Particle and nuclear astro-physics projects in low background laboratories

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- **Summary**
  - **Why underground experiments and laboratories**
  - **Beyond the standard theory**
    - **Results already obtained**
      - **Neutrinos from the Sun**
      - **Neutrinos from the atmosphere**
    - **How to proceed**
      - **Neutrinos from the Sun**
      - **Neutrinos from accelerators**
      - **Neutrinos from the atmosphere**
      - **Neutrinos from supernovae**
    - **Search for Majorana mass**
    - **Search for dark matter**
  - **International co-ordination of particle and nuclear astro-physics**
- **Conclusions**

Complementariness

Our knowledge of the fundamental building blocks of matter and of their interactions has made enormous progresses in the past decades. We have now an unified picture, the Standard Theory.

Progress has been due to the availability of accelerators (colliders) of ever increasing energy. The Standard Model has been tested with unprecedented accuracy.

But we know that the model is not complete (gravity!). Important pieces of the picture still await discovery.

The next hadron collider, LHC at CERN, will certainly provide us some of these pieces

Other fundamental progress is expected to come from a high energy linear collider.

All this will not be enough. On the way of ever increasing accelerator energy we will hit insuperable limits. And Nature has probably placed some fundamental pieces of the picture beyond those limits.

We have a possibility: intrinsically high energy phenomena happen spontaneously also at low energies.
But they are extremely rare

- we need large detectors
- we need very low background
- we cannot prepare the status of the system

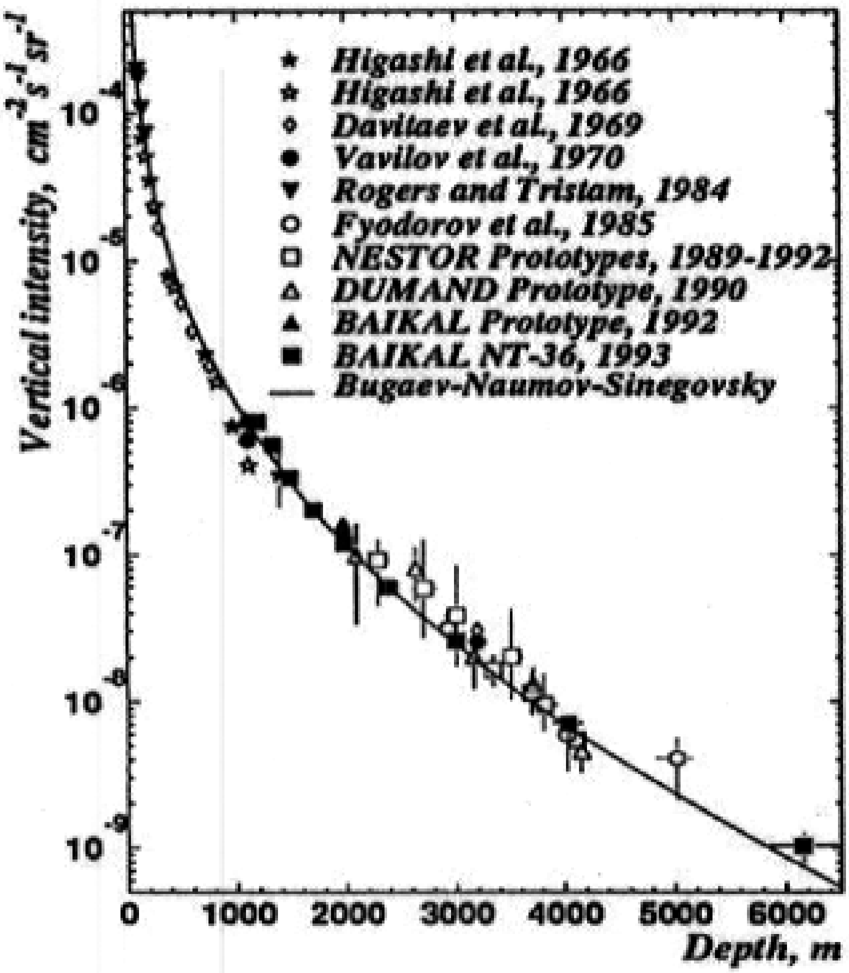
We cannot see stars during the day because the "background" light of the sky is much stronger than the starlight

To have low background we must go underground (or under sea)

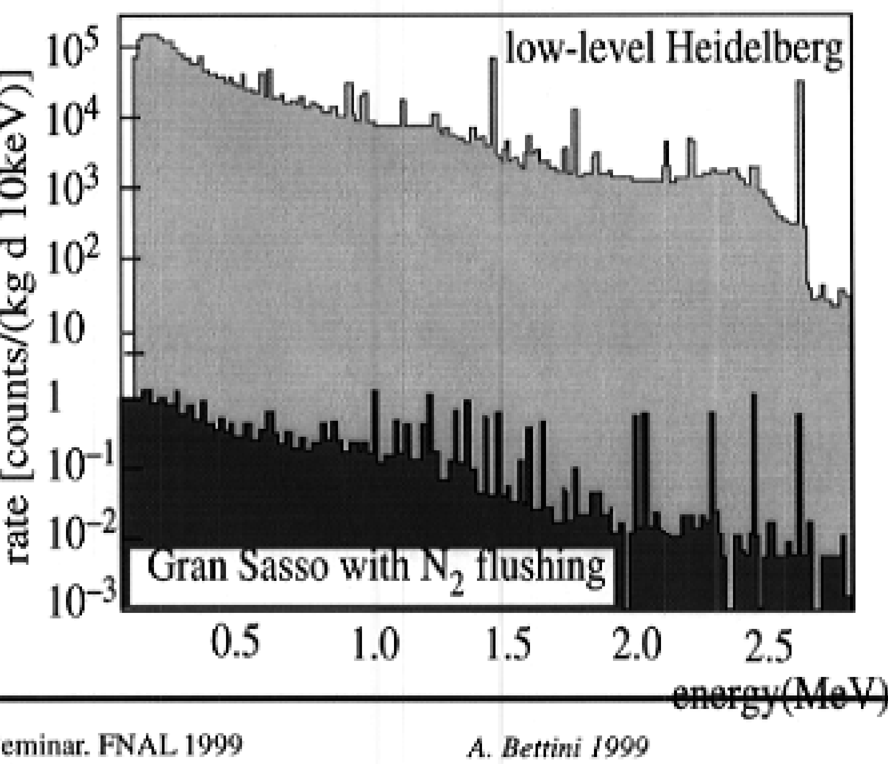
Underground environment

Search for rare phenomena requires low background environment

Cosmic ray flux in underground laboratories is millions times less than on surface



Background rates in Gran Sasso are five orders of magnitude lower then on surface

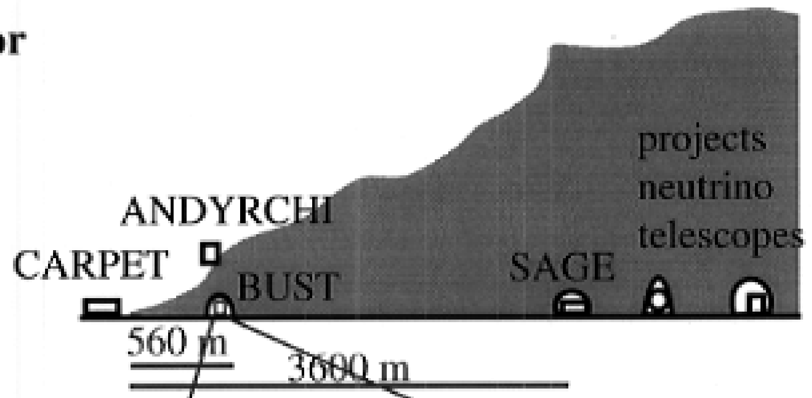


Underground laboratories and experiments

Name	Country	Institution	Status
Baksan	Caucasus	INR (RAS)	Operational
Canfranc	Spain		Operational
Frejus two experiments	France		Operational
Gran Sasso	Italy	INFN	Operational
Homstake mine single experiment	USA		Operational
Mozumi mine few experiments	Japan (Kamioka)		Operational
Pyhäsalmi	Finland		Project
Soudan mine few experiments	USA (Minnesota)		Operational
SNO single experiment	Canada		Operational
UKDMC	England		Operational

A few other, in garages of freeway tunnels under the Alps (Mont Blanc, Gotthard,..), in mines, etc.

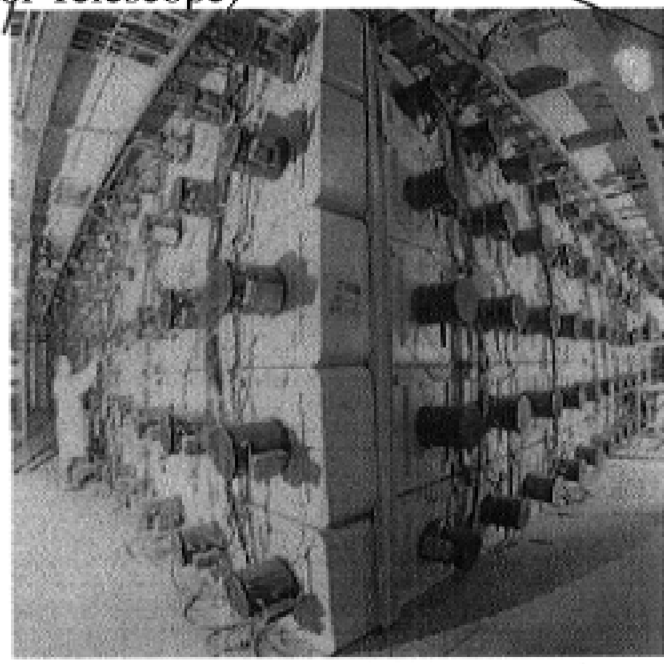
Baksan Neutrino Observatory



Experimental facility of INR for
- atomic physics
- nuclear physics
- elementary particle physics
- cosmic rays
- neutrino astrophysics

Experiments underground

BUST (Baksan Underground Scintillator Telescope)
- Depth = 850 m water equiv.
- volume =16.7x16.7x11.1 m^3
- mass = 2.17 kt
- liquid and plastic scintillators
- Physics
  - muon flux
  - atmospheric neutrinos
  - neutrinos from SN
  - primary CR composition
- Future: continue data taking



SAGE
- @ 4700 m equivalent water depth
- Liquid Gallium metal. mass = 55 tonnes
- Physics
  - Solar neutrino
    - 233 keV threshold
- Future: Take data for a solar cycle

Experiments on surface

ANDYRCHY array
- EAS (coincidences with BUST)

CARPET array

Canfranc

Director. A. Morales

Location. Huesca (Spain) Railway tunnel (not used) under Pyrenees
Depth: 890 m (2400 m water equiv.)
Cold dark matter search

Experiments

Rosebud (Zaragoza, Orsay, IAP Paris)
Search for WIMP's (mass of a few GeV)
Two small sapphire bolometers (25g + 50g)
Status. To be commissioned

Canfranc Sodium Iodine Dark Matter Experiment (Zaragoza)
NaI. 3 scintillators
Mass = 32.1 kg
Shieldings = Pb, Cu, Paraffin
Status: taking data

IGEX International Germanium Experiment
(South Carolina, PNNL, Zaragoza, BNO, ITEP Moscow, Yerevan)
The experiment looks for double beta decay in Ge (86% ^{76}Ge)
Five Ge detectors at Canfranc (7.3 kg)
One Ge detector at Baksan (1 kg)

Salopard (Zaragoza, Lisbon, Paris)
Feasibility tests with superconducting detector
100 g mass composed of Sn microspheres 20μm diametre

Future
Enlarge underground installations taking advantage of current public works to open a road tunnel between Spain and France (90 m from present site)
If OK Canfranc will become a **National Laboratory.**

Modane Underground Laboratory

LSM Laboratoire Souterrain de Modane

Location

Free way tunnel under Alps @ French-Italian border
Depth: 4800 mwe
Cosmic ray flux attenuation = one million

Experiments

NEMO 2

Double beta decay
mass = 17 g of ^{100}Mo
Electron tracking (multiwire drift tubes); scintillators
Status: Running

NEMO 3

Double beta decay
mass = 10 kg of ^{100}Mo
Electron tracking (multiwire drift tubes); scintillators
Sensitivity for $0\nu\beta\beta$: 10^{26} y for $0\nu\beta\beta$
Status: Expected data taking 2000

EDELWEISS

Goal: Search for WIMP's
French collaboration
Present: 70 g Ge bolometer
Future: Three bolomoters 250 g mass each

UKDMC

Boulby salt mine in northern England

Depth	1100 m, in a salt (K) mine
Laboratories	3 halls 10m x 20 m each
Infrastructures	Control rooms, electrical supplies, data links
Mission	Experiments on dark matter
Users	RAL, IC London, Sheffield University

A request for enlargement of the lab. and additional infrastructures on a British special fund has been submitted, but not approved

Homestake

Site Homestake gold mine. South Dakota (USA)
Depth 1478 m (4200 m water equivalent)
Experiment

Solar neutrino

Status. Data taking since 1970.

Historically first experiment on solar neutrino.

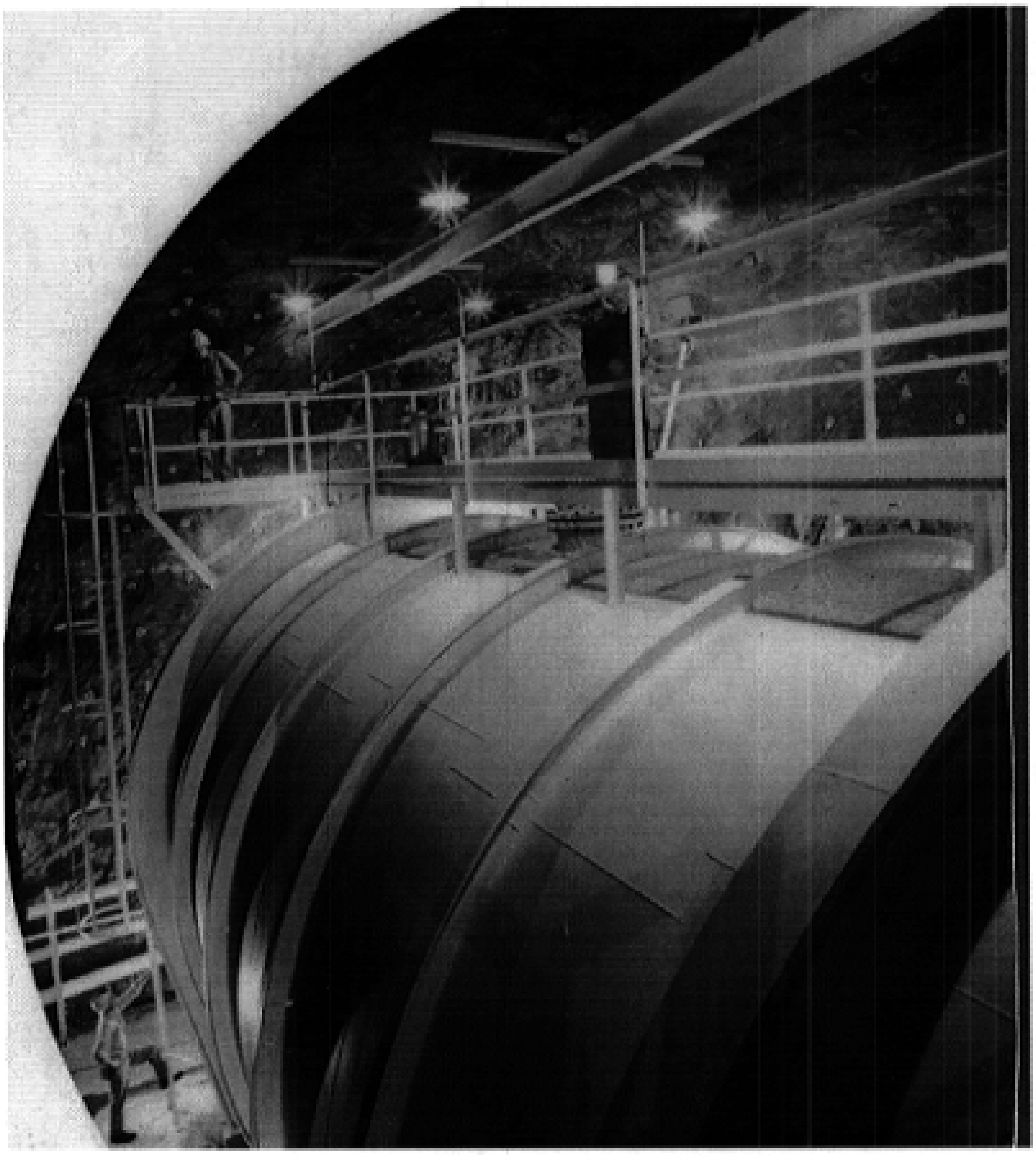
Solar neutrino puzzle

Detector.

Radiochemical $\nu_e + {}^{37}Cl \rightarrow {}^{37}Ar + e^-$

615 ton of tetrachloroethylene(C_2Cl_4)

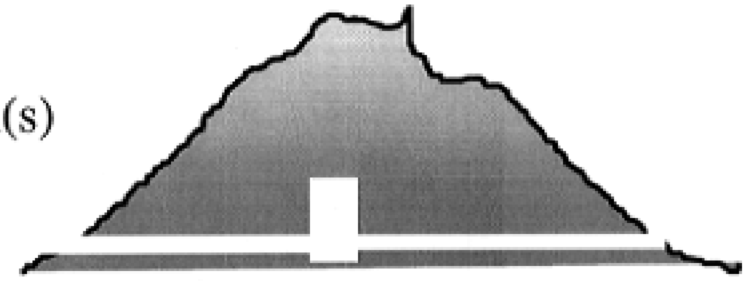
threshold = 814 keV



Kamioka

Site Mozumi mine (Japan). 200 km North of Tokyo
Depth 1000 m (2700 m water equivalent)

Access through horizontal tunnel(s)



Experiments
KAMIOKANDE **COMPLETED**
Detector. Water Cerenkov. 15.6 m diameter, 16 m height, 3000 tons mass
Physics
Solar neutrinos, atmospheric neutrinos, neutrinos from SN, p-decay
SuperKAMIOKANDE
Water Cerenkov. 40 m diameter, 40 m height, 50 kton mass
12000 PM's
Energy threshold = 5 MeV
Position resolution = 50 cm
Physics
As KAMIOKANDE
Long Baseline neutrino from KEK (K2K); 12 GeV proton beam; Dist = 250 km

See later

ELEGANT V
Double beta decay on ^{100}Mo (179 g)
Drift chamber
$0\nu\beta\beta$ sensitivity: 10^{23} y

Future: KAMLAND
Liquid scintillator detector in KAMIOKANDE place.
Solar neutrino from ^{7}Be
Antineutrinos from reactors @ 150-200 km distance. $\Delta m^2 < 10^{-5}$ eV
1500 m^3 liquid scintillator, 3300 m^3 buffer liquid, 1000 ton sensitive mass

Phyasalmi

Phyäsalmi mine in central Finland

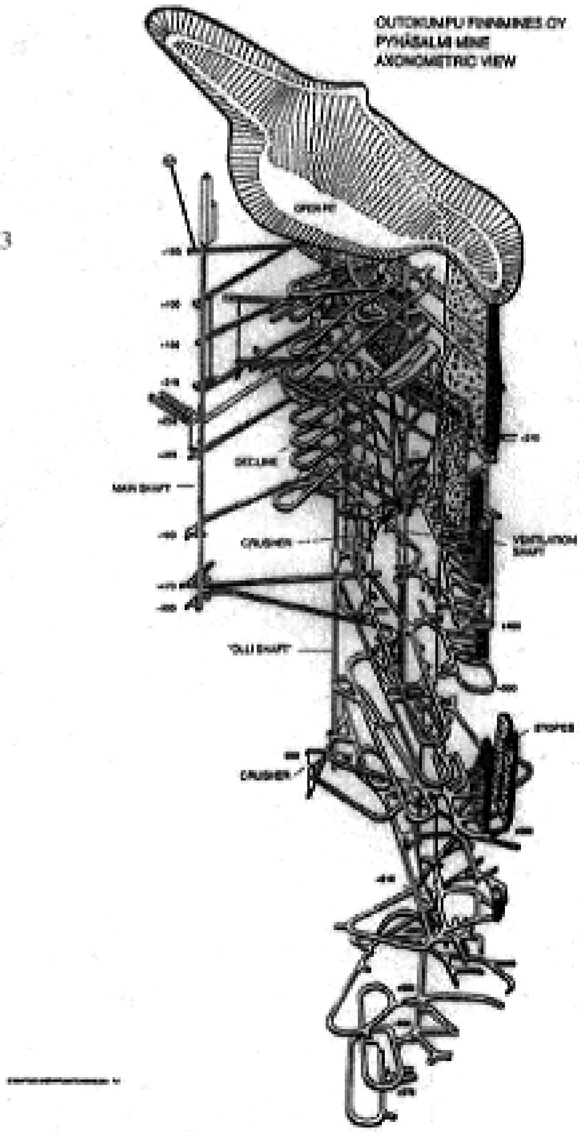
Project manager: Matti Vallinkoski

Located midway between Jyväskylä and Oulu
Mining to be discontinued in 2000 - 2002
Interest of Finnish government to guarantee continuation of activities
    Funding from Ministry of Labor
Try to build a new underground laboratory

