ν–Factory Front End
Phase Rotation Simulations

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Outline

- Neutrino Factory Front End Optimization
  - Improve neutrino factory scenario
  - For International Scoping study

- “High-frequency” Buncher and $\phi-\delta E$ Rotation
  - Study 2A scenario, Obtains $\sim 0.2 \mu/p$
  - Gas filled cavities
    - Higher gradients? In magnetic fields?
    - Cooling in buncher and rotator/shorter cheaper? System
Neutrino Factory – Study 2A

- **Proton driver**
  - Produces proton bunches
  - 8 GeV  $10^{15}$ p/s

- **Target and drift**
  - $\pi \rightarrow \mu$ ($> 0.2 \ \mu/\text{p}$)

- **Buncher, bunch rotation, cool**

- **Accelerate $\mu$ to 20 GeV**
  - Linac, RLA and FFAGs

- **Store at 20 GeV (0.4ms)**
  - $\mu \rightarrow e + \nu_\mu + \nu_e^*$

- **Long baseline $\nu$ Detector**
  - $>10^{20} \ \nu/\text{year}$
Study2AP June 2004 scenario

- **Target**: Hg-jet within 20T solenoid
- **Drift**: -110.7m – within 1.75T solenoid
- **Bunch**: -51m
  - $V\delta(1/\beta) = 0.0079$
  - 12 rf freq., 110MV
  - 330 MHz $\rightarrow$ 230MHz
- **$\phi$–E Rotate**: -54m – (416MV total)
  - 15 rf freq. 230 $\rightarrow$ 202 MHz
  - $P_1=280, P_2=154$ $\delta N_V = 18.032$
- **Match and cool**: (80m)
  - 0.75 m cells, 0.02m LiH
- “Realistic” fields, components
Simplest Modification from Study 2A

- Add gas + higher gradient to obtain **cooling within rotator**
- ~300MeV energy loss in cooling region
- Rotator is 54m;
  - Need ~4.5MeV/m H₂ Energy
  - 133atm, 295°K gas
  - ~250 MeV energy loss
- Alternating Solenoid lattice in rotator
- 20MV/m rf
- Lattice changes
“Final” configuration

- Drift, buncher as before:
  - 300 → 230MHz rf
  - 51m, $V = 3\frac{z}{z_0} + 9\left(\frac{z}{z_0}\right)^2$
- “match” from 2 T to 2.75T alternating solenoid at end of buncher
- Rotator lattice
  - 0.75m cells, 0.5m rf/cell
  - 133A H$_2$, 3.4 MeV/cell
  - $V=20$MV/m, $\phi=20^\circ$
  - 54m
- Post Rotator Cooling lattice
  - $V=16$MV/m
  - 133A H$_2$
ICOOL results– gas cavities

- \( \sim 0.20 \, \mu/p \) within reference acceptance at end of \( \phi-E \) Rotator
- \( \sim 0.10 \, \mu/p \) within restricted acceptance \( (\epsilon_\perp < 0.015 \text{m}) \)
- Rms emittance cooled from \( \epsilon_\perp = 0.019 \) to \( \epsilon_\perp = \sim 0.009 \)
- Longitudinal rms emittance \( \cong 0.075 \)
- Continuing Study 2A cooling does not greatly improve acceptance
Cooling simulation results

- Region 361: 4437 particles
  - $F_{rms} = 1.6254$
  - $L = 159.470$ m
  - $dE = 0.1919$ GeV
  - $\langle P_z \rangle_{rms} = 0.031989$ GeV/c

- Region 655: 2754 particles
  - $F_{rms} = 1.2789$
  - $L = 214.220$ m
  - $dE = 0.1986$ GeV
  - $\langle P_z \rangle_{rms} = 0.032923$ GeV/c

- Region 105: 4470 particles
  - $F_{rms} = 1.7060$
  - $L = 111.420$ m
  - $dE = 0.1987$ GeV
  - $\langle P_z \rangle_{rms} = 0.031899$ GeV/c

- Region 655: 2754 particles
  - $F_{rms} = 1.2789$
  - $L = 214.220$ m
  - $dE = 0.1986$ GeV
  - $\langle P_z \rangle_{rms} = 0.032923$ GeV/c

- Region 055: 2754 particles
  - $F_{rms} = 1.2789$
  - $L = 214.220$ m
  - $dE = 0.1986$ GeV
  - $\langle P_z \rangle_{rms} = 0.032923$ GeV/c

