Staged Approach to the NF

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“cum grano salis”

- Proton driver
- Target
- Front End
- Muon acceleration
- Decay ring

Overall Cost - for discussion

![Pie chart showing cost distribution]

- **Black** = similar for all facilities (SB plus $\beta$-beam)
- **Blue** = similar with $\beta$-beam (the cost for LENF rather half - 1/3)
- **Red** = NF only
Comment from physics group at IDS Glasgow
Even with neutrino flux reduced by ~ factor 25, NF is competitive with LBNE superbeam
LBNE cost estimate is $2.6 Billion
Without stating the secret cost number that everyone knows... but NF looks competitive with LBNE at least
Can we consider an upgrade scheme that can improve things?
Main technical risks:
- Cooling channel
  - Also “perceived” as a technical risk by community due to MICE
- Target station
  - Though risk is decreasing as design matures

Big cost to performance ratio item:
- Cooling channel

It would be nice if we could put these items in an upgrade path
Just taking the cooling channel out is undesirable
Can we use the chicane to do something clever?
3.2 Helical Motion

In the presence of a field of this nature, some particles can be shown to travel in a helix. Starting from the Lorentz equations,

\[
F = \frac{d\vec{p}}{dt} = q\vec{v} \times \vec{B}
\]  
(4)

it is possible to derive the criterion for helical motion. Assume no radial velocity, so that

\[
\vec{v} = \frac{c \left(p_y \vec{y} + p_s \vec{s}\right)}{E}
\]  
(5)

with speed of light \(c\). Then if the particle is travelling at radius \(\rho\)

\[
F = qc \frac{p_y b_0}{E \rho}
\]  
(6)

For circular or helical motion, with constant energy,

\[
F = m \gamma \rho \omega^2 = \frac{m \gamma \beta_s^2 c^2}{\rho} = \frac{c^2 p_s^2}{E r_0}.
\]  
(7)

By equating the two expressions for \(F\)

\[
\frac{c^2 p_s^2}{E \rho} = qc \frac{p_y b_0}{E \rho}.
\]  
(8)

Then if

\[
p_y = \frac{q p_s^2}{b_0}
\]

\[
b_s = b_d/\rho = 1.5 \text{ T}
\]  
(9)

particle motion will be on a helix. It should be noted that the slope of the helix is independent of the radius.
3.3 Vertical Displacement

In a chicane-type geometry vertical displacement into a collimator used to reject high momentum particles. The vertical displacement is given by

\[ \delta_y = \frac{dy}{ds} \delta_s \quad (10) \]

where \( \delta_s \) is the total path length through the circular orbit,

\[ \delta_s = \rho \delta_\theta \quad (11) \]

and \( \delta_\theta \) is the total bend angle of the chicane. The vertical divergence is given by

\[ \frac{dy}{ds} = \frac{p_y}{p_s} = \frac{q \rho s}{b_0} \quad (12) \]

so

\[ \delta_y = \frac{q \rho s}{b_0} \rho \delta_\theta = \frac{q \rho s}{b_s} \delta_\theta \quad (13) \]

and the vertical displacement is a independent of the radius of the helix. This is a useful feature as the chicane can be designed to fit the available space by adjusting the radius of curvature as appropriate.
Concept – Stage 1

p

Target
A

Decay

Buncher
Rotator
Acceleration
Concept – Stage 2

Target A

p

Decay

Target B

Decay

Buncher

Rotator

Cooling

Acceleration
Does it really work?

short chicane $r < 300$ mm, $p_{id} = \mu^+$, total energy $= 1.17$ [TeV]

Mu+ yield 10 m chicane 1 m dx

short chicane $r < 300$ mm, $p_{id} = \mu^+$, total energy $= 1.47$ [TeV]

Mu+ yield 50 m chicane 5 m dx
Does it really work?

- Short chicane $r < 300$ mm, pid = proton, total energy = 0.16 [TeV]
  - p yield
  - 10 m chicane
  - 1 m dx

- Short chicane $r < 300$ mm, pid = proton, total energy = 0.31 [TeV]
  - p yield
  - 50 m chicane
  - 5 m dx

Diagram:
- Target A
- Decay
- Target B
- Buncher
- Rotator
- Cooling
- Acceleration
Comments

- Good muon yield is pretty stable
- Is 5 m enough room
  - Need to have space for target hall plus RF hardware in front end tunnel
- In reality, may prefer two chicanes
  - One for momentum collimation
  - One for geometry

<table>
<thead>
<tr>
<th>Chicane</th>
<th>Good muon yield (ecalc9f after p_abs)</th>
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<tbody>
<tr>
<td>100 m</td>
<td>490</td>
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<tr>
<td>50 m</td>
<td>574</td>
</tr>
<tr>
<td>10 m</td>
<td>510.7</td>
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</tbody>
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Scheme

- LENF-
  - Use existing proton driver
    - Say Fermilab booster @ 700 kW
    - ~1/5 rate
    - Needs bunch compressor?
  - Remove cooling channel
    - ~1/2 rate
  - Use horn-type target
    - ~1/2 rate
  - Overall ~ 1/20 rate
  - In line with physics requirements

<table>
<thead>
<tr>
<th></th>
<th>LENF-</th>
<th>LENF+</th>
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<tbody>
<tr>
<td>Proton driver</td>
<td>0%</td>
<td>22%</td>
</tr>
<tr>
<td>Target, capture, decay</td>
<td>5%</td>
<td>11%</td>
</tr>
<tr>
<td>Front End</td>
<td>10%</td>
<td>23%</td>
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<tr>
<td>Acceleration</td>
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<td>0%</td>
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<tr>
<td>Decay Ring</td>
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<td>7%</td>
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<tr>
<td>Total</td>
<td>46%</td>
<td>63%</td>
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