CUPP - KEHITTÄMISHANKE (KSM)

Main characteristics

- Depth: 960 m now; 1200 m in 2002
- Accessible by lorry road
- Existing caverns: few 15x5x5 m^3
- Possible new caverns: 100x10x10 m^3
- Infrastructures: existing



LOPPURAPORTTI 1.1. - 31.12.1996

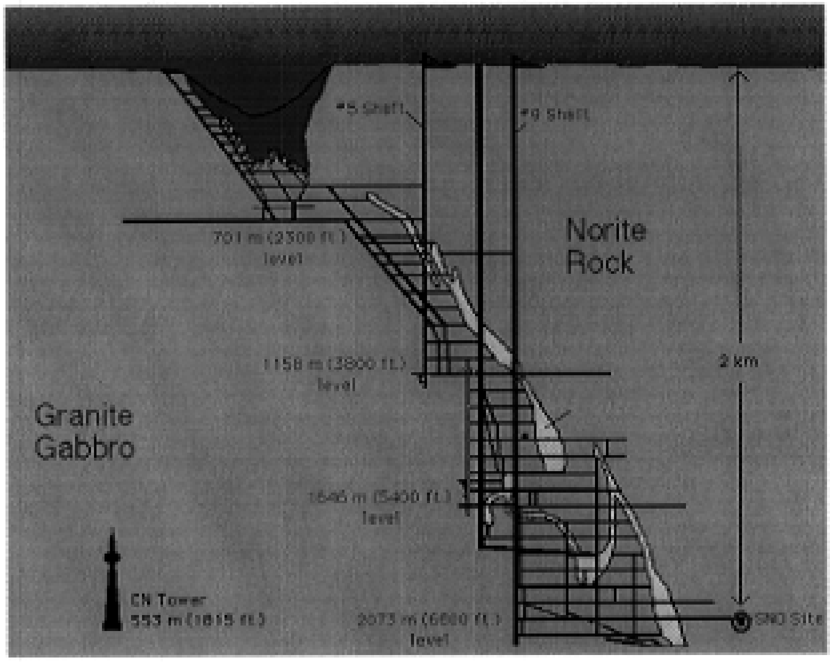
Possible research topics

- Proton stability
- Double beta decay
- Solar neutrino
- Atmospheric neutrinos
- Supernova neutrinos
- Low temperature physics
- Cold dark matter
- WIMPs
- Airshower muon flux spectrum
  multilevel experiments

SNO

Site Creighton mine - near Sudbury, Ontario (Canada)
Depth 1900 m

Detector
1000 t D_2O Cerenkov
in a 12 m acrylic vessel
9 500 (50 cm) PM's
buffer liquid: H_2O
cavity in Norite rock



Goals
measure flux, energy, direction of electrons produced by solar neutrinos

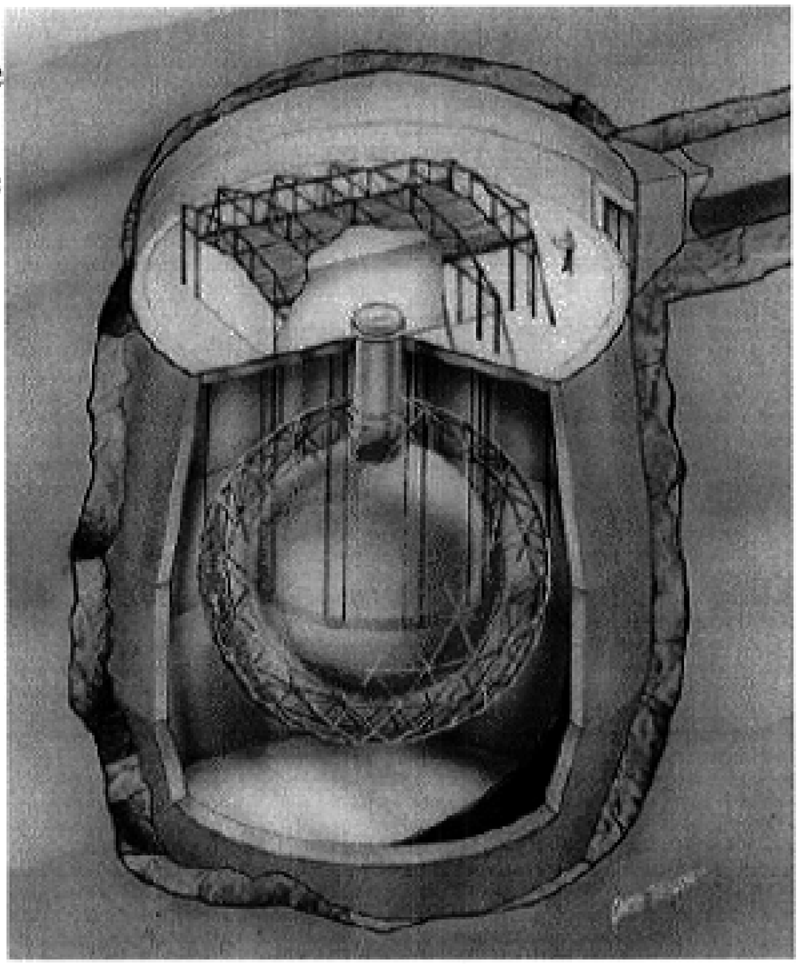
$\nu_e + d \rightarrow e^- + p + p$ flavor sensitive
5-6 MeV threshold

$\nu_x + e \rightarrow \nu_x + e$ flavor insensitive

$\nu_x + d \rightarrow \nu_x + p + n$ flavor insensitive

special detectors
or/and Cl addition
foreseen for *n* detection

Status Data taking
Excellent measurement of ^{8}B neutrino flux.
Measure NC/CC ratio
After 18 months of data taking will distinguish between at 6σ:
1. neutrino flavour changes
2. electron neutrino flux from Sun lower then model pred.



Soudan

Soudan 2
Site Tower - Soudan mine - Minnesota (USA)
Depth 800 m (2090 m we)

Detector
- 960 ton Fe tracking calorimeter, surrounded by active shield of proportional tubes
- hit reconstruction accuracy:
  - 11 mm in drift direction, 3.5 mm in perpendicular plane
- dE/dx measurement
- surface array of Cerenkov counters in coincidence
- exposure now = 4 kt*year

Goals
- proton decay
- magnetic monopoles
- point sources of CR's
- composition of CR's

Future
- Run till 5 kt*y exposure (1998-99)

MINOS experiment on Long Base Line Neutrino beam from Fermilab (NUMI) approved.
Data taking expected by end 2002

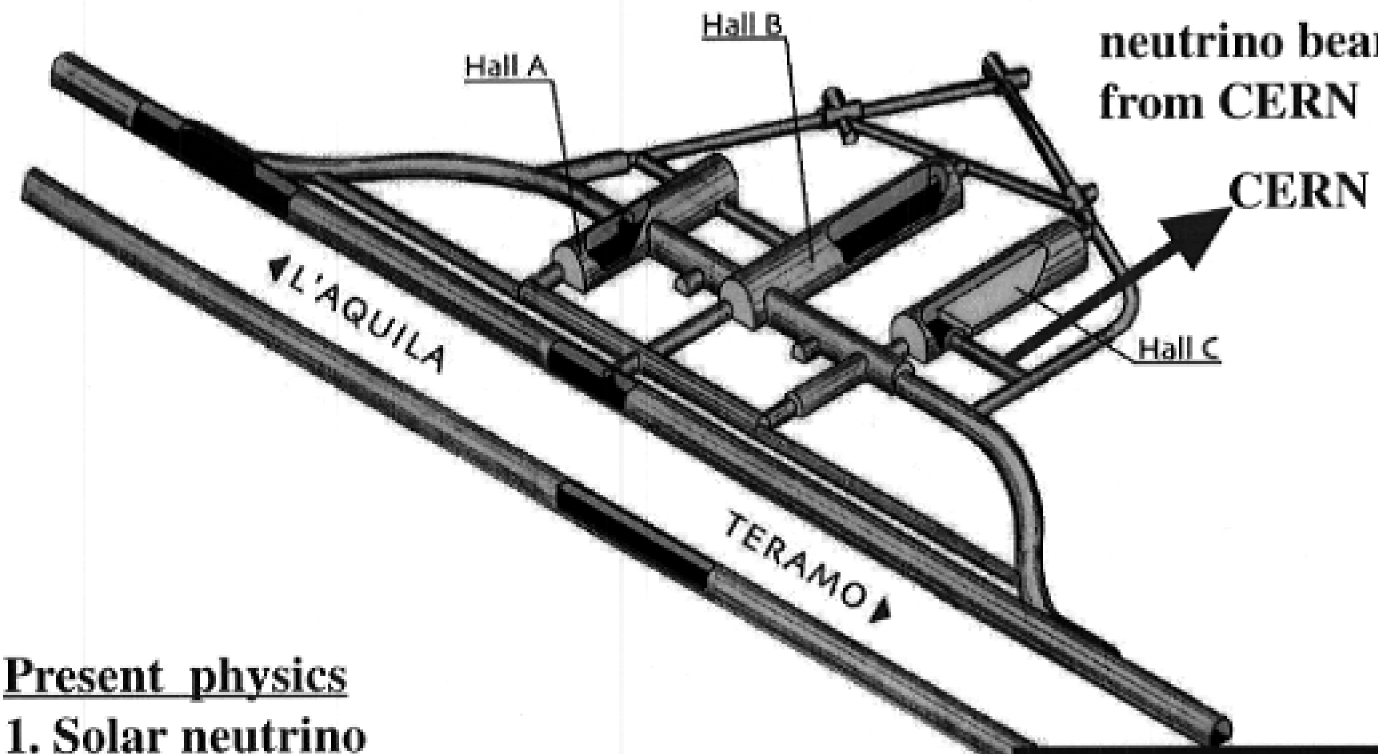
Gran Sasso

Location
On the Apenines, 120 km (freeway) form Rome

Underground halls
1400 m rock overburden
Cosmic ray flux attenuation = 10^{-6} (1 per square metre per hour)
Complementary facility at 2000m height

Staff 64 permanent positions
Operative budget (≠ experiments) = 25 Glit/y

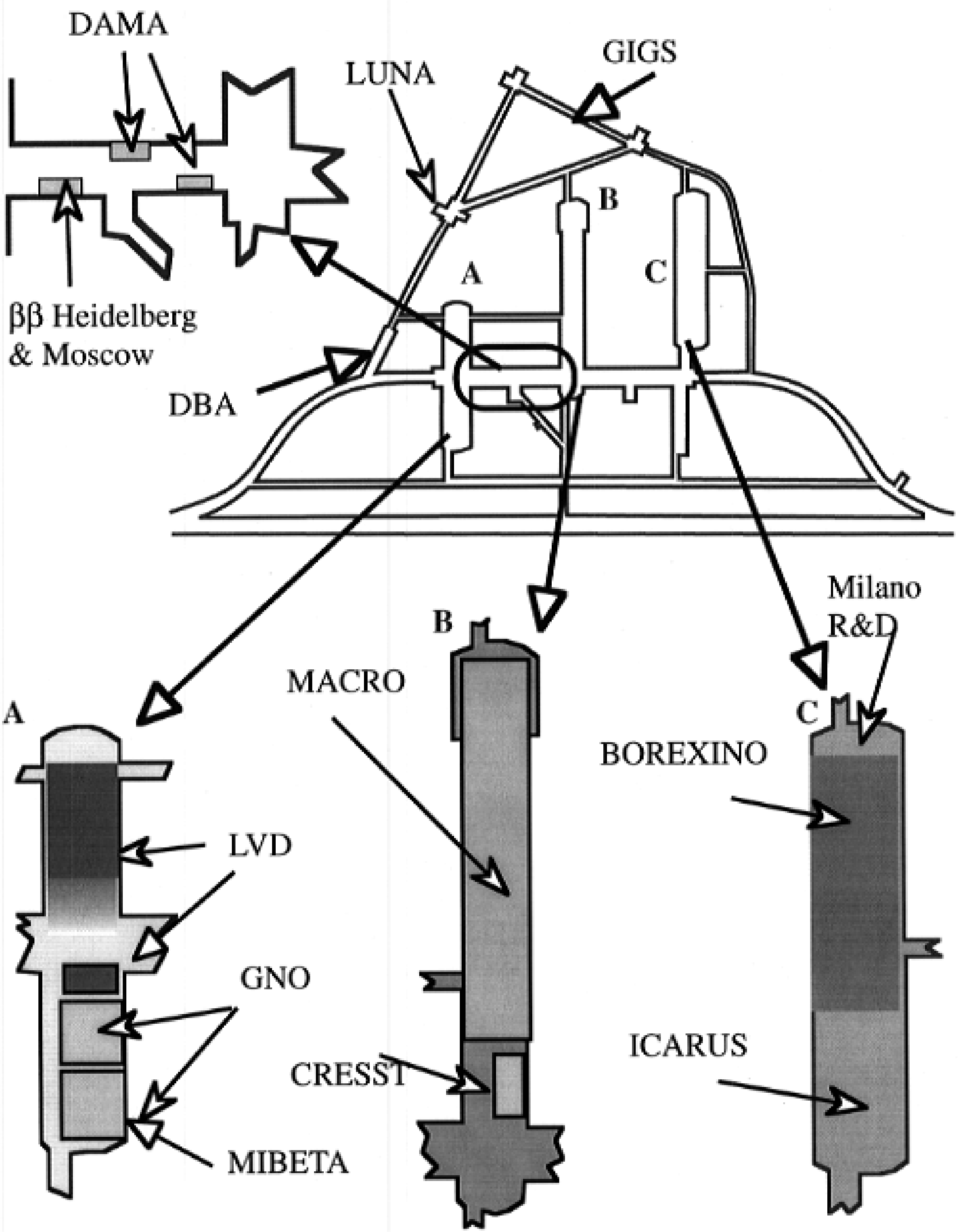
Halls orientation conceived by Zichichi in the direction of a neutrino beam from CERN



450 scientific users (half non Italian)

Present physics
1. Solar neutrino
2. Neutrinos from star collapses
3. Rare decays (double beta, proton decay, etc.)
4. Dark matter search
5. Small cross section reactions
6. High energy cosmic rays
7. Search for exotics (monopoles, wimps, etc.)
8. Geophysics & biology

LNGS. Running experiments



Near future

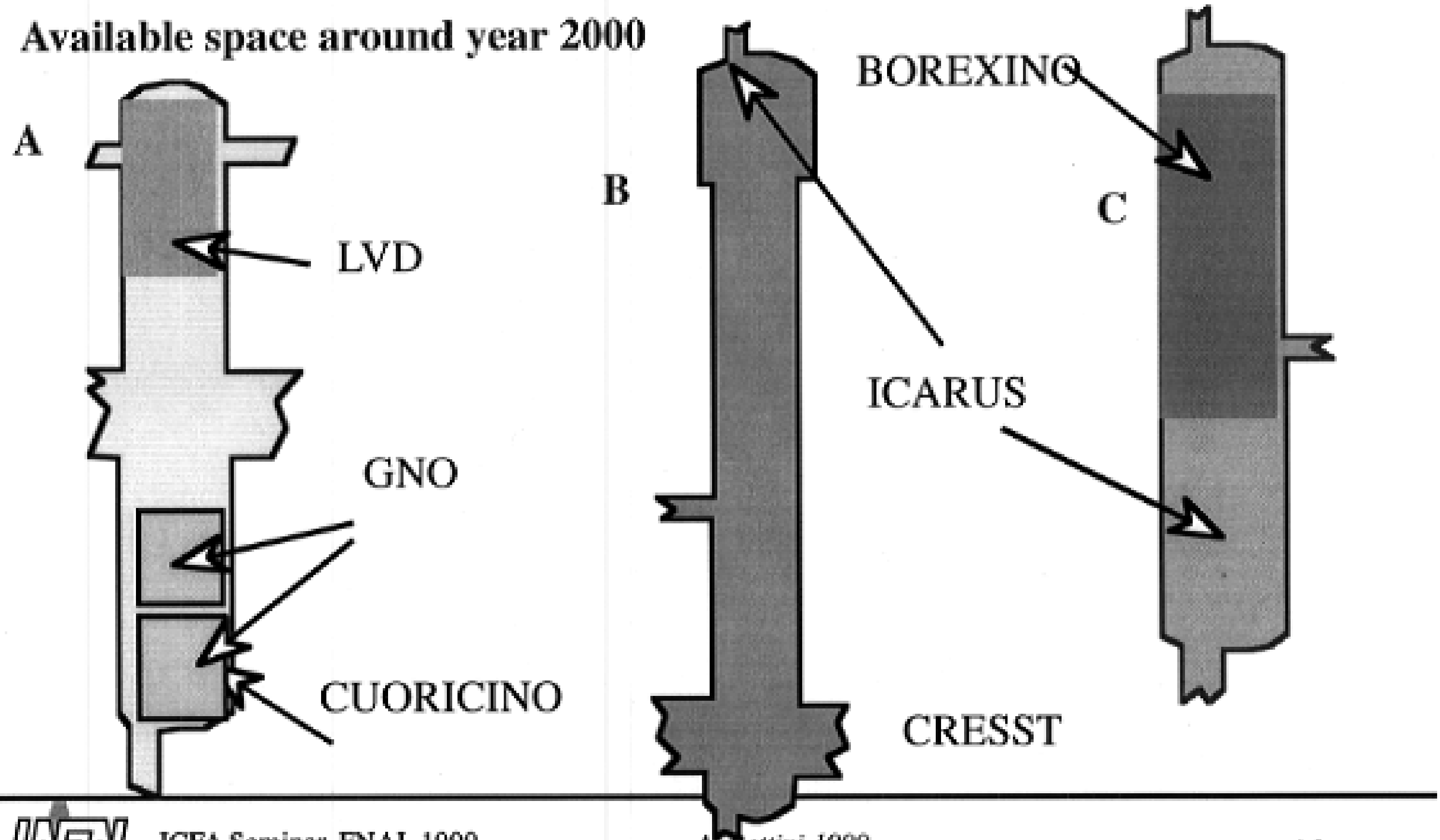
- **The laboratory has achieved so far outstanding scientific results**
  - GALLEX has put on very strong grounds the solar neutrino problem and shown, when associated with (Super)Kamiokande that no astrophysical solution exists
  - **the simplest (only?) explanation is neutrino oscillation**
  - MACRO has confirmed the discovery of atmospheric neutrino oscill.
  - experiments on the leading edge are present in the search for dark matter (DAMA) and double beta decay (Heidelberg Moscow)
- **First generation experiments are approaching their end**

