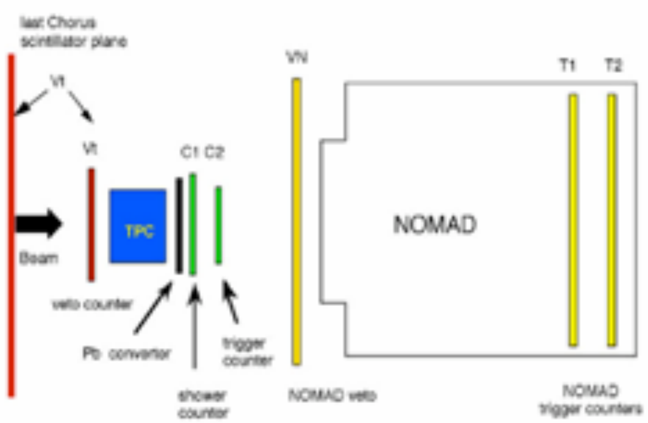
1987: First LAr TPC. Proof of principle. Measurements of TPC performances.

3 ton prototype



1991-1995: First demonstration of the LAr TPC on large masses. Measurement of the TPC performances. TMG doping.

50 litres prototype 1.4 m drift chamber



1997-1999: Neutrino beam events measurements. Readout electronics optimization. MLPB development and study. 1.4 m drift test.

10 m^3 industrial prototype

1999-2000: Test of final industrial solutions for the wire chamber mechanics and readout electronics.

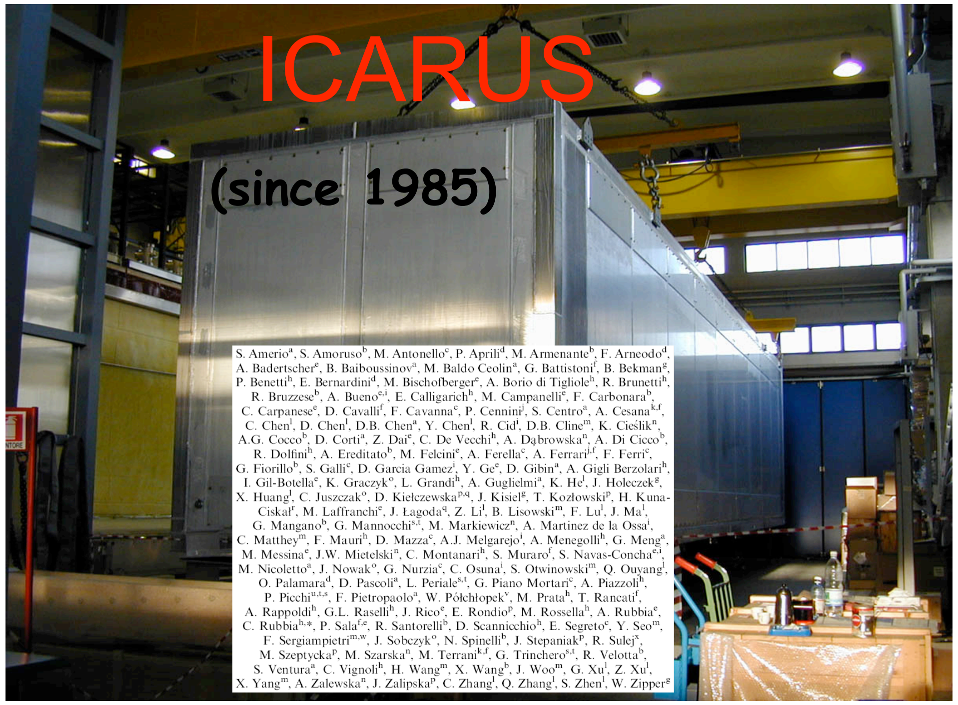
600 ton detector

2001- present: 300 ton detector tested on surface in Pavia. 600 ton detector being presently assembled at LNGS.

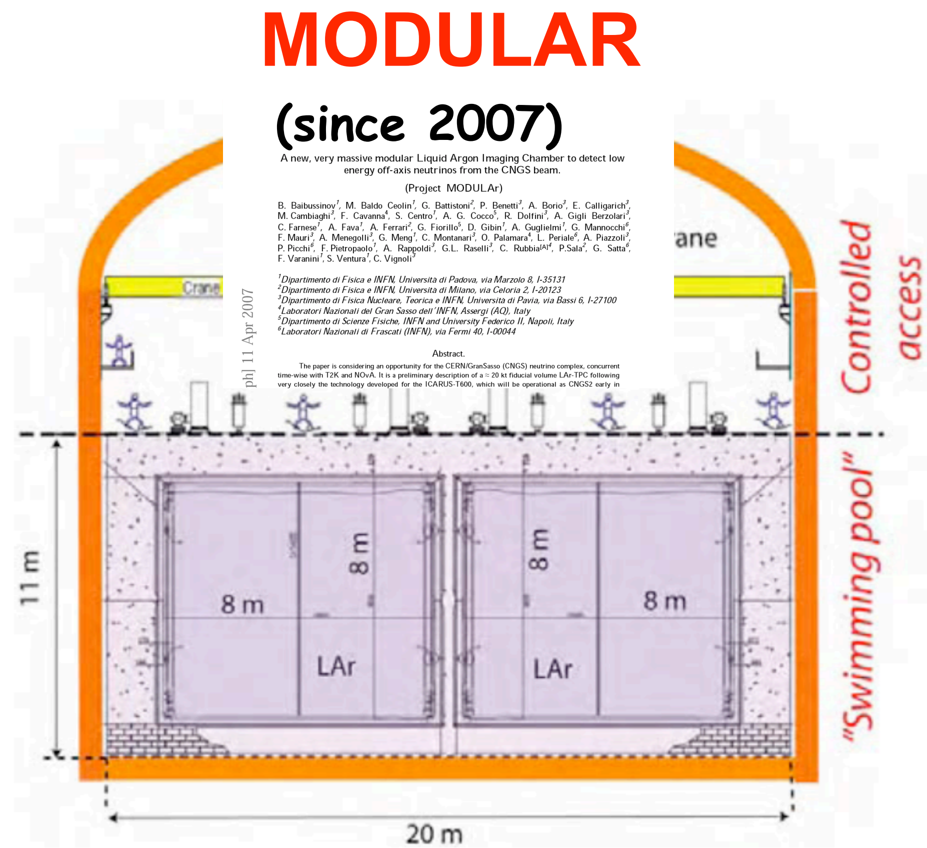
20 years later...

