Large Underground Observatory for Proton Decay, Neutrino Astrophysics and CP-violation in the Lepton Sector

A new research infrastructure supporting deep underground cavities able to host a very large multipurpose next-generation neutrino observatory of a total volume in the range of 100,000 to 1,000,000 m³ will provide new and unique scientific opportunities in the field of particle and astroparticle physics, attracting interest from scientists worldwide to study proton decay and neutrinos from many different natural sources, very likely leading to fundamental discoveries.

The Superkamiokande Water Cerenkov Imaging detector with a total volume of 50,000 m³ and the T2K long baseline neutrino oscillation experiment in Japan represent today the state-of-the-art in this field, addressing neutrino astrophysics and studying neutrino properties. Swiss groups are visibly engaged in the T2K experiment since 2006. First physics results are expected in summer 2010.

One of the main reasons for a new observatory beyond Superkamiokande is to find direct evidence for the Unification of all elementary forces, by searching for a rare process called proton decay. The new underground detector will pursue the only possible path to directly test physics at the GUT scale, significantly extending the proton lifetime search sensitivities up to 10^{35} years, a range compatible with several theoretical models.

While searching for proton decays, the continuously sensitive underground observatory will offer the opportunity to concurrently detect several other rare phenomena. In particular, it will sense a large number of neutrinos emitted by exploding galactic and extragalactic type-II supernovae, allowing an accurate study of the mechanisms driving the explosion. The neutrino observatory will also allow precision studies of other astrophysical or terrestrial sources like solar and atmospheric ones, and search for new sources of astrophysical neutrinos, like for example the diffuse neutrino background from relic supernovae or those produced in Dark Matter (WIMP) annihilation in the centre of the Sun or the Earth.

In addition, the recent measurements of neutrino oscillations point forward to the need to couple the new neutrino observatory to advanced neutrino beams for instance from CERN, to study matter-antimatter asymmetry in neutrino oscillations, thereby addressing the outstanding puzzle of the origin of the excess of matter over antimatter created in the very early stages of evolution of the Universe.

Europe currently has four world-class national deep underground laboratories with high-level technical expertise, located in Boulby (UK), Canfranc (Spain), Gran Sasso (Italy), and Modane (France), hosting

The proton can spontaneously disintegrate into lighter elementary constituents if the strong, weak and electromagnetic forces become unified at a very high-energy scale (10^{16} GeV or beyond, at a much higher energy scale than what can be directly probed by the LHC), as predicted by Grand Unified Theories (GUT).

Superkamiokande did not so far find proton decay, implying that the proton has a lifetime greater than 10^{33} years. Precision measurements performed at the CERN LEP collider in the 1990's do support GUT and further information could come from the LHC.
LAGUNA Design Study

Large Apparatus for Grand Unification and Neutrino Astrophysics

- Objective: defining and realizing this research programme in Europe
- Participation (open): very interdisciplinary - most European physicists interested in massive detectors; geo-technical experts, geo-physicists; structural engineers; tank and mining engineers
- EC contribution: 1.7 M€ to be mainly devoted to the sites infrastructure studies (FP7 “Design Studies” Research Infrastructures LAGUNA Grant Agreement No. 212343)

21 beneficiaries in 9 countries: 9 higher education entities, 8 research organizations, 4 private companies (+4 additional universities)

Discuss and assess:
- rock engineering → feasibility
- needed infrastructure
- cost of excavation
- assembly of underground tank
- physics programme

Detector R&D to be funded at national level

WP2: Underground infrastructures and Engineering
WP3: Safety, environmental and socio-economic issues
WP4: Science Impact and Outreach

Saturday, October 10, 2009
Science of LAGUNA

Particle Physics and Particle Astrophysics

Supernova neutrinos | Solar neutrinos | Proton decay | Atmospheric neutrinos | Reactor neutrinos | Dark matter

Long baseline neutrinos with accelerators

Superbeams | Betabeams | Neutrino factory
LAGUNA detector options

- A new far detector at a new far site
  - three options considered (MEMPHYS, LENA, GLACIER) with total mass in the range 50-500 kton

- Water Cerenkov [MEMPHYS]
- Liquid scintillator [LENA]
- Liquid Argon TPC [GLACIER]

• A new far detector at a new far site
  - three options considered (MEMPHYS, LENA, GLACIER) with total mass in the range 50-500 kton

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- Liquid scintillator [LENA]
- Liquid Argon TPC [GLACIER]
LAGUNA detector options

- **A new far detector at a new far site**
  - three options considered (MEMPHYS, LENA, GLACIER) with total mass in the range 50-500 kton

- Large scale detectors R&D in Europe
  - MEMPHYS Water Cerenkov: see M. Marafini’s talk
  - GLACIER liquid Argon: see A. Marchionni’s talk
  - LENA liquid scintillator: see T. Lachenmaier’s talk

- Water Cerenkov

- Liquid Argon
  - TPC

- Liquid scintillator
7 potential sites

1. Boulby
2. Canfranc
3. Fréjus
4. Pyhäsalmi
5. Sieroszowice
6. Slanic
7. Umbria
7 potential sites

1. Boulby, UK
2. Canfranc, Spain
3. Fréjus, France
4. Pyhäsalmi, Finland
5. Sieroszowice, Poland
6. Slanic, Romania
7. Caso, Italy