We are defining the Lab scientific program for the next ten years

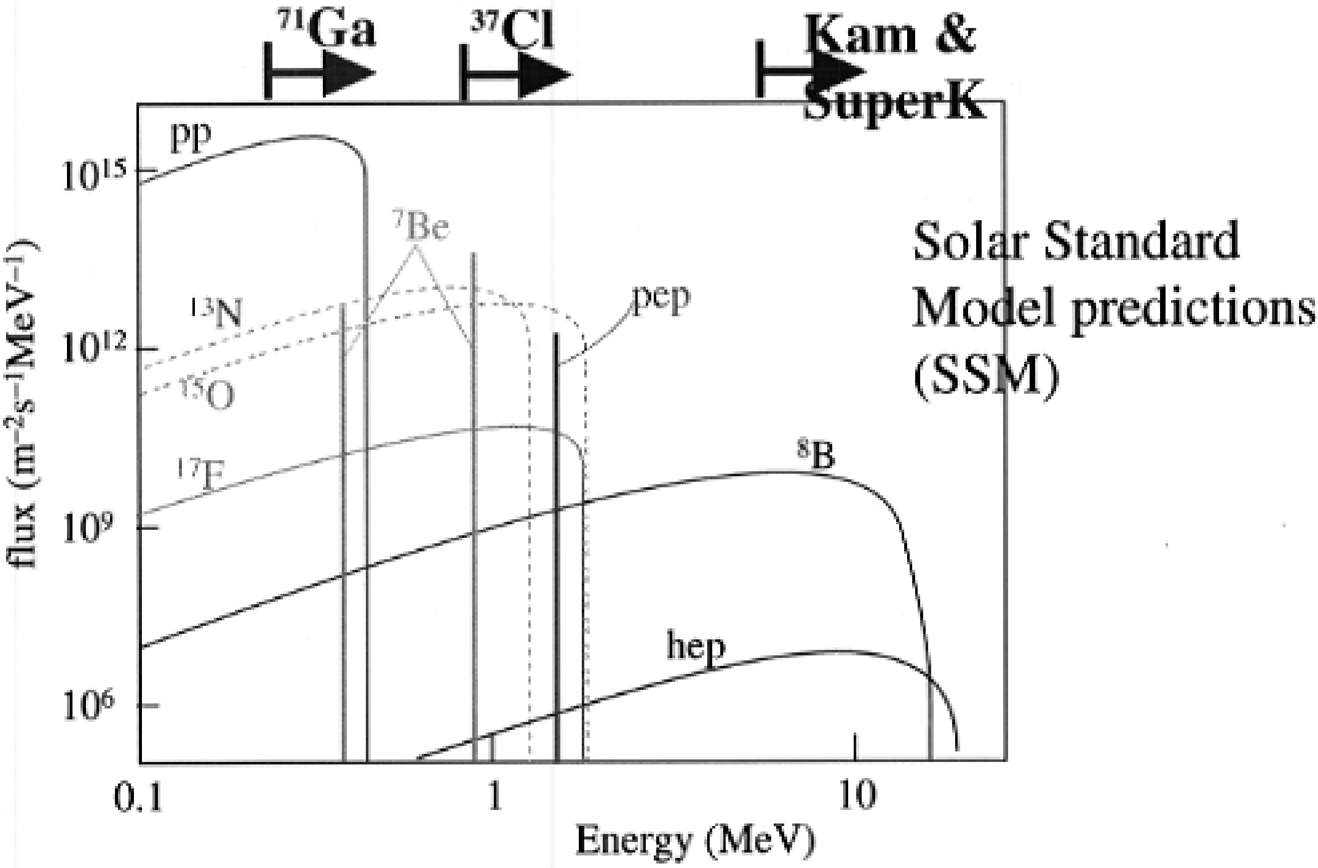
Experiments already approved

- GNO Ten years run of an "improved GALLEX". Running
- BOREXINO Real time Solar neutrino spectroscopy @ Be line
  - Running in 2001
- ICARUS Large LAr TPC, bubble chamber quality images
  - 600 t module @ LNGS by end 2000
  - 3 more modules proposed (but later SuperI, more recently ICANOE)

Available space around year 2000



Solar neutrino problems



- Radiochemical experiments measure the product flux x cross-section integrated above threshold (only ν_e)
- SuperK and K measure flux x cross-section vs. energy (above threshold) [all neutrino flavours]
- Ga is the only sensitive to fusion pp (dominant mechanism)

All the 5 experiments see a deficit

	Homesta-ke	Kamiok-ande	SuperK	GALLEX	SAGE
Threshold (MeV)	0.814	7.5	6.5	0.233	0.233
Deficit (%)	33±6	55±12	47±8	60±7	52±7

$\Phi_{GALLEX} - \Phi_{pp}$(Sun luminosity) $- \Phi_{Boron}$(SuperK) $= \Phi_{Beryllium} < 0$
But Be must be there because B neutrinos have been observed
Homestake deficit> Kam & SuperK deficit $\Rightarrow \Phi_{Beryllium} < 0$

LUNA & LUNA2

AIMS **STATUS = COMPLETED in 1999**

measurements of σ(E) of thermonuclear reactions in the energy range of astrophysical interest

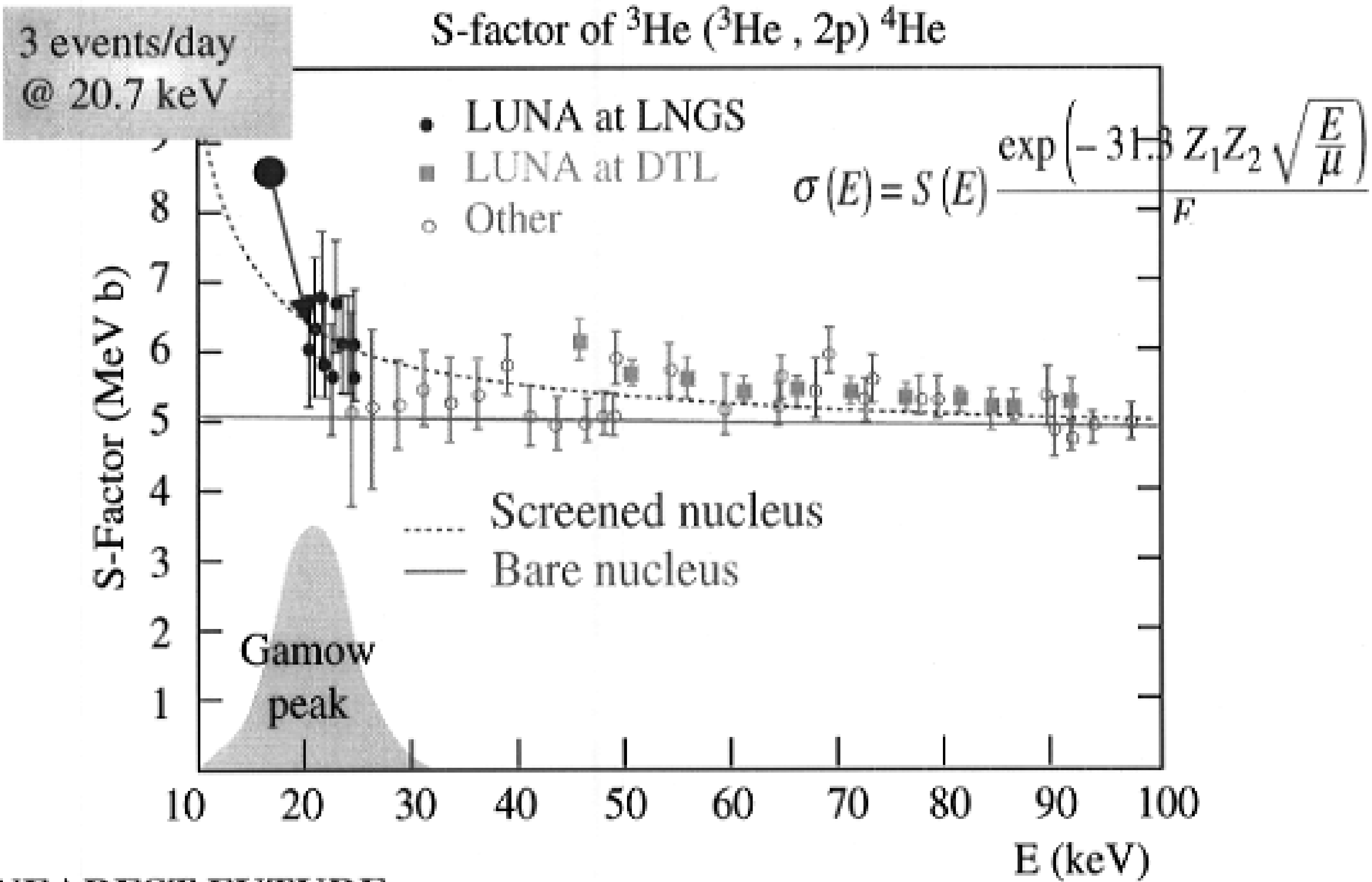
study of electron screening effects in the laboratory

50 kV accelerator at LNGS:

compact design; intense currents (^3He+ beam of 500 mA)

double focusing analyzing magnet; windowless gas target

5x5 cm^2 silicon detectors for ΔE - E measurements



NEAREST FUTURE

new detection setup to reach E_{cm} = 17 keV

measurement to E_{cm} = 4 keV of reactions D (^3He, p) ^4He and D (p, γ) ^3He

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FUTURE LUNA2

200 kV accelerator being built E_{cm} ~ 50 keV

^7Be (p, γ) ^8B ^{14}N (p, γ) ^{15}O ^3He (^4He, γ) ^7B

STATUS = APPROVED
will run in 2000

Atmospheric neutrino oscillations from SuperK

$$p + N \Rightarrow \pi^+ + X$$
$$\pi^+ \Rightarrow \mu^+ + \nu_\mu$$
$$\mu^+ \Rightarrow e^+ + \nu_e + \bar{\nu}_\mu$$

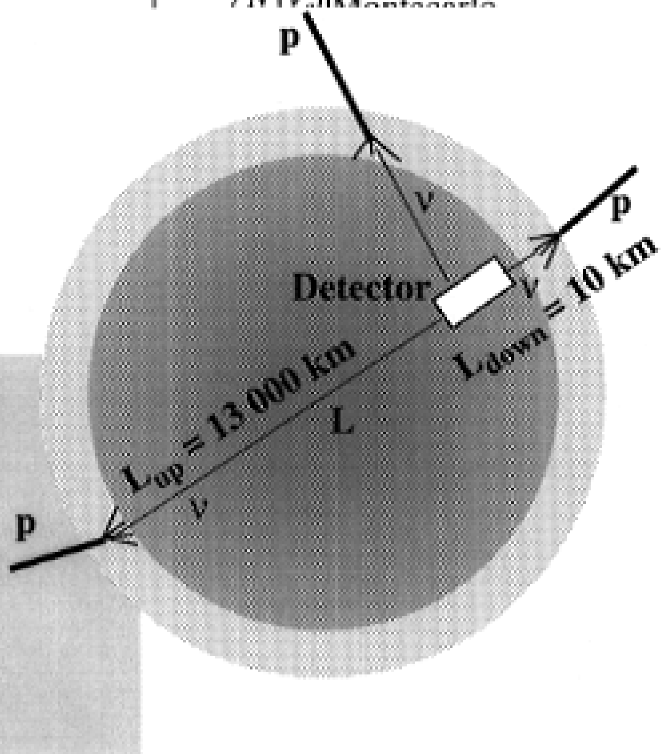
Hence $\dfrac{N(\nu_\mu)}{N(\nu_e)} = 2$. In first approximation

First observations (all experiments with sufficient sensitivity)

$$R = \frac{\left[N(\nu_\mu)/N(\nu_e)\right]_{\text{Mesured}}}{\left[N(\nu_\mu)/N(\nu_e)\right]_{\text{Montecarlo}}} \cong ($$

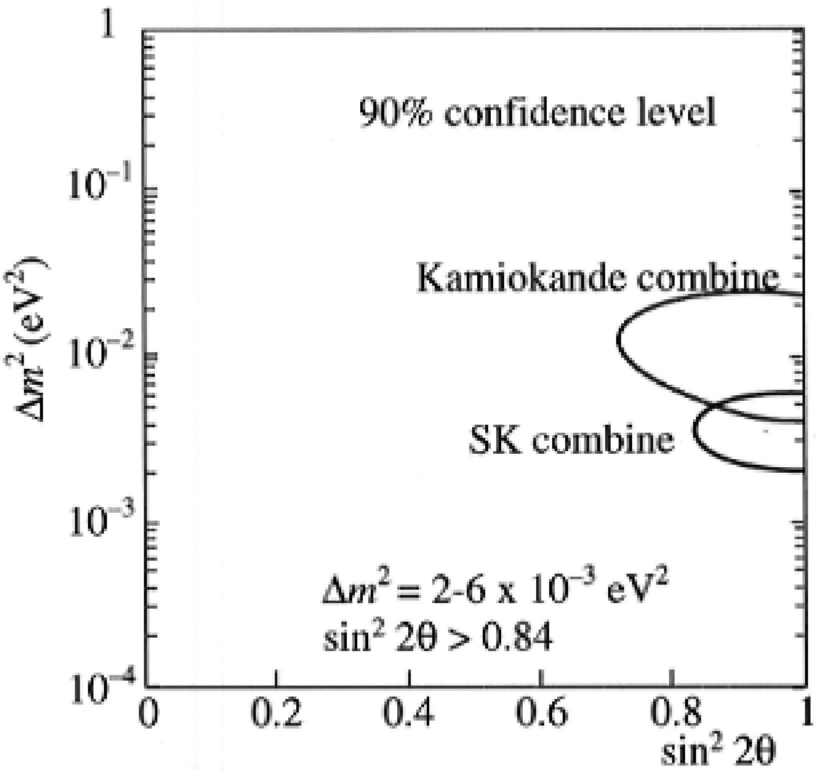
Atmospheric neutrino problem

SuperKamiokande (SUPERK)
Technique: Water Cerenkov
Fid. mass : 22 kt
sensitive to ν_e e ν_μ not to ν_τ
Location: Kamioka mine (Japan)

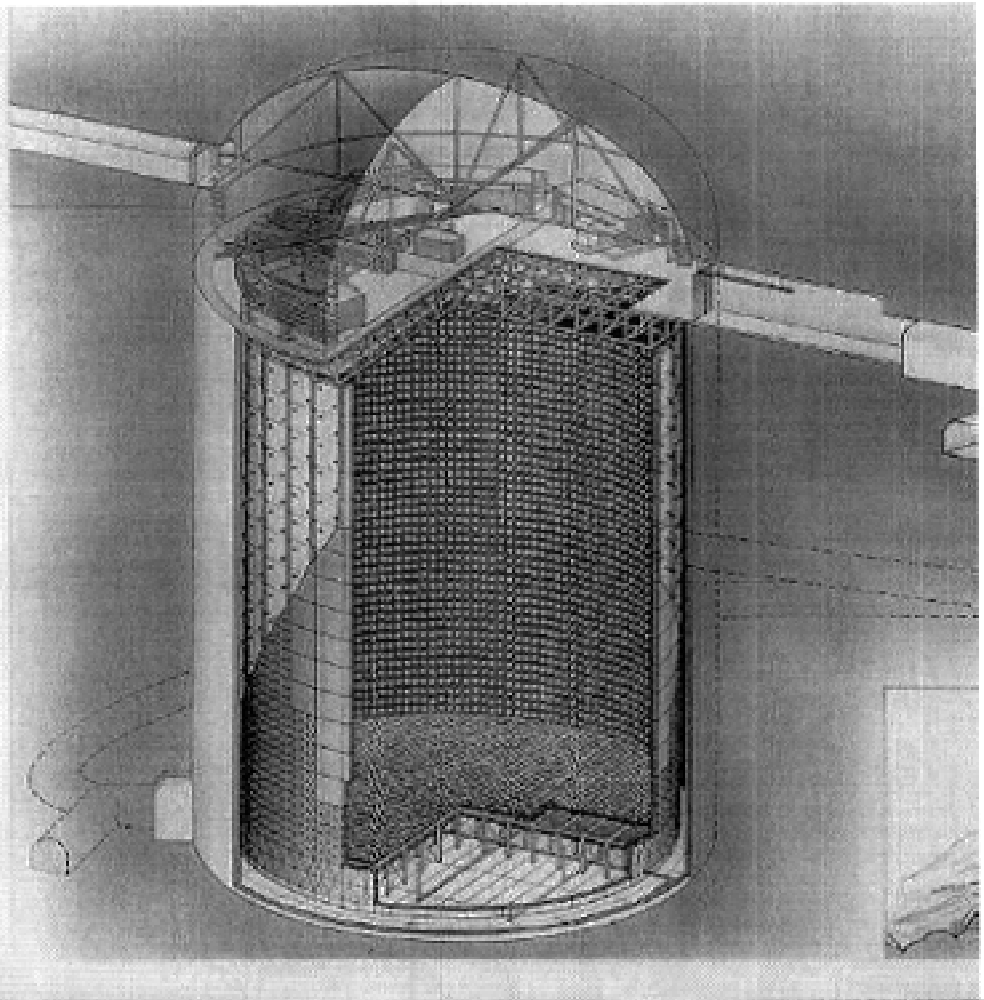


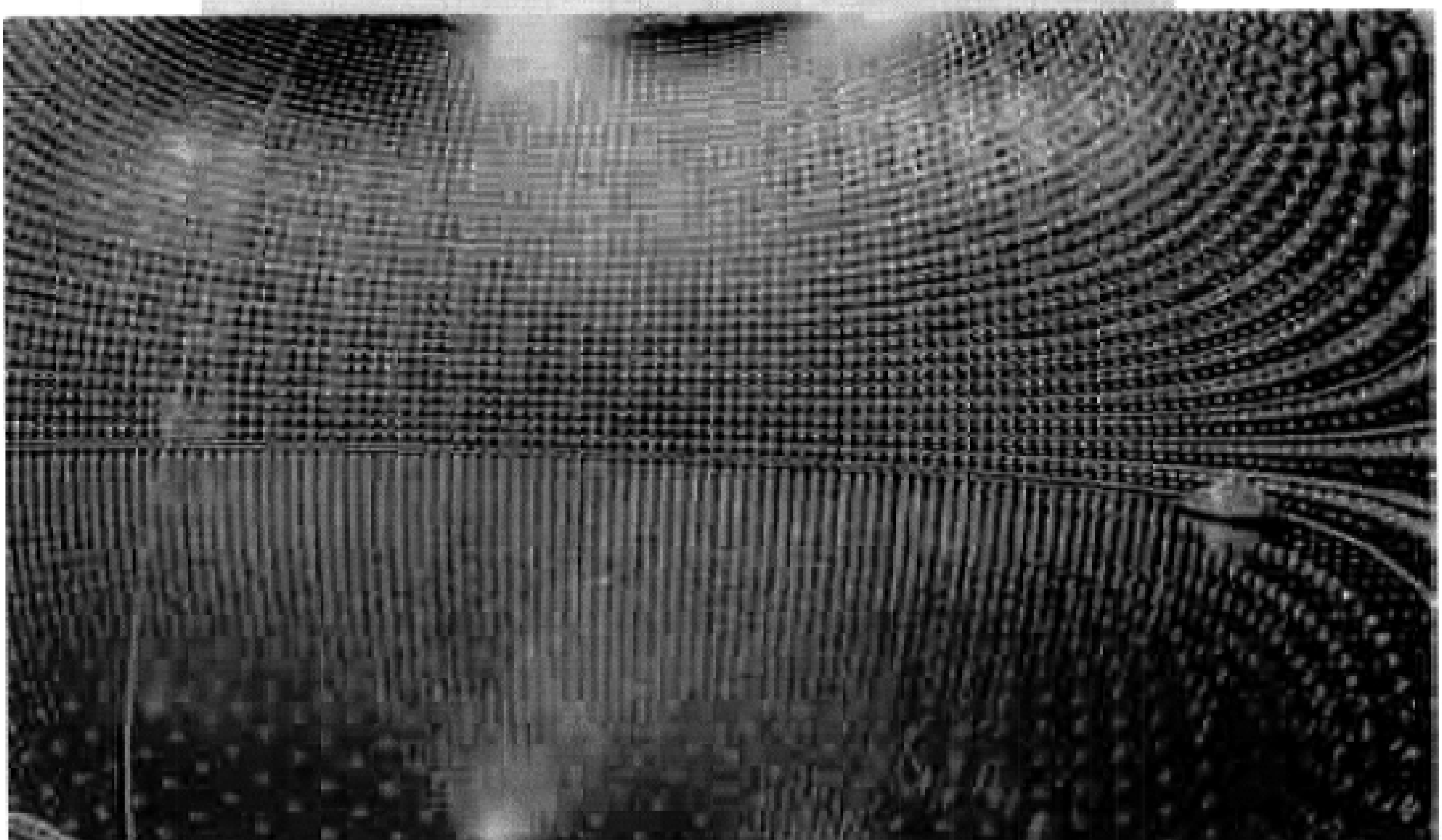
New observation:
1. ν_e flux = MC at all azimuths
2. ν_μ flux = MC at small azimuth
= 1/2 MC at large azimuth

Hence ν_μ oscillates
ν_μ does not oscillate into ν_e
(oscillates into ν_τ?)



