Front End for MAP Neutrino Factory/Collider
rf considerations

David Neuffer

May 29, 2014
Outline

- Previous baseline was 200 MHz (IDS nu Factory)
  - Rf, power req.

- Front End for MAP NF/MC 325 MHz
  - Bunch train shorter than IDS ...
  - With Chicane/Absorber
  - Current baseline
    - Use short taper

- Variations under study
325MHz System “Collider”

**Drift**
- 20T → 2T

**Buncher**
- \( P_0 = 250\text{ MeV/c} \)
- \( P_N = 154 \text{ MeV/c}; \ N = 10 \)
- \( V_{rf} : 0 \rightarrow 15 \text{ MV/m} \)
  - (2/3 occupied)
- \( f_{RF} : 490 \rightarrow 365\text{MHz} \)

**Rotator**
- \( V_{rf} : 20\text{MV/m} \)
  - (2/3 occupied)
- \( f_{RF} : 364 \rightarrow 326\text{MHz} \)
- \( N = 12.045 \)
- \( P_0, P_N \rightarrow 245 \text{ MeV/c} \)

**Cooler**
- \( 245 \text{ MeV/c} \)
- \( 325 \text{ MHz} \)
- \( 25 \text{ MV/m} \)
- \( 2 \ 1.5 \text{ cm LiH absorbers} / 0.75\text{m} \)
- Add 30 m drift after chicane
  - 6.5 m → +15°, -15°
- Add chicane + absorber
  - particle 1-283 MeV/c
  - particle 2-194 MeV/c
    - absorber at 41m
      - 10 cm Be
      - particle 1-250 MeV/c
      - particle 2-154 MeV/c
- Bunch (N = 12) 0→15 MV/m: 496 → 365 MHz
- Rotate (N=12.045) - 20 MV/m: 365 → 326.5 MHz
- Cool -325 MHz -25 MV/m
  - $P_{ref} = 245$ MeV/c
ICOOL results

- **325 “muon collider” with chicane absorber**
  - with added drifts between chicane and absorber
    - ~30 m
  - ~ 0.105 μ/p → but smaller emittance beams
    - scraped to better fit?

- **Change to shorter taper**
  - 15 m → 6 m
  - (Hisham) slight improvement in throughput (~ 5%)
  - We are using Hisham’s more recent distributions
    - Gains ~ 5-10%
    - Total is now ~ 0.115 μ/p (in baseline ICOOL simulation units)

- **Better Rotator/Cooler match (Diktys)**
  - +5%
  - Cooler will be replaced by better 6-D cooler (Alexahin)
Compare 325 w chicane vs old 200

High P cutoff is ~700 MeV/c (from ~500 MeV/c)
Rf cavity

Concept  design  construction  operation
MAP rf properties (~ MICE rf)

- **Assume pillbox, Cu walls**
  - Compare with MICE rf

- **Q = ~58000**
  - \( a=0.574\text{m}, L=0.5, f=200\text{MHz} \)
  - \( T_t=0.83 \)

- **\( P_0 = 1.35\text{ MW at 10MV/m} \)**
  - \( f=200\text{MHz}, L=0.5\text{m}, E_0=10\text{MV/m} \)
  - \( U_0 = 62\text{J}, T_{\text{fill}} = 63.7\mu\text{s} \)
  - \( P_0 = 3\text{MW at 15MV/m} \)

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<table>
<thead>
<tr>
<th>MICE rf parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radius (mm)</td>
<td>610</td>
</tr>
<tr>
<td>Length (mm)</td>
<td>430</td>
</tr>
<tr>
<td>( RT^2 \text{ (MV/m)} )</td>
<td>22</td>
</tr>
<tr>
<td>Power needed (16MV/m)</td>
<td>4MW</td>
</tr>
<tr>
<td>Quality factor, ( Q_0 )</td>
<td>54,000</td>
</tr>
</tbody>
</table>