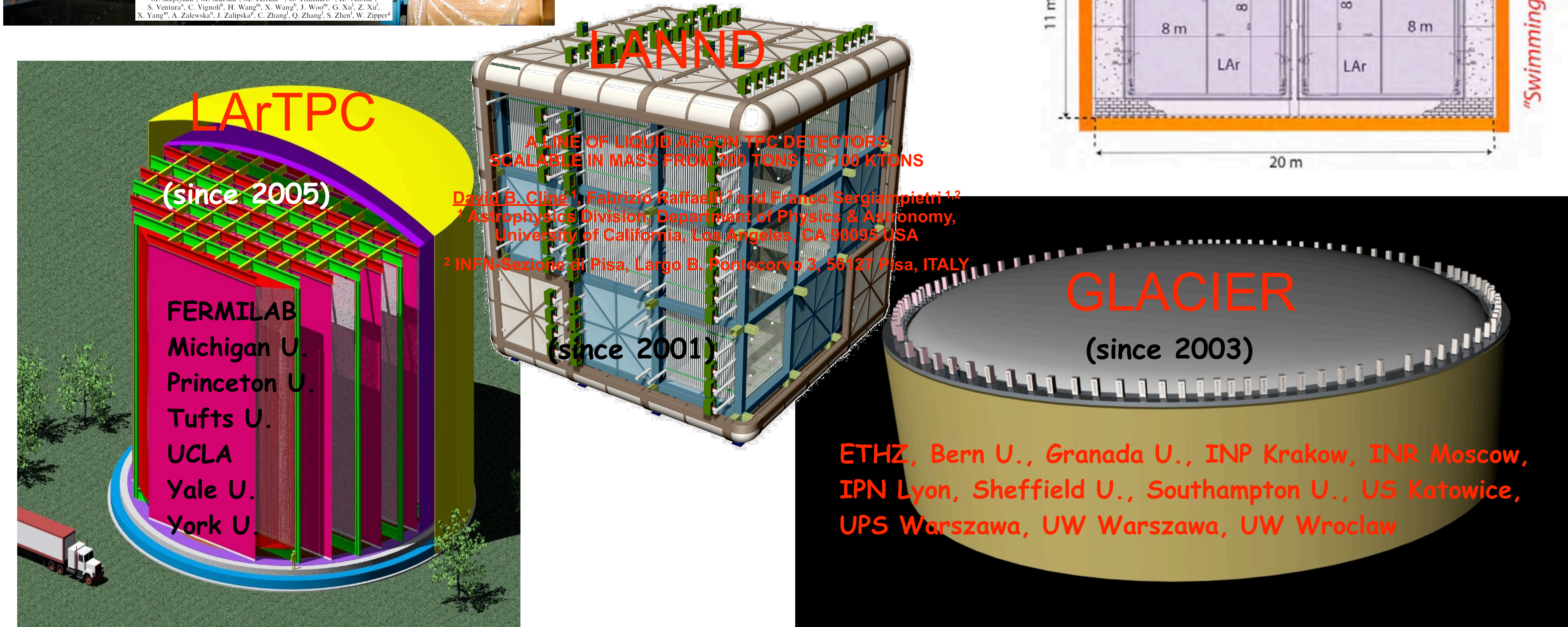
After 20 years…Different approaches:

- a **modular** or a **scalable** detector for a total LAr mass of 50-100 kton
- **evacuable** or **non-evacuable** dewars
- detect ionization charge in LAr **without amplification** or with **amplification**



- ICARUS 1985
- LANND 2001
- GLACIER 2003
- LArTPC 2005
- MODULAR 2007





> LAGUNA design study

> Research goals

- Large underground, liquid based detectors for astro-particle physics in Europe (arXiv:0705.0116)
- Unified and common European approach for large underground infrastructures capable of hosting total liquid volumes in the range of 100'000 to 1'000'000 m^3
- Concerted effort among MEMPHYS, LENA and GLACIER groups to address and solve common issues (24 participants: ETH Zürich, Bern, Jyväskylä, Oulu, Rockplan, CEA/DSM/DAPNIA, IN2P3, MPG, TUM, Hamburg, IFJ PAN, IPJ, US, UWr, KGHM CUPRUM, IGSMiE PAN, LSC, Granada, Durham, Sheffield, Technodyne, ETL, Aarhus, AGT)
- Timescale : CDR around 2010

> Physical and Technical R&D phase

- Address technical and economical feasibility of an underground observatory of this magnitude, perhaps ultimate in size via a strong, coordinate and coherent European strategy
- 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)** excavation and preparation of the underground space
  - **(2)** design and construction of the tank
  - **(3)** detector instrumentation
  - **(4)** safety aspects.

> Estimated costs

- Up to 1.7M€ funded by EC to be focused on points (1), (2) and (4) above.

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Six national underground science laboratories

IUS

Institute of Underground Science in Boulby mine, UK

CENTRE FOR UNDERGROUND PHYSICS IN PYHÄSALMI MINE

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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Laboratori Nazionali del Gran Sasso, Italy

