“Oscillazioni di neutrini alle nuove macchine”

- Oscillazioni di neutrini
- Come e quando
- Descrizione delle possibili facilities.
- Physics reach e qualche confronto.
ν oscillations are the most important discovery in hep of the last 15 years.

**They measure fundamental parameters of the standard model.** Mixing angles, neutrino masses and the CP phase $\delta_{CP}$ are fundamental constants of the standard model.

**They are a probe of the GUT scales.** The smallness of neutrino masses is connected to the GUT scale through the see-saw mechanism.

**They are directly linked to many fields in astrophysics and cosmology:** baryogenesis, leptogenesis, galaxies formation, dynamic of supernovae explosion, power spectrum of energy anisotropies, etc.

They open the perspective of the measure of **leptonic CP violation.**
If you are skeptical about that ....

Experimental articles with more than 500 cites in the last 15 years in the QSPIRES database (at 04/04/03):

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SK</td>
<td>Evidence for Oscillation of Atmospheric Neutrinos.</td>
</tr>
<tr>
<td>2</td>
<td>SCP</td>
<td>Measurements of $\Omega$ and $\Lambda$ from 42 High Redshift SN.</td>
</tr>
<tr>
<td>3</td>
<td>SST</td>
<td>Observational Evidence from SuperNovae for an Accelerating Universe and a Cosmological Constant.</td>
</tr>
<tr>
<td>4</td>
<td>COBE</td>
<td>Structure in the COBE DMR First Year Maps.</td>
</tr>
<tr>
<td>5</td>
<td>CDF</td>
<td>Observation of TOP Quark Production in $\bar{p} - p$ Collisions.</td>
</tr>
<tr>
<td>6</td>
<td>D0</td>
<td>Observation of the Top Quark.</td>
</tr>
<tr>
<td>7</td>
<td>SK</td>
<td>Atmospheric $\nu_\mu/\nu_e$ Ratio in the MultiGeV Energy Range.</td>
</tr>
<tr>
<td>8</td>
<td>Chooz</td>
<td>Initial Results from CHOOZ.</td>
</tr>
<tr>
<td>9</td>
<td>Boomerang</td>
<td>A Flat Universe from High Resolution Maps of the CMB.</td>
</tr>
<tr>
<td>10</td>
<td>Chooz</td>
<td>Limits on Neutrino Oscillations from the CHOOZ Experiment.</td>
</tr>
<tr>
<td>11</td>
<td>Kamiokande</td>
<td>Observation of a Small Atmospheric $\nu_\mu/\nu_e$ Ratio.</td>
</tr>
<tr>
<td>12</td>
<td>CLEO</td>
<td>First Measurement of the Rate for the Inclusive $b \rightarrow s \gamma$.</td>
</tr>
<tr>
<td>13</td>
<td>SNO</td>
<td>Measurement of the rate of $\nu_e + d \rightarrow p + p + e^- ...$</td>
</tr>
<tr>
<td>14</td>
<td>Homestake</td>
<td>Measurement of the Solar $\nu_e$ Flux ...</td>
</tr>
<tr>
<td>15</td>
<td>LSND</td>
<td>Evidence for $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ Oscillations from LSND.</td>
</tr>
<tr>
<td>16</td>
<td>SK</td>
<td>Measurement of a Small Atmospheric $\nu_\mu/\nu_e$ Ratio.</td>
</tr>
<tr>
<td>17</td>
<td>CDF</td>
<td>Evidence for TOP Quark Production in $\bar{p} - p$ ....</td>
</tr>
<tr>
<td>18</td>
<td>SK</td>
<td>Study of the Atm. $\nu$ Flux in the MultiGeV Energy Range.</td>
</tr>
<tr>
<td>19</td>
<td>IMB</td>
<td>The $\nu_e$ and $\nu_\mu$ Content of the Atmospheric Flux.</td>
</tr>
<tr>
<td>20</td>
<td>SK</td>
<td>Solar Neutrino Data Covering Solar Cycle 22.</td>
</tr>
<tr>
<td>21</td>
<td>LSND</td>
<td>Neutrino Oscillations from LSND.</td>
</tr>
</tbody>
</table>
Most of the parameters are waiting to be measured

\[ \delta m_{12} \quad \text{SOLARS+KAMLAND} \quad \delta m_{12}^2 = (7 \pm 1) \times 10^{-5} \text{ eV}^2 \]

\[ \theta_{12} \quad \text{SOLARS+KAMLAND} \quad 0.2 < \sin^2 \theta_{12} < 0.5 \]

\[ \delta m_{23}^2 \quad \text{ATMOSPHERICS} \quad \delta m_{23}^2 = (2.0 \pm 0.4) \times 10^{-3} \text{ eV}^2 \]

\[ \theta_{23} \quad \text{ATMOSPHERICS} \quad 0.9 < \sin^2 \theta_{23} < 1 \]

\[ \theta_{13} \quad \text{CHOOZ LIMIT} \quad \theta_{13} < 14^0 \]

\[ \delta_{CP} \quad \text{Mass hierarchy} \]

\[ \Sigma m_\nu \quad \text{BETA DECAY END POINT} \quad \Sigma m_\nu < 6.6 \text{ eV} \]

Dirac/Majorana
I Leptoni nel modello standard hanno caratteristiche MOLTO diverse dai quark

\begin{align*}
  u &\sim 5 \text{ MeV} & c &\sim 1 \text{ GeV} & t &\sim 175 \text{ GeV} \\
  d &\sim 8 \text{ MeV} & s &\sim 0.1 \text{ GeV} & b &\sim 5 \text{ GeV} \\
  e &\sim 0.5 \text{ MeV} & \mu &\sim 0.1 \text{ GeV} & \tau &\sim 2 \text{ GeV} \\
  \nu_e &\leq \mathcal{O}(1 \text{ eV}) & \nu_\mu &\leq \mathcal{O}(1 \text{ eV}) & \nu_\tau &\leq \mathcal{O}(1 \text{ eV})
\end{align*}

Come’ possibile nello stesso modello generare rapporti di massa così’ diversi? ⇒ See-saw mechanism

Solar+Atmospherics indicano una matrice di mixing quasi bi-maximal, MOLTO DIFFERENTE dalla matrice CKM (quasi diagonale)!