\[
Q_0 = \frac{2.405 Z_0}{2(\pi f_{rf} \rho \mu_0)^{\frac{1}{2}} (1 + \frac{a}{L})}
\]

\[
R_s = \sqrt{\rho_{Cu} \pi \mu_0 f_0}
\]

\[
U_0 = \pi \varepsilon_0 L a^2 0.52^2 \frac{E_0^2}{2}
\]

\[
P_0 = \frac{\pi R_s 0.519^2 E_0^2 a (L + a)}{Z_0^2}
\]

\[
T_t = \sin \left( \frac{\pi f_{rf} L}{c} \right)
\]

\[
T_{\text{fill}} = Q_0 \frac{\ln(2.0)}{8 \pi f_{rf}}
\]
IDS RF requirements

- **Buncher**
  - 37 cavities (13 frequencies)
  - 13 power supplies (~1—3MW)

- **RF Rotator**
  - 56 cavities (15 frequencies)
  - 12 MV/m, 0.5m
  - ~2.5MW (peak power) per cavity

- **Cooling System - 201.25 MHz**
  - 100 0.5m cavities (75m cooler), 15MV/m
  - ~4MW/cavity

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<table>
<thead>
<tr>
<th>Front End section</th>
<th>Length</th>
<th>#rf cavities</th>
<th>frequencies</th>
<th># of freq.</th>
<th>rf gradient</th>
<th>rf peak power requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buncher</td>
<td>33m</td>
<td>37</td>
<td>319.6 to 233.6</td>
<td>13</td>
<td>4 to 7.5</td>
<td>~1 to 3.5 MW/freq.</td>
</tr>
<tr>
<td>Rotator</td>
<td>42m</td>
<td>56</td>
<td>230.2 to 202.3</td>
<td>15</td>
<td>12</td>
<td>~2.5MW/cavity</td>
</tr>
<tr>
<td>Cooler</td>
<td>75m</td>
<td>100</td>
<td>201.25MHz</td>
<td>1</td>
<td>15 MV/m</td>
<td>~4MW/cavity</td>
</tr>
<tr>
<td>Total drift</td>
<td>~240m</td>
<td>193</td>
<td>29</td>
<td></td>
<td></td>
<td>~1000MV ~550MW</td>
</tr>
</tbody>
</table>

Table XIV: Summary of front-end magnet requirements.

<table>
<thead>
<tr>
<th>Length</th>
<th>Inner radius</th>
<th>Radial thickness</th>
<th>Current density</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial transport</td>
<td>0.5</td>
<td>0.68</td>
<td>0.04</td>
<td>47.5</td>
</tr>
<tr>
<td>Cooling channel</td>
<td>0.15</td>
<td>0.35</td>
<td>0.15</td>
<td>±107</td>
</tr>
</tbody>
</table>
Rf Buncher/Rotator requirements

- **Buncher -21m**
  - 37 cavities (14 frequencies)
  - 13 power supplies (~1–3MW)

- **RF Rotator -24m**
  - 64 cavities (16 frequencies)
  - 20 MV/m, 0.25m
  - ~2 MW (peak power) per cavity

- **Cooling System - 201.25 MHz**
  - 200 0.25m cavities (75m cooler), 25MV/m
  - ~4MW /cavity

### Table: Rf Buncher/Rotator requirements

<table>
<thead>
<tr>
<th>Front End section</th>
<th>Length</th>
<th># of cavities</th>
<th>Frequencies</th>
<th># of freq.</th>
<th>rf gradient</th>
<th>rf peak power requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buncher</td>
<td>21m</td>
<td>37</td>
<td>484 to 365</td>
<td>14</td>
<td>0 to 16</td>
<td>0—1.34 MW/cavity</td>
</tr>
<tr>
<td>Rotator</td>
<td>24m</td>
<td>56</td>
<td>364 to 326</td>
<td>16</td>
<td>20</td>
<td>~2.4 MW/cavity</td>
</tr>
<tr>
<td>Cooler</td>
<td>75m</td>
<td>200</td>
<td>325</td>
<td>1</td>
<td>25 MV/m</td>
<td>~3.7MW/cavity</td>
</tr>
<tr>
<td>Total</td>
<td>~134m</td>
<td>93</td>
<td>325</td>
<td>30</td>
<td>~500MV</td>
<td>140MW</td>
</tr>
</tbody>
</table>
First result on discretization