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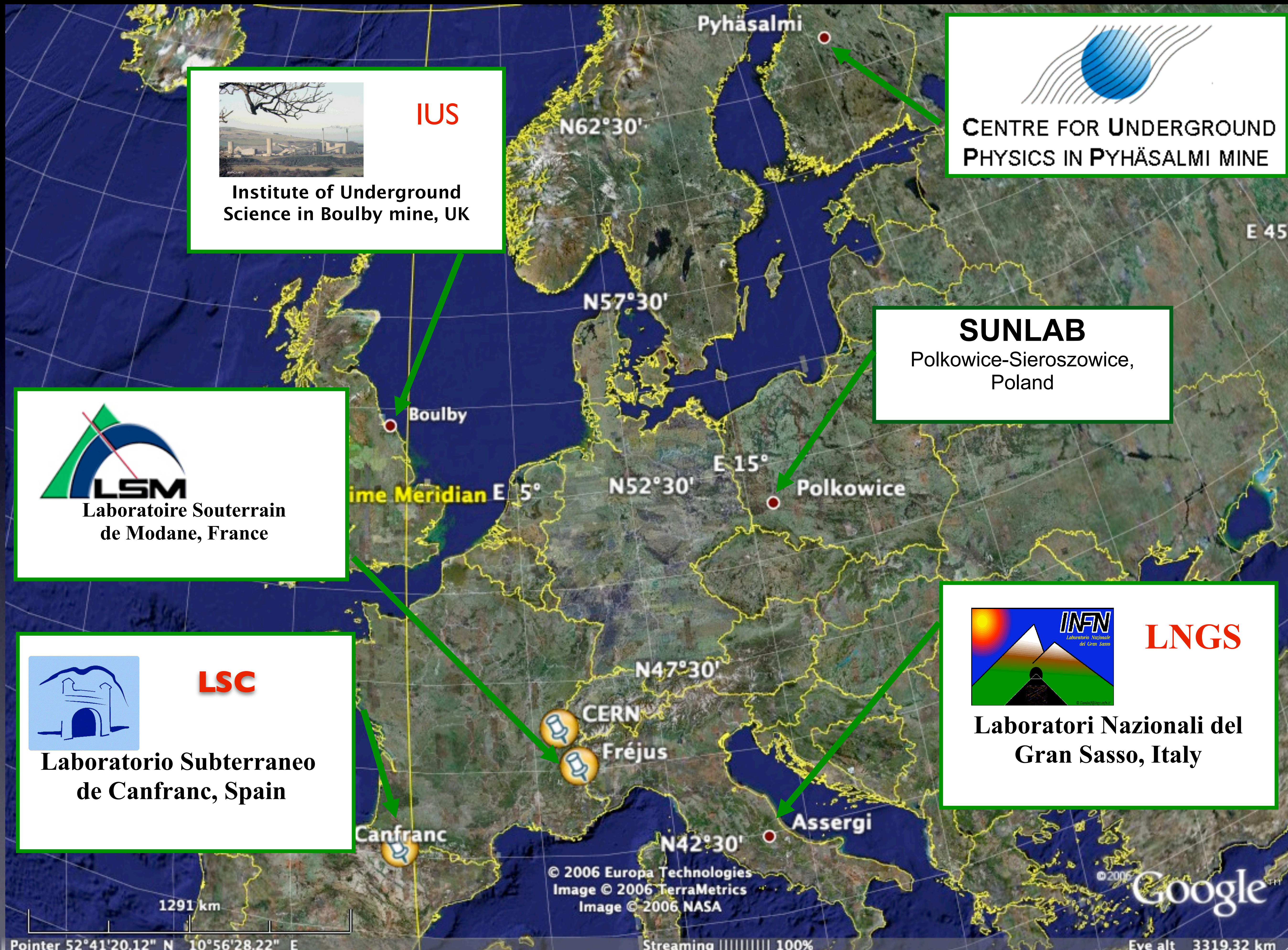

IUS
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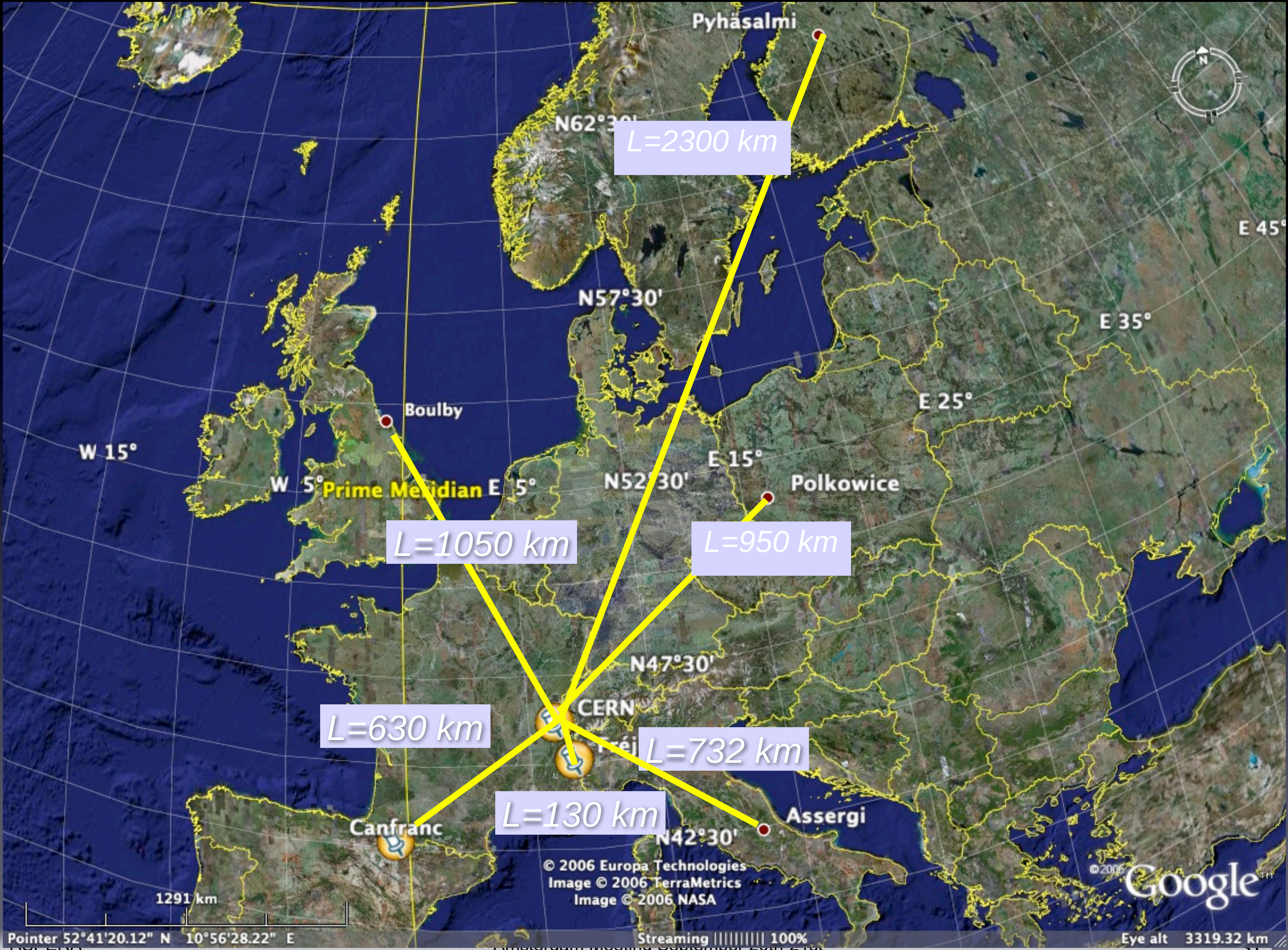
Pyhäsalmi
Boulby
Polkowice
CERN
Fréjus
Canfranc
Assergi
N62°30'
N57°30'
N52°30'
N47°30'
N42°30'
E 15°
E 45°
ime Meridian
E 5°
1291 km
© 2006 Europa Technologies
Image © 2006 TerraMetrics
Image © 2006 NASA
Google
Pointer 52°41'20.12" N 10°56'28.22" E
Streaming |||||||||| 100%
Eye alt 3319.32 km