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

\[\theta_{13} \to 0 \Rightarrow\] La matrice 3x3 rimane un semplice prodotto di due matrici 2x2.

\[\theta_{13} \text{ drives } \nu_\mu \to \nu_e\text{ subleading transitions} \Rightarrow\]

the necessary milestone for any subsequent search:

neutrino mass hierarchy and leptonic CP searches.
Sub leading $\nu_\mu - \nu_e$ oscillations

$p(\nu_\mu \rightarrow \nu_e)$ developed at the first order of matter effects

\[
p(\nu_\mu \rightarrow \nu_e) = 4c_{13}^2s_{13}^2s_{23}^2 \sin^2 \frac{\Delta m_{13}^2 L}{4E} \quad \theta_{13} \text{ driven}
\]
\[
+ 8c_{13}^2s_{12}s_{13}s_{23}(c_{12}c_{23}\cos\delta - s_{12}s_{13}s_{23}) \cos \frac{\Delta m_{23}^2 L}{4E} \sin \frac{\Delta m_{13}^2 L}{4E} \sin \frac{\Delta m_{12}^2 L}{4E} \quad \text{CP}_{\text{even}}
\]
\[
- 8c_{13}^2c_{12}c_{23}s_{12}s_{13}s_{23}\sin\delta \sin \frac{\Delta m_{23}^2 L}{4E} \sin \frac{\Delta m_{13}^2 L}{4E} \sin \frac{\Delta m_{12}^2 L}{4E} \quad \text{CP}_{\text{odd}}
\]
\[
+ 4s_{12}^2c_{13}^2\{c_{13}^2c_{23}^2 + s_{12}^2s_{23}^2s_{13}^2 - 2c_{12}c_{23}s_{12}s_{23}s_{13}\cos\delta\} \sin \frac{\Delta m_{12}^2 L}{4E} \sin \Delta m_{13}^2 L \quad \text{solar driven}
\]
\[
- 8c_{12}^2s_{13}^2s_{23}^2 \cos \frac{\Delta m_{23}^2 L}{4E} \sin \frac{\Delta m_{13}^2 L}{4E} \frac{aL}{4E} (1 - 2s_{13}^2) \quad \text{matter effect (CP odd)}
\]

where $a = \pm 2\sqrt{2}G_F n_e E_\nu = 7.6 \cdot 10^{-5} \rho [g/cm^3] E_\nu [GeV] \quad [eV^2]$
1) 2001-2010. K2K, Opera, Icarus, Minos. Ottimizzati per confermare il risultato sperimentale di SuperKamiokande/atmosferici, attraverso $\nu_\mu$ disappearance o $\nu_\tau$ appearance. Limitato progresso nella misura dei parametri. Non ottimizzati per $\nu_e$ appearance ($\theta_{13}$).

2) 2009-2015. T2K (approvato), Minos off-axis, Chooz II. Ottimizzati per la misura di $\theta_{13}$ (Chooz $\times$ 20) attraverso $\nu_e$ appearance o $\nu_e$ disappearance. Misura di precisione dei parametri atmosferici. Sensitività sulla fase di CP $\delta$ molto limitata, anche combinando assieme i loro eventuali risultati.

3) 2015 - 2025. SuperBeam e/o Beta Beam. Migliore sensitività su $\theta_{13}$ (Chooz $\times$ 200). A queste sensitività $\theta_{13}$ e $\delta$ sono così fortemente accoppiate che ogni sensitività va definita nel piano ($\theta_{13}$, $\delta$). Sensitività su $\delta$ e mass hierarchy.

Neutrino beam from the 50 GeV - 0.75 MW proton beam at the Hadron Facility at Jaeri, Japan. Taken off-axis to better match the oscillation maximum at the SuperKamiokande location (295 km).

<table>
<thead>
<tr>
<th>K2K</th>
<th>T2K</th>
</tr>
</thead>
<tbody>
<tr>
<td>$6 \cdot 10^{12}$</td>
<td>$3 \cdot 10^{14}$</td>
</tr>
<tr>
<td>2.2 s</td>
<td>3.4 s</td>
</tr>
<tr>
<td>12 GeV</td>
<td>50 GeV</td>
</tr>
<tr>
<td>40 Events in SK per year (no osc.)</td>
<td>2200</td>
</tr>
<tr>
<td>1.5 Mean neutrino energy</td>
<td>0.8</td>
</tr>
</tbody>
</table>
T2K $\nu_e$ appearance

<table>
<thead>
<tr>
<th></th>
<th>$\nu_\mu$ CC</th>
<th>$\nu_\mu$ NC</th>
<th>$\nu_e$ CC</th>
<th>Osc. $\nu_e$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generated in F.V.</td>
<td>10713.6</td>
<td>4080.3</td>
<td>292.1</td>
<td>301.6</td>
</tr>
<tr>
<td>1R e-like</td>
<td>14.3</td>
<td>247.1</td>
<td>68.4</td>
<td>203.7</td>
</tr>
<tr>
<td>$e/\pi^0$ separation</td>
<td>3.5</td>
<td>23.0</td>
<td>21.9</td>
<td>152.2</td>
</tr>
<tr>
<td>$0.4\ \text{GeV} &lt; E_{rec} &lt; 1.2\ \text{GeV}$</td>
<td>1.8</td>
<td>9.3</td>
<td>11.1</td>
<td>123.2</td>
</tr>
</tbody>
</table>

Sensitivity to $\theta_{13}$

90% C.L. sensitivities

- Expected Signal+BG
  $(\sin^2 2\theta_{\mu e} = 0.05, \Delta m^2 = 0.003)$
- Total BG
- BG from $\nu_\mu$

Reconstructed $E_\nu$ (GeV)

$\Delta m^2 (\text{eV}^2)$

$\sin^2 2\theta_{\mu e}$

After T2K, in the standard scenario

- $\theta_{13}$, discovery or precision measure
- Mass hierarchy
- Leptonic CP violation

Any major improvement of T2K will be extremely expensive:
- The proton driver is a next generation machine
- The detector is 10 times bigger of the second biggest: Minos.
- The designed close detectors system is very ambitious.

