LAGUNA Project

W. H. Trzaska

Department of Physics, University of Jyväskylä, Finland

on behalf of LAGUNA collaboration

Erice, 16 – 24 September 2010
Roadmap recommends projects that have strong potential for taking the experimental science above the threshold of new, exciting discoveries addressing questions like the nature of dark matter and dark energy; the stability of protons and the physics of the Big Bang; the properties of neutrinos and their role in cosmic evolution; the interior of the Sun or supernovae as seen with neutrinos; the origin of cosmic rays and the view of the sky at extreme energies; and violent cosmic processes as seen with gravitational waves.
On the top of the recommendation list

- Next-generation underground Megaton-scale detector for the search for
  - proton decay,
  - neutrino astrophysics
  - investigation of neutrino properties.

- This device is LAGUNA detector – Large Apparatus for Grand Unification and Neutrino Astrophysics.
Super-K

- One of the most successful devices in modern physics
  - Discovery of neutrino oscillations
  - Solar neutrino measurements
  - Best upper limits on proton lifetime

- The largest running underground experiment
  - 50 000 ton H₂O
  - 1 km underground
To be a worthy successor, LAGUNA has to be:

- 10 x bigger or
- 10 x better
Considered technologies

- **GLACIER** – 100 kton of liquid argon
  - Excellent tracking (TPC)
  - Rapidly developing technology
  - Needs more R&D (a 1 kton prototype)
  - Requires 2500 m.w.e (900 m of rock)

- **LENA** – 50 kton liquid scintillator
  - Big astrophysics potential (Super Borexino)
  - Robust and proven technology
  - Requires 4000 m.w.e (1400 m of rock)

- **MEMPHYS** – 500 kton water Cherenkov
  - Competitor for Hyper - K
  - Requires 3000 m.w.e (1100 m of rock)
7 European sites are being considered:

- **Pyhäsalmi** in Finland (mine),
- **Sieroszowice** in Poland (mine),
- **Boulby** in the UK (mine),
- **Slanic** in Romania (mine),
- **Fréjus** in France (road tunnel),
- **Canfranc** in Spain (road tunnel) and
- **Umbria** region in Italy (a virgin site).
The purpose: evaluate the proposed sites and to give realistic estimates of the cost and the time needed to prepare large-scale underground laboratories for LAGUNA detectors

Supported with 1.7 M€ by the Framework Programme 7 of the EC (2008 – 2010)

Involves over 100 physicists and engineers from 10 countries.
What is required of a LAGUNA site?

- Quality of the rock
- Seismic stability
- Ready infrastructure & clear legal status
- Presence of scientific activity on site
- Experienced industrial partner
- Low background from nuclear power plants

Safety & construction cost
What is required of a LAGUNA site?

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Reduces construction time & cost
What is required of a LAGUNA site?

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- Presence of scientific activity on site
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Cooperation between science & industry can not be taken for granted.
What is required of a LAGUNA site?

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- Seismic stability
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Engineering & construction challenge!
What is required of a LAGUNA site?

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Essential for geo- and diffuse supernova neutrinos
Nuclear power plants in Europe (2009)
Neutrino Background from Power Plants
based on 2009 data (Kai Loo)

<table>
<thead>
<tr>
<th>Location</th>
<th>Counts / kton / year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyhäsalmi (FIN)</td>
<td>~ 78</td>
</tr>
<tr>
<td>Pyhäsalmi after 2012</td>
<td>~ 86</td>
</tr>
<tr>
<td>Caso (ITA)</td>
<td>~ 110</td>
</tr>
<tr>
<td>Slanic (ROM)</td>
<td>~ 130</td>
</tr>
<tr>
<td>Sieroszowice (POL)</td>
<td>~ 200</td>
</tr>
<tr>
<td>Canfranc (ESP)</td>
<td>~ 300</td>
</tr>
<tr>
<td>Frejus (FRA)</td>
<td>~ 700</td>
</tr>
<tr>
<td>Boulby (GBR)</td>
<td>~ 1600</td>
</tr>
<tr>
<td>Boulby w/o Hartlepool</td>
<td>~ 280</td>
</tr>
</tbody>
</table>

Measured spectra of reactor neutrinos for U-235, Pu-239 and Pu-241 were used. For U-238 calculated spectra were used. Event rates were calculated for a KamLand-type scintillator det.
Influence of reactor neutrino background on determination of the Th/U ratio

Assumptions and methods as described by S. Dye in Earth Planet. Sci. Lett. (2010), doi:10.1016/j.epsl.2010.06.012:
- Crust contribution: 30 – 38 TNU; Th/U = 4.3
- Mantle contribution: 12 TNU; Th/U = 3.1
- Core contribution ignored; BGD only from reactors

X-axis: measurement time with LENA detector
Y-axis: error (%) of the measured Th/U ratio
What future experiments will have to measure