Pyhäsalmi
L=2300 km
N62°30'
N57°30'
E 45°
E 35°
E 25°
E 15°
Boulby
W 15°
W 5°
Prime Meridian
E 5°
N52°30'
Polkowice
L=1050 km
L=950 km
N47°30'
CERN
L=630 km
L=732 km
L=130 km
Canfranc
Assergi
N42°30'
© 2006 Europa Technologies
Image © 2006 TerraMetrics
Image © 2006 NASA
Google
1291 km
Pointer 52°41'20.12" N 10°56'28.22" E
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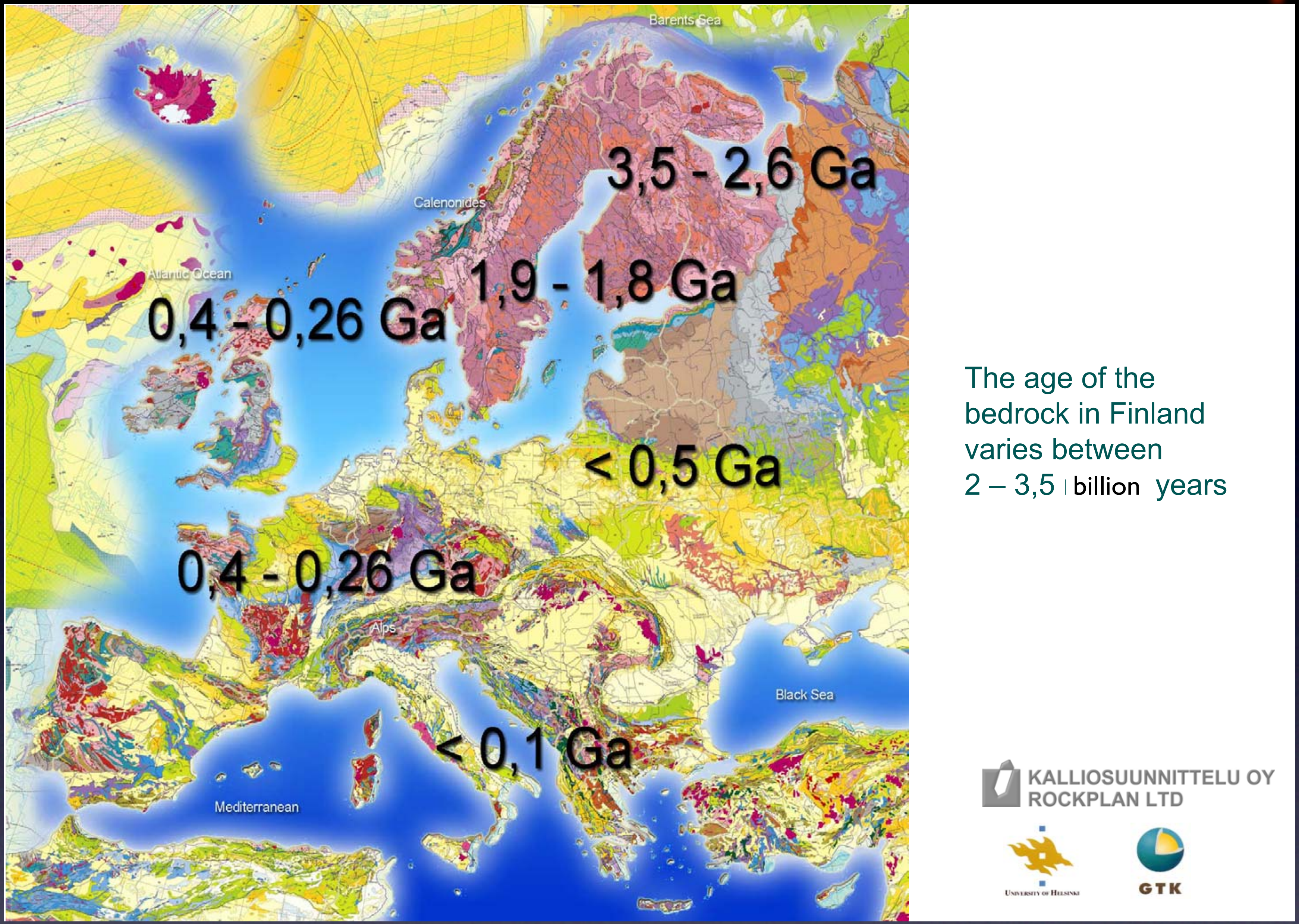
Bedrock conditions in Europe