THE $\theta_{13}$ DILEMMA

The knowledge of $\theta_{13}$ is necessary to guarantee the conditions to measure $\delta$ and to optimize the facility. Waiting for the T2K results (or Numi Off-Axis or Reactors) implies a 10 years delay. If we wait and $\theta_{13}$ remains undetected we should consequently stop any further neutrino oscillation initiative (because of the cost).

Any future initiative should have enough physics potential besides neutrino oscillations to justify the risk of starting the Leptonic CP violation searches without any guarantee.
Leptonic CP

Two conditions to make Leptonic CP detectable:

- Solar LMA confirmed (Done! now \( 5 < \sin^2 2\theta_{12} < 10 \cdot 10^{-5} \text{ eV}^2 \) (3\(\sigma\))
- \( \theta_{13} \geq 0.5^0 \) (see the following).

A big step from a \( \theta_{13} \) search:

\[
\text{from } p(\nu_\mu \rightarrow \nu_e) \neq 0 \text{ to } \begin{cases} p(\nu_\mu \rightarrow \nu_e) \neq p(\bar{\nu}_\mu \rightarrow \bar{\nu}_e) \text{ (direct CP)} \\ p(\nu_\mu \rightarrow \nu_e) \neq p(\nu_e \rightarrow \nu_\mu) \text{ (T search)} \end{cases}
\]

This will require:

1. Neutrino beams of novel conception.
2. Detectors of unprecedent mass
3. Improved control of systematics \( \Rightarrow \) Dedicated experiments on neutrino cross-section, hadron production, particle ID.
Detecting the $\delta$ phase at the Neutrino Factories

$A_\delta = [P(\nu_e \rightarrow \nu_\mu , \delta = +\pi/2) - P(\nu_e \rightarrow \nu_\mu , \delta = 0)]/[P(\delta = +\pi/2) + P(\delta = 0)]$

Compare the measured $\nu_e \rightarrow \nu_\mu$ oscillation probability, as a function of the neutrino energy $E_\nu$, to a “Monte-Carlo” prediction of the spectrum in absence of $\delta$-phase.

Problems: it’s model dependent, requires a precise knowledge of the other oscillation parameters, possible degeneracy between solutions and strong correlation with the $\theta_{13}$ parameter.

$A_{CP}(\delta) = [P(\nu_e \rightarrow \nu_\mu , \delta) - P(\bar{\nu}_e \rightarrow \bar{\nu}_\mu , \delta)]/[P(\nu_e \rightarrow \nu_\mu , \delta) + P(\bar{\nu}_e \rightarrow \bar{\nu}_\mu , \delta)]$

Compare the appearance of $\nu_\mu$ ($\bar{\nu}_\mu$) in a beam of stored $\mu^+$ ($\mu^-$) decays as a function of the neutrino energy $E_\nu$.

Problems: It must compete with the fake CP from matter effects. Run time is more than doubled: $\bar{\nu}$ cross sections are half the $\nu$ cross section and matter effects disfavor $\bar{\nu}$ oscillations.

$A_T(\delta) = [P(\nu_e \rightarrow \nu_\mu , \delta) - P(\nu_\mu \rightarrow \nu_e , \delta)]/[P(\nu_e \rightarrow \nu_\mu , \delta) + P(\nu_\mu \rightarrow \nu_e , \delta)]$

Compare the appearance of $\nu_\mu$ in a $\nu_e$ beam AND $\nu_e$ in a $\nu_\mu$ beam as a function of the neutrino energy $E_\nu$.

Problems: Electron charge must be measured in case of a neutrino factory experiment. Systematics of muon and electron efficiencies must be kept to very small values.
### Phase 3 Players

<table>
<thead>
<tr>
<th>Facility</th>
<th>Momentum</th>
<th>Power</th>
<th>Baseline</th>
<th>Events</th>
<th>Bacgkr.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Super Beams firing to a 20x SuperKamiokande like detector</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BNL AGS</td>
<td>28 GeV/c</td>
<td>1 MW</td>
<td>2500 or 2990 Km</td>
<td>1115</td>
<td>126</td>
</tr>
<tr>
<td>JPARC Phase II</td>
<td>50 GeV/c</td>
<td>4 MW</td>
<td>295 Km</td>
<td>8237</td>
<td>1378</td>
</tr>
<tr>
<td>CERN SPL</td>
<td>2 GeV</td>
<td>4 MW</td>
<td>130 Km</td>
<td>3137</td>
<td>454</td>
</tr>
</tbody>
</table>

| **Beta Beams firing to a 20x SuperKamiokande like detector** |          |       |                  |        |         |
|-------------------------------------------------------------------------------------------------------------|
| $\bar{\nu}_e$                                                                                             | 348      | 0.5   |
| $\nu_e$                                                                                                    | 3358     | 198   |

| **Neutrino Factories**                                                                                   | 40582    | 112   |

Event numbers are $\nu_e$ appearance at the Chooz limit ($\sin^2 2\theta_{23} = 0.12$), $\delta = 0$, 5 yrs running. JPARC phase II and Nufact are taken from P. Huber, EPS 2003.

Upgrade the proton driver from 0.75 MW to 4 MW
Upgrade SuperKamiokande by a factor $\sim 20 \implies \text{HyperKamiokande}$
Both upgrades are necessary to address leptonic CP searches.
Systematics at 2% are tight
4 MW at 50 GeV/c are tight
Target and optics at 4 MW are tight and will require some compromise

$\sin^2 2\theta_{13} \times 10^{-2}$

- $\Delta m_{23}^2 = 2.8 \times 10^{-3}$
- $\Delta m_{12}^2 = 6.9 \times 10^{-5}$
- $\theta_{23} = \pi/4$
- $\theta_{12} = 0.594$
- 4 MW, 540 kt
- 2 + 6.3 years
The very far detector detects the first and the second oscillation maximum.