Basic characteristics of the European sites:

From existing road tunnels: Canfranc, Fréjus
From existing deep mines: Boulby, Pyhäsalmi, Sieroszowice
Existing large shallow cavern: Slanic
Greenfield tunnel site: Umbria

Present situation at Fréjus, Boulby and Canfranc:

see F. Piquemal’s talk
Various depths
Requirement depends on detector technology

At surface intensity ≈ $3 \times 10^9 \, \mu m^2/\text{y}$

Muon flux vs overburden

Various depths

At surface intensity ≈ $3 \times 10^9 \, \mu m^2/\text{y}$
Various depths

Requirement depends on detector technology

At surface intensity
≈ 3x10⁹ μ/m²/y

Muon flux vs overburden

Depth, meters water equivalent

Muon Intensity, m²·y⁻¹

GLACIER

MEMPHYS

LENA

WIPP

Soudan

Kamioka

Canfranc

Sieroszowice

Boulby

Pyhäsalmi

Fréjus

Baksan

Mont Blanc

Sudbury

Slanic

Umbria

Removal of background

Requirement depends on detector technology

Saturday, October 10, 2009
Big range of baselines possible

<table>
<thead>
<tr>
<th>Distance (km)</th>
<th>1st oscillation (GeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>130</td>
<td>0.26</td>
</tr>
<tr>
<td>630</td>
<td>1.27</td>
</tr>
<tr>
<td>665</td>
<td>1.34</td>
</tr>
<tr>
<td>950</td>
<td>1.92</td>
</tr>
<tr>
<td>1050</td>
<td>2.12</td>
</tr>
<tr>
<td>1570</td>
<td>3.18</td>
</tr>
<tr>
<td>2300</td>
<td>4.65</td>
</tr>
</tbody>
</table>

Canfranc 2

L=630 km

Fréjus 3

L=130 km

Sieroszowice 5

L=950 km

Umbria 7

L=665 km

Boulby 1

L=1050 km

Pyhäsalmi 4

L=2300 km

Slanic 6

L=1570 km

Umbria

Distance/km

Big range of baselines possible

Monday, October 12, 2009
Opportunities of long baselines

The determination of the CP violation effect is plagued by the mass hierarchy degeneracy:

- NH, 0<\(\delta<180^\circ\) degenerate with IH, 180<\(\delta<360^\circ\) at shorter baselines.
- Degeneracy is lifted by matter effects (L > 900km, improves with L).
- At a given energy (E \(\approx\) 3GeV for 2300km and IH) probability is independent of CP phase \(\delta\) - clean mass hierarchy determination.
Synergies with worldwide programs

Future at JPARC

Three Possible Scenario Studied at NP08 Workshop

NP08 is The 4th International Workshop on Nuclear and Particle Physics at J-PARC
http://j-parc.jp/NP08

Korea
Okinoshima
Kamioka

1000km
1deg. Off-axis

658km
2.5deg. Off-axis

295km
0.8deg almost on-axis

Basic ingredients considered:
- very high intensity beams (> 1 MW)
- a new very large far underground neutrino detector based on Water Cerenkov or Liquid Argon technology ("megaton-scale")

FNAL-DUSEL (USA)

Soudan, Ash River

1300km

DUSEL
at Homestake, SD

Fermilab vision: The Intensity Frontier with Project X:
Great site for high power facility while simultaneously advancing energy frontier accelerators technology

Massive Detectors (Liquid Argon, Water Cerenkov, Scintillator, etc) that are scalable in the Multi Kt scale
Typical questions addressed

- assessment of strengths and weaknesses
- rock mechanics of caverns
- design of tanks in relation to sites
- overburden vs. detector options
- transport, access, delivery of liquids
- safety e.g. tunnel vs. mine
- environment e.g. rock removal
- relative costs

Site visits and meeting

- sites work together on common areas
16 deliverables (2008-2010)

Interim safety, socio-economic, environmental report:

- 207 pages, delivered on schedule
- report on the Health and Safety issues for each of the seven LAGUNA sites
- list of local authorities and responsible entities and establish contact with them
- address basic environmental issues
- address impact on local area
- identify potential show-stoppers

Interim geotechnical reports:           Final report:
                                          Nov 2009
                                          July 2010
Several different options are being systematically assessed and compared. In the following I will try to illustrate a few examples.
(1) Tank concepts
Engineering of large tanks becoming well understood

Designs by Technodyne Ltd

<table>
<thead>
<tr>
<th>Item</th>
<th>MEMPHYS</th>
<th>Lena</th>
<th>Glacier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Single Containment</td>
<td>Single Containment</td>
<td>Single or Double Containment</td>
</tr>
<tr>
<td>Inner Membrane</td>
<td>Plastic</td>
<td>Nylon</td>
<td></td>
</tr>
<tr>
<td>Liquid Holding Tank</td>
<td>Stainless Steel</td>
<td>Stainless Steel</td>
<td>Stainless Steel</td>
</tr>
<tr>
<td>Cavern Liner</td>
<td>Stainless Steel</td>
<td>Stainless Steel</td>
<td>9% Nickle Steel or Carbon Steel</td>
</tr>
</tbody>
</table>

LENA

GLACIER
(2) Main cavern engineering

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

GLACIER@Sierozsowice

Dimensions of tank
- Tank: cylinder 65m Ø x 65m height
- SS cylinder of 30m Ø x 105 m height, inside a external tank of ~ cylindrical shape, of at least 34m Ø for water-buffer.