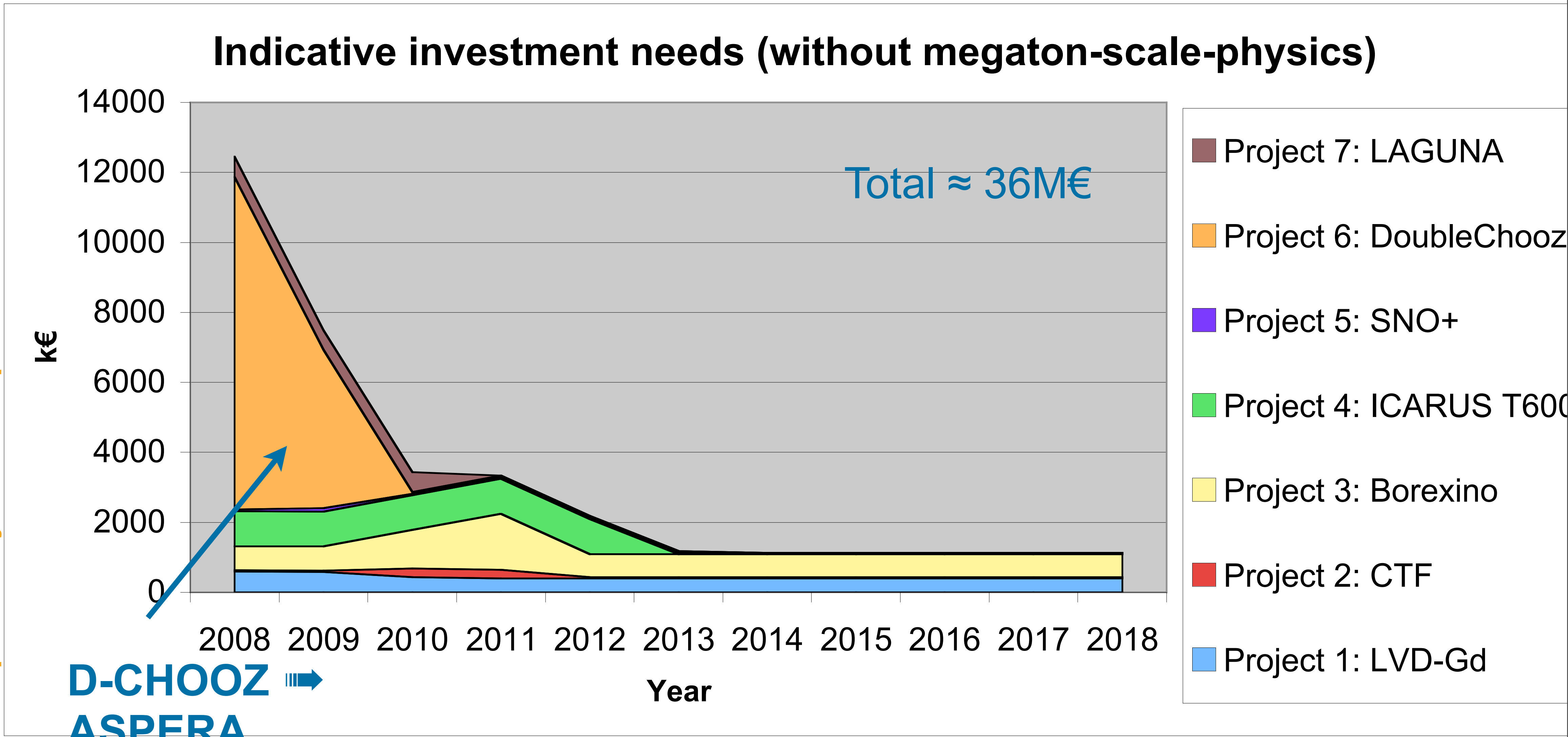


LAGUNA ➠Detailed feasibility studies (for all potential sites) including thorough rock sampling & rock simulations

➠Pre-plan for construction

➠Cost estimates

> Stavros Plots: on-going projects total



D-CHOOZ ➠ ASPERA funding ≈65%

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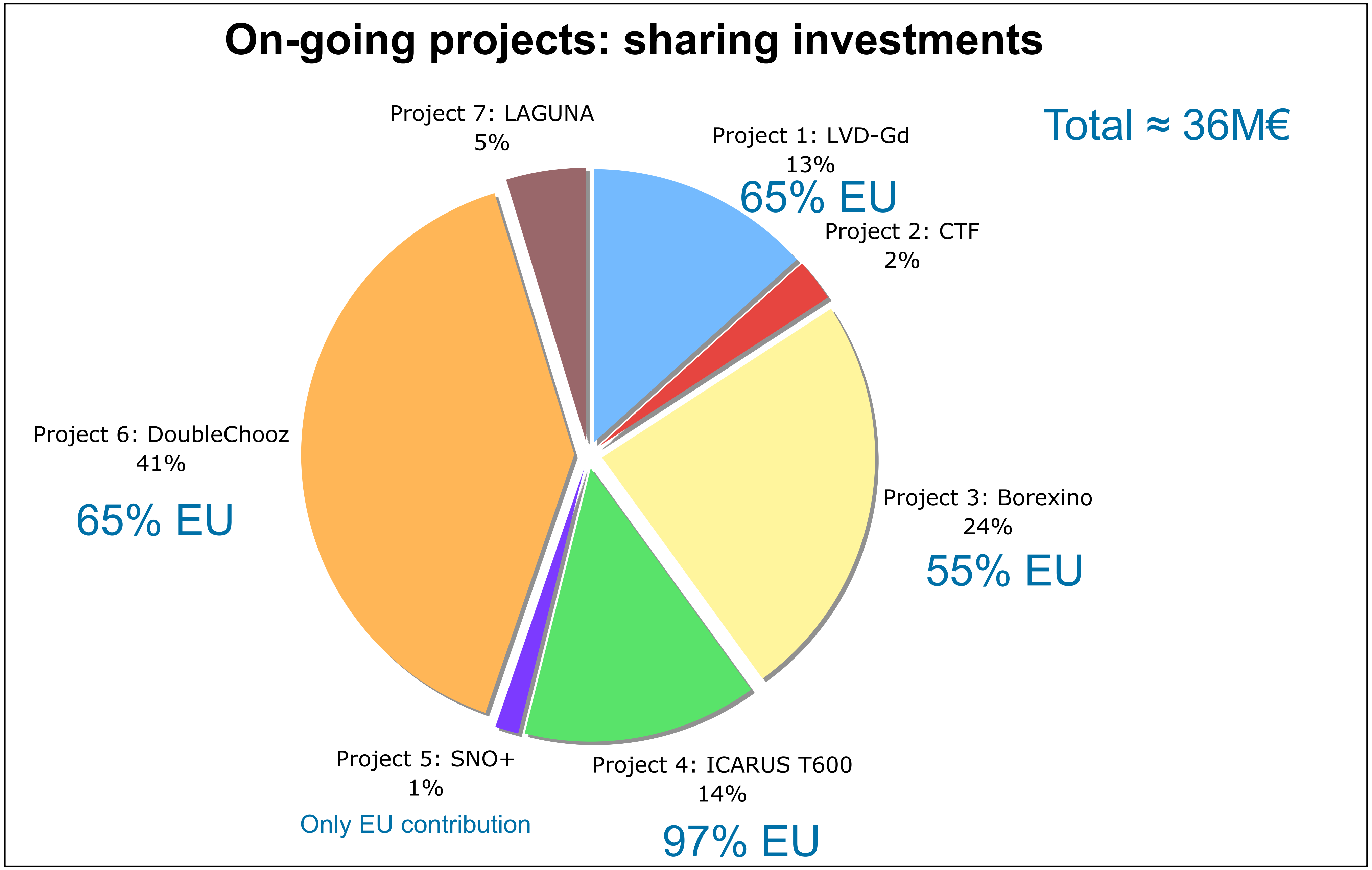
From 2008 → 2018: total estimated investment for on-going projects is ≈ 36M€
New project beyond 2012 to be envisioned.
Challenge ➠"Megaton-scale-physics"-detector : total estimated integrated effort ≈ 200-500 M€