SUPERKAMIOKANDE



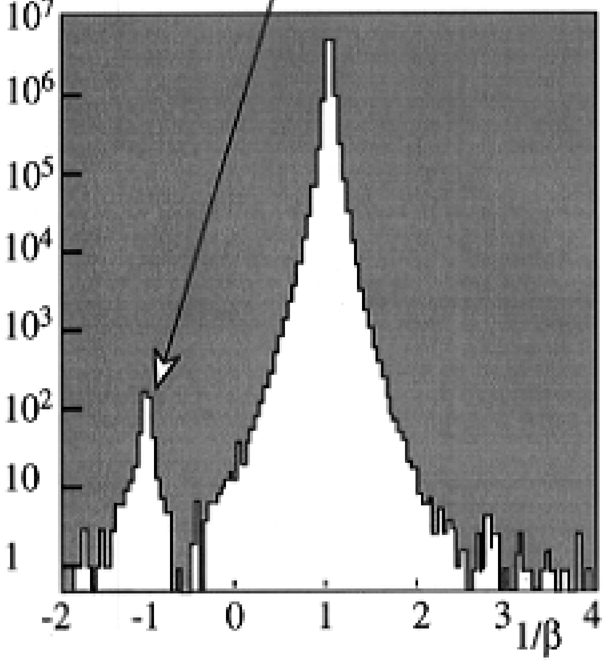


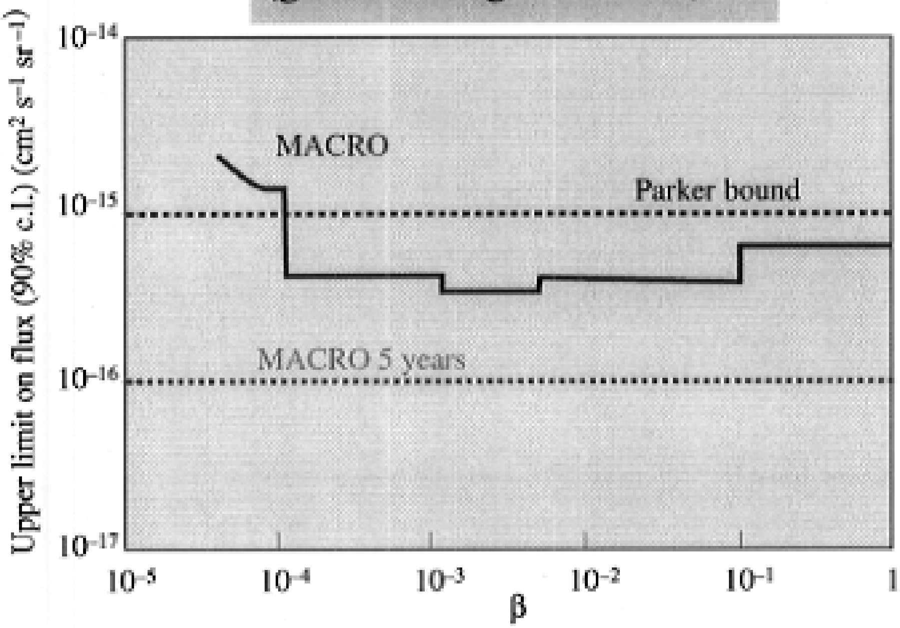
MACRO

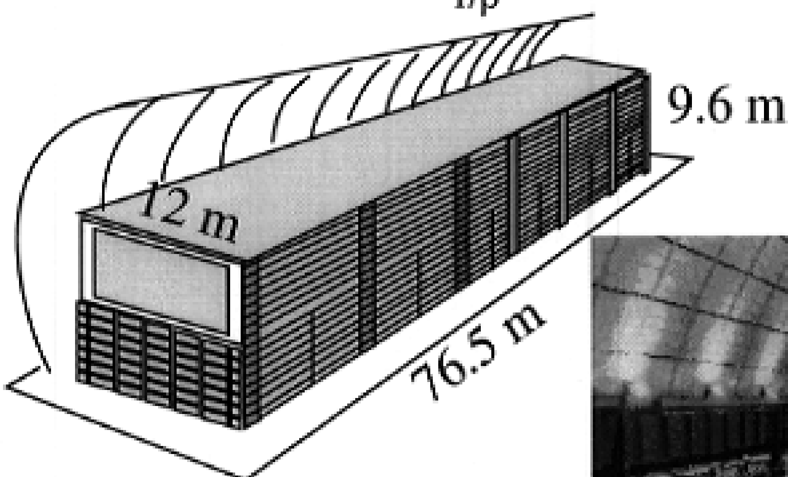
STATUS = RUNNING till may 2000

Minimum muon energy (3200m weq.) = 1.2 TeV
Unambiguous measurement of upward going μ from ν interacting with earth
one thousand upward going μ @ full expositio

Search for monopoles beyond Parker bound (galactic magnetic field)





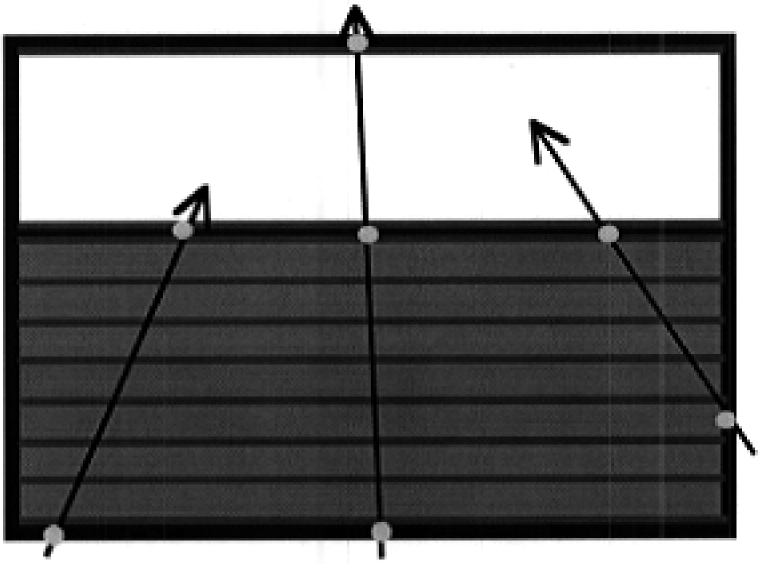


Tracking (LST). 0.2° resolution
Timing (scintillators) 0.5 ns resol.
Track etch plastics

Atmospheric neutrino oscillations

MACRO is blind to electrons, but has good angular resolution

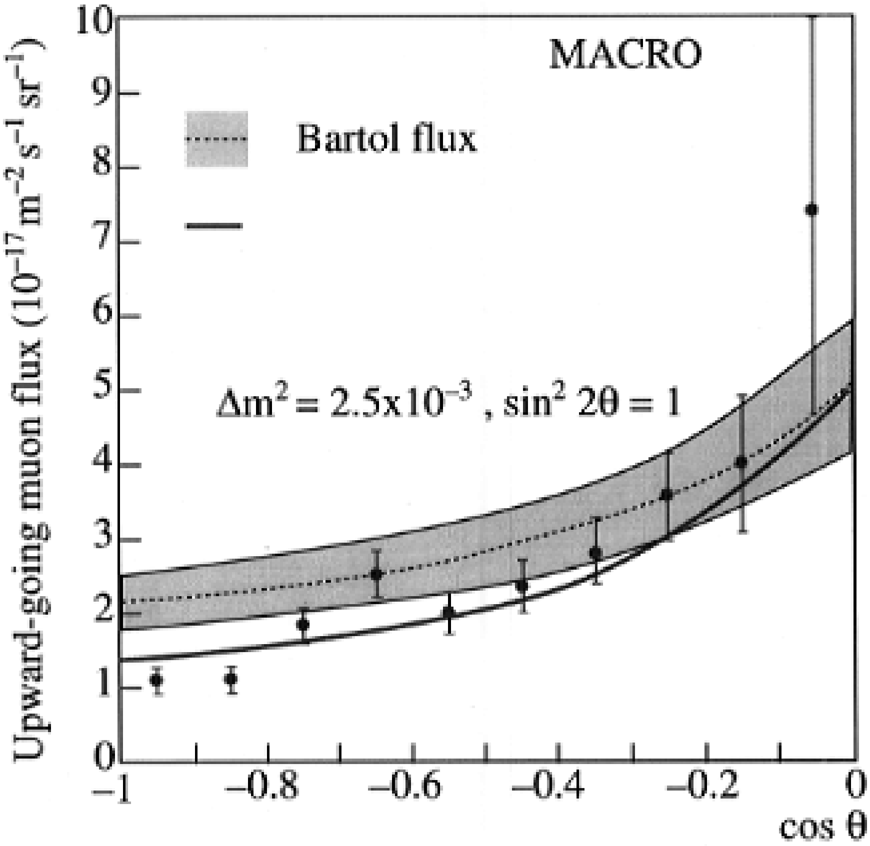
Upward going muons = tracks giving signal in at least two scintillators
timing consistent with upward direction



Observed total flux and angular distribution incompatible with expectations in no-oscillation case (fit probability 0.1%)

Fit with oscillations gives maximum mixing and @ $\Delta m^2 = 0.0025$ eV^2

Confirmation of SuperK result, with complementary technique



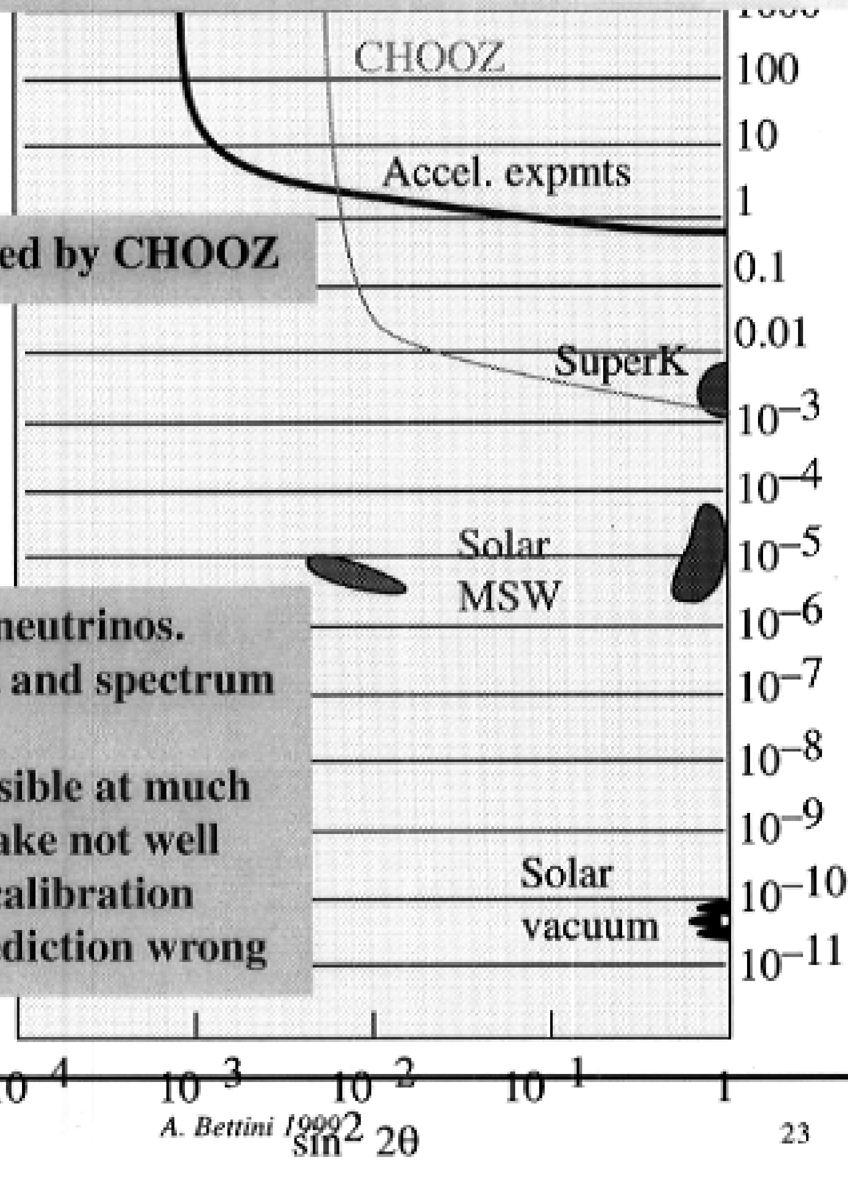
expected 612 events
observed 479 events

from Nadir horizontal

Beyond standard theory

- **Neutrino physics. Masses and mixing parameters**
  Strong evidence of physics beyond standard model is (only) from the observation of oscillations of neutrinos from the Sun and the atmosphere
    - Neutrinos have non zero masses
    - Lepton numbers are not conserved

  CHOOZ has excluded electron neutrino oscillations in a large zone
  Means to explore the interesting regions
    - **Neutrino beam from accelerators to underground labs**
      - Disappearance
      - Appearance (tau neutrino, but don't forget U_{3e} matrix element)
    - **Neutrinos from reactors** (Best for U_{3e} matrix element meas.?)
    - **Next generation atmospheric neutrinos experiments**
    - **Next generation solar neutrino experiments**
    - **Neutrinos from supernova**
- **Is neutrino mass (partially) Majorana?**
- **Dark matter**

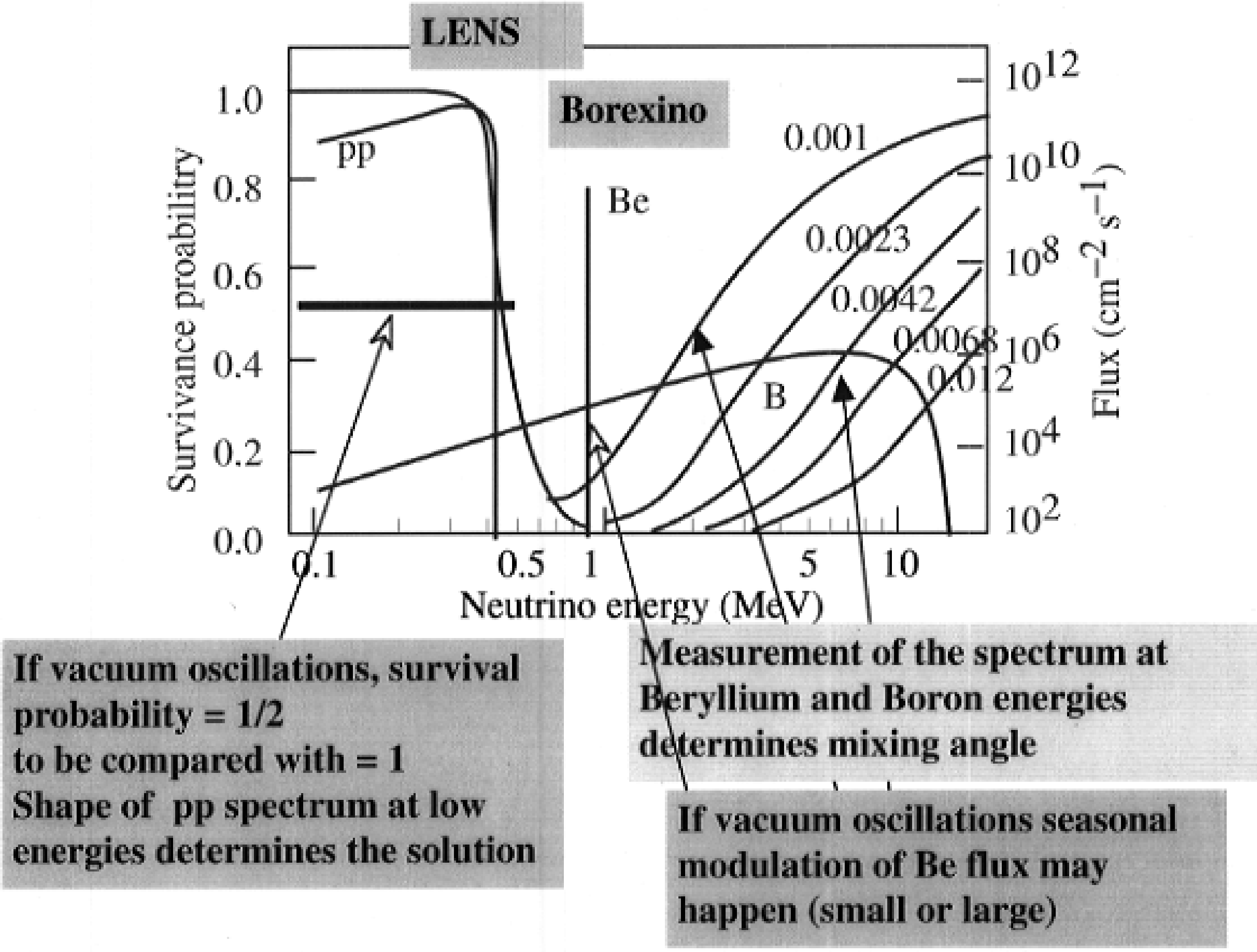


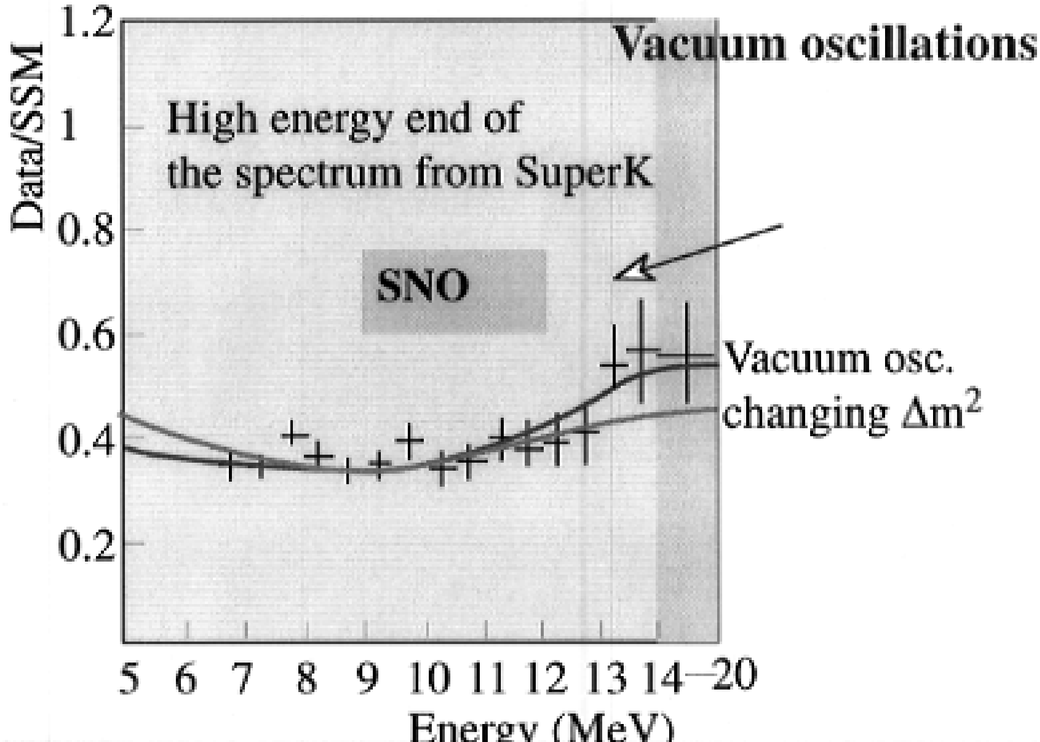
$\nu_\mu \rightarrow \nu_e$ excluded by CHOOZ

- **Three solutions for solar neutrinos.**
  - **SK data on day/night and spectrum not included in fit**
  - **Vacuum solutions possible at much larger Δm^2 if Homestake not well calibrated (no direct calibration done) or if B yield prediction wrong**

Solar neutrinos

MSW small mixing solution (Berezinski, Fiorentini, Lissia)