GLACIER@Umbria

Dimensions of Cavern
- 65m Ø x 70m height + dome
- Egg-shaped to house external tank
- Cylinder: 72.4m Ø x 26.5m height dome: 12.7m height x 144.8m Ø

MEMPHYS@Fréjus

Concrete voute
Concrete structural galleries
Structural and drainage galleries
(3) Geomechanical studies

Rock data gathered for all sites
Numerical modeling based on these parameters:
- Convergence
- Spalling
- Rock-bolting
- Mucking
- Multi-strata rock issues
- Cavern shapes

Pyhäsmali

Rock spalling vs depth

- GLACIER
  - 300 m (850mwe)
  - 0.6 m
- 600 m (1700mwe)
  - 0.3 m
- 900 m (2550mwe)
  - 0.8 m
  - 1.2 m
- 1200 m (3400mwe)
  - 1.4 m
- 1400 m (3950mwe)
  - 3 m
- 1700 m (4800mwe)
  - 2.2 m
- LENA@400m
  - 2.5000e+000 to -1.2477e+000
  - -5.0000e+000 to -2.5000e+000
  - -7.5000e+000 to -5.0000e+000
  - -1.0000e+001 to -7.5000e+000
  - -1.7500e+001 to -1.5000e+001
  - -2.5000e+001 to -2.2500e+001
  - -2.7500e+001 to -2.5000e+001
  - -3.0000e+001 to -2.7500e+001
  - -3.4402e+001 to -3.2500e+001

Boulby
- Middle Halite
- Middle Anhydrite
- Lower Halite
- “A”
- “B”

Pyhäsalmi

Gradient Calculation
- Magfac = 1.000e+000
- Contour of SYY
  - Dist: 1.525e+003
  - Y: 1.013e+002
  - X: 3.080e+001
  - Center:

Magfac = 1.000e+000
- Contour of SXX
- Contour of SZZ

Sieroszowice

Workshop on Next generation Nucleon decay and Neutrino detectors (NNN09)
A. Rubbia

Workshop on Next generation Nucleon decay and Neutrino detectors (NNN09)

Saturday, October 10, 2009

Layout: Pyhäsalmi mine

- Region of Pyhäjärvi, Finland
- Mine owned by Inmet Mining based in Toronto, Canada
- One of the deepest sites (4000mwe)
- Farthest from CERN (2300km) - large matter effects in neutrino oscillations

- Letter of Intent set up with mine owners, LAGUNA accepted
- Main rock mechanical calculations done
- Lay out design in progress
- Rock excavation related aspects of ventilation in progress
- Safety, environmental: first risk analysis done, main focus safety during excavation (collapse, fire, environment)
- Project introduced to local and national political bodies. Socioeconomic impact analysis in progress.
Pyhäsalmi

- GLACIER +900 m level
- MEMPHYS +1100 m level
- LENA +1430 m level
Layout: **Sieroszowice mine**

- Located Near Wrocław, south-west of Poland
- Mine owned by KGHM Cuprum
- Strong support from mine company
- Main rock mechanical calculations done
- Anhydrite / Dolomite P-VII shaft (658 m depth) position selected
- Safety, environmental: first risk analysis done, no ventilation issues, shaft has large capacity
- Project introduced to local and national political bodies.
- Socioeconomic impact analysis in progress (LAGUNA selected as one of the 4 Polish national priorities in fundamental science)
- Distance from CERN = 950 km

### Table: Cavern stability calculations

<table>
<thead>
<tr>
<th>Surrounding rocks</th>
<th>Tectonic stress</th>
<th>Cavern vertical convergence after 40 years (m)</th>
<th>Cavern horizontal convergence after 40 years (m)</th>
<th>Cavern stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salt rock Depth: 983.5 m (borehole S-383)</td>
<td>No</td>
<td>-3.23</td>
<td>-1.25</td>
<td>Bed separation within floor strata</td>
</tr>
<tr>
<td>Anhydrite Depth: 1112,5 m (borehole S-384)</td>
<td>Yes</td>
<td>-3.23</td>
<td>-1.14</td>
<td>as above</td>
</tr>
<tr>
<td>Anhydrite Depth: 617.5 m (P-VII Shaft)</td>
<td>No</td>
<td>0.0025</td>
<td>0.024</td>
<td>Slight spalling of wall surface</td>
</tr>
<tr>
<td>Anhydrite/Dolomite Depth: 658 m (P-VII Shaft)</td>
<td>Yes</td>
<td>0.001</td>
<td></td>
<td>as above</td>
</tr>
<tr>
<td>Anhydrite/Dolomite Depth: 1369 m (borehole S-460)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Figures:

- **Sieroszowice mine (part of the KGHM holding)**
- **GLACIER LOCATION CONCEPT**