1. Leptonic CP violation
2. Mass Hierarchy
3. $\theta_{13}$
4. $\pi/4 - \theta_{23}$ and the octant

- Plus new physics searches through non standard neutrino interactions (NSI) and/or the unitarity of the mixing matrix

The above order following the prescriptions of the CERN strategy group

Neutrino mass model builders would probably order as 3,2,1,4
The longer the baseline the stronger matter effects in the oscillations. This implies an increased sensitivity to the type of neutrino mass spectrum and a better resolution of the degeneracies.
T2K has started January 2010

T2K first event Feb. 24, 2010
Three possible scenarios studied at NP08 workshop:

- Korea to Okinoshima: 1000 km, 1 deg. Off-axis
- Okinoshima to Kamioka: 658 km, 0.8 deg. almost On-axis
- Kamioka: 295 km, 2.5 deg. Off-axis

NP08 is The 4th International Workshop on Nuclear and Particle Physics at J-PARC
http://j-parc.jp/NP08
Observation of a first $\nu_r$ candidate event in the OPERA experiment in the CNGS beam

Long-Baseline Neutrino Experiment

- Homestake
  - 300kT fiducial
  - Water Cherenkov
  - 3 modules
  - 4850ft level

- Fermilab
  - Neutrino beam using high energy high intensity proton accelerator (0.5-2.0 MW)

Distance: 1300 km
Preferred long baselines

Figure 2. Three of the major potential NF laboratories and possible detector locations at $L = 3000\text{ km}$ (thin solid curves), $L = 7250\text{ km}$ (dashed curves), and inner core crossing baselines (shaded regions) in the corresponding lab colors.
### Long baseline distances to the proposed LAGUNA sites

<table>
<thead>
<tr>
<th>Location</th>
<th>CERN (km)</th>
<th>J-PARC (km)</th>
<th>FNAL (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyhäsalmi</td>
<td>2290 (76%)</td>
<td>7090 (98%)</td>
<td>6630 (91%)</td>
</tr>
<tr>
<td>Boulby</td>
<td>1050 (35%)</td>
<td>8480 (117%)</td>
<td>5980 (82%)</td>
</tr>
<tr>
<td>Canfranc</td>
<td>650 (22%)</td>
<td>9280 (128%)</td>
<td>6550 (90%)</td>
</tr>
<tr>
<td>Frejus</td>
<td>130 (4%)</td>
<td>8900 (123%)</td>
<td>6840 (94%)</td>
</tr>
<tr>
<td>Sieroszowice</td>
<td>940 (31%)</td>
<td>8180 (113%)</td>
<td>6960 (96%)</td>
</tr>
<tr>
<td>Slanic</td>
<td>1540 (51%)</td>
<td>8150 (112%)</td>
<td>7780 (107%)</td>
</tr>
<tr>
<td>Umbria</td>
<td>670 (22%)</td>
<td>8850 (122%)</td>
<td>7300 (101%)</td>
</tr>
</tbody>
</table>
Site example: Pyhäsaumi mine in Finland
Pyhäsalmi mine
3D model, 2004
www.inmetmining.com

Decline
Main shaft
Ventilation shaft
Stopes
Timo shaft
Crusher
Main level
New mine
To reach the bottom by car:
11 km serpentine

... or in 3 minutes with the elevator
At 1.4 km below the surface
Productivity of the Pyhäsalmi mine

Productivity 2007 World Wide Zinc UG Operations

Source: BROOK HUNT

Boliden
All 3 proposed LAGUNA detectors can be safely & cost-effectively located in Pyhäsalmi!
This tunnel was excavated halfway (250 m) towards the proposed L E N A site.
excavated up to here
Dry, room temperature conditions at the 1430m level (below the ground)
Summary

- LAGUNA Design Study (FP7 funded) is a very successful project and is well underway.
- Feasibility of 3 detector types at 7 sites was evaluated.
- We are now finalizing deliverables, adding comparison among sites, and prioritizing the sites.
- “LAGUNA NEXT” will be submitted in November 2010.
  - long baseline neutrino beam from CERN.
- If the project can start in 2013, LAGUNA detectors will come into operation around 2020-2025.
<table>
<thead>
<tr>
<th></th>
<th>GLACIER</th>
<th>LENA</th>
<th>MEMPHYS</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAVERN</td>
<td>50 – 75</td>
<td>40 – 85</td>
<td>130 - 200</td>
</tr>
<tr>
<td>DETECTOR</td>
<td>380</td>
<td>280</td>
<td>580</td>
</tr>
<tr>
<td>TOTAL</td>
<td>455</td>
<td>365</td>
<td>780</td>
</tr>
</tbody>
</table>

If the project can start in 2013, LAGUNA detectors will come into operation around 2020-2025.
Latest developments

