Joint session – Beta-beams

Mats Lindroos
Questions

- Beta-beam concept

- Can we achieve $\gamma=350$ with LHC upgrades?
- What storage ring for $\gamma=350$, taking into account relaxed duty cycle?
- Activation of PS, SPS, storage ring?
- Production of ions: status of Rubbia’s proposal, Li/B vs He/Ne
- What is harder: increase production or gamma?
LHC injector upgrades (PAF-RG-May08)

Output energy

- 50 MeV
- 160 MeV
- 1.4 GeV
- 4 GeV
- 26 GeV
- 50 GeV
- 450 GeV
- 1 TeV
- 7 TeV
- ~ 14 TeV

- Linac2
- PSB
- PS
- SPS
- SPS+
- LHC / SLHC
- (LP)SPL
- Linac4
- PS2
- SPS+
- DLHC
- SLHC: “Superluminosity” LHC (up to $10^{35}$ cm$^2$s$^{-1}$)
- DLHC: “Double energy” LHC (1 to ~14 TeV)

Proton flux / Beam power

20 July 2007

(LP)SPL: (Low Power) Superconducting Proton Linac (4-5 GeV)
PS2: High Energy PS (~ 5 to 50 GeV – 0.3 Hz)
SPS+: Superconducting SPS (50 to 1000 GeV)
SLHC: “Superluminosity” LHC (up to $10^{35}$ cm$^2$s$^{-1}$)
DLHC: “Double energy” LHC (1 to ~14 TeV)
## Benefits for physics

<table>
<thead>
<tr>
<th>STAGE</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DESCRIPTION</strong> <em>(new accelerator)</em></td>
<td>Linac4</td>
<td>Linac4</td>
<td>Linac4</td>
<td>Linac4</td>
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<tr>
<td></td>
<td>PSB</td>
<td>PSB</td>
<td>SPL</td>
<td>SPL</td>
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<tr>
<td></td>
<td>PS</td>
<td>PS2 or PS2+</td>
<td>PS2 or PS2+</td>
<td>PS2 or PS2+</td>
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<td></td>
<td>SPS</td>
<td>(&amp; PS)</td>
<td>SPS</td>
<td>SPS+</td>
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<tr>
<td><strong>Performance of LHC injectors (SLHC)</strong></td>
<td>+</td>
<td>++</td>
<td>++</td>
<td>+++</td>
</tr>
<tr>
<td></td>
<td>Ultimate beam from PS</td>
<td>Ultimate beam from SPS</td>
<td>Maximum SPS performance</td>
<td>Highest performance LHC injector</td>
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<tr>
<td><strong>Higher energy LHC</strong></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+++</td>
</tr>
<tr>
<td><strong>β beam</strong></td>
<td>-</td>
<td>-</td>
<td>++ (γ ~150 $^6\text{He}$)</td>
<td>++ (γ ~350 $^6\text{He}$)</td>
</tr>
<tr>
<td><strong>ν Factory</strong></td>
<td>-</td>
<td>-</td>
<td>+++ (~5 GeV prod. beam)</td>
<td>+++ (~5 GeV prod. beam)</td>
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<tr>
<td><strong>k, μ</strong></td>
<td>-</td>
<td>~150 kW beam at 50 GeV</td>
<td>~400 kW beam at 50 GeV</td>
<td>~400 kW beam at 50 GeV</td>
</tr>
<tr>
<td><strong>EURISOL</strong></td>
<td>-</td>
<td>-</td>
<td>+++</td>
<td>+++</td>
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High energy storage rings

- Requires high energy injectors or a saw-saw acceleration/deceleration cycle in the decay ring
  - SPS+
- Loss of intensity due to “longer half life”
- Increased space charge problems as the “longer half life” has to be compensated
- Compromise between magnetic field in dipoles (R&D) and length of decay ring (civil engineering cost)
Higher gamma and longer life time

Graph: Annual rate vs. Gamma for 6He
# Gamma and decay-ring size, $^6$He

<table>
<thead>
<tr>
<th>Gamma</th>
<th>Rigidity [Tm]</th>
<th>Ring length $T=5\ T$ $f=0.36$</th>
<th>Dipole Field rho=300 m Length=6885m</th>
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<tbody>
<tr>
<td>100</td>
<td>935</td>
<td>4197</td>
<td>3.1</td>
</tr>
<tr>
<td>150</td>
<td>1403</td>
<td>6296</td>
<td>4.7</td>
</tr>
<tr>
<td>200</td>
<td>1870</td>
<td>8395</td>
<td>6.2</td>
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<tr>
<td>350</td>
<td>3273</td>
<td>14691</td>
<td>10.9</td>
</tr>
<tr>
<td>500</td>
<td>4676</td>
<td>20987</td>
<td>15.6</td>
</tr>
</tbody>
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New SPS  | Civil engineering  | Magnet R&D
Open midplane Dipoles

- Design for SLHC by the US LARP team (Gupta et al., MT-18, Morioka, Jp)

  - Aperture: H 135 mm, V 20 mm
  - Field: 15 T (13.5 T operation)
  - Warm targets to intercept lost ions, 40 W/m
Low duty cycle, from dc to very short bunches…

...or how to make meatballs out of sausages!