- Region 055: 2754 particles
  - $F_{rms} = 1.2789$
  - $L = 214.220$ m
  - $dE = 0.1986$ GeV
  - $\langle P_z \rangle_{rms} = 0.032923$ GeV/c
Modify initial solution

- Change pressure to 150 Atm
- Rf voltage to 24 MV/m
- Transverse rms emittance cools 0.019 to ~0.008 m
- Acceptance ~0.22 μ/m at \( \epsilon_T < 0.03 \) m
- ~0.12 μ/m at \( \epsilon_T < 0.015 \) m

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![Graphs showing emittance and acceptance](image-url)
Same geometry – Be Windows

- Replace 150 A gas with 0.65cm thick Be windows on cavities
- Similar dynamics as H\textsubscript{2} but
- Much worse Study 2A performance (?)
- Transverse emittance cooling: 0.019 → 0.0115
- Muons within Study 2A acceptance:
  - 0.134 \mu/p (\epsilon_t < 0.03)
  - 0.056 \mu/p (\epsilon_t < 0.015)
  Needs reoptimization?

Needs reoptimization?
Try LiH Windows

- Replace 150 A gas with 1.2cm thick LiH windows on cavities
- Similar dynamics as Be but
- **Slightly better** than Be performance (?)
- Transverse emittance cooling: 0.019 → 0.0102
- Muons within Study 2A acceptance:
  - 0.160 μ/p (ε_t < 0.03)
  - 0.075μ/p (ε_t < 0.015)

Needs reoptimization?
Cost estimates:

- Costs of a neutrino factory (MuCOOL–322, Palmer and Zisman):

<table>
<thead>
<tr>
<th>System</th>
<th>Study 2</th>
<th>Study 2B</th>
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</thead>
<tbody>
<tr>
<td>Target, capture, 18 m drift</td>
<td>97.3 M$</td>
<td>96.1 M$</td>
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<tr>
<td>Target</td>
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<td>89.7</td>
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<tr>
<td>18 m Drift</td>
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<td>Bunch and Phase Rotate</td>
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<td>Rotator</td>
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<td>Match</td>
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<td>Pre-Acc</td>
<td>136.8 M$</td>
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<td>FFAG 1</td>
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<tr>
<td>FFAG 2</td>
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<td>Ring</td>
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<td>82.5</td>
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<tr>
<td>Total</td>
<td>1427 M$</td>
<td>934 M$</td>
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</table>

Combining cooling and phase rotation may reduce cost by ~ 100 M$
# Component cost basis

Table 5: Study IIb Buncher and Phase Rotation Costs

<table>
<thead>
<tr>
<th></th>
<th>M$/GeV</th>
<th>Length</th>
<th>$/m</th>
<th>GeV</th>
<th>$/GeV</th>
<th>Scaling</th>
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<td>Buncher</td>
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<td>V/E</td>
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<td>200 MHz RF 12.5 MV/m</td>
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<td>.469</td>
<td>20x(16.1/12.5)=25.8</td>
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<td>V/E</td>
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<td>200 MHz PS</td>
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<td>120x(12.5/16.1)=93.2</td>
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</tbody>
</table>
Cost impact of Gas cavities

- Removes 80m cooling section (−185 M$)

- Increase $V_{rf}'$ from 12.5 to 20 or 24 MV/m
  - Power supply cost $\propto V'^2$ (?)
  - 44 M$ \rightarrow 107$M$ or 155$M$

- Magnets: 2T $\rightarrow$ 2.5T Alternating Solenoids
  - 23 M$ \rightarrow 26.2$ M$

- Costs due to vacuum $\rightarrow$ gas–filled cavities (??)

- Total change:
  - Cost decreases by 110 M$ to 62$ M$ (???)
Summary

• High-frequency Buncher and $\phi-\delta E$ Rotator (v-Factory)
  • Variations (Poklonskiy may help),
  • Shorter systems ?
  • Other frequencies ?

• Gas-filled rf cavities
  • Higher gradient??
  • Optimize $V'$
  • Cool in buncher rotator

To do:

• Optimizations, Best Scenario, cost/performance ...
Motivation ...
Front end with high-pressure cavities

- See K. Paul
- More for $\mu$-Collider
- Keep beam within 1 or fewer bunches
- Cavities start near target
  - (More radiation)
- Capture / phase rotate within a few meters
- Gas cavities enable cooling