Concepts and R&D for beta beam facilities

Elena Wildner, CERN
on behalf of
the EURISOL Beta Beam Study Group
Outline

- Beta Beam Concepts and Options
- The EURISOL Beta Beam Scenario
- Ion Production
- Loss Management
- Improvements
- Continuation
Beta-beam principle

- **Aim:** production of (anti-)neutrino beams from the beta decay of radio-active ions circulating in a storage ring
  - Similar concept to the neutrino factory, but parent particle is a beta-active isotope instead of a muon.
- **Beta-decay at rest**
  - $\nu$–spectrum well known from electron spectrum
  - Reaction energy $Q$ typically of a few MeV
- **Accelerate parent ion to relativistic $\gamma_{\text{max}}$**
  - Boosted neutrino energy spectrum: $E_\nu \leq 2\gamma Q$
  - Forward focusing of neutrinos: $\theta \leq 1/\gamma$
- **Pure electron (anti-)neutrino beam!**
- **Two different parent ions for neutrino and anti-neutrino beams**
- **Physics applications of a beta-beam**
  - Primarily neutrino oscillation physics and CP-violation
  - Cross-sections of neutrino-nucleus interaction

Beta Beam Concepts and R&D, 30 Oct 2008,  
Elena Wildner
The beta-beam options

- Baselines, L (Distance from production to detector)
  - Short ≤ 300 km (Genuine CP asymmetry measurements)
  - Medium
  - Long ~ 7500 (Matter effects)
  - Magic (most optimal sensitivities for physics reach)
- Neutrino energy and angle (γ boost and Q value)
  - Sets optimal L and flux in detector
- Interacting νμ in detector
  - Merit factor M ~ γ / E_0
- Long Baselines
  - Higher γ or higher ion Q, needs more decays
- The Electron capture beta-beam
- Ion choice limited: life time, Q-value, β⁺ & β⁻, Z/A…
The EURISOL scenario

- Based on CERN boundaries
- Ion choice: $^6$He and $^{18}$Ne
- Based on existing technology and machines
  - Ion production through ISOL technique
  - Bunching and first acceleration: ECR, linac
  - Rapid cycling synchrotron
  - Use of existing machines: PS and SPS
- Relativistic gamma=100 for both ions
  - SPS allows maximum of 150 ($^6$He) or 250 ($^{18}$Ne)
  - Gamma choice optimized for physics reach
- Opportunity to share a Mton Water Cerenkov detector with a CERN super-beam, proton decay studies and a neutrino observatory (Frejus)

Achieve an annual neutrino rate of
- $2.9 \times 10^{18}$ anti-neutrinos from $^6$He
- $1.1 \times 10^{18}$ neutrinos from $^{18}$Ne

The EURISOL scenario will serve as reference for further studies and developments: Within Euroν we will study $^8$Li and $^8$B
EURISOL Beta Beam complex

**Low-energy part**
- Ion production
- Proton Driver
  - SPL
- Ion production
  - ISOL target & Ion source
- Beam preparation
  - ECR pulsed
- Ion acceleration
  - Linac, 0.4 GeV
- Acceleration to medium energy
  - RCS, 1.5 GeV

**High-energy part**
- Acceleration
- Acceleration to final energy
  - PS & SPS
- Neutrino source
  - Decay ring
    - \( B \rho = 1500 \text{ Tm} \)
    - \( B = \sim 6 \text{ T} \)
    - \( C = \sim 6900 \text{ m} \)
    - \( L_{ss} = \sim 2500 \text{ m} \)
    - \(^6\text{He}: \gamma = 100\)
    - \(^{18}\text{Ne}: \gamma = 100\)

**Existing!!!**
- SPS
  - 93 GeV
- PS
  - 8.7 GeV

**Detector in the Frejus tunnel**

Beta Beam Concepts and R&D, 30 Oct 2008,
Elena Wildner
Options for production

- ISOL method at 1-2 GeV (200 kW)
  - $>1 \times 10^{13}$ $^{6}$He per second
  - $<8 \times 10^{11}$ $^{18}$Ne per second
  - Studied within EURISOL

- Direct production
  - $>1 \times 10^{13}$ $^{6}$He per second
  - $1 \times 10^{13}$ $^{18}$Ne per second
  - Studied at LLN, Soreq, WI and GANIL

- Production ring
  - $10^{14}$ (?) $^{8}$Li
  - $>10^{13}$ (?) $^{8}$B
  - Will be studied within EUROν

N.B. Nuclear Physics has limited interest in those elements → Production rates not pushed!