The comparison of the two maxima can allow the detection of $\theta_{13}$, $\delta$ and $\text{sign}(\Delta m^2)$, without the need of an antineutrino run.

An original and powerful method to extract the mixing matrix parameters

**HOWEVER**

The very long baselines wastes the most critical parameter of SuperBeams: statistics

The spectrum analysis requires good control of energy reconstruction in a critical energy range for Water Cerenkov detector and for the cross section knowledge

First maximum neutrinos are pion daughters while second maximum neutrinos are kaon daughters.
A feasibility study of the CERN possible developments

Possible Low Energy Super Beam Layout

Flux intensities at 50 km from the target

<table>
<thead>
<tr>
<th>Flavour</th>
<th>Absolute Flux ( (\nu/10^{23} \text{pot/m}^2) )</th>
<th>Rel. Flux (%)</th>
<th>( \langle E_\nu \rangle ) (GeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \nu_\mu )</td>
<td>( 3.2 \cdot 10^{12} )</td>
<td>100</td>
<td>0.27</td>
</tr>
<tr>
<td>( \bar{\nu}_\mu )</td>
<td>( 2.2 \cdot 10^{10} )</td>
<td>1.6</td>
<td>0.28</td>
</tr>
<tr>
<td>( \nu_e )</td>
<td>( 5.2 \cdot 10^9 )</td>
<td>0.67</td>
<td>0.32</td>
</tr>
<tr>
<td>( \bar{\nu}_e )</td>
<td>( 1.2 \cdot 10^8 )</td>
<td>0.004</td>
<td>0.29</td>
</tr>
</tbody>
</table>
**MW-Linac: SPL (Superconducting Proton Linac)**

- **Source** Low Energy section
- **DTL**
- **Superconducting section**
- **Stretching and collimation line**

**Re-use superconducting LEP cavities**

- H$^-$
- RFQ1 chop.
- RFQ2
- DTL
- CCDTL
- β 0.52
- β 0.7
- β 0.8
- LEP-II
- **dump**

**MW-Linac Parameters**

- **$E_{KIN} = 2.2 \text{ GeV}$**
- **Power = 4 MW**
- **Protons/s = $10^{16}$**

**Accumulator Ring**

**PS / Isolde**

**23**

**10 protons/year**
Proposed Roadmap

Consistent with the content of a talk by L. Maiani at the “Celebration of the Discovery of the W and Z bosons”. Contribution to a document to be submitted to the December Council (“CERN Future Projects and Associated R&D”).

Assumptions:
- construction of Linac4 in 2007/10 (with complementary resources, before end of LHC payment)
- construction of SPL in 2008/15 (after end of LHC payments)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LINAC4</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design refinement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Construction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commissioning</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Start operation with PSB</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SPL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design refinement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Construction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Linac4 displacement + commissioning</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Start operation as PS Injector</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Linac 4 approval
- SPL approval
- LHC upgrade

The Megaton detector

- Fiducial volume: 440 kton: 20 times SuperK.
- 60,000 PMTs (20") in the inner detector, 15,000 PMTs in the outer veto detector.
- Energy resolution is poor for multitrack events but quite adequate for sub-GeV neutrino interactions.
- It would be hosted at the Frejus laboratory, 130 km from CERN, in a $10^6 \, m^3$ cavern to be excavated.

The ultimate detector for proton decay, atmospheric neutrinos, supernovae neutrinos.
The Frejus project

• Italy and France actively involved in promoting the construction of a million cubic meter laboratory under the Frejus
• The rock characteristics and the distance to CERN make Frejus a unique opportunity to build such a detector.
• The only possibility to build such a detector is to have a worldwide collaboration, including Japanese and Americans from SuperKamiokande. (only one detector of this size is reasonable in the world)
• The second highway tunnel excavation will be finished in 2008
• This opens the possibility to dig the laboratory at a very reduced price
• 3+3 years since then is the (optimistic) schedule to have the detector ready.

-> a very large Laboratory to allow the installation of a Megaton-scale Cerenkov Detector ( $10^6$ m$^3$)
Interesting features of a low energy conventional neutrino beam.

\( \nu \) beam:
- \( \langle E_{\nu_\mu} \rangle \approx 0.25 \text{ GeV} \)
- \( \nu_e \) production by kaons largely suppressed by threshold effects.

- \( \nu_e \) in the beam come only from \( \mu \) decays.

\[
\begin{array}{c}
\pi^+ \rightarrow \mu^+ \nu_\mu \\
\downarrow \\
e^+ \nu_e \bar{\nu}_\mu
\end{array}
\]

they can be predicted from the measured \( \nu_\mu \) CC spectrum both at the close and at the far detector with a small systematic error of \( \sim 2\% \).

Detector Backgrounds
- Good e/\( \pi^0 \) separation following the large \( \pi^0 \rightarrow \gamma\gamma \) opening angle
- Good e/\( \mu \) separation in a Čerenkov detector because \( \mu \) are produced below or just above the Čerenkov threshold.
- Charm and \( \tau \) production below threshold.

Less exiting aspects of a low energy neutrino beam
- Cross sections are small \( \Rightarrow \) large detectors are necessary in spite of the very intense neutrino beam.
- \( \bar{\nu}_\mu \) production is disfavored for two reasons:
  - Smaller \( \pi^- \) multiplicity at the target.
  - \( \bar{\nu}_\mu / \nu_\mu \) cross section ratio is at a minimum (1/5).
- Visible energy is smeared out by Fermi motion.
A comparison of CP sensitivities: Nufact vs. SuperBeam

CP sensitivity, defined as the capacity to separate at 99%CL max CP ($\delta = \pi/2$) from no CP ($\delta = 0$).

Nufact and SPL-SuperBeam sensitivities computed with the same conditions.