> Stavros Plots: on-going projects total



From 2008 → 2018: total estimated investment for on-going projects is ≈ 36M€
In comparison, "Megaton-scale-physics"-detector : total estimated integrated effort ≈ 200-500 M€

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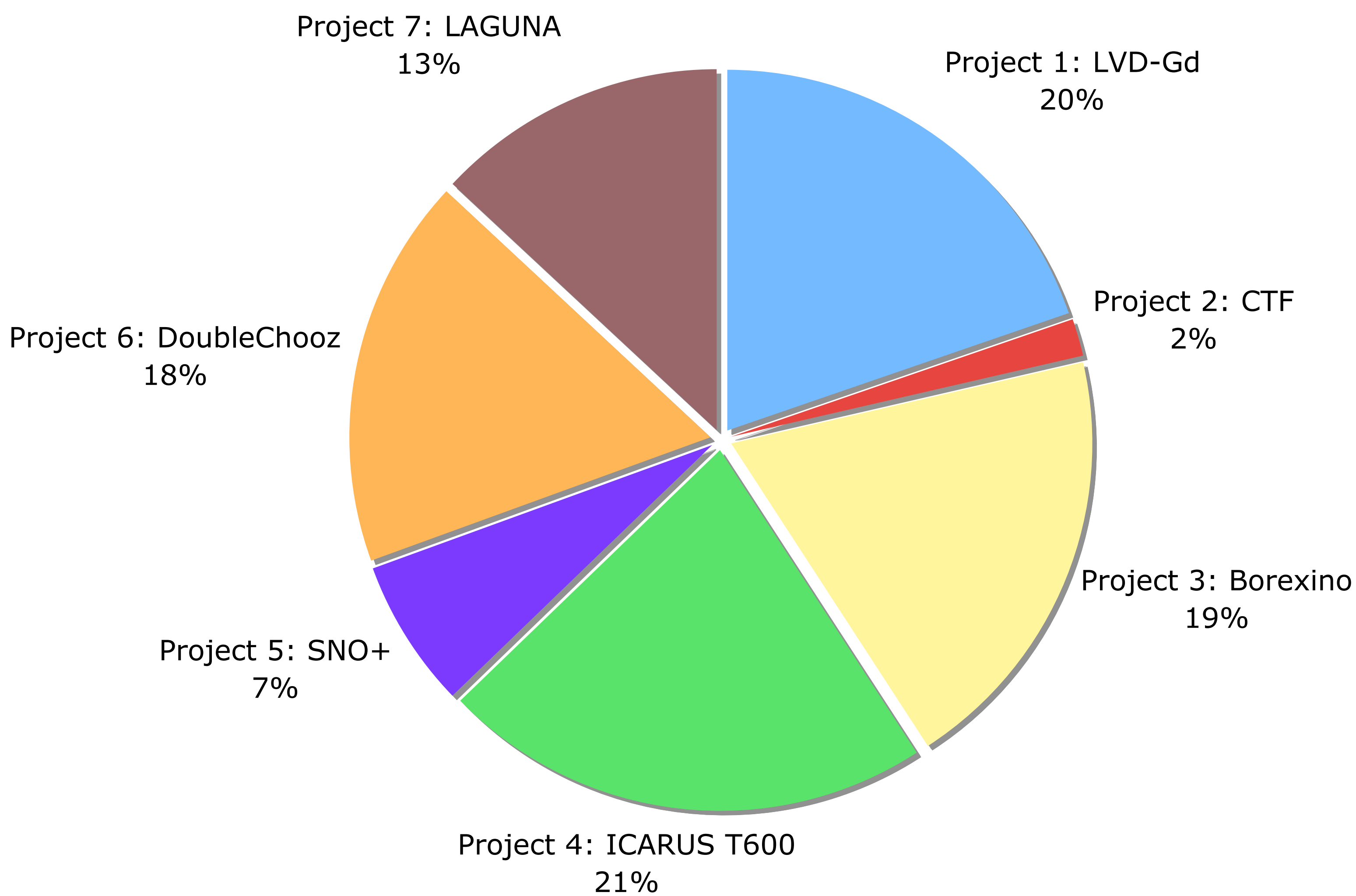
> Stavros Plots: integrated man effort

On-going projects: total man x year ≈ 1000



From 2008 → 2018: on-going estimate an integrated effort ≈ 1000 man x years
In comparison, "Megaton-scale-physics"-detector : total estimated integrated effort ≈ 1750 man x year