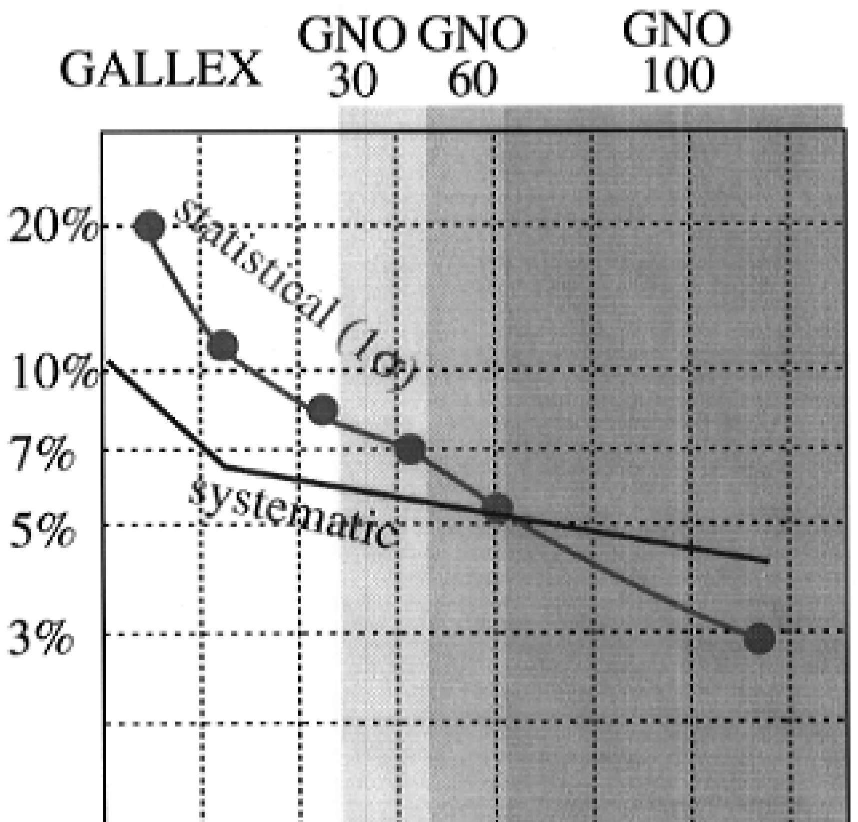




GNO
Gallium Neutrino Observatory

Continuous data taking for a long period (one solar cycle)
Increase Ga mass (only 30 t approved till now)
Reduce error to 5%
Look for time variations of signal

On the basis of solar luminosity the absolute minimum of the Ga counting is = **80 SNU**
GALLEX result **76±8 SNU**
With reduced error GNO alone might exclude standard neutrinos



BOREXINO

STATUS = Data taking 2001

Real time detector for low energy (>0.4 MeV) solar neutrinos

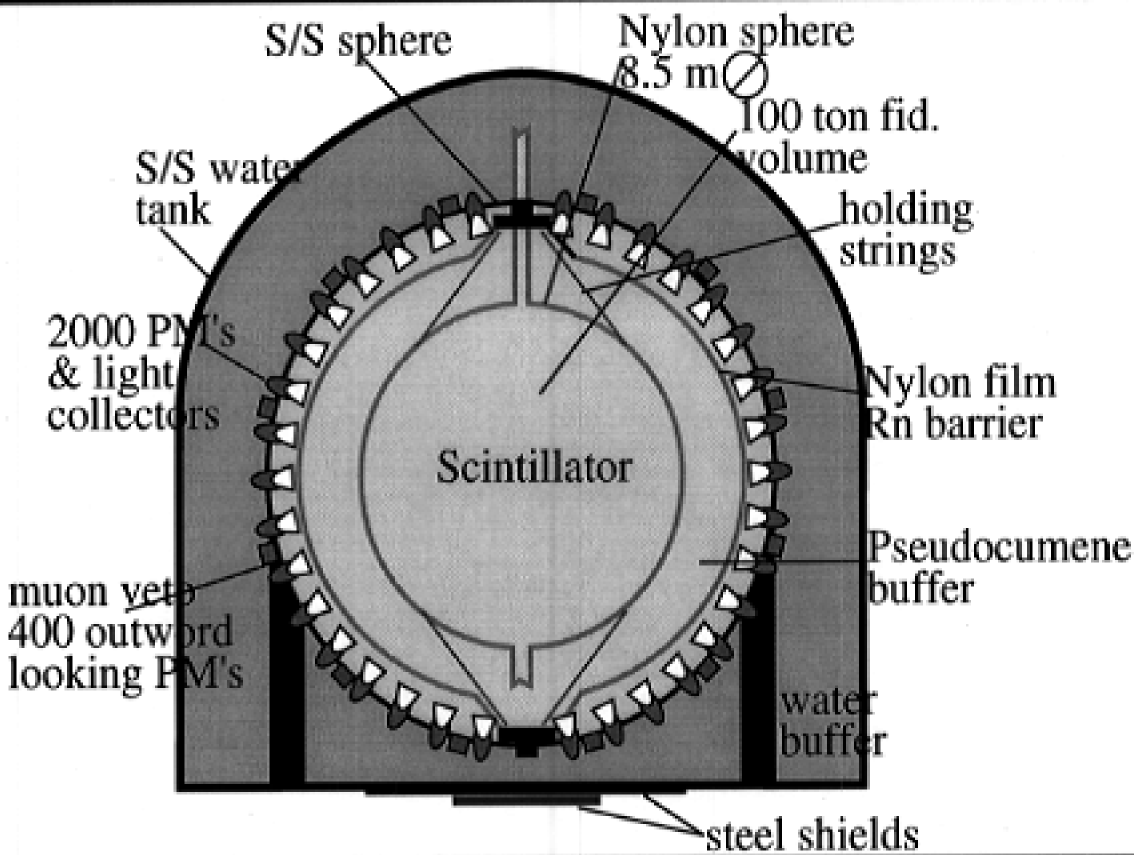
Physics

Measure electrons from monoenergetic neutrinos (0.86 MeV) of ^{7}**Be**

Compton plateau from 862 keV

Rate very sensitive to parameters (Δm^2 and mixing)

40 ev/day ife SSM, 0 for other solutions, strong seasonal variations possible

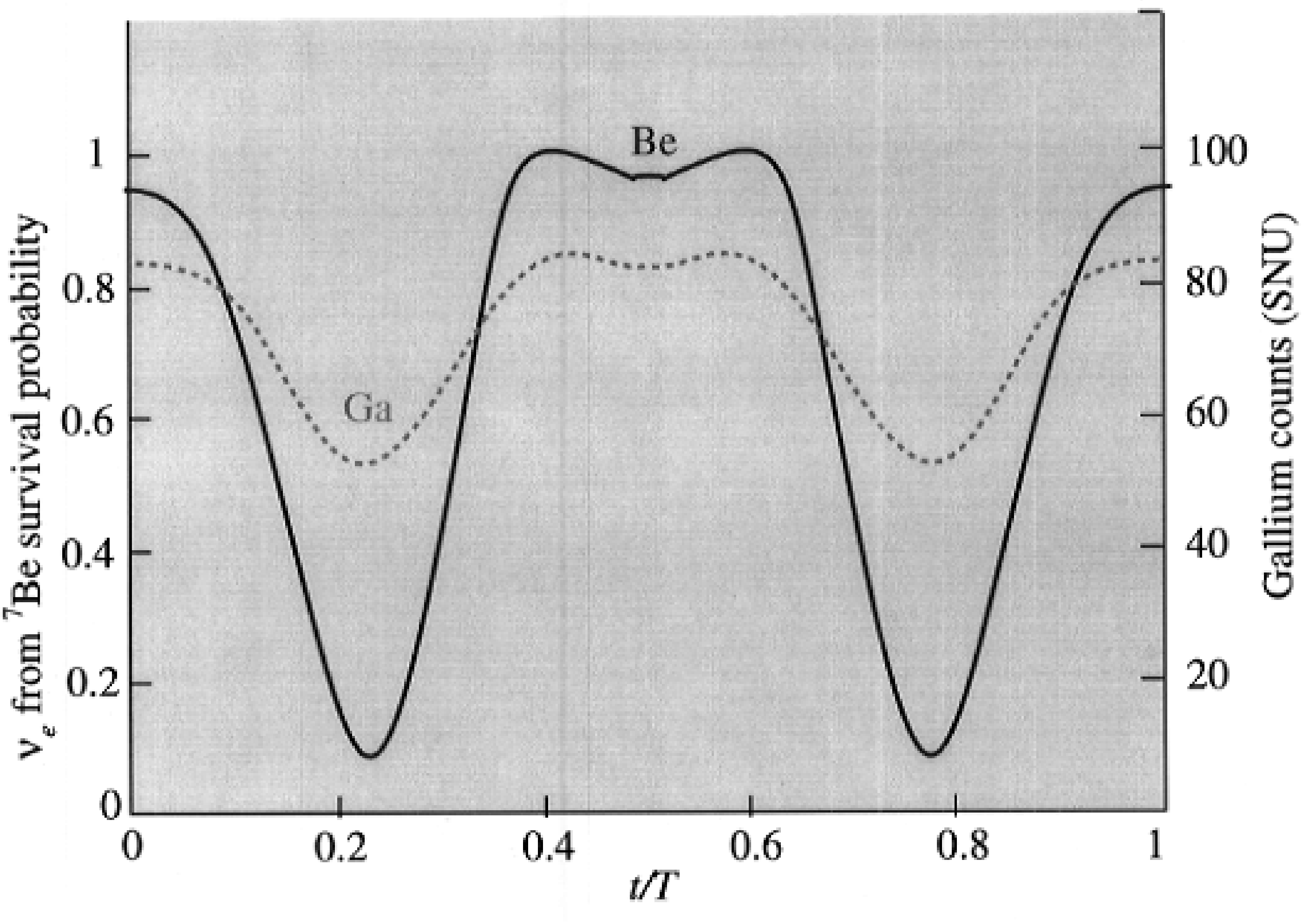


300 tons liquid scintillator (Pseudocumene + PPO)
surrounded by a S/S sphere, 13.7 m diameter, supporting 2200 PMT's & optical concentrators.
space between nylon vessel and sphere is filled with pure Pseudocumene
second nylon balloon, 11m diameter: barrier against Rn diffusion
the S/S sphere is immersed in 2500 t of purified water contained in a tank (18m diam., 16.9m height)

PM coverage	30%
en resol (200-800 keV)	8%
spatial resolution	10-15 cm

Berzinski et al. solution

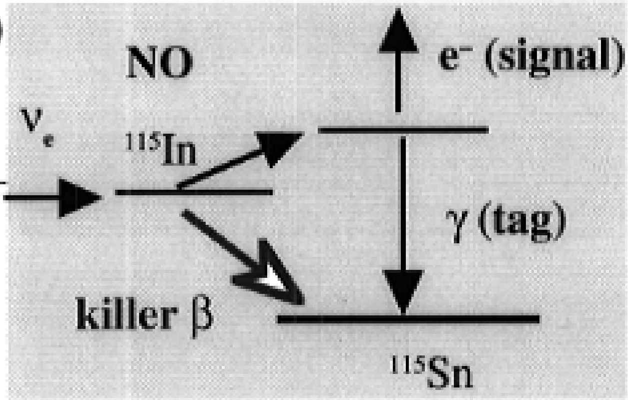
One solution (Berezinski+Fiorentini+Lissia)
Take the liberty to admit
  Homestake * 130%
  Some freedom on the B flux
Find from fit
  $\Delta m^2 = 10^{-8}\ eV^2$
Large semiannual modulation of Be flux!!



LENS (Low Energy Neutrino Spectroscopy)

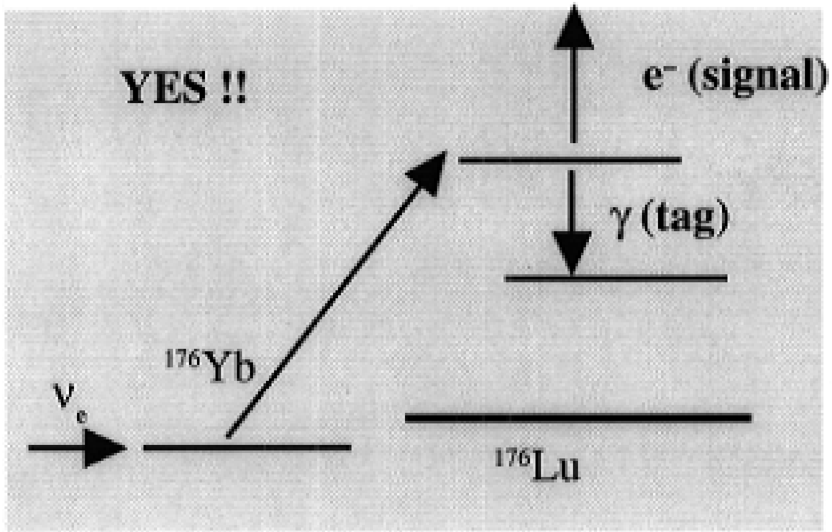
For a complete programme we need
- real time sensitivity to low energy neutrinos
- flavour specificity
- source specificity (pp, ^{7}Be, pep, ^{8}B, CNO)

Only way
- Electron neutrino capture $\nu_e + I \rightarrow F + e^-$
- followed by $F \rightarrow G + \gamma$ (tag
- necessary for background suppression)



20 years long search **TAGGED, LOW Q, STABLE TARGET**
<u>Breakthrough (April 1996) by R. S. Raghavan (Bell Labs)</u>

Two stable targets
^{176}Yb Thresh. E_ν = 301 keV
^{160}Gd Thresh. E_ν = 241 keV



Foresee a sensitive mass = 30 t (be sensitive to flux variations)

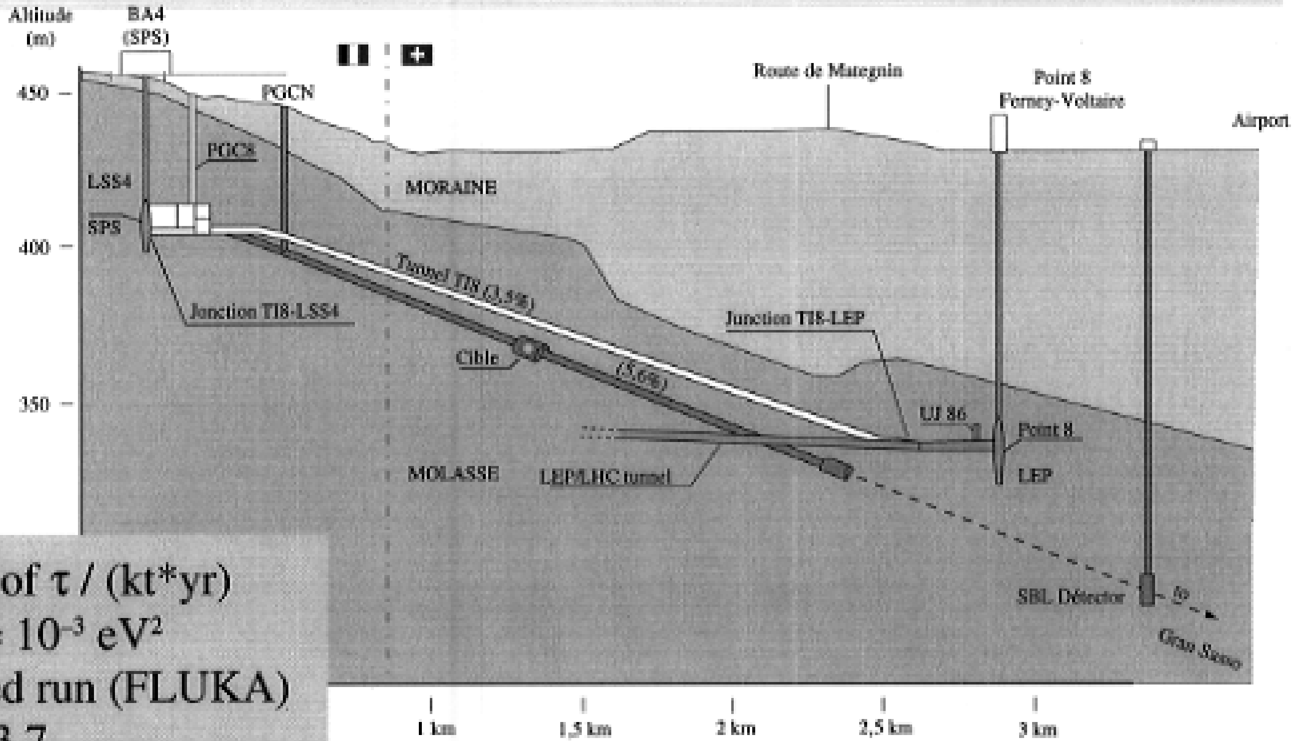
LENS counts per year and per 10 t

	pp	Be	pep
Yb	**100**	**140**	**8.2**
Gd	**92**	**101**	**7.2**

Critical R&D still needed

Neutrino beam from CERN to LNGS (CNGS)

Technical design completed; by an INFN - CERN group; three spectrum options (standard, medium energy, low energy).
4×10^{19} pot/y in shared mode; 7.5×10^{19} pot in dedicated mode
Cost (no near station) 71 MSF
INFN willing to contribute at 2/3 level. 24MSF from other interested partners
End of August 1999. Dead line for (pre)proposals
Sept. 1999. LNGS SC and SPSC met to discuss (pre)proposals
Nov. 1999. LNGS SC and SPSC meetings
Dec. 1999. Council asked for approval
If yes, ready by 2005



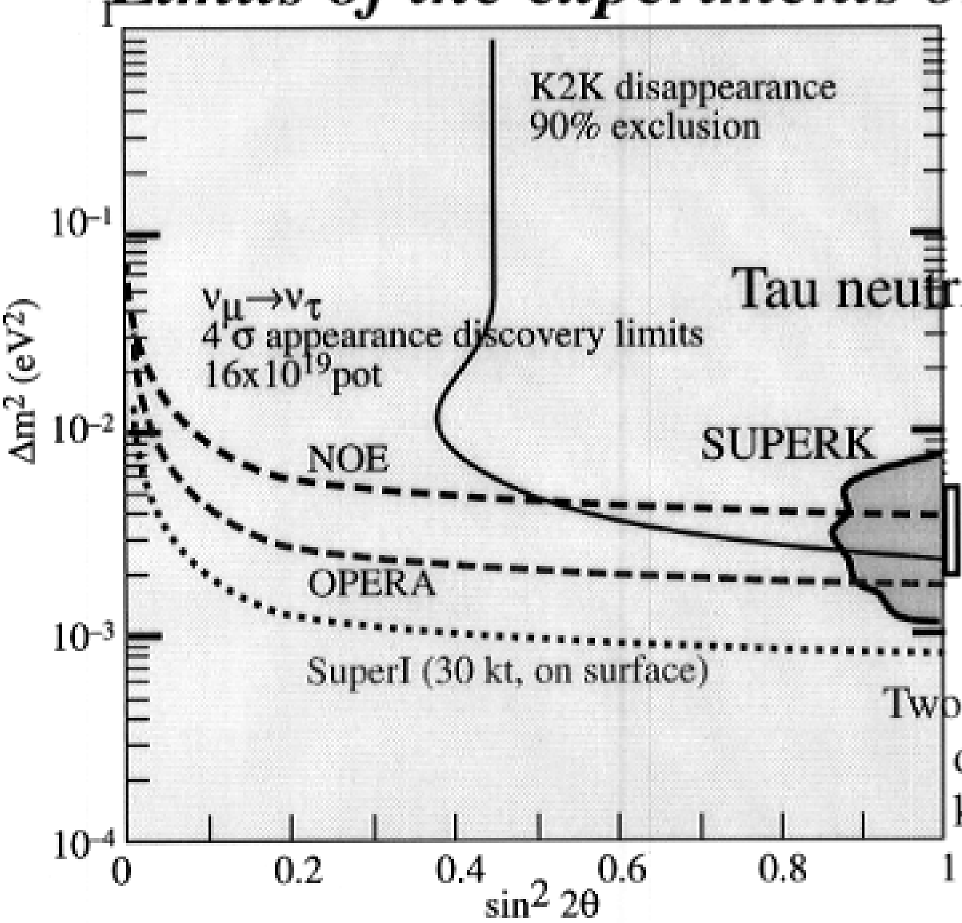
Number of τ / (kt*yr)
@ $\Delta m^2 = 10^{-3}$ eV^2
Dedicated run (FLUKA)
NGS = 3.7
Numi = 4.2

Other complementary / competing programs

Japan. K2K (KEK to Kamioka mine)
L/E = 250km / 2 GeV. Disappearance (below threshold). Lower intensity
Begins in 1999

USA. NUMI+MINOS. Fermilab to Soudan mine
L/E = 730km / 6-15 GeV. Disappearance (statistically appearance).
Approved. Will start in 2002.