The limiting factors for the SuperBeam at small $\theta_{13}$ values are:

- The low flux of $\nu$ and their small cross section. This limits the overall statistic.
- The beam related backgrounds that increase the statistical errors, hiding the CP signal.

As an example for $\theta_{13} = 3^\circ$, $\delta m_{12}^2 = 0.7 \cdot 10^{-4} \text{eV}^2$, $\sin^2 2\theta_{12} = 0.8$:

<table>
<thead>
<tr>
<th></th>
<th>$\nu_\mu$ beam 2 years</th>
<th>$\bar{\nu}_\mu$ beam 8 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu$CC (no osc)</td>
<td>36698</td>
<td>23320</td>
</tr>
<tr>
<td>Oscillated events (total)</td>
<td>45</td>
<td>133</td>
</tr>
<tr>
<td>Oscillated events (cp-odd)</td>
<td>-84</td>
<td>53</td>
</tr>
<tr>
<td>Intrinsic beam background</td>
<td>140</td>
<td>101</td>
</tr>
<tr>
<td>Detector backgrounds</td>
<td>36</td>
<td>49</td>
</tr>
</tbody>
</table>
Conventional neutrino beams will hit their ultimate limitations.

In a conventional neutrino beam, neutrinos are produced by pions (and kaons) generated by the proton beam interaction on the target. Given the short life time of the pions ($2.6 \cdot 10^{-8}$s), they can only be focused (and charge selected) by means of magnetic horns. Then they are let to decay in a decay tunnel, short enough to prevent most of the muon decays.

- Beside the main component ($\nu_\mu$) at least 3 other neutrino flavours are present ($\bar{\nu}_\mu$, $\nu_e$, $\bar{\nu}_e$), generated by wrong sign pions, kaons and muon decays.
- Hard to predict the details of the neutrino beam starting from the primary proton beam, since it derives from hadronic interactions.
- Difficult to tune the energy of the beam in case of ongoing optimizations.
- Difficult to manage the targets at very high proton intensities (Super Beams: conventional neutrino beams where conventional targets would be evaporated).

All these problems are overcome if the neutrino parents can be collected, focused and accelerated at a given energy. This is impossible within the pion lifetime, but can be tempted within the muon lifetime (Neutrino Factories) or within some radioactive ion lifetime (Beta Beams).

M. Lindroos and collaborators, see http://beta-beam.web.ch/beta-beam

EURISOL

- 1 ISOL target to produce He$^6$, 100 $\mu$A, $\Rightarrow 2.9 \cdot 10^{18}$ ion decays/straight session/year. $\Rightarrow \nu_e$.
- 3 ISOL targets to produce Ne$^{18}$, 100 $\mu$A, $\Rightarrow 1.2 \cdot 10^{18}$ ion decays/straight session/year. $\Rightarrow \nu_e$.
- The 4 targets could run in parallel, but the decay ring optics requires:

$$\gamma(\text{Ne}^{18}) = 1.67 \cdot \gamma(\text{He}^6).$$
### Fluxes

**Fluxes @ 130 km**

<table>
<thead>
<tr>
<th>$\nu / m^2/yr$</th>
<th>$&lt; E_{\nu} &gt;$ (GeV)</th>
<th>CC rate (no osc) events/kton/yr</th>
<th>$&lt; E_{\nu} &gt;$ (GeV)</th>
<th>Years</th>
<th>Integrated events (440 kton × 10 years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\nu_{\mu}$</td>
<td>$4.78 \cdot 10^{11}$</td>
<td>0.27</td>
<td>41.7</td>
<td>2</td>
<td>36698</td>
</tr>
<tr>
<td>$\bar{\nu}_{\mu}$</td>
<td>$3.33 \cdot 10^{11}$</td>
<td>0.25</td>
<td>6.6</td>
<td>8</td>
<td>23320</td>
</tr>
<tr>
<td>$\nu_{e}$ ($\gamma = 60$)</td>
<td>$1.97 \cdot 10^{11}$</td>
<td>0.24</td>
<td>4.5</td>
<td>10</td>
<td>19709</td>
</tr>
<tr>
<td>$\bar{\nu}_{e}$ ($\gamma = 100$)</td>
<td>$1.88 \cdot 10^{11}$</td>
<td>0.36</td>
<td>32.9</td>
<td>10</td>
<td>144783</td>
</tr>
<tr>
<td>$\nu_{e}$ ($\gamma = 100$)</td>
<td>$2.88 \cdot 10^{11}$</td>
<td>0.36</td>
<td>32.9</td>
<td>10</td>
<td>144783</td>
</tr>
</tbody>
</table>
### Distinctive features of the Beta Beam

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Just one neutrino flavour in the beam. No intrinsic contamination.</td>
<td></td>
</tr>
<tr>
<td>Short baseline: no subtraction of the fake CP violating matter effects.</td>
<td></td>
</tr>
<tr>
<td>Tunable: easy to adapt to the optimal $\Delta m_{23}^2$.</td>
<td></td>
</tr>
<tr>
<td>In the proposed scheme the $\bar{\nu}_e$ channel is completely background free!</td>
<td></td>
</tr>
<tr>
<td>Neutrino fluxes are completely defined by the beta decay properties of the parent ion and by the knowledge of the number of ions in the decay ring. This assures very small systematic errors and a powerful measure of neutrino cross-sections in the close detector.</td>
<td></td>
</tr>
<tr>
<td>The $\nu_e$ and $\bar{\nu}<em>e$ beams allow for the disappearance channel with a very good control of the systematics, with a direct access to $\theta</em>{13}$. Their comparison offers a tool to investigate CPT.</td>
<td></td>
</tr>
<tr>
<td>When combined with the $\nu_\mu$ and $\bar{\nu}_\mu$ SPL beams, the $\nu_e$ and $\bar{\nu}_e$ Beta Beams allow for CP, T, and CPT searches.</td>
<td></td>
</tr>
</tbody>
</table>
Beta Beam Backgrounds

Computed with a full simulation and reconstruction program. (Nuance + Dave Casper).