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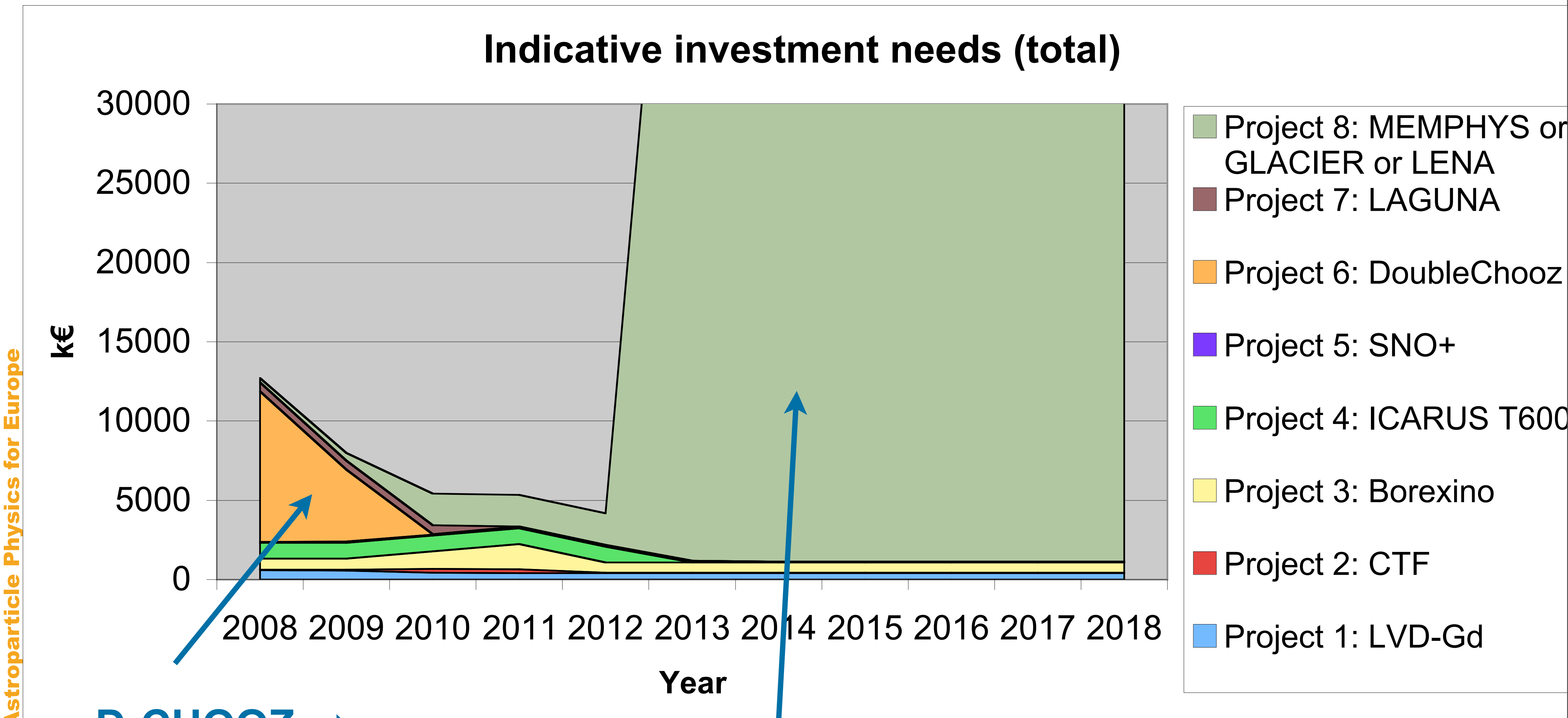
> Stavros Plots: investments



D-CHOOZ ➠ ASPERA funding ≈65%

“Megaton-scale-physics”-detector : estimated 30-80 M€/year over 6 years.

If EU siting is chosen, then European fraction = 50%?

➠ ASPERA funding 15-40M€/year over 6 years

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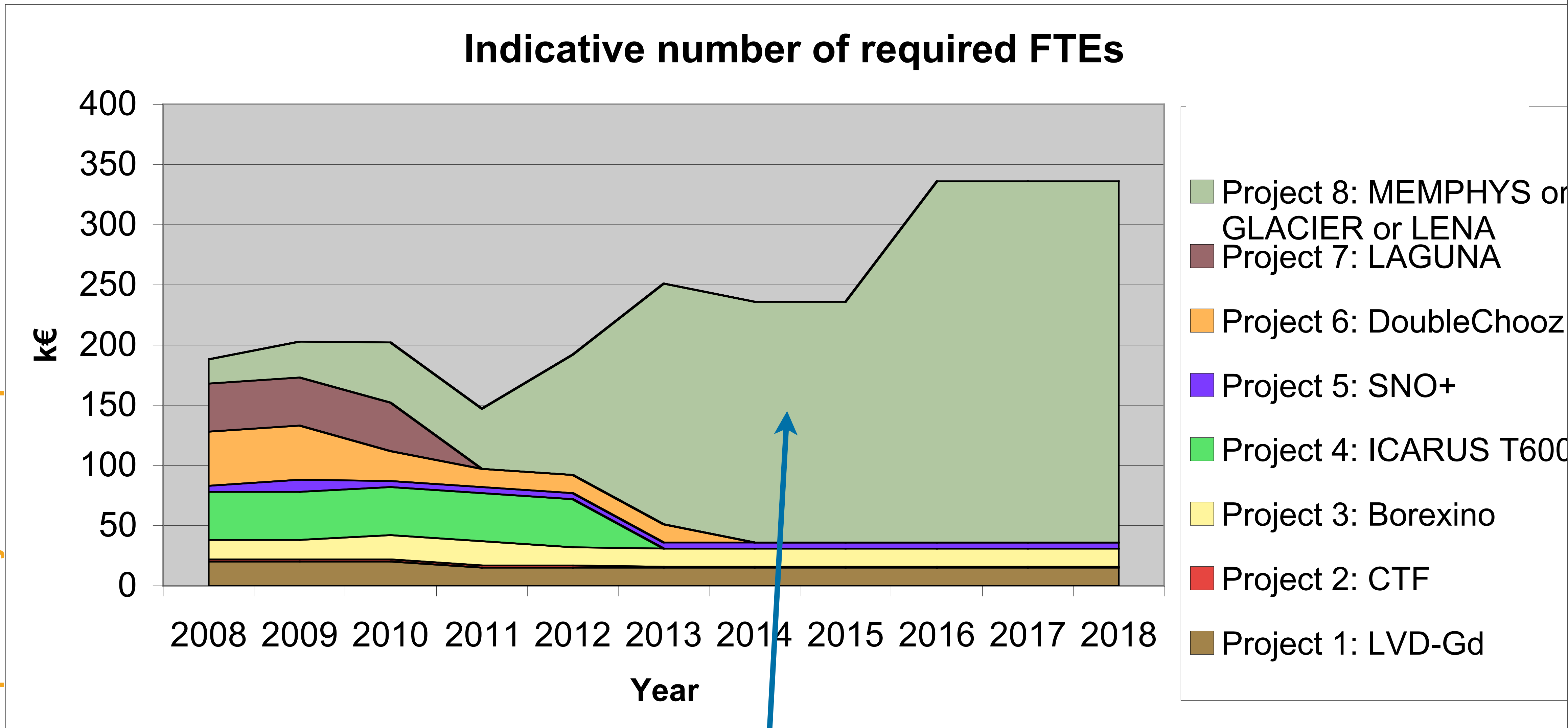
> Stavros Plots: people