---

*Saturday, October 10, 2009*
Layout: Boulby mine

- NE Coast, UK, 1050 km CERN
- Layouts studied for 3 detector options in dolomite hard rock (1050m). 1500m from 2010
- 20 year history of science labs and strong cooperation with mine company CPL
- Prospect of undersea position (reactor neutrino physics with nuclear ship under study)
- Safety, environment, socio-economic well understood
Layout: **Slanic salt mine**

- An existing, shallow site (600 mwe) with low natural radioactivity in Romania
- Temperature ≈ 13°C, humidity 65-70%
- Excavated volume 2.9 million m³ (!)
- Floor area 70000 m²
- Height of excavated rooms 52-57 m
- CERN distance = 1570 km
- Local community supportive
- Possibility to reuse existing caverns
Layout: **Road tunnels**

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

### Canfranc
- 630 km from CERN
- Likely requires new tunnel + shaft (current depth 800m)
Shallow site for GLACIER
1 deg off-axis w.r.t CNGS
Overburden \(\approx 1500\) mwe
Horizontal tunnel access
Distance CERN \(\approx 665\) km
Study performed by AGT Ingegneria
Contact with regional authorities:
  - Regione Umbria \(\rightarrow\) at the moment unofficial support
  - A.R.P.A. Umbria (Regional Environment Agency) \(\rightarrow\) Environment & Hazard issues
  - Fire Service (Provincial Headquarters) \(\rightarrow\) Safety & Hazard issues
No significant show-stoppers have been identified.
Several options at different CNGS OA
(4) Sequence of excavation

Details of construction sequence also studied at various sites
- Rock disposal
- Geotechnical stability and safety at each stage of excavation
- Requirements for rock removal and rock bolting
- Egress routes and evacuation safety

Example: GLACIER@Sieroszowice
LENA@Pyhäsalmi
(5) Additional infrastructure

Details of ancillary laboratories, storage caverns and egress

- Design of liquid transit, storage and emergency dump
- Ancillary caverns for construction phase
- Clean rooms, electronics and mechanical workshops
- Emergency safe havens, double egress routes
Important aspect in the eyes of the EU and the funding agencies

- Socio-economic
- HAZCON (with Technodyne)
- Safety, risk analysis
- Environment...

(6) Socio-Economic, Safety, Environment
(7) LAGUNA sites & CERN

- Two parallel strategies:
  - Intensity upgraded CNGS beamline
  - New neutrino beam line (in principle to any of the LAGUNA sites)

- At this stage both strategies can be considered

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Envisaged Depth (m.w.e)</th>
<th>Distance from CERN (km)</th>
<th>Energy 1st osc. max (GeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fréjus (F)</td>
<td>Road tunnel</td>
<td>≈ 4800</td>
<td>130</td>
<td>0.26</td>
</tr>
<tr>
<td>Canfranc (ES)</td>
<td>Road tunnel</td>
<td>≈ 2100</td>
<td>630</td>
<td>1.27</td>
</tr>
<tr>
<td>Umbria (IT)</td>
<td>Green field</td>
<td>≈ 1500</td>
<td>665 (≈ 1.0°OA)</td>
<td>1.34</td>
</tr>
<tr>
<td>Sieroszowice (PL)</td>
<td>Mine</td>
<td>≈ 2400</td>
<td>950</td>
<td>1.92</td>
</tr>
<tr>
<td>Boulby (UK)</td>
<td>Mine</td>
<td>≈ 2800</td>
<td>1050</td>
<td>2.12</td>
</tr>
<tr>
<td>Slanic (RO)</td>
<td>Salt mine</td>
<td>≈ 600</td>
<td>1570</td>
<td>3.18</td>
</tr>
<tr>
<td>Pyhasalmi (FI)</td>
<td>Mine</td>
<td>≈ 4000</td>
<td>2300</td>
<td>4.65</td>
</tr>
</tbody>
</table>

New LHC injection chain (SLHC)

- The LHC injector complex has to be renewed to deliver protons with upgraded characteristics and higher intensity (FT $1.2 \times 10^{14}$ ppp)

  - More protons in SPS(FT) $\Rightarrow$ CNGS
  - New FT based on 50 GeV PS2 machine

### Table 2: PS2 characteristics (with respect to the PS).

<table>
<thead>
<tr>
<th></th>
<th>PS2</th>
<th>PS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injection energy (kinetic) [GeV]</td>
<td>4</td>
<td>1.4</td>
</tr>
<tr>
<td>Maximum energy (kinetic) [GeV]</td>
<td>50</td>
<td>25</td>
</tr>
<tr>
<td>Cycle time [s]</td>
<td>2.4</td>
<td>2.4</td>
</tr>
<tr>
<td>Nb max for LHC (25ns spacing)</td>
<td>$4 \times 10^{11}$</td>
<td>$1.7 \times 10^{11}$</td>
</tr>
<tr>
<td>Nb max for fixed target physics</td>
<td>$1.2 \times 10^{14}$</td>
<td>$3.3 \times 10^{13}$</td>
</tr>
<tr>
<td>Maximum energy per pulse [kJ]</td>
<td>1000</td>
<td>70</td>
</tr>
<tr>
<td>Maximum beam power [kW]</td>
<td>400</td>
<td>60</td>
</tr>
<tr>
<td>Circumference [m]</td>
<td>1346</td>
<td>628</td>
</tr>
</tbody>
</table>

*CERN NEUTRINOS TO GRAN SASSO*
Underground structures at CERN

Figure 6: Present and proposed future accelerators:
- Linac4: 160 MeV H- linac
- (LP)SPL: (Low Power) Superconducting Proton (H-) Linac (~5 GeV)
- PS2: new proton synchrotron (~50 GeV)
- SPS+: superconducting SPS (~1 TeV)
- SLHC: LHC with luminosity upgrade
- DLHC: double energy LHC.