Limits of the experiments on the beam

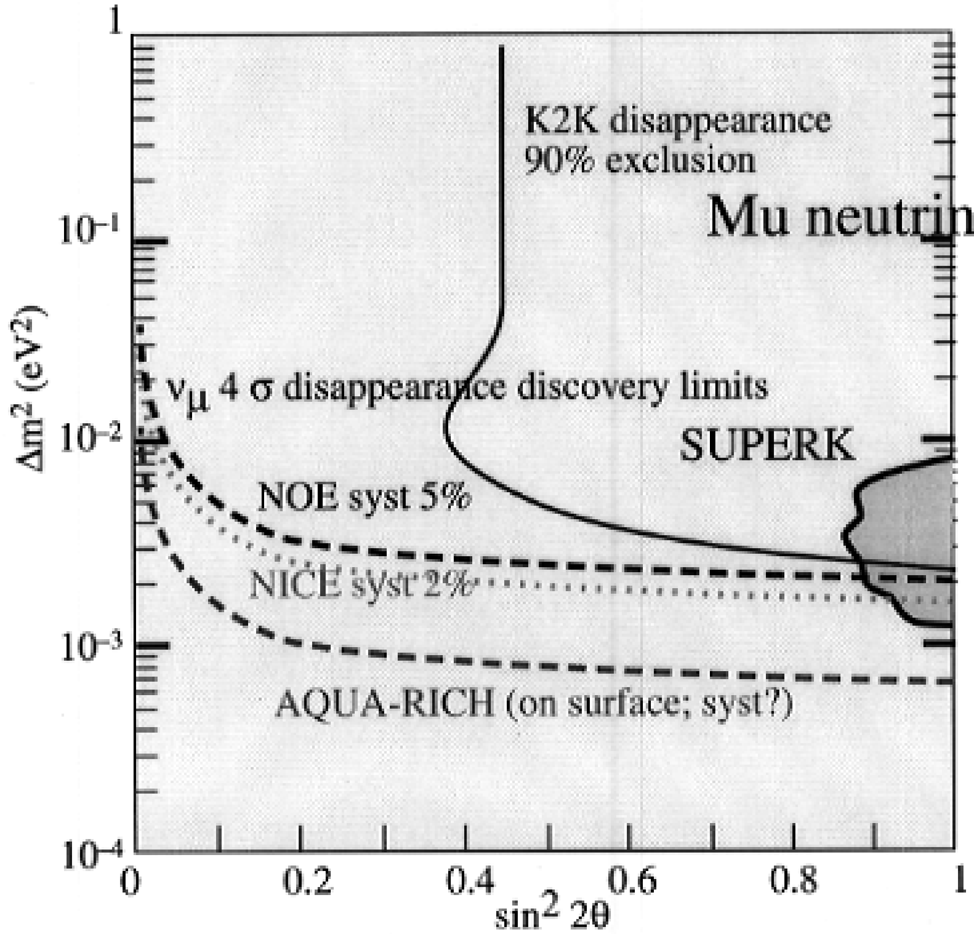


Assume 4×10^{19} pot/y and 4 years running

Tau neutrino appearance

Combining all SK data
(thru+ stop/thru)
$2\times10^{-3} < \Delta m^2 < 5\times10^{-3}$ eV^2

Two possibilities
detect tau track (OPERA)
kinematic cuts (NOE)



Mu neutrino disappearance

Limits determined
by systematic error
on beam profile
knowledge

Guidelines for proposals

Conclusions of Gran Sasso Director from the analysis of the CERN and Gran Sasso Scientific Committees (Nov. 3 and 4, 1998)

A complete scientific program must include

1. the definitive confirmation that observations of SuperK (and MACRO) are due to neutrino oscillations
2. measurement of square mass difference and mixing angle(s)
3. verification if oscillation is into ν_τ

The reach of disappearance experiments is close to that of the appearance ones (around $\Delta m^2 = 10^{-3}\, eV^2$)

Produce two experimental proposals
to be ready by autumn 1999
in large international collaborations

1. atmospheric neutrinos experiment
large sensitive mass (> 30 kt)
good neutrino energy and direction resolution

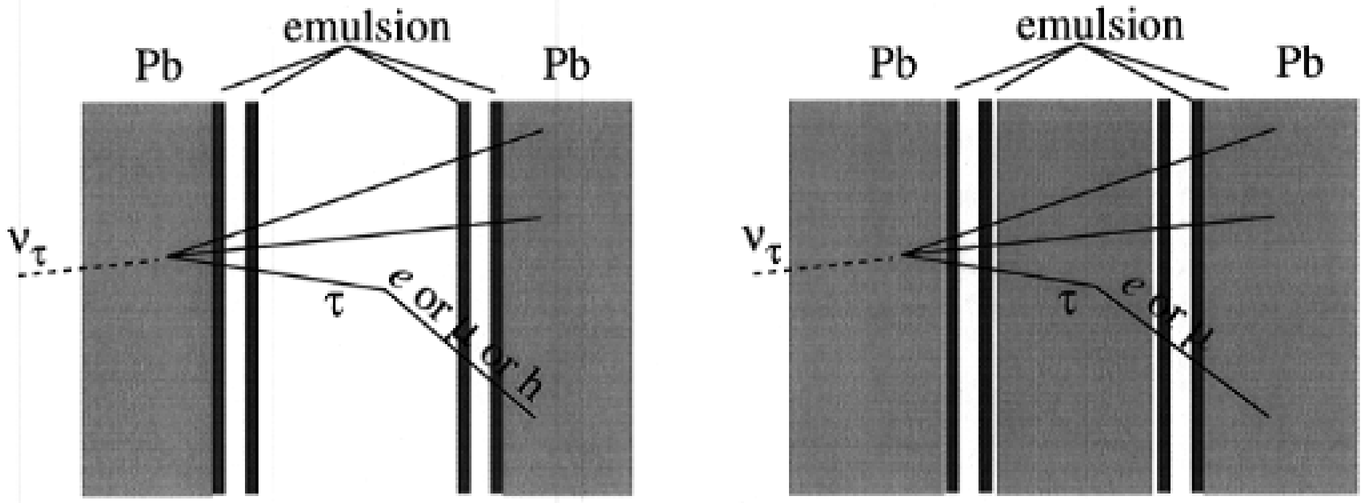
2. tau appearance experiment on the neutrino beam
sensitive down to very low Δm^2

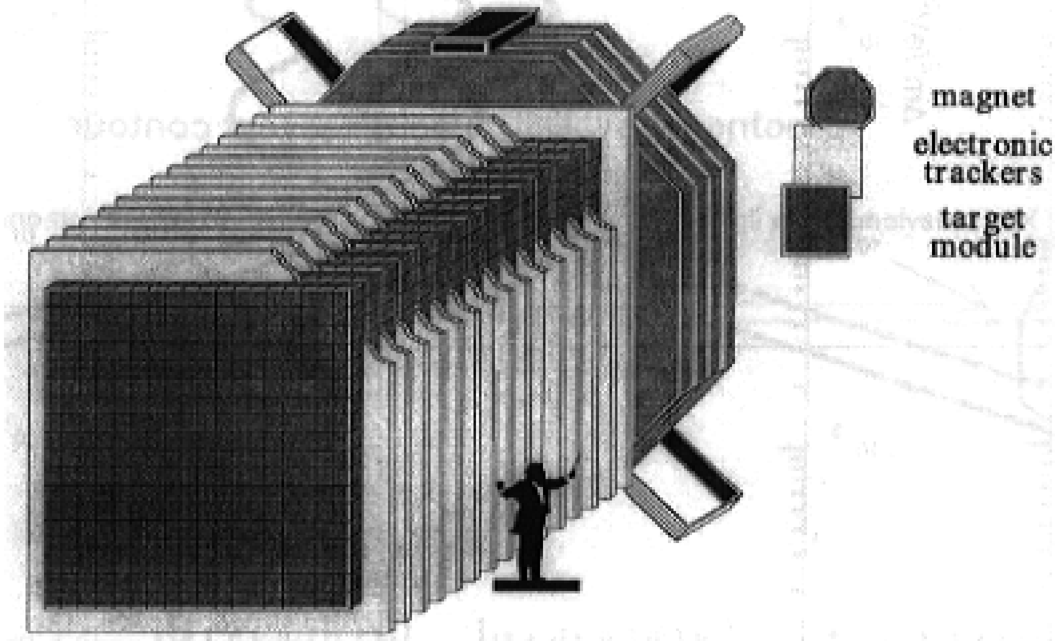
Create maximum synergy between the two Collaborations
Keep separate the two detectors concepts
Both are very difficult
Avoid compromises

OPERA

OPERA.
Neutrinos from the long base line beam
ν_τ appearance
Lead target
Emulsion (Nagoya) tracking
Mass 800-1500 t
Expected backgrounds very small
R&D still necessary

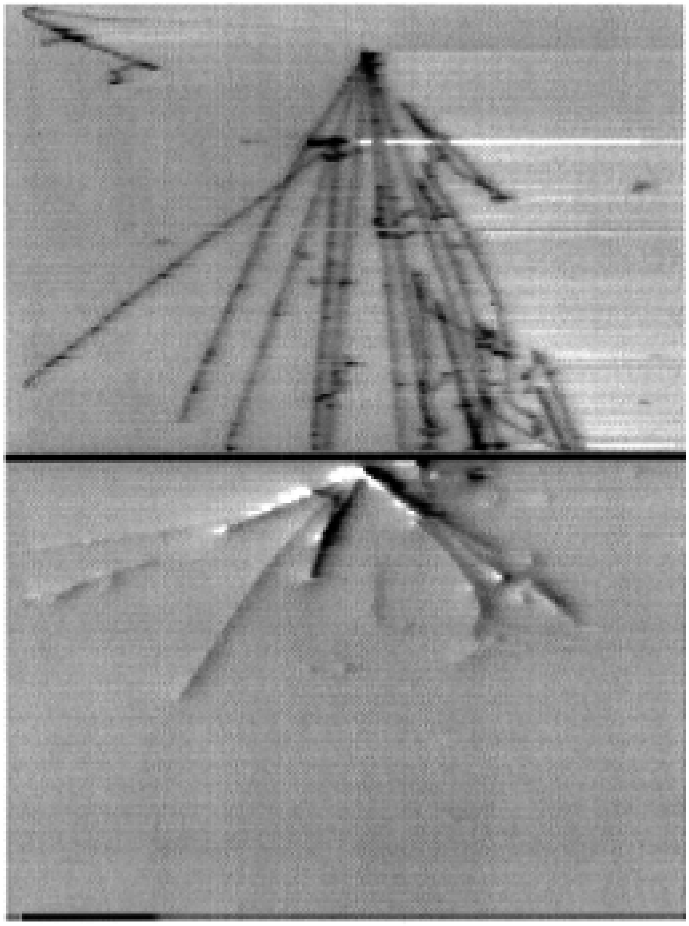
Two possible geometries. Being evaluated





@ $\Delta m^2 = 3.5 \times 10^{-3}$ eV ^{2}, 5 years running (shared)
expected 18 events, background = 0.5 events

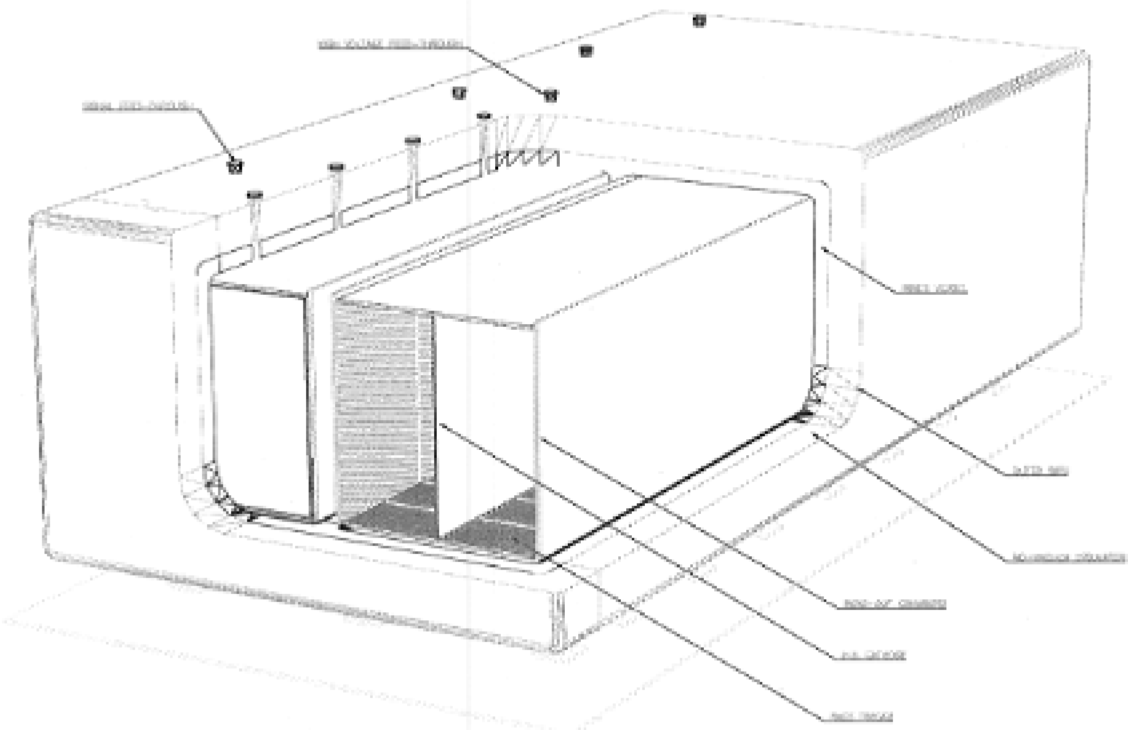
ICARUS T600



ICARUS
Liquid Ar Time Projection Chamber
with

- Bubble chamber quality 3D images
- Continuous sensitivity
- Self-triggering
- Calorimetry with high granularity
- dE/dx measurement

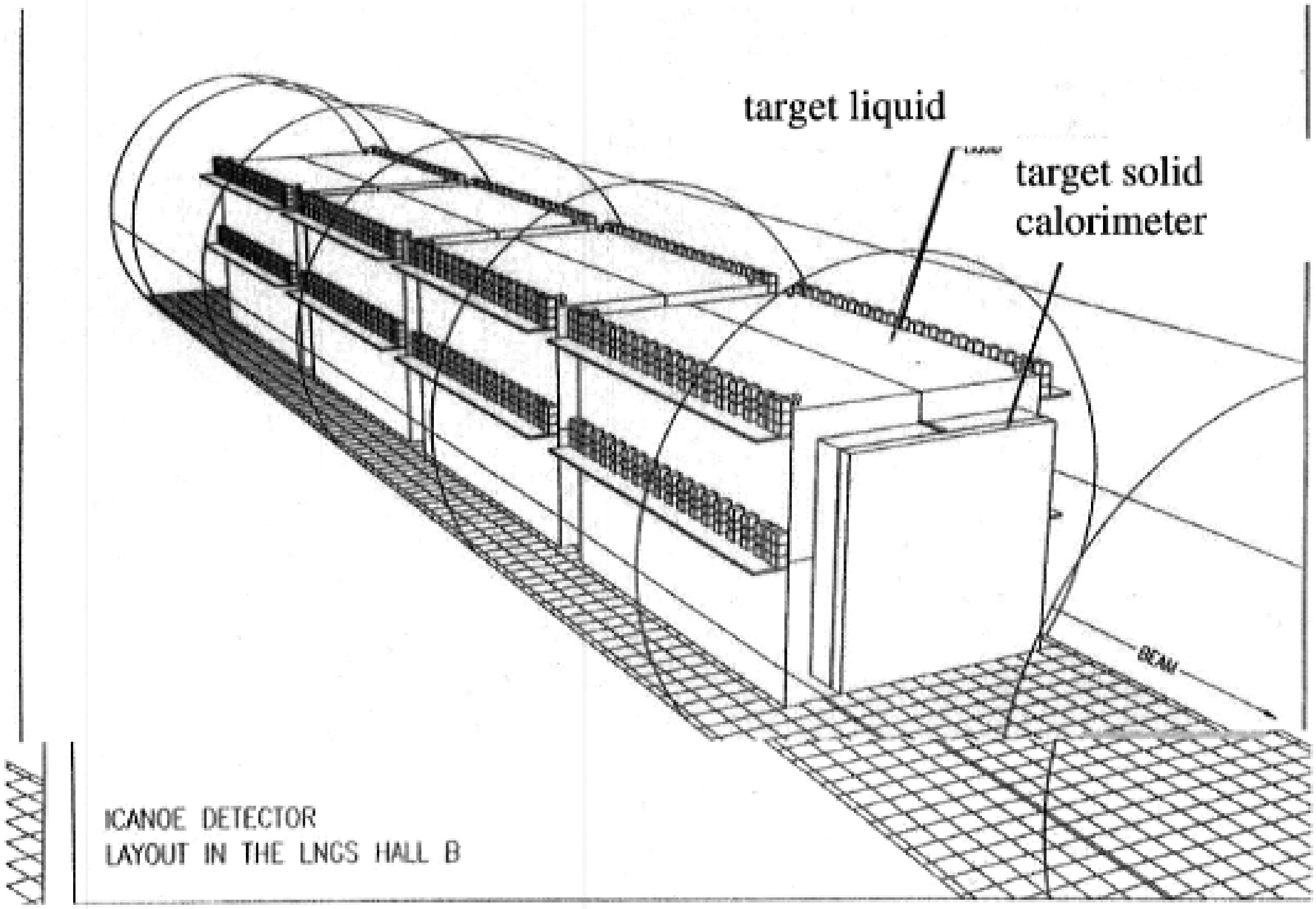
Technique has been proven on small-medium size prototypes (up to 3 t)
600t in construction at Pavia for definitive test on large scale
18 m long track expected by September 2000



ICANOE

ICANOE
ICARUS technology for the liquid target (event image)
NOE technology for the solid target (calorimetry)

Waiting for the test of ICARUS tau at Pavia (summer 2000)



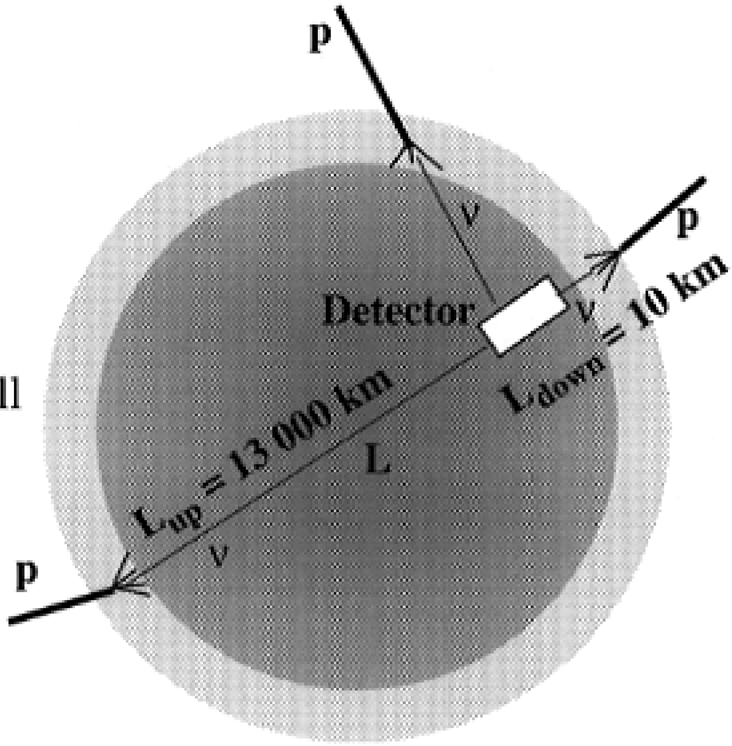
@ $\Delta m^2 = 3.5 \times 10^{-3}\ eV^2$
20 kt year run (4 modules, 4 years, shared running)
35 events, background = 5 events

Atmospheric neutrinos

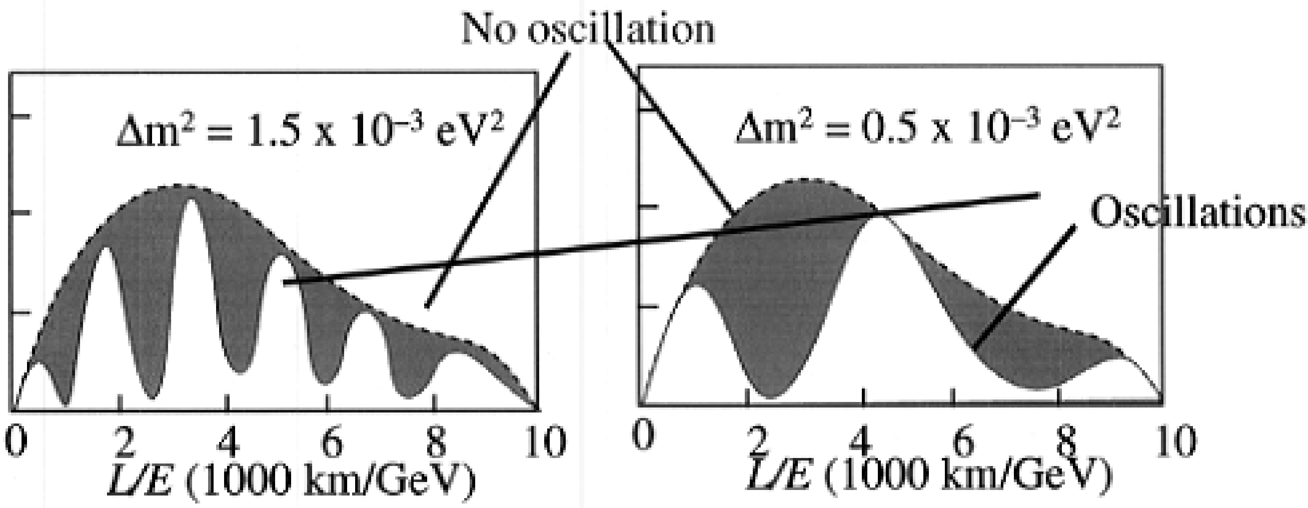
Atmospheric neutrinos are the only way beyond $\Delta m^2 \approx 1\text{-}2\ 10^{-3}$ eV (if large mixing)

To proceed we must develop

- Better Montecarlo simulations (complete kinematics, etc.)
- Large mass detectors (>30 kt)
- Good neutrino energy resolution
- Good neutrino direction resolution



Picchi and Pietropaolo method
Measure event by event energy and direction (giving L)
Upward/downward ratio vs. L/E (small MonteCarlo dependence)
Oscillations pattern well visible if large mixing and
$10^{-4} < \Delta m^2 < 8\ (?) \times 10^{-3}$ eV^2
at lower masses only deficit seen

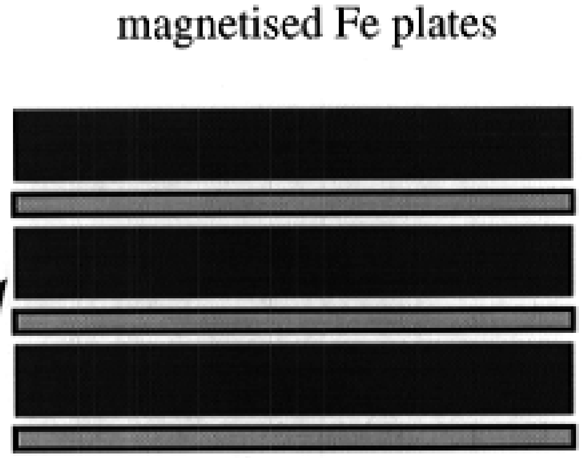


Half of the ν_μ upward coming flux is lost. Are they ν_τ?
If yes the flux is high. Can it be distinguished from background?