根据我们的初步模拟，LEN A 应该具有相对良好的跟踪能力在 0.5 – 5 GeV 范围内！

Oscillometry 应该提供一个有吸引力的选择/替代方案来长基线测量中与中微子超级束的测量。

如果上述声明得到证实，LEN A 在 Pyhäsalmi 将是 LAGUNA 第一阶段的最佳选择。
Thank you for your attention!
Tracking with LENA
HE particles create along their track a light front very similar to a Cherenkov cone. But: 50x more light!
Tracking Performance

**Single Tracks/Single Pion Prod.:**
- Flavor recognition almost absolute
- Position resolution: few cms
- Angular resolution: few degrees
- Energy resolution: ca. 1% for 2-5 GeV range, depends on particle, read-out information

**Multiparticle Events:**
- 3 tracks are found if separated
- More tracks very demanding
- Muon tracks always discernible
- Overall energy resolution: few %
- Track reconstruction less accurate
Oscillometry
"Global" values for the neutrino oscillation parameters

\[ \Delta m_{21}^2 \equiv m_2^2 - m_1^2 \approx 7.9 \cdot 10^{-5} \text{ eV}^2 \]
\[ \Delta m_{31}^2 \approx \Delta m_{32}^2 \equiv m_3^2 - m_2^2 \approx 2.4 \cdot 10^{-3} \text{ eV}^2 \]
\[ \sin^2 \theta_{12} \approx 0.31 \]
\[ \sin^2 \theta_{23} < 0.9 \]
\[ \sin^2 \theta_{13} < 0.4 \]

Still unknown (!!!):
- Neutrino/antineutrino mass values,
- Type of neutrino (D. or M.),
- \( \theta_{13}, \theta_{23} \) and \( L_{32} \)

\[ L_{32} \, [m] = 2.5 \, E_\nu / \Delta m_{32}^2 \quad [m \cdot \text{MeV/eV}^2] \]
\[ L_{32} \, [m] \approx E_\nu \, [\text{keV}] \]
Sketch for comparison of "one-point" oscillation identification in long base-line experiments with continuous oscillometry measurement within the sizes of detector with the low energy monoenergetic neutrinos.

Long baseline ($E_\nu \gg 1 \text{ MeV}$) → $L$ in [km]

Short baseline ($E_\nu \ll 1 \text{ MeV}$) → $L$ in [m] - oscillometry

Courtesy of Yu. Novikov
Table of candidates for the low energy monoenergetic neutrino oscillometry.

The intensity of 20 MCi for \(^{51}\text{Cr}\) and \(^{75}\text{Se}\) can be produced with the appropriate time irradiation in the neutron reactor.

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>(T_{1/2}) (d)</th>
<th>(Q_\varepsilon) (keV)</th>
<th>(E_\nu = Q_\varepsilon - B_1 - E_\gamma) (keV)</th>
<th>(L_{23}/2) (m)</th>
<th>(E_{e,max}) (keV)</th>
<th>Irradiated target during 10 days</th>
<th>(\nu)-intensity (per 1 kg of target, per s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(^{37}\text{Ar})</td>
<td>35</td>
<td>814</td>
<td>811 (100%)</td>
<td>406</td>
<td>617</td>
<td>(\text{Ar})</td>
<td>(8.3 \times 10^{15})</td>
</tr>
<tr>
<td>(^{51}\text{Cr})</td>
<td>28</td>
<td>753</td>
<td>747 (90%)</td>
<td>373</td>
<td>560</td>
<td>(^{50}\text{Cr})</td>
<td>(2.3 \times 10^{16})</td>
</tr>
<tr>
<td>(^{75}\text{Se})</td>
<td>120</td>
<td>863</td>
<td>450 (96%)</td>
<td>225</td>
<td>287</td>
<td>(\text{Se})</td>
<td>(1.1 \times 10^{14})</td>
</tr>
<tr>
<td>(^{113}\text{Sn})</td>
<td>116</td>
<td>1037</td>
<td>617 (98%)</td>
<td>308</td>
<td>436</td>
<td>(\text{Sn})</td>
<td>(8 \times 10^{11})</td>
</tr>
<tr>
<td>(^{145}\text{Sm})</td>
<td>340</td>
<td>616</td>
<td>510 (91%)</td>
<td>255</td>
<td>340</td>
<td>(\text{Sm})</td>
<td>(2 \times 10^{12})</td>
</tr>
<tr>
<td>(^{169}\text{Yb})</td>
<td>32</td>
<td>910</td>
<td>470 (83%)</td>
<td>235</td>
<td>304</td>
<td>(\text{Yb})</td>
<td>(1.1 \times 10^{15})</td>
</tr>
</tbody>
</table>

Courtesy of Yu. Novikov
Number of expected ν-e events from $^{51}$Cr -source installed at the top of the LS-detector LENA in dependence on the length L. Geometrical factor of cylinder g is taken into account. Red, green and blue with the error bands correspond to the $\sin^2 2\theta_{13} = 0.17$, 0.085 and 0.045, respectively. Differences of curves are very well seen.