Figure 7: Layout of the new injector complex.

Table 3: LPSPL and SPL characteristics.

<table>
<thead>
<tr>
<th></th>
<th>LPSPL</th>
<th>SPL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circumference [m]</td>
<td>1346</td>
<td>628</td>
</tr>
<tr>
<td>Maximum energy per pulse [kJ]</td>
<td>1000</td>
<td>70</td>
</tr>
<tr>
<td>Nb max for LHC (25ns spacing)</td>
<td>$4 \times 10^{11}$</td>
<td>$1.7 \times 10^{11}$</td>
</tr>
<tr>
<td>Nb max for fixed target physics</td>
<td>$1.2 \times 10^{14}$</td>
<td>$3.3 \times 10^{13}$</td>
</tr>
<tr>
<td>Average current during pulse [mA]</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>Beam pulse duration [ms]</td>
<td>1.2</td>
<td>0.4</td>
</tr>
<tr>
<td>Cycle time [ms]</td>
<td>500</td>
<td>20</td>
</tr>
<tr>
<td>Output energy [kJ]</td>
<td>1000</td>
<td>4</td>
</tr>
</tbody>
</table>

A. Rubbia
Workshop on Next generation Nucleon decay and Neutrino detectors (NNN09)
Proton intensities @ SPS / PS2

Baseline CNGS (shared): $4.5 \times 10^{19}$ pot
2008 CNGS run: Total $1.78 \times 10^{19}$ pot (typ. $2 \times 10^{13}$ ppp)
2009 CNGS run: $2.5 \times 10^{19}$ pot till Oct 09

Baseline PS2(FT): $1.2 \times 10^{13}$ ppp, 2.4 s cycle (400kW)
Upgraded SPL+PS2++: $2.5 \times 10^{13}$ ppp, 1.2 s cycle (1.6MW)
The physics potential of an intensity upgraded CNGS beam coupled to a new off-axis detector has been first addressed in JHEP 0611:032, 2006.

- **Distance from CERN**
  - 500 km
  - 600 km

- **Off-axis angles**
  - 20 or 100 kton LAr
  - 5 yrs ν
  - $2.4 \times 10^{20}$ pots/yr

---

**POT/year [$10^{19}$] for 200 days of operation with 80% machine efficiency**

<table>
<thead>
<tr>
<th>SPS cycle length</th>
<th>Injection Energy</th>
<th>Max SPS intensity @ 400GeV [$10^{19}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 s</td>
<td>14 GeV</td>
<td>0.45</td>
</tr>
<tr>
<td>4.8 s</td>
<td>26 GeV</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.85</td>
</tr>
</tbody>
</table>

- **Present injectors + machines’ improvement**
  - 4.8
  - 5
  - 9.4

- **Future injectors (>2016) + SPS RF upgrade**
  - 7
  - 5.9
  - 11.1

- **Future injectors + new SPS RF system + CNGS new equipment design**
  - 10
  - 12.9
  - 24.5

---

**Umbria + upgraded CNGS**

- **90% C.L.**
- **3σ C.L.**

- **ν run only 20 kton**
- **ν run only 100 kton**
New beamline from PS2++

100 kton LAr
5 yrs $\nu$
$3 \times 10^{21}$ pots/yr @ 50 GeV

(sensitivities computed with preliminary horn designs & GLOBES)

100 kton LAr
5 yrs $\nu$ + 5 yrs $\bar{\nu}$
$3 \times 10^{21}$ pots/yr @ 50 GeV

$\theta_{13}$ Sensitivity - CNXX NOvA Horns - 50 GeV protons

$\theta_{13}$ sensitivity

Mass Hierarchy Exclusion - CNXX NOvA Horns-50 GeV protons

$\delta_{CP}$ sensitivity

Mass hierarchy

Figure 1: Discovery potential for $\theta_{13}$, for CNXX uNOvA Horns beam for different LAGUNA locations, $3 \times 10^{21}$ pots/yr and 5 years of neutrino run.

2
100 kton LAr
5 yrs $\nu$
$3 \times 10^{21}$ pots/yr @ 50 GeV

Figure 3: Discovery potential for CP-violation for CNXX uNOvA Horns beam for different LAGUNA locations.

Figure 4: Discovery potential for Mass Hierarchy for CNXX sNOvA Horns 50 GeV proton beam for different LAGUNA locations.