Proposed techniques

- Large mass RICH (AQUARICH) [does not fit in the present halls]
- High density tracking detector (with magnetic spectrometer) MONOLITH

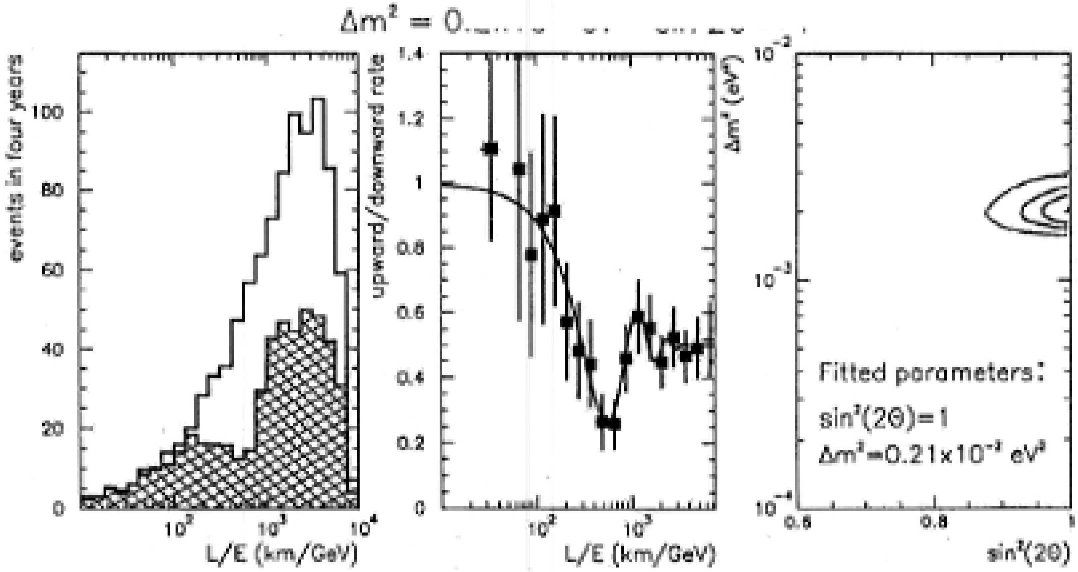
MONOLITH



Take high energy neutrinos (several GeV)
 neutrino direction = charged lepton dir.
Good μ/π separation efficiency
Forget oscillations into electron nus
 Filter out electron component
 Muon energy (momentum)
  from range
  from B

Cosmic rays flux @ high energy small.
Large detector mass needed (several kt)
Assume 35 kt mass
High density calorimeter
  8 cm thick Fe absorbers between tracking detectors
 good spatial resolution (1 mm)
 good temporal resolution (2 ns)

$\Delta m^2 = 2 \times 10^{-3}$ eV^2



Oscillation pattern detectable at large mixing in a wide Δm^2 range
$10^{-4} < \Delta m^2 < 8 \times 10^{-3}$ eV^2
Easier for low Δm^2 . Complementary to long base line beam

Neutrinos from supernovae

If neutrinos contribute to dark matter their mass should be of a few eV
Given the very small mass differences they would be almost degenerate
Observation of supernova neutrino may give information on the mass
From Supernova 1987A $m_{\nu e} < 10 - 20$ eV

sensitivity limited by uncertainty in the assumptions about neutrino light curve and energy spectra.

Delay due to non zero mass $\Delta t = 5.15 \left(\frac{d}{10\text{ kpc}}\right)\left(\frac{m_\nu}{1\text{ eV}}\right)^2\left(\frac{10\text{ MeV}}{E_\nu}\right)^2$ ms

If longer than intrisic duration of the burst (20-50 s) we can claim a mass value
Limit from SN 1987A difficult to improve

SuperK (4.000 events @ 8 kpc), SNO (800), LVD (300-600), MACRO (150) (BOREXINO and ICARUS) may give interesting limit for ν_τ mass $m_{\nu\tau} < 50 - 150$ **eV**

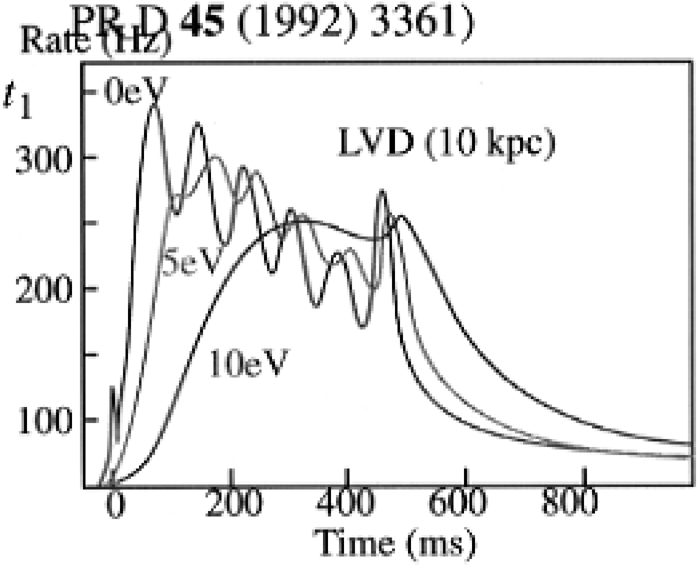
From delay of the first detected neutrino relative to gravitational wave
If we are really lucky

$$\Delta t = 5.15 \left(\frac{d}{10\text{ kpc}}\right)\left(\frac{m_\nu}{1\text{ eV}}\right)^2\left(\frac{10\text{ MeV}}{E_\nu}\right)^2 \text{ ms} + t_1$$

energy of the first neutrino

delay between neutrino and gravitational signal at supernova site (order of millisecond)

A model (Burrow, Klein, Gandhi PR D **45** (1992) 3361)



Time measurement becomes crucial

Neutrino detector accuracy 1 ms

Gravitational wave antenna will go below 1 ms accuracy when equivalent SQUID temp. reduced to 100 ħ

LVD (etc.) could reach (optimistically) $m_\nu < 1$ **eV** even with t_1 unknown

No accurate calculation done so far (to my knowledge)

Explicit calculations and Monte Carlo simulations needed

Evaluate importance of energy resolution

LVD

three "tower" configuration finally approved (1080 ton)
two tower configuration running
third tower completion expected in 1999
Supernova Observatory - no dead line

Physics.
Neutrinos from SN
High energy cosmic rays
Penetrating component
exotica

Detector
Liquid scintillator 1080 ton

Numbers of events expected from a stellar collapse @ 8.5 kpc (centre of the Galaxy) with 3×10^{46} J total neutrino energy

Main processes

$\overline{\nu}_e + p \rightarrow n + e^+$ **300-600 events**
followed by *n* capture
$n + p \rightarrow n + \gamma + d + 2.2$ MeV
$\tau = 185$ μs
detected with 60% efficiency

$\nu_x + e^- \rightarrow \nu_x + e^-$ **8-15 events**

$\nu_x + {}^{12}\mathrm{C} \rightarrow \nu_x + {}^{12}\mathrm{C}^*$ **15-45 events**
${}^{12}\mathrm{C} + \gamma$

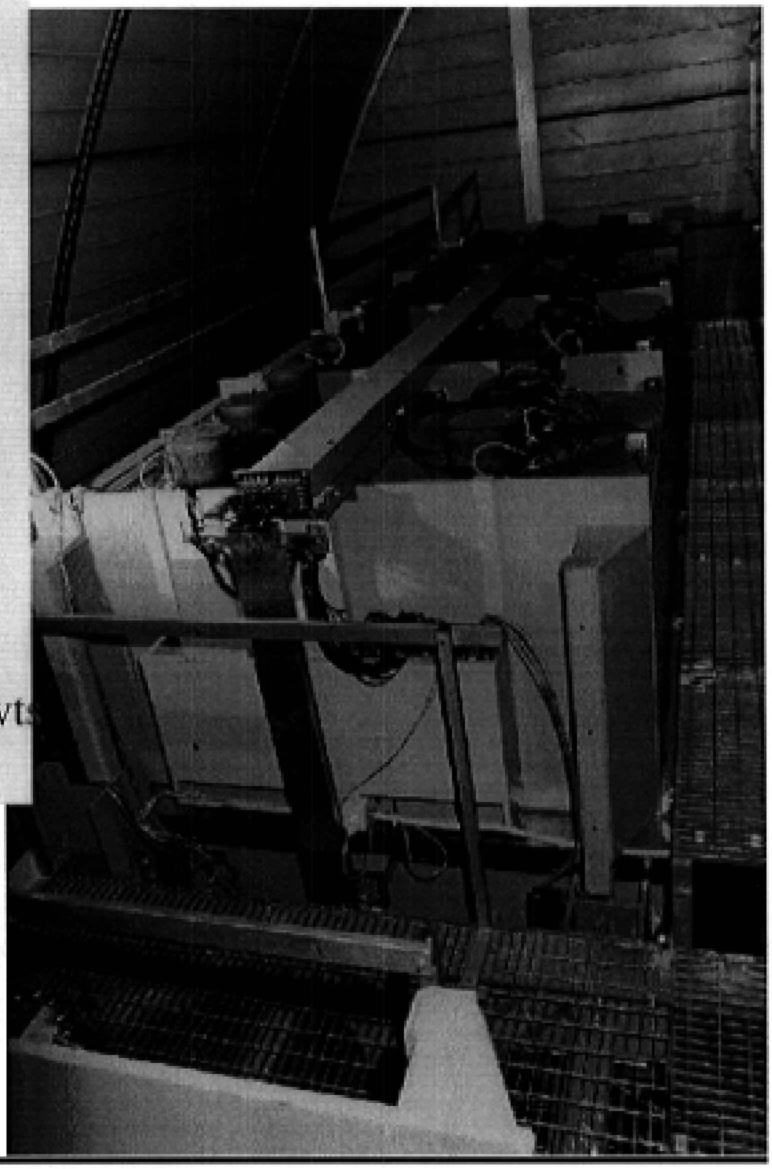
$\nu_e + {}^{12}\mathrm{C} \rightarrow e^- + {}^{12}\mathrm{N} \rightarrow {}^{12}\mathrm{C} + e^+ + \nu_e$

$\overline{\nu}_e + {}^{12}\mathrm{C} \rightarrow e^+ + {}^{12}\mathrm{B} \rightarrow {}^{12}\mathrm{C} + e^- + \overline{\nu}_e$

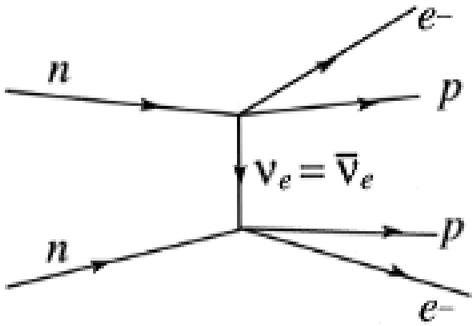
} 6 evts

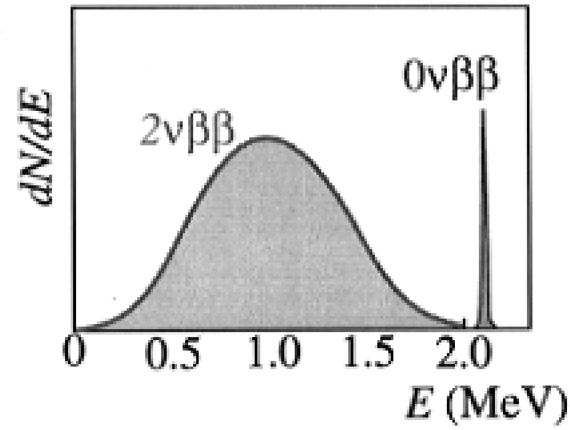
few tens of events if oscillations

On top of the first "tower"
One 8-tank module (three PM each tank
38 modules per tower
114 in three towers

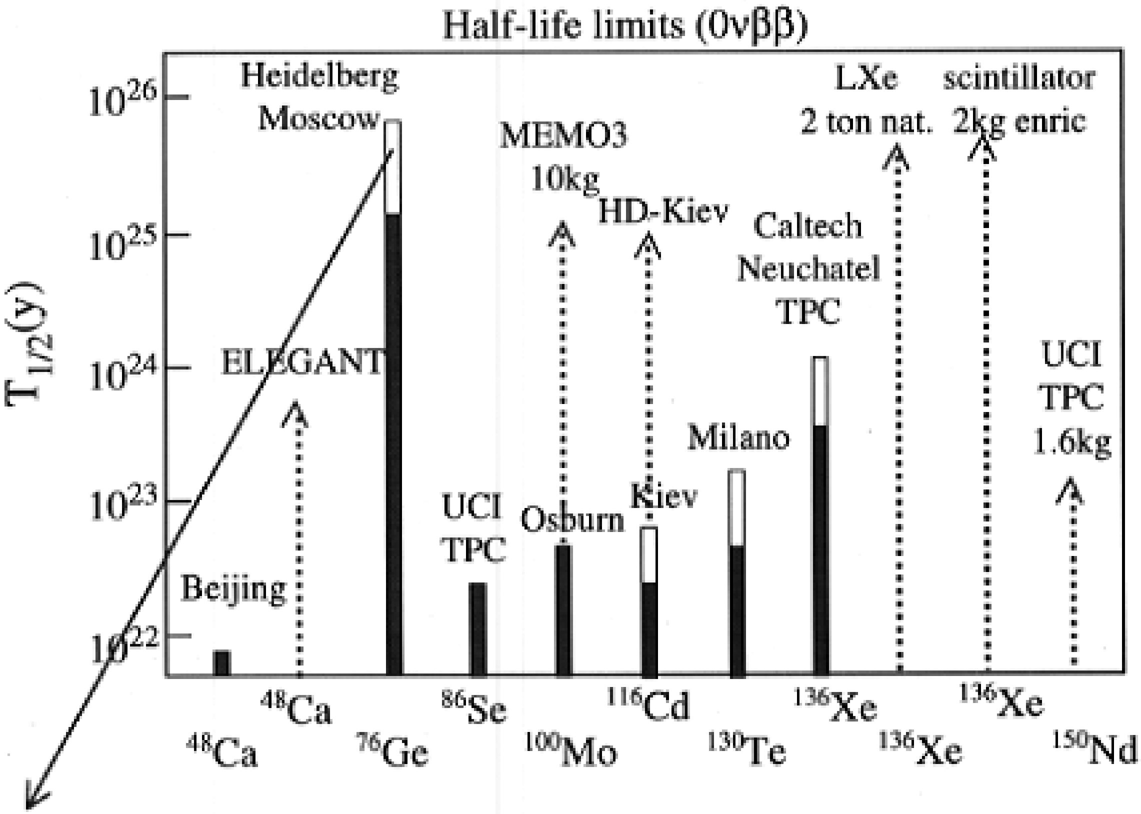


Double beta decay and Majorana mass





Neutrinos have masses
Lepton numbers (flavours) are violated
If total lepton number is violated, neutrinos may be Majorana particles, neutrino = antineutrino,
then neutrinoless double beta decay may happen **(0νββ)**
Lower limits on the lifetimes give upper limits on neutrino mass
Matrix elements uncertainty (typically a factor 2)



Heidelberg - Moscow. The most sensitive experiment in the world
Enriched Ge detectors (19.2 kg) with 86% ^{76}Ge
^{76}Ge sensible mass = 10.96 kg
Best limit on Majorana neutrino mass $< m_\nu > < 0.3$ eV

CUORE

Cryogenic Underground Observatory for Rare Events
Search for cold dark matter (WIMPs) with bolometric detectors

The Milano group has advanced in the development of cryogenic detectors.
Twenty, 340 g each, TeO_2 bolometers are presently in operation at Gran Sasso
Total mass almost 7 kg (natural Te; ^{130}Te 34% = 2.3 kg)

Present physics program: search for
- double beta decay of ^{130} Te
- WIMPs and solar axions

CUORICINO = 100 TeO_2 bolometers
total mass 75 kg (natural Te)
total mass of ^{130}Te 25.5 kg

APPROVED

CUORE = 1000 TeO_2 bolometers, 600 g each, natural Te
total mass 600 kg
total mass of ^{130}Te 200 kg
other detector materials under consideration (Ge, $PbWO_4$, etc.)

Physics
double beta decay
sensitive to $T_{1/2} = 10^{26}$ y
Majorana mass sensitivity not specified
should be less than 100 meV
WIMP search

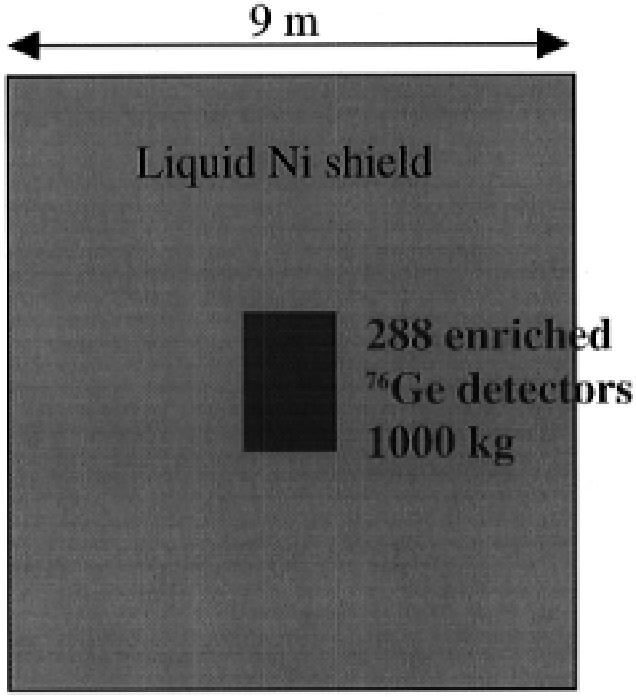
GENIUS

GErmanium detectors in liquid NItrogen shielding in Underground Setup
Collaboration: MPI Heidelberg
Recent results of Heidelberg-Moscow experiment have shown the large potential of neutrinoless double beta decay to search for new physics beyond the standard model: R-Parity breaking, leptoquarks masses, right handed W, ...

