Case Study

Design 5 - group 3

**Neutrino Source**

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Requirements

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Pulse length</td>
<td>3 ns</td>
</tr>
<tr>
<td>No. of bunches</td>
<td>5 bunches</td>
</tr>
<tr>
<td>Repetition rate</td>
<td>50 – 60 Hz</td>
</tr>
<tr>
<td>Average beam power</td>
<td>~ 4 MW</td>
</tr>
<tr>
<td>Beam energy</td>
<td>2 – 8 GeV</td>
</tr>
<tr>
<td>Particle type</td>
<td>p+ or H-</td>
</tr>
</tbody>
</table>

3 possibilities:

- Neutrino factory (µ decay)
- Super-beam (π decay)
- Beta-beams (β decay of unstable nuclei, i.e. $^{18}\text{He}^{8}\text{L}^{8}\text{B}$)
Physics considerations (I)

- $\nu$ production chain:

$$p + \text{TARGET} \rightarrow \pi \rightarrow \mu + \nu_\mu \rightarrow e + \nu_\mu + \nu_e$$

- Fast pulsed (to trap the $\pi/\mu$)
- High power: $P = I \times E_p \times f$
- Large number
- High energy
- Small energy spread
- High intensity
- High energy
- Known spectrum
- Low contamination

<table>
<thead>
<tr>
<th>High Energy ($E_p$)</th>
<th>2 – 8 GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>High repetition rate ($f$)</td>
<td>50 – 60 Hz</td>
</tr>
<tr>
<td>High power ($P$)</td>
<td>$\sim 4$ MW</td>
</tr>
<tr>
<td>Short bunches</td>
<td>5 x 3 ns</td>
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Physics considerations (II)

- From the “Interim Design Report” of the IDS-NF collaboration
Beam intensity @ TARGET

• Given the optimal parameters we can compute the number of p+ per bunch $n_p$ at the target:

$$P = e \times E_p \times n_b \times n_p \times F$$

4 MW = $e \times (2-8) \text{GeV} \times 5 \times 3 \text{ ns} \times n_p \times 50 \text{ Hz}$

• For $E_p = 2 \text{ GeV} \rightarrow n_p = 5 \times 10^{13} \text{ p+ / bunch}$

• For $E_p = 8 \text{ GeV} \rightarrow n_p = 1.25 \times 10^{13} \text{ p+ / bunch}$

*typical values for neutrino factory: $n_p \sim 10^{14}$*
Accelerator Choices

• Given the high beam intensity, power, and pulse $f_{\text{rep}}$, we should consider a LINAC-based setup
  – Provides opportunity to use the facility for other applications simultaneously

• Similar design planned for Project X (8 GeV) and studied for SPL complex (5 GeV, 534 m)

However:
  – A linac alone is not adequate for creating the necessary pulse structure at the target
  ➔ We need an accumulator + bunch compressor
LINAC parameters

- $t_{\text{pulse}} = 0.4 \text{ ms}$ (typical value)
- $f = 50 \text{ Hz}$ (required pulse repetition rate)
- H$^-$ injection
  - We computed:
    - Duty cycle: $\eta = 2\%$
    - Average current: $I = P / (E \times \eta) = 25 \text{ mA}$
  - Comparing with SPL design [see picture], we should go to higher frequency (1.4 GHz) and benefit from ILC technology (cryogenic, RF cavities)
ACCUMULATORATOR parameters

- Conventional magnets: $B = 1 \, \text{T}$
  particle energy from linac: $E = 8 \, \text{GeV}$

- We computed:
  - curvature: $\rho = 26.7 \, \text{m}$  
    ($B\rho = 3.3(p/q)$)
  - circumference: $C = 167.76 \, \text{m}$ (neglecting straight sections)
  - revolution $\tau_{\text{rev}} = 0.56 \, \mu\text{s}$
  - number of turns for injection: 715 turns

  Injection can only be made with charge exchange scheme
  - If we use a isochronous machine, no RF system needed

- We shall optimize time structure of injected beam with 5 bunches of 50 ns separated by 60 ns gaps.
Bunch structure

• **Injection into accumulator ring will be challenging**

• **Time structure:**

  ![Diagram of bunch structure with time intervals and compression process]

  - $\rho, \tau_{rev}$ will be the same as the compressor
  - RF harmonic number will be 5

• A compressor will then shorten the bunches from 50 ns to 3 ns, by phase rotation.
Summary

• Elements in our ν facility:

LINAC (H-, E = 8 GeV, \( t_{\text{pulse}} = 0.2 \text{ ms} \), \( I = 25 \text{ mA} \), duty cycle = 2%)

ACCUMULATOR (isochronous, \( n_b = 5 \), \( t_{\text{bunch}} = 50 \text{ ns} \), \( t_{\text{sep}} = 60 \text{ ns} \), \( n_p = 1.25 \times 10^{13} \))

COMPRESSOR (5 bunches, \( t_{\text{bunch}} = 50 \text{ ns} \rightarrow 3 \text{ ns} \))

• Challenges:
  – Very long linac
  – Cryogenic technology
  – Fast chopping
  – Beam losses in the linac
Thanks for Listening