OA0.25 (Pyhäsalmi - 2300 km)
OA0.25 (Slanic - 1544 km)
OA0.5 (Sieroszowice - 950 km)

OA0.25 (Pyhäsalmi - 2300 km)
OA0.25 (Slanic - 1544 km)
OA0.5 (Sieroszowice - 950 km)

OA0.25 (Pyhäsalmi - 2300 km)
OA0.5 (Sieroszowice - 950 km)
OA0.25 (Slanic - 1544 km)
LAGUNA - Schedule

Paper Design Study (EU funded): 2008-2010
Prioritize the sites and down-select: July 2010

Phase 1 construction (intermediate step): 2012-2016
Phase 2 construction: >2016

Timeline matched to new potential CERN neutrino (super)beams in >2018
Conclusions

Growing interest and activities on large neutrino and proton decay detectors, both new sites and detector technologies

In Europe LAGUNA has a well defined timeline
- no obvious geo-technical show-stoppers so far - but several challenges (e.g. underground construction, liquid procurement, financing...)
- prioritize sites in 2010

Big range of CERN baselines are feasible (130 km - 2300 km)
- timeline matched to potential superbeam in >2018
- could be operated in connection with more advanced beams like beta-beams or neutrino factories

It is clear that Europe has great relevant infrastructure and expertise to build LAGUNA, we can benefit from this
- LAGUNA mainly towards a European research infrastructure but should also be strongly linked to projects world-wide that consider same physics goals

"recommend that a new large European infrastructure is put forward as a future international multi-purpose facility on the 100-1000 ktons scale for improved studies of proton decay..."
Acknowledgements

- FP7 Research Infrastructure “Design Studies” LAGUNA (Grant Agreement No. 212343 FP7-INFRA-2007-1)
BACKUP SLIDES
**CONVENTIONAL ν BEAMS: SPS with new injectors (2/4)**

An upgraded CNGS will require a re-classification and/or partial reconstruction of the neutrino beam-line infrastructure.

## Intensity limitation from the design values of the CNGS facility

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Protons per extraction</th>
<th>Protons per cycle</th>
<th>POT per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiation Protection calculation and optimisation</td>
<td></td>
<td></td>
<td>Soil/concrete activation: (4.5 \times 10^9)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Residual dose for intervention: (1.38 \times 10^{20})</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Air/water activation: (7.6 \times 10^9)</td>
</tr>
<tr>
<td>Target</td>
<td>(3.5 \times 10^{13})</td>
<td>(1.4 \times 10^{14})</td>
<td>(2 \times 10^{20}) from radiation damage</td>
</tr>
<tr>
<td></td>
<td>from dynamic stresses</td>
<td>from target cooling</td>
<td></td>
</tr>
<tr>
<td></td>
<td>and assuming increased time</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>between 2 extractions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horns</td>
<td>(3.5 \times 10^{13})</td>
<td>(7 \times 10^{13})</td>
<td>(1.38 \times 10^{20}) from air cooling system</td>
</tr>
<tr>
<td></td>
<td>from powering system:</td>
<td>from water cooling system</td>
<td></td>
</tr>
<tr>
<td></td>
<td>maximum of 2 extractions</td>
<td></td>
<td>and mechanical fatigue lifetime (2 E7 pulses)</td>
</tr>
<tr>
<td>Shielding, Decay Tube, Hadron stop design</td>
<td></td>
<td></td>
<td>(1.38 \times 10^{20}) from air/water cooling systems</td>
</tr>
<tr>
<td>Kicker system</td>
<td>(3.5 \times 10^{13})</td>
<td>(1 \times 10^{14})</td>
<td></td>
</tr>
<tr>
<td></td>
<td>from ferrite heating,</td>
<td>marginal, pending</td>
<td></td>
</tr>
<tr>
<td></td>
<td>with MKE equipped with shielding stripes (TBC)</td>
<td>2007 SPS beam</td>
<td></td>
</tr>
<tr>
<td></td>
<td>from powering system:</td>
<td>measurements</td>
<td></td>
</tr>
<tr>
<td></td>
<td>maximum of 2 extractions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Instrumentation</td>
<td>(3.5 \times 10^{13})</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>from dynamic range –</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Electronics system</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Detailed MDC concept

Example: GLACIER

roof and side wall protection
by organic–mineral, elastic
membrane spraying

mesh fasten

stainless steel
wire mesh

cavern access
from "-1" level

cavern access
from "-2" level

detail A

detail A

bed in concrete

polyester–glass bolt
fixed by resin charge
l=10–15 m

polyester–glass bolt
fixed by resin charge
l=–1.6 m

Witold Pytel

Step 55465 Model Projection
08:43:05 Tue Mar 10 2009
Center:
X: 3.080e+001
Y: 1.013e+002
Z: 4.000e+000

Rotation:
X:   0.000
Y:   0.000
Z:   0.000

Dist: 1.525e+003
Size: 6.515e+001

Job Title: GLACIER 100kt - LARGE ANHYDRITE CAVERN
View Title:
Contour of SXX
Magfac =  1.000e+000
Gradient Calculation
-3.4422e+001 to -3.2500e+001
-3.2500e+001 to -3.0000e+001
-3.0000e+001 to -2.7500e+001
-2.7500e+001 to -2.5000e+001
-2.5000e+001 to -2.2500e+001
-2.2500e+001 to -2.0000e+001
-2.0000e+001 to -1.7500e+001
-1.7500e+001 to -1.5000e+001
-1.5000e+001 to -1.2500e+001
-1.2500e+001 to -1.0000e+001
-1.0000e+001 to -7.5000e+000
-7.5000e+000 to -5.0000e+000
-5.0000e+000 to -2.5000e+000
-2.5000e+000 to -1.2699e+000