For a major step forward in sensitivity
increase sensitive mass by large amount
decrease background by large factor

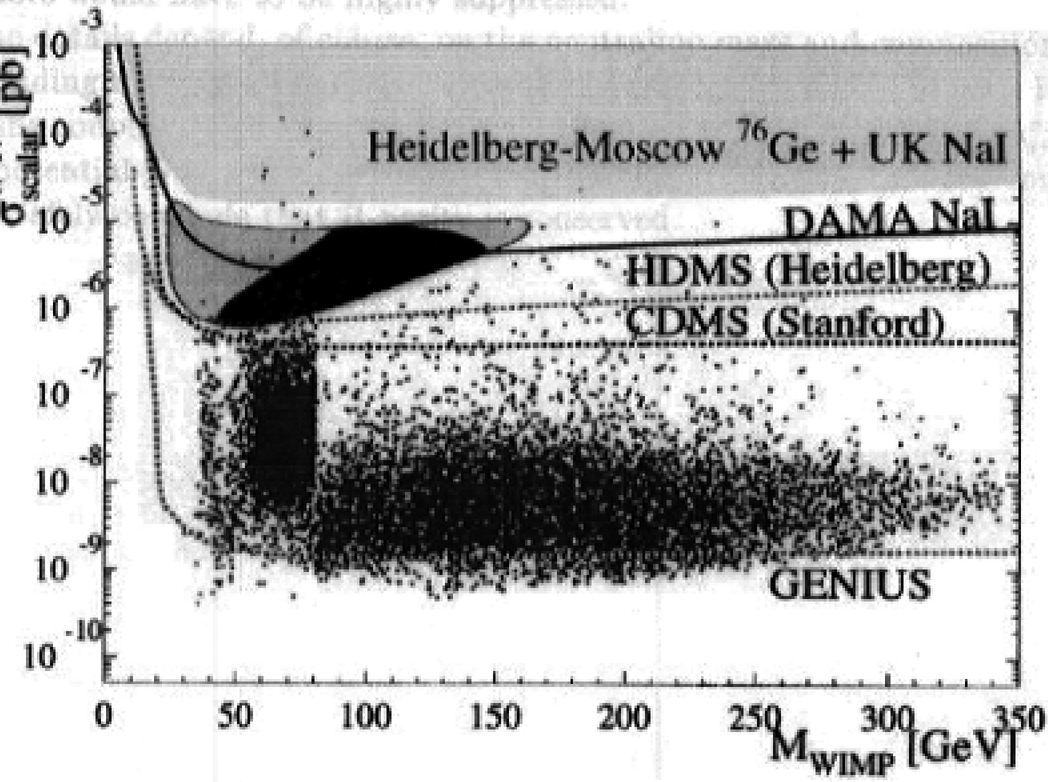
Proposed technique
"naked" enriched Ge crystals
in the middle of a 10 m diametre liquid
Nl volume (shield).

Sensitive mass
1000 kg enriched Ge (^{71}Ge)
Majorana neutrino mass sens.
10 meV

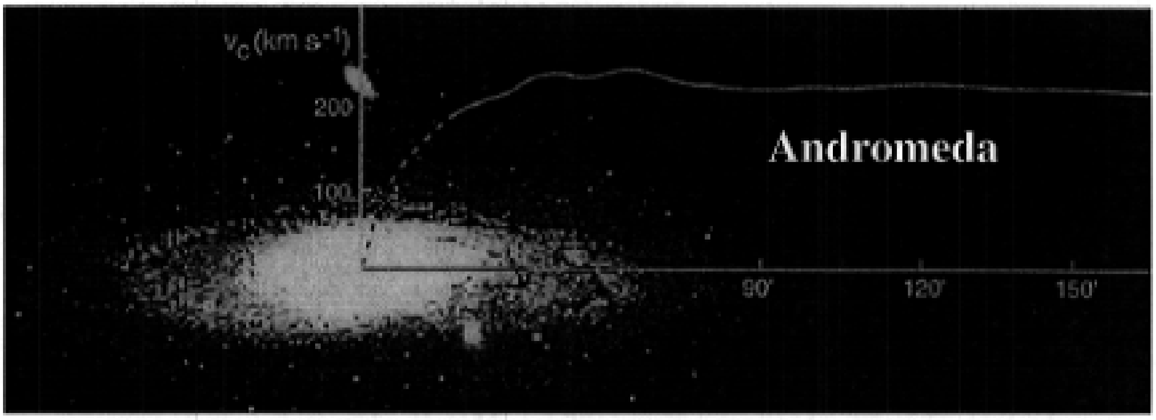


Cold dark matter search with the same apparatus.

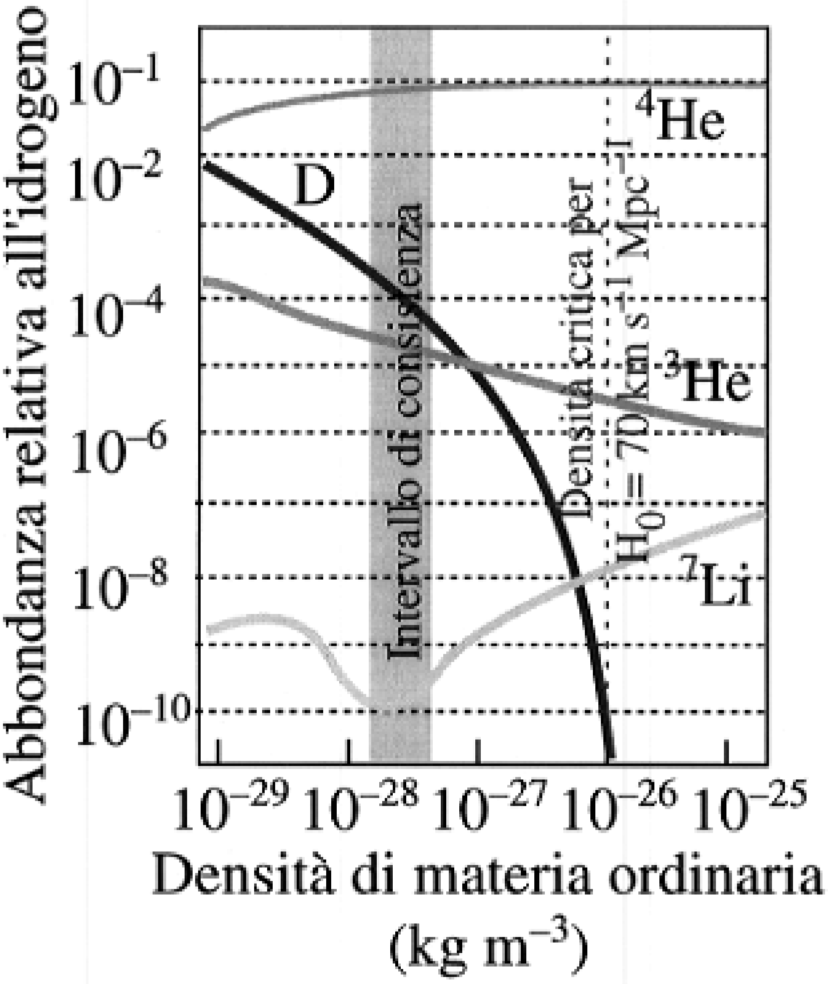
In a first phase, with 100 kg enriched or even natural Ge mass, neutralinos can be searched in all the MSSM parameter space



Dark matter



From rotation curves of Galaxies: matter density = 10* luminous matter density



Hubble constant is now known at about 10%. HST gives **H_0 = 71±6 km s^{-1} Mpc^{-1}**

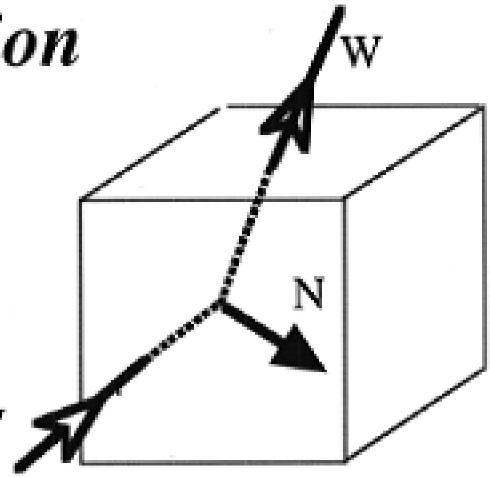
From deuterium abundance Baryonic density/critical density **= 0.04±0.004**

From many peaces of evidence Total matter density/critical density = **0.4±0.1**

From large scale structures spectrum, cold dark matter needed

We need something else. From particle physics
neutrinos if degenerate around eV masses
neutralino if SUSY

Direct WIMP detection



The nucleus recoiling from WIMP elastic scattering must be detected

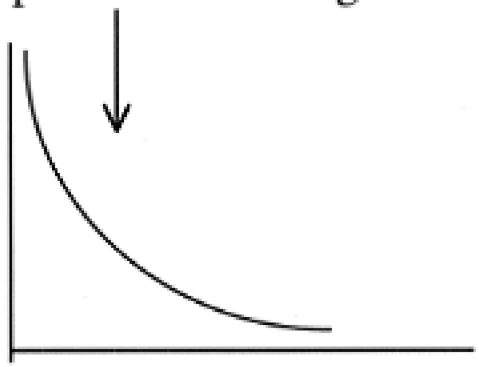
kinetic recoil energy $E_k = \frac{\mu^2}{M} v^2 (1 - \cos\theta)$

velocity v O(10^{-3} c), m = GeV - TeV → E_k = 1 - 100 keV
only a fraction Q is visible in the detector
(Examples Q = 0.1 for I, 0.25 for Ge, 0.6 for Xe)

Detectors till now
- Ge and Si diodes
- Scintillators: NaI, Xe, CaF_2,...
- Bolometers: Al_2O_3, TeO_2

New detectors
- Xe, Ar Liquid & Gas phases
- Drift chambers
- etc.

Problems
- Very small expected signal
- Very small expected rate
- Spectrum shape similar to background
- Small S/N



World wide effort
Use deep underground laboratories, in low radioactivity environment
Improve radiopurity
- Present records
  - Ge. Heidelberg-Moscow > 9 keV: 0.05 counts/keV kg day
  - NaI. DAMA > 2 keV 1.5-2 counts/keV kg day

Use coherent interactions on nuclei
Look for annual rate modulations (large detector mass)
Measure two quantities (heat and light or ionisation and light)
Reduce energy threshold

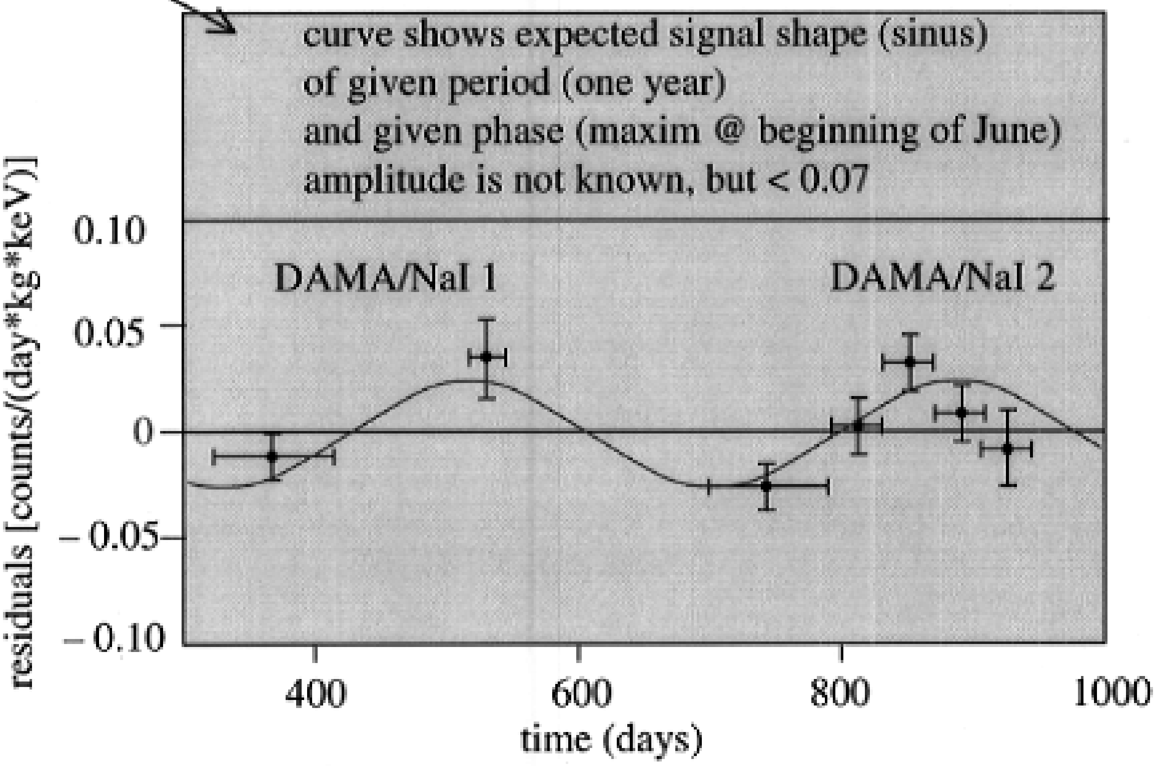
DAMA

115.5 kg NaI(Tl) high radiopurity

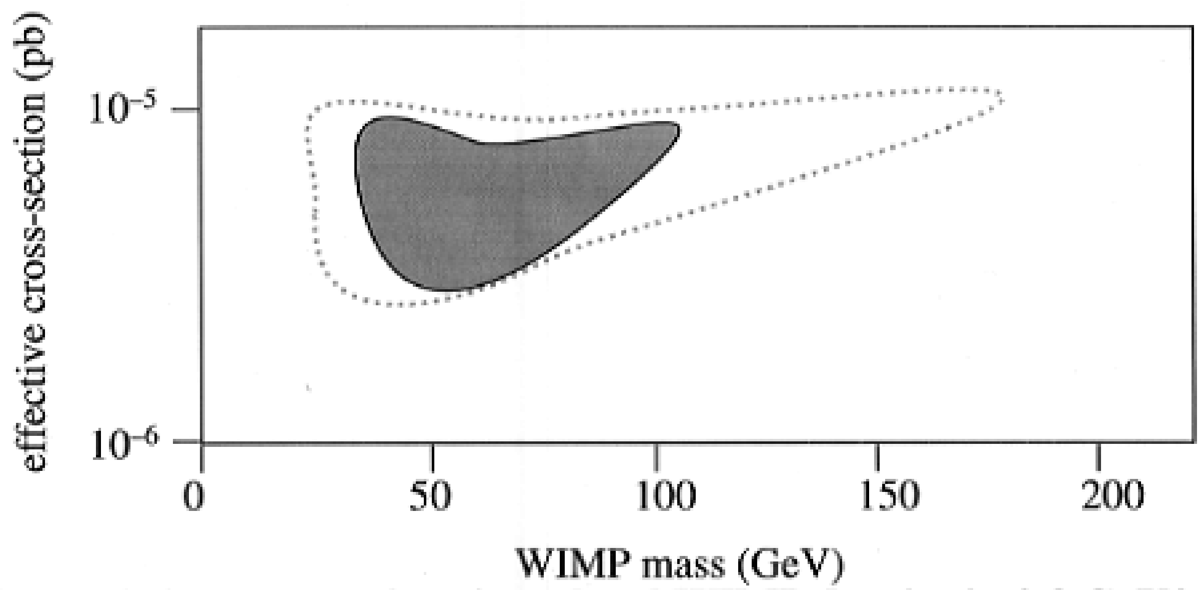
6.5 kg liquid Xe (no Kr) - 99.5% ^{129}Xe

curve included by me (A. B.) to show compatibility bet. signal and expectations

Annual modulation



Best fit gives $M = 59^{+17}_{-14}\ GeV, \quad \sigma^p = 7.0^{+0.4}_{-1.2} \times 10^{-6}\ pb$



Vertical axis is cross section times local WIMP density in 0.3 GeV/cm³

Where we stand, where we go

(see A. Morales at TAUP 99)

Several types of WIMPs have been constrained or excluded as DM for a wide range of masses and cross sections

LEP data exclude WIMP masses below 30 GeV

coherent interaction searches exclude $\sigma_p > (10^{-5} - 10^{-4})$ pb for WIMP masses of 50 - 100 GeV

A seasonal modulation has been reported (1997-98) by DAMA (at 99.6% C.L.) and attributed to a WIMP signal

$$M = 59^{+17}_{-14}\, GeV, \quad \sigma^p = 7.0^{+0.4}_{-1.2} \times 10^{-6}\, pb$$

Some detectors are reaching the region of DAMA effect

About 30 experiments are running or in preparation in underground labs around the world
(**COSME, IGEX, HEIDELBERG-MOSCOW, HDMS, ELEGANT-V AND VI, DAMA, SACLAY, UKDMC, ANAIS, TWO-PAHSES Xe, LIQUID Xe, CASPAR, SIMPLE, MICA, DRIFT, CRESST, ROSEBUD, MIBETA, CUORICINO, CDMS, EDELWEISS, ORPHEUS,**...)

Both with conventional and cryogenic techniques

Some are large projects with 100 to 1000 kg mass
(**CUORE, GEDEON, GENIUS, ..**).

They might be able to explore all parameter space

large (order of 1000kg) needed

extremely low background conditions

The progress in the field will be strongly linked to the experimental ingenuity of the scientists

Accelerator vs non accelerator experiments

◆ Accelerator Laboratories have powerful infrastructures with

many scientists
well equipped shops
R&D laboratories
computer divisions
....

◆ Accelerator physics is internationally (in Europe and worldwide) co-ordinated by consolidated international committees and organizations: ECFA, ICFA, C11 IUPAP

◆ Astroparticle physics experiments take place far from cities

in high altitude flats
in caves in the mountains or mines
in the depths of Oceans
under the polar ices
....

◆ **Unfavorable boundary conditions tend to discourage the interest of researchers for particle and nuclear astrophysics**

Must be corrected now.

◆ Experiments in particle and nuclear astrophysics are different

discovery potential is directly linked to experimental ingenuity
novel detectors development
experimental groups are smaller and stimulate individual creativity

◆ Geographical location and nature of some astroparticle experiments might make them more easily affordable to scientists from developing countries (e.g. Southern Mediterranean, South America, etc.)

◆ Some laboratories are interesting for other scientific disciplines

Geophysics
Biology
Astronomy
Oceanography
...

PaNAGIC
Particle And Nuclear Astrophysics and Gravitation International Committee

- The Committee has been created in 1998 by IUPAP to support international exchange of ideas and help convergence of the international scientific community in the large scale activity in the emerging field of particle and nuclear astrophysics, gravitation and cosmology

- **Its purposes are**
  - **Study of the basic constituents of matter and their interactions by non accelerator means**
  - **Study of sources, acceleration mechanism and propagation of high energy particles in the Universe**
  - **Study of nuclear and particle properties of astrophysical interest in the Universe**
  - **Study of gravity, including detection of the sources of gravitational waves**

- The Committee has 15 members, selected primarily on the basis of intellectual leadership and representing the major components of the field. One member is appointed by each C4, C11, C12 and C19.
  Present membership
  - A. Bettini (Chair), B. C. Barish, M. Cerdonio, T. K. Gaisser, I. Grenier, W. Haxton, E. Lorenz, V. Matveev, A.B. McDonald, J. Peoples, M. Rees,B. Sadoulet, M. Spiro, Y, Totsuka, A. Watson

- Sub-panels for some of the subfields, when necessary
  - Gravitational waves
    - GWIC was existing, now subpanel of PaNAGIC too (Chair B. Barish)
  - Deep sea observatories
    - HENAP, just created by PaNAGIC (Chair J. Peoples)

- Sponsor a Conference series (as a general conference of the field)
    - TAUP

Conclusions

- Underground experiments are complementary to accelerator experiments
- The only (strong) experimental evidence of physics beyond the standard theory comes from underground laboratories (mainly Kamioka and Gran Sasso)
- We have good chances to discover and measure new physics
  - Oscillations of neutrinos from the Sun
  - Oscillations of neutrinos from far accelerators and reactors
  - Oscillations of neutrinos from the atmosphere
  - Neutrinos from supernovae
  - Double beta decay (Majorana mass)
  - Neutralinos discovery (SUSY)
- But astroparticle physics requires (world wide) an increasing
  - interest in the scientific communities
  - economical resources
  - personnel