Discretization of rf frequencies

Our goal is to reduce the number of frequencies.
Going from 120 to 30 frequencies -> 8% loss

<table>
<thead>
<tr>
<th>Buncher rf parameters</th>
<th>Rotator rf parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency (MHz)</td>
<td>Gradient (MV/m)</td>
</tr>
<tr>
<td>493.71</td>
<td>0.30</td>
</tr>
<tr>
<td>482.21</td>
<td>1.24</td>
</tr>
<tr>
<td>470.27</td>
<td>1.93</td>
</tr>
<tr>
<td>458.40</td>
<td>3.38</td>
</tr>
<tr>
<td>448.07</td>
<td>4.45</td>
</tr>
<tr>
<td>437.73</td>
<td>5.52</td>
</tr>
<tr>
<td>427.86</td>
<td>6.60</td>
</tr>
<tr>
<td>418.43</td>
<td>7.67</td>
</tr>
<tr>
<td>409.41</td>
<td>8.74</td>
</tr>
<tr>
<td>400.76</td>
<td>9.81</td>
</tr>
<tr>
<td>392.48</td>
<td>10.88</td>
</tr>
<tr>
<td>384.53</td>
<td>11.95</td>
</tr>
<tr>
<td>376.89</td>
<td>13.02</td>
</tr>
<tr>
<td>369.55</td>
<td>14.30</td>
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</tbody>
</table>

[Graph showing comparison of rf pairs with different numbers]
Dependence on rf gradient

- With same cooling channel
  - 25MV/m IDS 4-D cooling
- Change Buncher/Rotator peak rf voltage
  - 0 – 25 MV/m
- Longer bunch train captured with larger V'

![Graph showing dependence on rf gradient](image-url)
Dependence on $B_{\text{final}}$

**Front end performance at different end fields**

![Graph showing the dependence of muon/proton ratio on end field strength.](image-url)
We are studying 325 MHz based front end

- produces more bunches in same length bunch train than 200 MHz
- requires more bunches to be recombined \( \sim 12 \rightarrow 21 \)
  - more difficult ... ?
  - HCC recombiner ?
- Including chicane/absorber
  - Improved matching
- Would like to fit more \( \mu \) in fewer bunches
Current Status

P5 process:

I NEED YOU TO WRITE A BUSINESS PLAN FOR OUR NEW LINE OF PRODUCTS.

IS THAT BECAUSE BUSINESS PLANS HAVE A GOOD TRACK RECORD OF BEING USEFUL AND ACCURATE?

NO, IT’S NOTHING LIKE THAT. GOOD, BECAUSE I PLAN TO MAKE UP ALL OF THE NUMBERS.

P5 Result:

I HAD A QUESTION ABOUT YOUR FEEDBACK ON MY BUSINESS PLAN.

YOU CALLED IT A "LUMBERING MONUMENT TO INCOMPETENCE, DISHONESTY AND CORPORATE DYSFUNCTION."

WHAT’S YOUR QUESTION? DO YOU THINK IT SHOULD BE LONGER?
~60 m long bunch train
- ~60 325 MHz buckets

For collider choose “best 21 bunches”
- (~19m)

Includes ~2/3 of captured μ’s
- many are lost

21 bunches are recombined to 1 in collider scenario
- It is more difficult to recombine 21 than 12

Would like to extend acceptance or generate shorter train
P5 result

The short theoretical physicist Oliver W. Jones struggles to find "The Grand Unification"... a theory linking relativity and quantum mechanics. It is the key to the mysteries of the universe.

Sir... any discoveries to report yet?

Discoveries?

Seven sixes in a circle look like a dandelion.