"Megaton-scale-physics"-detector : medium-sized international collaborations ? (e.g. T2K ≈ 350 members) or even bigger?

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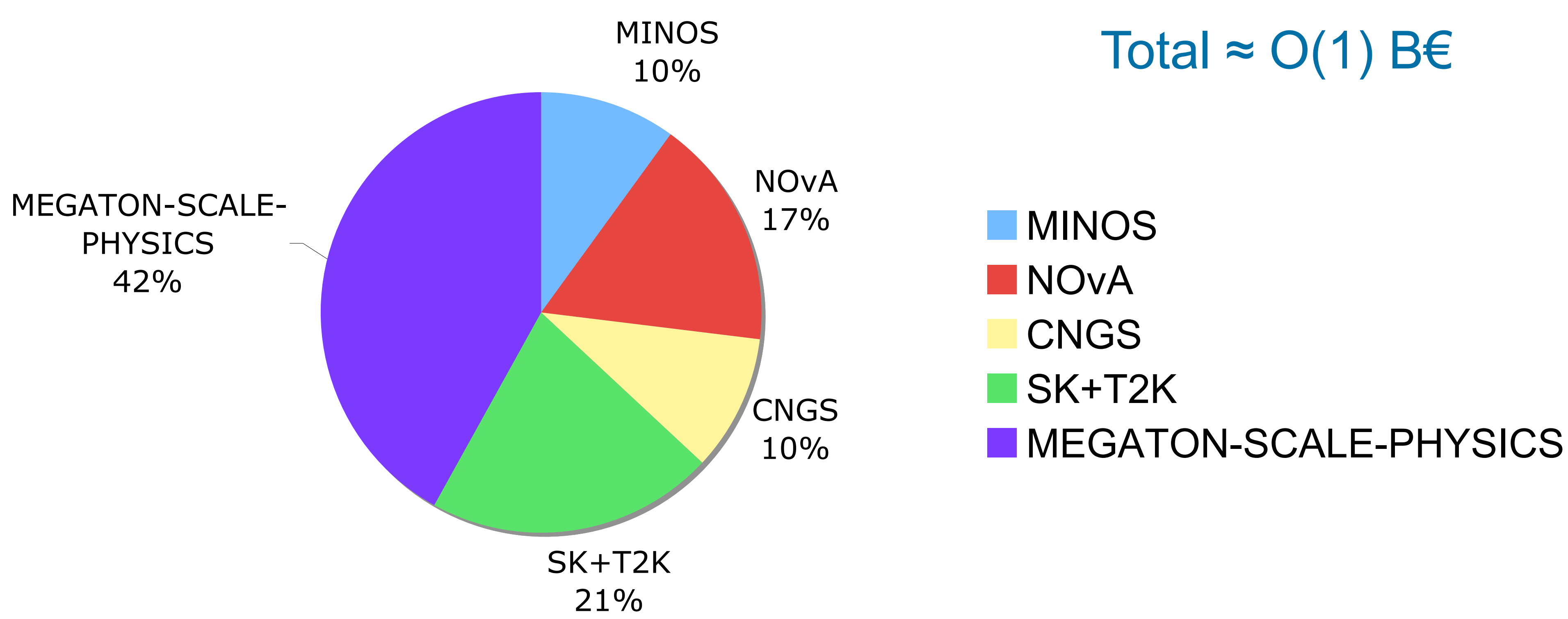
> Cost of Megaton-scale-physics compared to some other neutrino projects



Cost of long-baseline neutrino projects is indicative.

Conclusions

> Several on-going projects. Total foreseen investment required ≈36M€.

> Following ApPEC and general consensus (also international roadmaps)
⇒ must prepare for major next step with “megaton-scale-physics”

underground observatories to significantly improve proton decay sensitivity, enhanced low energy neutrino astronomy and 3rd generation long-baseline neutrino experiments

> Investigation of different options for European infrastructures able to site “megaton-scale-physics” detectors to be performed within the LAGUNA DS → feed-back around 2010.

> Timescale 2010 compatible with (1) ongoing R&D in different detection techniques (2) new results from LHC and 2nd generation long-baseline neutrino experiments (3) worldwide “next-step” decisions (roadmaps) in particle physics.

> Megaton-scale detectors would require 30-80 M€/year over 6 years → implies strong international (worldwide) coordination and agreement.

> If EU siting is chosen: European fraction 50%? consequence ➠ ASPERA funding 15-40M€/year over 6 years

> In the preparation of the next generation of facilities, we should strive to go beyond "national" interests and/or "international competition" towards a commonly agreed policy in the spirit of the ASPERA roadmap. This is the only winning strategy.

> Big opportunities and challenges ahead for the community !

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