Variations of the front end for a neutrino factory

David Neuffer

FNAL

(September 15, 2009)
Outline

- Front End for the Neutrino Factory/MC
  - Shorter front end example-
    - basis for present study
- Rf cavities in solenoids?
  - high gradient cavities may not work in ~2T fields
  - Option explored
    - Use lower fields (B, V')
- Need baseline design for IDS
  - need baseline for “5-year Plan”
IDS - Shorter Version

- Reduce drift, buncher, rotator to get shorter bunch train:
  - 217m $\Rightarrow$ 125m
  - 57m drift, 31m buncher, 36m rotator
  - Rf voltages up to 15MV/m ($\times 2/3$)
- Obtains $\sim 0.26 \mu/p_{24}$ in ref. acceptance
  - Similar or better than Study 2B baseline
- Better for Muon Collider
  - 80+ m bunchtrain reduced to < 50m
  - $\Delta n$: 18 $\rightarrow$ 10
Buncher-Rotator settings

- Buncher and Rotator have rf within ~2T fields
  - rf cavity/drift spacing same throughout (0.5m, 0.25)
  - rf gradient goes from 0 to 15 MV/m in buncher cavities

- Cooling baseline
  - ASOL lattice
  - 1 cm LiH slabs (3.6MeV/cell)
  - ~15MV/m cavities
  - also consider H_2 cooling
Optimizations

- Major uncertainty is high-gradient rf within solenoidal fields
  - $V'_\text{rf} / B_{\text{solenoid}}$ ??
  - Currently have $B = 1.5$ to $2$T, $V' = 12$ to $15$ MV/m
  - baseline frequency is $\sim 200$ MHz

- Experiments have achieved $\sim 14$ MV/m at $2.5$-T
  - ($\sim 0.75$-T at nearest thin Be window)
  - Solenoid near $201$ MHz cavity
Current study

- Change magnetic field, $V'_{\text{rf}}$ to study limits
- Use “short” front end for studies
  - Baseline had 2T solenoid in drift and buncher
    - 0 to 15 MV/m rf
  - 15 MV/m in rotator; 15 MV/m in cooler
    - vary rotator from 9 to 15 MV/m;
    - Cooler 10 to 18 MV/m
      - all in 0.5m rf, 0.25 drift cells
      - with lower gradient

![Diagram of particle beam path]

- FE Target
- Solenoid
- Drift
- Buncher
- Rotator
- Cooler

$p \rightarrow \pi \rightarrow \mu$

10 m  ~50 m  ~32 m  36 m  up to ~100 m
### $B_0 = 2.0T$ Results

#### Muons per 10 8-GeV protons

<table>
<thead>
<tr>
<th>Cooler/Rotator</th>
<th>10</th>
<th>12</th>
<th>14</th>
<th>15</th>
<th>17</th>
<th>18 MV/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.35 (0.63)</td>
<td>0.55 (0.67)</td>
<td>0.66</td>
<td>0.73</td>
<td></td>
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</tr>
<tr>
<td>12</td>
<td>0.57 (0.72)</td>
<td>0.754</td>
<td>0.77</td>
<td>0.80</td>
<td></td>
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</tr>
<tr>
<td>14</td>
<td></td>
<td>0.776</td>
<td>0.80</td>
<td>0.84</td>
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<tr>
<td>15</td>
<td></td>
<td></td>
<td>0.81</td>
<td>0.85</td>
<td>0.84</td>
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</tbody>
</table>

Variation is not strong; more rf still means more muons.
Next try changing $B$

- $B = 1.25$ T (~Study 2)

- match into alternating solenoid
  - Use old R. Palmer match

- As before, lower cooling gradient implies using less absorber per cell
  - $15$MV/m – $1$cm LiH
  - $12$MV/m – $0.8$cmLiH (~5% worse than 15MV/m)
  - $10$MV/m – $0.65$cm (~10% worse than ~15MV/m)
### B₀=1.25T Results

#### Muons per 10 8-GeV protons

<table>
<thead>
<tr>
<th>Cooler/ Rotator</th>
<th>10</th>
<th>12</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17 MV/m</th>
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<tbody>
<tr>
<td>9</td>
<td>0.58</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.68</td>
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<tr>
<td>10</td>
<td>0.61</td>
<td>0.65</td>
<td>0.655</td>
<td>0.705</td>
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<tr>
<td>12</td>
<td></td>
<td>0.67</td>
<td></td>
<td></td>
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<td>0.75</td>
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<td>0.72</td>
<td>0.77</td>
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<tr>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td>0.78</td>
<td>0.805</td>
<td>0.81</td>
</tr>
<tr>
<td></td>
<td>(0.65cm)</td>
<td>(0.8cm)</td>
<td>1.0cm</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>z=231m</td>
<td>z=220m</td>
<td>z=204m</td>
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</tr>
</tbody>
</table>

Variation is not strong; more rf still means more muons
B=2.0T $\rightarrow$ 1.25T

- B=2T is only slightly better than B=1.25T
  - only $\sim$5% fewer $\mu/p$ in acceptance at 1.25T

- Optimum B is (probably) somewhere in between
  - B=1.75T for study 2A
  - Cost optimum is (probably) less
Adequate acceptance can be obtained by reducing magnetic fields and gradients.

- $B \rightarrow 1.25\, \text{T}$, $V' \rightarrow 10\, \text{MV/m}$
  - (10MV/m is 7MV/m real estate gradient; could use 7MV/m if space is filled.)

- Reduced $B$, $V'$ are relatively certain to work.

- Cost optimum?
  - $B=1.5\, \text{T}$?, 12MV/m
Change cavity material - Palmer

- Tech-X rf breakdown modeling workshop

Bob is convinced Be would solve the Front End Problem?

Needs experimental tests !!!

Relative B for same strain

- Cold beryllium gives reduction $B_{\text{damage}} > 10$
  should solve the problem for all cases

Breakdown gradient $\varepsilon$ vs B for Cu, Be, Al
For other materials damage assumed at the same strain as Cu at 50 deg.
Plan for IDS

- Need one design likely to work for $V_{\text{rf}}/B$-field
  - rf studies are likely to be inconclusive
  - $B=1.25T; V'=10\text{MV/m}$ is very likely to work
  - $B=2T; V'=15\text{MV/m}$ should work with Be

- Hold review to endorse a potential design for IDS
  - likely to be acceptable ($V_{\text{rf}}/B$-field)
  - April 2010?

- Use reviewed design as basis for IDS engineering study
For IDS, we need an rf cavity + lattice that can work.

Potential strategies:

- Use lower fields \((V', B)\)
  - 10MV/m at 1.5T?
- Use non-\(B\) = constant lattices
  - alternating solenoid
- Magnetically insulated cavities
  - Is it really better ???
  - Alternating solenoid is similar to magnetically insulated lattice
- Shielded rf lattices
  - low B-field throughout rf
- Use gas-filled rf cavities
  - same gradient with/without fields
  - but electron effects?