Interval =  2.5e+000

Witold Pytel

Step 55465 Model Projection
08:44:04 Tue Mar 10 2009
Center:
X: 3.080e+001
Y: 1.013e+002
Z: 4.000e+000

Rotation:
X:   0.000
Y:   0.000
Z:   0.000

Dist: 1.525e+003
Size: 6.515e+001

Job Title: GLACIER 100kt - LARGE ANHYDRITE CAVERN
View Title:
Contour of SYY
Magfac =  1.000e+000
Gradient Calculation
-3.4402e+001 to -3.2500e+001
-3.2500e+001 to -3.0000e+001
-3.0000e+001 to -2.7500e+001
-2.7500e+001 to -2.5000e+001
-2.5000e+001 to -2.2500e+001
-2.2500e+001 to -2.0000e+001
-2.0000e+001 to -1.7500e+001
-1.7500e+001 to -1.5000e+001
-1.5000e+001 to -1.2500e+001
-1.2500e+001 to -1.0000e+001
-1.0000e+001 to -7.5000e+000
-7.5000e+000 to -5.0000e+000
-5.0000e+000 to -2.5000e+000
-2.5000e+000 to -1.2477e+000

Interval =  2.5e+000

Witold Pytel

Step 55465 Model Projection
08:42:11 Tue Mar 10 2009
Center:
X: 3.080e+001
Y: 1.013e+002
Z: 4.000e+000

Rotation:
X:   0.000
Y:   0.000
Z:   0.000

Dist: 1.525e+003
Size: 6.515e+001

Job Title: GLACIER 100kt - LARGE ANHYDRITE CAVERN
View Title:
Contour of SZZ
Magfac =  1.000e+000
Gradient Calculation
-5.3244e+001 to -5.0000e+001
-5.0000e+001 to -4.5000e+001
-4.5000e+001 to -4.0000e+001
-4.0000e+001 to -3.5000e+001
-3.5000e+001 to -3.0000e+001
-3.0000e+001 to -2.5000e+001
-2.5000e+001 to -2.0000e+001
-2.0000e+001 to -1.5000e+001
-1.5000e+001 to -1.0000e+001
-1.0000e+001 to -5.0000e+000
-5.0000e+000 to  0.0000e+000
0.0000e+000 to  2.2271e-001

Interval =  5.0e+000
Considering a new neutrino line

- We can consider two options:
  - 400 GeV protons from SpS with PS2 as new injector
  - 50 GeV protons from an intensity upgraded PS2 (PS2++)
- Neutrino flux scaling: \( \text{(pot @ 50 GeV)} \approx 8 \times \text{(pot @ 400 GeV)} \)

**New \( \nu \) line must be designed to sustain several MW beam power**
GLACIER: Giant Liquid Ar Charge Imaging ExpeRiment


- Single module cryo-tank based on industrial LNG technology
- Cylindrical shape with excellent surface / volume ratio
- Simple, scalable detector design, possibly up to 100 kton
- Single very long vertical drift with full active mass
- A very large area LAr LEM-TPC for long drift paths
- Possibly immersed visible light readout for Cerenkov imaging
- Possibly immersed (high Tc) superconducting solenoid to obtain magnetized detector
- Reasonable excavation requirements (<250'000 m$^3$)

- R&D phase (ETHZ-KEK Collaboration)
- Interest expressed from European groups from France, Poland and United Kingdom

LAr LEM TPC setup @ CERN

Passive perlite insulation

up to $\Phi \approx 70$ m

Max drift length

up to $h = 20$ m

Saturday, October 10, 2009
LAr TPC as high E neutrino detector

- provides high efficiency for $\nu_e$ charged current interactions
- high rejection against $\nu_\mu$ NC and CC backgrounds also in MultiGeV region
  - $e/\pi^0$ separation
    - fine longitudinal segmentation (few % $X_0$) – to be optimized!
    - fine transverse segmentation, finer than the typical spatial separation of the 2 $\gamma$’s from $\pi^0$ decay
  - $e, \mu/\pi, K, p$ separation
- embedded in a magnetic field provides the possibility to measure both wrong sign muons and wrong sign electrons samples in a neutrino factory beam
- unlike WC detectors, detection and reconstruction efficiency does *not* depend on volume of detector → direct near / far detector comparison (apart from flux extrapolation)

$\nu_\mu n \rightarrow \mu^- \Delta^+ \rightarrow \mu^- p \pi^0$

$\nu_e$ CC MC

F. Sergiampietri, “On the possibility to extrapolate liquid argon technology to a super massive detector for a future neutrino factory”, NUFACT01, Tsukuba, 2001
L. Bartoszek et al., “FLARE, Fermilab liquid argon experiments (LOI)”, hep-ex/0408121, Aug. 2004
D. Finley et al. “A large liquid argon time projection chamber for long baseline, off-axis neutrino oscillation physics with the NuMI beam”, FERMILAB-FN-0776-E, Sept. 2005
A. Meregaglia, A. Rubbia, “Neutrino oscillation physics at an upgraded CNGS with large next generation liquid argon TPC detectors”, JHEP 0611:032, 2006
A. Meregaglia, A. Rubbia, “Neutrino Oscillations With A Next Generation LAr TPC Detector in Kamioka or Korea Along The J-PARC Neutrino Beam “, arXiv:0801.4035
A. Badertscher et al., “A Possible Future Long Baseline Neutrino and Nucleon Decay Experiment with a 100 kton Liquid Argon TPC at Okinoshima using the J-PARC Neutrino Facility “, arXiv:0804.2111
(1) Grand Unification - proton decay

