Neutrino oscillation

The results of Kamiokande, Superkamiokande and Soudan on atmospheric neutrino and the null result of the CHOOZE experiment can be interpreted in the terms of $\nu_\mu - \nu_\tau$ oscillation.
A year ago CERN Council took the decision to build a neutrino beam for neutrino oscillation search

The aim of the project:

detect $\nu_e$ appearance in a $\nu_\mu$ beam sent from CERN to Gran Sasso (732 km)
‘Parallel’ $\nu_\mu$ beam

A 400 Gev proton interacted in a graphite target produces in average 2.36 positive pions and .25 positive kaons (E>2Gev)

Then the pions and kaons decay into:

$\pi^+ \rightarrow \mu^+ + \nu_\mu$ 100 %

$K^+ \rightarrow \mu^+ + \nu_\mu$ 63.4 %

$K^+ \rightarrow \pi^0 + \pi^+$ 21 %

Production of the $\nu_\tau$ is negligible.

A recipe for a ‘parallel’ $\nu_\mu$ beam:

• ‘Parallel’ pion and kaon beam toward the detector
• Conditions for pions and kaons decays
CNGS at CERN site

- The beam line starts at BA4, cross the boundary and stops under Meyrin
- Vertical slope 5.6%
- Service gallery for equipment and personnel
- Equipment is about 1km away from the nearest building
Secondary beam line elements

- Horn and Reflector
- He tubes
- Decay pipe
- Hadron stop
- Muon monitoring station
- Collimators, shielding, etc...
Focusing of charged particles by Horns

It was found the combination of two of such a lens produces the best neutrino beam. Historically the first lens is referred to as Horn and second as Reflector.

To create a strong magnetic field the Horn and Reflector currents should be high:

\[ I(\text{Horn}) = 150 \text{ kA}, \ I(\text{Reflector}) = 180 \text{ kA} \]

As it is inefficiently to keep such a current permanently, the Horn and Reflector are pulsing devices.

CNGS focusing optics (positive sign particle trajectories)

- 36 GeV trajectories (Horn focusing) - 80 - 680 MeV pt
- 22 GeV trajectories (Reflector focusing) - 100 - 400 MeV pt
- 50 GeV trajectories (Reflector focusing) - 180 - 780 MeV pt
CNGS timing

SPS operating for CNGS and standard fixed target physics (e.g. test-beams, experiments)

SPS operating for CNGS while filling LHC

- Two 10µs fast extractions with 50ms interval between them.
- 6 seconds CNGS cycle.

Horn/Reflector Electrical Layout

- Charging power supply: 8kV - 15A (Nominal 6.8kV)
- Pulse 1, Pulse 2
- Shorting relay
- Manual switch
- Current transformer
- Transformer ratio = 14
- High Voltage primary
- Low Voltage secondary
- Transformer ratio
- Current transformer
- Polarity changer & Access safety
- Charging power supply: 8kV - 15A
- Transformer ratio
- Current transformer
- Polarity changer & Access safety
- Charging power supply: 8kV - 15A
- Transformer ratio
- Current transformer
- Polarity changer & Access safety
- Charging power supply: 8kV - 15A
Horn/Reflector Cooling

Important amount of energy dissipated in the Horn/Reflector by electrical current and beam is evacuated by water cooling.

*Items to control:*

- Primary and strip lines currents (each pulse)
- PS’s and discharge circuits
- Temperatures and water flows
- Timing
He tubes  Reduce probability of particle interaction with air before decay. 83m³ of He
Items to control: He flow rate and purity

Decay pipe  992m length, 1mbar pressure, $\Phi$ 2.45m
2mm thick titanium window on target chamber side
Shutter in front of the titanium window to protect personnel and equipment during an access
Items to control: pressure, shutter movement

Hadron stop

- 3.2m of graphite + 15m of iron
- water cooling
- up to 170 °C at the hottest point after 200 days of running
Items to control: temperature, water flow
Muon monitoring station

2 muon chambers (5 x 6 x 6 m each) separated by 67m of ‘molasse’

Maximal muon fluxes:

- $5 \times 10^7$ particles/cm$^2$/10µs in muon chamber 1
- $7 \times 10^5$ particles/cm$^2$/10µs in muon chamber 2

Current proposal is a system based on the solid state detectors like one which was used for a WANF (West Area Neutrino Facility) muon monitoring.

Silicon detector as flux measurement device

- About $10^4$ electrons-holes pairs/particle independent on particle nature and energy
- The detector is not counting the particles, but measuring the total charge.
- Integrated charge is proportional to the particles flux.

![Muon flux distribution](image1.png)

![Muon flux distribution](image2.png)
Neutrino Flux Monitor of WANF (94-98)

43 detectors mounted inside of the water-tight boxes and installed on the support plates

3 muon pits, 63 detectors: Pit3 - 10 fixed + 5 in Cal. Box

A remotely controlled girder (“lift”) equipped with a calibration box was able be positioned in front of any point of support plate. There was a space on each lift to transport at the same time a second box of the same type (reference box)
The disassembled detector mounting together with the light box. The detector plane shown has an active area of 2 cm².

Geometry of the detector support plane. The numbers are the position indicators.
Other main features of the system

- Individual bias voltages
- Charge sensitive amplifiers with variable gain (the gain changed from 1 to 500) with direct coupling to the detectors
- Permanent leakage current compensation (automatically each 15 min) up to the 10 µA maximum current. Changing of the detectors with higher current.
- Permanent detector calibration, which allowed to keep flux measurement resolution of individual detectors in range of 1%
- A good electronics linearity and resolution (better than 0.5% in average)
- Adaptation of the detector size to the measured flux

Muon flux profiles

- The beam centre and width were determined by the fixed detectors for each spill with a precision of ±2mm for pits 1 and 2, and ±3mm for pit 3.
- Independent beam profile scans were done by calibration boxes moved either horizontally or vertically.
  Advantage: independent on the relative SSD calibrations
  Disadvantage: average flux only
  Precision: ±1mm
Features of CNGS muon monitoring

Access to the equipment is very difficult. The challenge is to build a system which don’t need any access during 200 days run.

⇒ High reliability and redundancy

For example one possibility is to split the monitoring system into two independent ones.

Detector performance (first estimation)

<table>
<thead>
<tr>
<th>Muon Chamber 1</th>
<th>Muon Chamber 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step</strong></td>
<td><strong>Step</strong></td>
</tr>
<tr>
<td>20 cm</td>
<td>30 cm</td>
</tr>
<tr>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>1.5 mm</td>
<td>2.5 mm</td>
</tr>
<tr>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>3.0 mm</td>
<td>4.0 mm</td>
</tr>
<tr>
<td>40 cm</td>
<td>60 cm</td>
</tr>
<tr>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>2.5 mm</td>
<td>3.5 mm</td>
</tr>
<tr>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>4.0 mm</td>
<td>5.0 mm</td>
</tr>
</tbody>
</table>

Final number and positions of the detectors is under study.
Items not included in this presentation

- Control system, including synchronised with the beam DAQ
- Timing distribution, etc...

CNGS schedule/status

Summary

The main elements of the CNGS secondary beam line are:

- Horn and Reflector
- He tubes
- Decay tunnel
- Muon monitoring station

All these elements should be designed, constructed, tested and installed before the beginning of 2005.