π from NC interactions
The main source of background comes from pions generated by resonant processes ($\Delta^{++}$ production) in NC interactions. Pions cannot be separated from muons. However the threshold for this process is $\sim 400$ MeV. Angular cuts have not be considered.

e/µ mis-identification
The full simulation shows that they can be kept well below $10^{-3}$ applying the following criteria:
- One ring event.
- Standard SuperK particle identification with likelihood functions.
- A delayed decay electron.

Atmospheric neutrinos
Atmospheric neutrino background can be kept low only by a very short duty cycle of the Beta Beam. A reduction factor bigger than $10^3$ is needed.
This is achieved by building 10 ns long ion bunches.
Optimizing the Lorentz Boost $\gamma$ (L=130 km): preferred values: $\gamma = 55 \div 75$

Higher $\gamma$ produce more CC interactions
More collimated neutrino production and higher cross sections.

Background rate rises much faster than CC interactions
From resonant pion production in $\bar{\nu}_e$ NC interactions

$\nu$ flux must match the CP-odd oscillating term

Detection efficiency as function of $\nu$ energy
The SuperBeam - BetaBeam synergy: $\theta_{13}$ sensitivity

Computed for 5 years running, no signal in the experiment.

- No way to disentangle $\theta_{13}$ from $\delta$ in a high sensitivity experiment.
- The full information of experiment sensitivity is given by a bidimensional $\theta_{13}$ vs $\delta$ plot.
- Beta Beam can measure $\theta_{13}$ both in appearance and in disappearance mode. All the ambiguities can be removed for $\theta_{13} \geq 3.4^\circ$.

Assuming $\Delta m_{23}^2 = 2.5 \times 10^{-3}$ eV$^2$
\[ \delta m_{12}^2 = 7 \cdot 10^{-5} \text{ eV}^2, \ \theta_{13} = 3^\circ, \ \delta_{CP} = \pi/2, \ \text{sign}(\Delta m^2) = +1 \]

\[ \begin{array}{c|cc|cc}
\text{Beta Beam} & \text{SPL-SB} \\
^{6}\text{He} & ^{18}\text{Ne} & \nu_\mu & \bar{\nu}_\mu \\
(\gamma = 60) & (\gamma = 100) & (2 \text{ yrs}) & (8 \text{ yrs}) \\
\hline
\text{CC events (no osc, no cut)} & 19710 & 144784 & 36698 & 23320 \\
\text{Oscillated at the Chooz limit} & 612 & 5130 & 1279 & 774 \\
\text{Oscillated} & 44 & 529 & 93 & 82 \\
\delta \text{ oscillated} & -9 & 57 & -20 & 12 \\
\text{Beam background} & 0 & 0 & 140 & 101 \\
\text{Detector backgrounds} & 1 & 397 & 37 & 50 \\
\end{array} \]

\(\delta\)-oscillated events indicates the difference between the oscillated events computed with \(\delta = 90^\circ\) and with \(\delta = 0\).
A comparison of CP sensitivities: Beta Beam vs. Nufact

CP sensitivity, defined as the capacity to separate at 99%CL max CP ($\delta = \pi/2$) from no CP ($\delta = 0$).

Nufact sensitivity as computed in J. Burguet-Castell et al., Nucl. Phys. B 608 (2001) 301:

- 50 GeV/c $\mu$.
- $2 \cdot 10^{20}$ useful $\mu$ decays/year.
- 5+5 years.
- 2 iron magnetized detectors, 40 kton, at 3000 and 7000 km.
- Full detector simulation, including backgrounds and systematics.

\[
\Delta m^2_{12} = 10^{-4} \text{eV}^2 \quad \sin^2 \theta_{13}
\]

- 1
- 2
- 3
- 4
- 5

- Nufact
- BetaBeam
- SPL SB
- SPL+Beta
- SB+BB, 1Mton

Best LMA after SNO Salt

JParc sensitivity
Minimum value of $\delta$ at 3$\sigma$ from zero as function of $\theta_{13}$.

$\Delta m_{12}^2 = 7 \cdot 10^{-3}$ eV$^2$.


Nufact curve is silver+gold, preliminary, courtesy of O. Mena. Its extension below 2° is under investigation.
Is the $\gamma_{HE} = 60, \gamma_{NE} = 100$ the absolute optimal configuration?

Suggestion of P. Hernandez and J.J. Gomez-Cadenas

- The present SPS configuration allows max. 139 GeV/u. In this scenario the $\gamma_{HE} = 60 - \gamma_{NE} = 100$, baseline=130 km is the optimal configuration.

- Relaxing the SPS constrain and allowing for higher energies:
  - The resonant NC single pion productions cross section saturates.
  - The signal/background ratio starts to be favorable again.

- As for the neutrino factories the number of events per kton/year increases as $E_\nu$ when computed at the optimal baseline. In this energy range is even more favorable because below 1 GeV neutrino cross sections raise faster that $E_\nu^{+1}$.

- At higher energies it is possible to bin the events in energy bins.

The $\gamma_{HE} = 360, \gamma_{NE} = 600$ configuration, baseline=732 km, is still comfortable as far as concerns energy reconstruction in a water Čerenkov detector and would have a $\sim 10$ increase in CC rates.

This would require something like a SPS to Tevatron upgrade (that means replace all the magnets with a 2-3 years stop of operations) or the usage of LHC as a third stage accelerator.