• 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

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

(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

(3) Long baseline neutrino oscillations

$\theta_{13}, \delta, \text{sgn}(\Delta M^2)$

$\nu_\mu \rightarrow \nu_e$
High intensity low energy conventional neutrino sources

$\nu_e \rightarrow \nu_\mu$
New neutrino production technology

“superbeams”? MW power >2016


Workshop on Next generation Nucleon decay and Neutrino detectors (NNN09)

Saturday, October 10, 2009
### Proton “economics”? or crisis...

<table>
<thead>
<tr>
<th></th>
<th>J-PARC</th>
<th>CERN SpS</th>
<th>CERN PS2</th>
</tr>
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<tbody>
<tr>
<td>design</td>
<td>[2]</td>
<td>+[61]</td>
<td>[73]</td>
</tr>
<tr>
<td>upgrade</td>
<td>[72]</td>
<td>1[73]</td>
<td></td>
</tr>
<tr>
<td>ultimate</td>
<td>[2]</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Proton energy $E_p$</td>
<td>30 GeV/c</td>
<td>400 GeV/c</td>
<td>50 GeV/c</td>
</tr>
<tr>
<td>$ppp$($\times 10^{13}$)</td>
<td>33</td>
<td>4.8</td>
<td>12.5</td>
</tr>
<tr>
<td>$T_c$ (s)</td>
<td>3.64</td>
<td>6</td>
<td>2.4</td>
</tr>
<tr>
<td>Efficiency</td>
<td>1.0</td>
<td>0.55</td>
<td>1.0</td>
</tr>
<tr>
<td>Running (d/y)</td>
<td>130</td>
<td>220</td>
<td>200</td>
</tr>
<tr>
<td>$N_{pot}$/yr ($\times 10^{19}$)</td>
<td>100</td>
<td>7.6</td>
<td>90</td>
</tr>
<tr>
<td>Beam power (MW)</td>
<td>0.6</td>
<td>0.5</td>
<td>0.4</td>
</tr>
<tr>
<td>$E_p \times N_{pot}$ ($\times 10^{22}$ GeV·pot/yr)</td>
<td>4</td>
<td>3</td>
<td>4.5</td>
</tr>
<tr>
<td>Relative increase</td>
<td>$\times 3$</td>
<td>$\times 2$</td>
<td>–</td>
</tr>
<tr>
<td>Timescale</td>
<td>$\approx$ 2014</td>
<td>&gt;2008</td>
<td>&gt;2018</td>
</tr>
</tbody>
</table>

#### KEK roadmap

- Increase SPS integrated intensity to CNGS by a factor $x3-x10$ compared to baseline $4.5x10^{19}$ pots/yr?
- and/or increase baseline PS2 parameters by a factor $x4$ to satisfy potential next generation $\nu$ experiments?
Neutrinos from $\beta$ beams: case study

- Acceleration of $^6$He (antineutrinos) and $^{18}$Ne (neutrinos) nuclei
- Design of the complex in the context of EURISOL DS (FP6)
- Large investments required at CERN (source + storage ring)
- Counting experiment?

Combine superbeam and $\beta$-beam for redundant test of CPT, and CPT

![Diagram showing the components of a neutrino experiment](image)
Neutrinos from $\beta$ beams: case study

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- Design of the complex in the context of EURISOL DS (FP6)
- Large investments required at CERN (source + storage ring)
- Counting experiment?

Combine superbeam and $\beta$-beam for redundant test of CPT, and CPT

<table>
<thead>
<tr>
<th>Low-energy part</th>
<th>High-energy part</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ion production</td>
<td>Neutrino source</td>
</tr>
<tr>
<td>Proton Driver</td>
<td>Acceleration to final energy</td>
</tr>
<tr>
<td>SPL</td>
<td>PS &amp; SPS</td>
</tr>
<tr>
<td>ISOL target &amp;</td>
<td>Acceleration</td>
</tr>
<tr>
<td>Ion source</td>
<td>to final energy</td>
</tr>
<tr>
<td>Beam preparation</td>
<td>SPS</td>
</tr>
<tr>
<td>ECR pulsed</td>
<td>Neutrino source</td>
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<tr>
<td>Ion acceleration</td>
<td>Decay Ring</td>
</tr>
<tr>
<td>Linac</td>
<td></td>
</tr>
<tr>
<td>Acceleration to</td>
<td></td>
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<tr>
<td>medium energy</td>
<td></td>
</tr>
<tr>
<td>RCS</td>
<td>Beam to experiment</td>
</tr>
</tbody>
</table>

Sensitivity to CP violation at 3$\sigma$

$\Delta\chi^2 (\delta_{CP} = 0, \pi) = 9$

±1$\sigma$ region from Fogli et al.

$\sigma_{syst} = 2\% - 5\%$

Friday, October 10, 2009