SPL-Fréjus optimisation.

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ECFA/BENE meeting – Hamburg - 3rd November 2004

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Outline

- Particle production
- Horn design optimisation
  - Design
  - Tracking
- Decay tunnel parameter optimisation
- Flux computation at Fréjus
- $\theta_{13}$ and $\delta_{CP}$ sensitivity
- Comparison and conclusion.

LAL - 04-102, submitted soon to EPJ C
Particle production

- Proton beam:
  - Pencil like
  - $E_k=2.2\text{GeV}, 3.5\text{GeV}, 4.5\text{GeV}, 6.5\text{GeV}$ and $8\text{GeV}$
  - $10^6$ protons on target

- Target:
  - 30cm long cylinder, $\varnothing 15\text{mm}$ in Liquid mercury.
  - FLUKA 2002.4

- Normalized to a power of 4MW.
Kaon production

500 000 protons, $E_k < 5\text{GeV}$

- at 2.2 GeV:
  - $0.26 \, \pi^+/\text{s}$
  - $0.8 \times 10^{-3} \, K^+/\text{s}$

- at 3.5 GeV:
  - $0.29 \, \pi^+/\text{s}$
  - $2.8 \times 10^{-3} \, K^+/\text{s}$

- at 4.5 GeV:
  - $0.32 \, \pi^+/\text{s}$
  - $5.2 \times 10^{-3} \, K^+/\text{s}$

see BENE meeting 11/09/03
Pion production

Pion production at the exit of the target
Comparison MARS FLUKA simulators
Horn simulation

- Drawing from the horn built at CERN
- Optimized for Super Beam:
  - $E_\nu \sim 260\text{MeV}$
    
    ($p_\pi = 600\text{MeV/c}$)
  - $E_\nu \sim 300\text{MeV}$
    
    ($p_\pi = 800\text{MeV/c}$)

Using Geant 3.2.1

NuFact-Note 138
Horn design parameter

Conductor thickness: 3mm
horn: 300kAmps
reflector: 600kAmps

\[ E_\nu \sim 260 \text{MeV} \]
\[ E_\pi \sim 600 \text{MeV} \]

\[ E_\nu \sim 300 \text{MeV} \]
\[ E_\pi \sim 800 \text{MeV} \]

<table>
<thead>
<tr>
<th>HORN</th>
<th>HORN</th>
</tr>
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<tbody>
<tr>
<td>inner radius</td>
<td>3.4cm</td>
</tr>
<tr>
<td>neck length</td>
<td>40cm</td>
</tr>
<tr>
<td>outer radius</td>
<td>20.5cm</td>
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<tr>
<td>total length</td>
<td>120cm</td>
</tr>
<tr>
<td>outer radius</td>
<td>40cm</td>
</tr>
<tr>
<td>total length</td>
<td>190cm</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>REFLECTOR</th>
<th>REFLECTOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>outer radius</td>
<td>40cm</td>
</tr>
<tr>
<td>total length</td>
<td>220cm</td>
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</tbody>
</table>
**Decay Tunnel Parameters**

- **Length**
  - modify purity
  - \( L = 10\text{m}, 20\text{m}, 40\text{m} \) and \( 60\text{m} \) have been tested.
  - \( 10\text{m} \rightarrow 40\text{m} \)
    - \( \nu_\mu, \bar{\nu}_\mu \) + 50% to 70%
    - \( \nu_e, \bar{\nu}_e \) + 50% to 100%
  - \( 40\text{m} \rightarrow 60\text{m} \)
    - \( \nu_\mu, \bar{\nu}_\mu \) + 5%
    - \( \nu_e, \bar{\nu}_e \) + 20%
  - \( 40\text{m} \) seems better

- **Radius**
  - modify acceptance
  - \( R = 1\text{m}, 1.5\text{m} \) and \( 2\text{m} \) have been tested
  - \( 1\text{m} \rightarrow 2\text{m} \) \((L=40)\)
    - \( \nu_\mu, \bar{\nu}_\mu \) +50%
    - \( \nu_e, \bar{\nu}_e \) +50% to 70%
  - **2m seems better**

This results have been checked on sensitivity to \( \theta_{13} \) and \( \delta_{CP} \)
Flux calculation

- Low energy → Small boost → low focusing
- Need a high number of events (~$10^{15}$ evts!!!)
- Use probability (M. Donega thesis approach)
  - Each time a pion, a muon, or a kaon is decayed by Geant, *compute the probability for the neutrino to reach the detector*
  - Use this probability as a weight, and fill an histogram with the neutrino energy
  - There are few kaons therefore a *kaon* produced in the target is duplicated many times: ~100.
- Gives neutrino spectrum.
Neutrino Flux 100km away

\[ E_k = 3.5 \text{GeV} \]
\[ E_\nu \sim 300 \text{MeV} \]
\[ L = 40 \text{m}, R = 2 \text{m} \]

\( \pi^+ \) focusing

Evts/100m²/yr

\[ E_{\text{kine}} (\text{GeV}) \]

\( \nu_\mu \) flux

\( \nu_\mu \) flux

\( \nu_e \) flux

\( \nu_e \) flux

From \( \pi \) and \( \mu \)
From \( K^0 \)
From \( K^\pm \)
Use Mauro Mezzetto’s private code.

detector:
- Water Cerenkov
- 440 kt
- at Fréjus (130 km from CERN)

Run:
- 5 years $\pi^+$
- 1 year $\pi^+$ + 4 years $\pi^-$
- 2 years $\pi^+$ + 8 years $\pi^-$

Computed with $\delta_{CP}=0$ (standard benchmark) and $\theta_{13} = 0$

other parameters...
- $\Delta m_{23} = 2.5 \times 10^{-3}eV^2$  
  $\sin^22\theta_{23} = 1.0$
- $\Delta m_{12} = 7.1 \times 10^{-5}eV^2$  
  $\sin^22\theta_{12} = 0.82$
5 years positive focusing

Energy comparison

Focusing comparison

\( \delta_{CP} = 0 \)

\( \sin^2 2\theta_{13} > 7.1 \times 10^{-4} \)

tunnel: 40m long  
2m radius

\( E_k = 4.5\,\text{GeV} \)
\( E_\nu = 300\,\text{MeV} \)

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positive focusing vs 10 years mixed scenario.

Energy comparison

Focusing comparison

Best tunnel: 40m long
2m radius

$E_k = 3.5\text{GeV}$
$E_\nu = 300\text{MeV}$

$\sin^2 2\theta_{13} > 2.02 \cdot 10^{-3}$
90\% CL
General comparison.

- for 10 years in mixed focusing, sensitivity around $\theta_{13} \sim 1^\circ$
- Clear complementarily between positive scenario and $\beta$beam ($\delta_{CP} > 0$)
Super Beam & beta Beam

3σ discovery potential curves

M. Mezzetto
Villars SPSC 04
Conclusion

- Higher proton energy is better!
  - sensitivity to $\theta_{13}$ +25%! (fixed tunnel, 2.2GeV→3.5GeV)
- $\theta_{13}$ sensitivity, in the worse $\delta_{CP}$ case:
  - down to 1.3° with the 10y mixed scenario
  - down to 1.6° with the 5y mixed scenario
    - $E_p = 3.5$GeV, $E_\nu \sim 300$MeV
    - L=40m, R=2m
- Can measure $\delta_{CP}$!