The fluxes in these configurations are not yet been studied.
Comment on BB cost estimates

<table>
<thead>
<tr>
<th>Educated guess on possible costs</th>
<th>USD/CHF</th>
<th>1.60</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNO</td>
<td>960</td>
<td>MCHF</td>
</tr>
<tr>
<td>SUPERBEAM LINE</td>
<td>100</td>
<td>MCHF</td>
</tr>
<tr>
<td>SPL</td>
<td>300</td>
<td>MCHF</td>
</tr>
<tr>
<td>PS UPGR.</td>
<td>100</td>
<td>MCHF</td>
</tr>
<tr>
<td>SOURCE (EURISOL), STORAGE RING</td>
<td>100</td>
<td>MCHF</td>
</tr>
<tr>
<td>SPS</td>
<td>5</td>
<td>MCHF</td>
</tr>
<tr>
<td>DECAY RING CIVIL ENG.</td>
<td>400</td>
<td>MCHF</td>
</tr>
<tr>
<td>DECAY RING OPTICS</td>
<td>100</td>
<td>MCHF</td>
</tr>
<tr>
<td>TOTAL (MCHF)</td>
<td>2065</td>
<td>MCHF</td>
</tr>
<tr>
<td>TOTAL (MUSD)</td>
<td>1291</td>
<td>MUSD</td>
</tr>
<tr>
<td>INCREMENTAL COST (MCHF)</td>
<td>705</td>
<td>MCHF</td>
</tr>
<tr>
<td>INCREMENTAL COST (MUSD)</td>
<td>441</td>
<td>MUSD</td>
</tr>
</tbody>
</table>
# Estimated losses—CERN scenario

<table>
<thead>
<tr>
<th>Machine</th>
<th>Ions extracted</th>
<th>Batches</th>
<th>Loss power</th>
<th>Power/length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source+Cyclotron</td>
<td>2 e6 /s</td>
<td>52.5 ms</td>
<td>3.0 W</td>
<td>19 mW/m</td>
</tr>
<tr>
<td>Storage ring</td>
<td>1.0 e12</td>
<td>1</td>
<td>7.4 W</td>
<td>47 mW/m</td>
</tr>
<tr>
<td>Fast cycling syncrotron</td>
<td>1.0 e12</td>
<td>16</td>
<td>7.4 W</td>
<td>47 mW/m</td>
</tr>
<tr>
<td>PS</td>
<td>1.0 e13</td>
<td>1</td>
<td>765 W</td>
<td>1.2 W/m</td>
</tr>
<tr>
<td>SPS</td>
<td>0.9 e13</td>
<td>inf</td>
<td>3.63 kW</td>
<td>0.41 W/m</td>
</tr>
<tr>
<td>Decay ring</td>
<td>2.0 e14 *</td>
<td></td>
<td>157 kW</td>
<td>8.9 W/m</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Machine</th>
<th>Ions extracted</th>
<th>Batches</th>
<th>Loss power</th>
<th>Power/length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source+Cyclotron</td>
<td>8 e11 /s</td>
<td>52.5 ms</td>
<td>0.18 W</td>
<td>1.1 mW/m</td>
</tr>
<tr>
<td>Storage ring</td>
<td>4.1e10</td>
<td>1</td>
<td>0.46 W</td>
<td>2.9 mW/m</td>
</tr>
<tr>
<td>Fast cycling syncrotron</td>
<td>4.1 e10</td>
<td>16</td>
<td>56.4 W</td>
<td>90 mW/m</td>
</tr>
<tr>
<td>PS</td>
<td>5.2 e11</td>
<td>1</td>
<td>277 W</td>
<td>32 mW/m</td>
</tr>
<tr>
<td>SPS</td>
<td>5.9 e11</td>
<td>inf</td>
<td>10.6 W</td>
<td>0.6 W/m</td>
</tr>
</tbody>
</table>

These numbers assumes 8s rep rate and only include decay losses from the beta beam!

* denotes equilibrium intensity in decay ring

A. Jansson, Rencontres de Moriond 2003
Introducing Neutrino Factories

- The dream beam of every neutrino physicist.
- The first case in which the whole neutrino production chain, including proton acceleration, is accounted on the budget of the neutrino beam construction.
- Beam intensities predicted to be two orders of magnitude higher than in traditional neutrino beams.
- No hadronic MonteCarlos to predict neutrino fluxes.
- Oscillated events $N_{osc}$ at a distance $L$:

$$N_{osc} \sim \text{Flux} \times \sigma_\nu \times P_{osc} \sim \frac{E_\nu^3}{L^2} \sin^2 \frac{L}{E_\nu} \propto E_\nu$$

$N_{osc}$ increases linearly with the beam energy. Optimal energy: as high as possible.
- Neutrino beams from muon decays contain ONLY two types of neutrinos of opposite helicities ($\nu_e \nu_\mu$ or $\nu_\mu \bar{\nu}_e$). It is possible to search for $\nu_\mu \rightarrow \nu_e$ transitions characterized by the appearance of WRONG SIGN MUONS, without intrinsic beam backgrounds.
The basic concept of a neutrino factory (the CERN scheme)

- High power (4 MW) proton beam onto a liquid mercury target.
- System for collection of the produced pions and their decay products, the muons.
- Energy spread and transverse emittance have to be reduced: “phase rotation” and ionization cooling.
- Acceleration of the muon beam with a LINAC and Recirculating Linear Accelerators.
- Muons are injected into a storage ring (decay ring), where they decay in long straight sections in order to deliver the desired neutrino beams.
- **GOAL:** \( \geq 10^{20} \) \( \mu \) decays per straight section per year
Iron calorimeter
Magnetized
Charge discrimination
$B = 1 \text{T}$
$R = 10 \text{ m}, L = 20 \text{ m}$
Fiducial mass = 40 kT

Also: L Arg detector: magnetized ICARUS
Wrong sign muons, electrons, taus and NC evts

Events for 1 year

<table>
<thead>
<tr>
<th>Baseline</th>
<th>$\bar{\nu}_\mu$ CC</th>
<th>$\nu_e$ CC</th>
<th>signal ($\sin^2 \theta_{13} = 0.01$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>732 Km</td>
<td>$3.5 \times 10^7$</td>
<td>$5.9 \times 10^7$</td>
<td>$1.1 \times 10^5$</td>
</tr>
<tr>
<td>3500 Km</td>
<td>$1.2 \times 10^6$</td>
<td>$2.4 \times 10^6$</td>
<td>$1.0 \times 10^5$</td>
</tr>
</tbody>
</table>

(cf 40 in JHF-SK)

Alain Blondel, Venice, March 2003
Can genuine CP effects be separated from matter effects?