- Radioactive ions are usually produced as a “dc” beam but synchrotrons can only accelerate bunched beams.
- For high energies, linacs are long and expensive, synchrotrons are cheaper and more efficient.
Accumulation with Barrier buckets (no duty cycle)

A Barrier Bucket Experiment for Accumulating
De-bunched Beam in the AGS'

M. Blaskiewicz, J.M. Brennan
AGS Dept. Brookhaven National Laboratory
Upton, NY 11973-5000 USA

RF voltages (Barriers)  Beam current
Activation

- We can probably live with it
  - Pushing for higher intensities, it seems as an objective of $10^{19}$ neutrinos per year at the end of one straight section could be reachable considering activation issues.
- Studies of shielding and activation in the injectors in progress
  - Studies confirm that the EURISOL objectives of $10^{18}$ neutrinos per year at the end of the straight section is OK
Radiation protection issues

- Radiation safety for staff making interventions and maintenance at the target, bunching stage, accelerators and decay ring
  - 88% of $^{18}$Ne and 75% of $^6$He ions are lost between source and injection into the Decay ring
- Safe collimation of “lost” ions during stacking
  - ~1 MJ beam energy/cycle injected, equivalent ion number to be removed, ~25 W/m average
- Magnet protection
- Dynamic vacuum
- First study (Magistris and Silari, 2002) shows that Tritium and Sodium production in the ground water around the decay ring should not be forgotten
Production of beta-beam isotopes

- The Isotope Separation On-Line (ISOL) method at medium energy
  - EURISOL type production, uses typically 0.1-2 GeV protons with up to 100-200 kW beam power through spallation, fission and fragmentation

- Direct production
  - Uses low energy but high intensity ion beams on solid or gas targets. Production through compound nuclei which forms with high cross section at low energies

- Direct production enhanced with a storage ring
  - Enhancing the efficiency of the direct production through re-circulation and re-acceleration of primary ions which doesn’t react in the first passage through the target.
  - Possible thanks to ionization cooling!
Intensities at source

- ISOL method at 1-2 GeV (200 kW)
  - >1 $10^{13}$ $^6$He per second
  - <8 $10^{11}$ $^{18}$Ne per second
  - $^8$Li and $^8$B not studied
  - Studied within EURISOL

- Direct production
  - >1 $10^{13}$ (?) $^6$He per second
  - 1 $10^{13}$ $^{18}$Ne per second
  - $^8$Li and $^8$B not studied
  - Studied at LLN, Soreq, WI and GANIL

- Production ring
  - $10^{14}$ (?) $^8$Li
  - >$10^{13}$ (?) $^8$B
  - $^6$He and $^{18}$Ne not studied
  - Will be studied in EURONU DS
Direct production: $^{16}\text{O}(^{3}\text{He},n)^{18}\text{Ne}$ at LLN

- Production of $10^{12}$ $^{18}\text{Ne}$ in a MgO target:
  - At 13 MeV, 17 mA of $^{3}\text{He}$
  - At 14.8 MeV, 13 mA of $^{3}\text{He}$

- Producing $10^{13}$ $^{18}\text{Ne}$ could be possible with a beam power (at low energy) of 1 MW (or some 130 mA $^{3}\text{He}$ beam).

- To keep the power density similar to LLN (today) the target has to be 60 cm in diameter.

- To be studied:
  - Extraction efficiency
  - Optimum energy
  - Cooling of target unit
  - High intensity and low energy ion linac
  - High intensity ion source
IFMIF

3-Dimensional View of IFMIF

IFMIF SCHEMATIC LAYOUT

Overlapping Deuteron Beams
(Total Power: 250 mA @ 30 to 40 MeV)

Medium Fluence Module (1-20 dpa/yr)
Low Fluence Module (0.1-1 dpa/yr)
Specimen Capsules

High Fluence Modules (>20 dpa/yr)
Target Area (5 cm x 20 cm)
Flowing Lithium Stream (2.5 cm Thick at Target)
~1 MJ beam energy/cycle injected → equivalent ion number to be removed ~25 W/m average

Momentum collimation: ~5*10^{12} \(^6\)He ions to be collimated per cycle

Decay: ~5*10^{12} \(^6\)Li ions to be removed per cycle per meter
Summary

- Target values for beta-beams?
  - $^6$He as an example:
    - Gamma=350 (SPS+, $B_\rho \approx 3300$)
    - Requires in the order of $5 \times 10^{13}$/second out of source
    - $10^{19}$ decays per year at the end of the straight section
    - 75 W/m in decay losses In DR (3 times EURISOL)
      - 40 W/m can be managed in LARP dipole
      - 1/2 have to be collected between dipoles or/and better LARP collection system
    - 0.1 in duty factor
  - $\approx A/Q$: $^6$He=3, $^{18}$Ne=1.8, $^8$Li=2.7, $^8$B=1.6