Genuine CP-odd, $\delta$ driven effects can be decoupled from matter effects, but paying a high price:

1. The experiment must be run at a baseline shorter than the optimal one.
2. A strong correlation between $\delta$ and $\theta_{13}$.
3. The experimental result is affected by the incertitude on the other parameters of the mixing matrix and by the incertitude on the matter density along the beam line.

From V. Barger et al., hep-ph/0003184.

$$|\Delta m_{32}^2| = 0.0035 \text{ eV}^2$$
$$|\Delta m_{21}^2| = 5 \times 10^{-5} \text{ eV}^2$$
$$\sin^2 2\theta_{13} = 0.004$$

![Diagram showing baseline and CP violation](image)
Simultaneous fits at $\delta$ e $\theta_{13}$ (from Nucl.Phys. B608(2001)301)
The $\delta$, $\theta_{13}$ degeneracy is better cured by the silver channel.

- From D. Autiero et al., hep-ph/0305185
- $\nu_e \rightarrow \nu_\mu$ and $\nu_e \rightarrow \nu_\tau$ oscillations have opposite sign dependence from the $\delta$ term\(^a\)
- This behavior better solves the $\delta$-$\theta_{13}$ ambiguities.
- $\nu_e \rightarrow \nu_\tau$ oscillations can be detected by an Opera/Icarus like detector.
- Computation for a detector twice as big as Opera (4 kton), at 732 km from Nufact (CERN-LNGS), coupled to a 40 kton iron magnetic detector at 2810 km (Cern-Canary Islands).

\(^a\)That can easily derived considering that 

$$p(\nu_e \rightarrow \nu_e)$$

cannot violate CP (is $T$ invariant), being

$$1 - p(\nu_e \rightarrow \nu_e) = p(\nu_e \rightarrow \nu_\tau) + p(\nu_e \rightarrow \nu_\mu),$$

the $\delta$ terms of the last two terms must cancel.
Precision measurements at the Neutrino Factories

Improve up to 4 orders of magnitude the Chooz sensitivity on $\theta_{13}$

Measure the $\Delta m^{2}_{23}$ sign

Measure the atmospheric parameters at 1%.
Neutrino Factory studies and R&D

USA, Europe, Japan have each their scheme. Only one has been costed, US study II:

<table>
<thead>
<tr>
<th>System</th>
<th>Sum ($M)</th>
<th>Others&lt;sup&gt;a&lt;/sup&gt; ($M)</th>
<th>Total ($M)</th>
<th>Reconciliation&lt;sup&gt;b&lt;/sup&gt; (FY00 $M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proton Driver</td>
<td>167.6</td>
<td>16.8</td>
<td>184.4</td>
<td>179.9</td>
</tr>
<tr>
<td>Target Systems</td>
<td>91.6</td>
<td>9.2</td>
<td>100.8</td>
<td>98.3</td>
</tr>
<tr>
<td>Decay Channel</td>
<td>4.6</td>
<td>0.5</td>
<td>5.1</td>
<td>5.0</td>
</tr>
<tr>
<td>Induction Linacs</td>
<td>319.1</td>
<td>31.9</td>
<td>351.0</td>
<td>342.4</td>
</tr>
<tr>
<td>Bunching</td>
<td>68.6</td>
<td>6.9</td>
<td>75.5</td>
<td>73.6</td>
</tr>
<tr>
<td>Cooling Channel</td>
<td>317.0</td>
<td>31.7</td>
<td>348.7</td>
<td>340.2</td>
</tr>
<tr>
<td>Pre-accel. linac</td>
<td>188.9</td>
<td>18.9</td>
<td>207.8</td>
<td>202.7</td>
</tr>
<tr>
<td>RLA</td>
<td>355.5</td>
<td>35.5</td>
<td>391.0</td>
<td>381.5</td>
</tr>
<tr>
<td>Storage Ring</td>
<td>107.4</td>
<td>10.7</td>
<td>118.1</td>
<td>115.2</td>
</tr>
<tr>
<td>Site Utilities</td>
<td>126.9</td>
<td>12.7</td>
<td>139.6</td>
<td>136.2</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>1,747.2</strong></td>
<td><strong>174.8</strong></td>
<td><strong>1,922.0</strong></td>
<td><strong>1,875.0</strong></td>
</tr>
</tbody>
</table>

+ detector: MINOS * 10 = about 300 M€ or M$

Neutrino Factory CAN be done.....but it is too expensive as is.

Aim: ascertain challenges can be met + cut cost in half.
Synergy and not competition

The cost and the time scale of the two facilities are different.

Their approach is completely complementary.

Super(Beta)Beams are needed to eliminate any parameter degeneracy in case $\theta_{13} < 2^\circ$.

The synergy of the two approaches must be used to reach the ultimate sensitivity to the leptonic CP violation.

Plot taken from A. Donini, hep-ph0310014, golden is a magnetic detector of 40 kton at 2810 km, silver is an emulsion detector of 4 kton at 732 km, SPL SB is the CERN SPL SuperBeam fired to a 400 kton Cerenkov detector at 130 Km.
Ongoing activities in Europe

Superbeam/neutrino Factory design study (sub 2005)

Neutrino factory
The ultimate tool for neutrino oscillations

APEC design study (sub 2005)

Very large underground lab
Water Cerenkov, Liq.Arg

SPL physics workshop: 25-26 May 2004 at CERN
CERN SPSC Cogne meeting sept. 2004
Conclusions

• The neutrino oscillation roadmap predicts several tens years to be completed in the simplest scenario.

• Leptonic CP violation searches require accelerators, detectors and cooperation at scales unknown to the neutrino physicists.

• A working group on physics at the future neutrino beams is active in Europe, sponsored by ECFA and the novel EU network BENE. The conveners are Pilar.Hernandez@cern.ch and Mauro.Mezzetto@pd.infn.it, the web page is http://axpd24.pd.infn.it/nowg