Aimed:
- He $2.9 \times 10^{18}$ ($2.0 \times 10^{13}$/s)
- Ne $1.1 \times 10^{18}$ ($2.0 \times 10^{13}$/s)

Courtesy M. Lindroos
Converter technology preferred to direct irradiation (heat transfer and efficient cooling allows higher power compared to insulating BeO).

- \( ^6\text{He} \) production rate is \( \sim 2 \times 10^{13} \) ions/s (dc) for \( \sim 200 \) kW on target.

**Projected values, known x-sections!**
Producing $10^{13}$ $^{18}$Ne could be possible with a beam power (at low energy) of 2 MW (or some 130 mA $^{3}$He beam on MgO).

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

S. Mitrofanov and M. Loislet at CRC, Belgium
Studied $^9$Be($n,\alpha$)$^6$He, $^{11}$B($n,\alpha$)$^8$Li and $^9$Be($n,2n$)$^8$Be production.

For a 2 mA, 40 MeV deuteron beam, the upper limit for the $^6$He production rate via the two stage targets setup is $\sim 6 \cdot 10^{13}$ atoms per second.

T.Y.Hirsh, D.Berkovits, M.Hass
(Soreq, Weizmann I.)
New approaches for ion production


Will be studied in Eurov FP7:
Design of ring
Cooling in ring
Collection device
ECR Source


\[ ^7\text{Li}(d,p)^8\text{Li} \]
\[ ^6\text{Li}(^3\text{He},n)^8\text{B} \]
# Overview, production

<table>
<thead>
<tr>
<th>Illustration</th>
<th>METHOD</th>
<th>Advantage</th>
<th>Drawback</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Production ring" /></td>
<td>Production ring</td>
<td>-“Re-use” of driver beam thanks to cooling&lt;br&gt;-Huge cross sections for compound nucleus</td>
<td>-Challenging gas target design&lt;br&gt;-Collection device efficiency</td>
</tr>
<tr>
<td><img src="image2.png" alt="Converter target" /></td>
<td>Converter target, with low and high energy driver</td>
<td>Can accept very high intensity driver beam (&gt;1 MW)</td>
<td>Limited to neutron produced isotopes such as $^6$He and $^8$Li</td>
</tr>
<tr>
<td><img src="image3.png" alt="ISOL with &gt;1 GeV protons" /></td>
<td>ISOL with &gt;1 GeV protons</td>
<td>Universal, any non-refractory isotope can be produced at high intensity with good beam quality</td>
<td>Can only accepted up to some 100 kW of driver beam</td>
</tr>
<tr>
<td><img src="image4.png" alt="Direct production" /></td>
<td>Direct production</td>
<td>-Low energy and high intensity driver&lt;br&gt;-Huge cross sections for compound nucleus</td>
<td>-Challenging very high intensity driver design&lt;br&gt;-Extraction efficiency</td>
</tr>
</tbody>
</table>

*Courtesy M. Lindroos*
Work on Radiation Issues

- **Radiation safety**
  - 88% of $^{18}$Ne and 75% of $^6$He ions are lost between source and injection into the Decay Ring
  - Detailed studies on RCS (manageable)
  - PS preliminary results available (heavily activated, 1 s flat bottom)
  - SPS and Decay Ring studies ongoing

- **Safe collimation** of ions during stacking, ongoing
  - ~1 MJ beam energy/cycle injected, equivalent ion number to be removed, ~25 W/m average

- **Magnet protection** (PS and Decay Ring manageable)

- **Dynamic vacuum**, studies ongoing

- Tritium and Sodium production in the **ground water** needs to be studied when site known (Magistris and Silari, 2002)
Radio protection: Stefania Trovati, CERN

1. Injection losses
2. RF capture losses
3. Decay Losses

- Shielding
- Airborne activity (in tunnel and released in environment)
- Residual dose

- All within CERN rules
- 1 day or one week depending on where for access* (20 mins for air)
- Shielding needed (with margin) 4.5 m concrete shield

* “Controlled area”
The coils could support 60 years operation with a EURISOL type beta-beam.
- Momentum collimation: $\sim5 \times 10^{12}$ $^{6}$He ions to be collimated per cycle
- Decay: $\sim5 \times 10^{12}$ $^{6}$Li ions to be removed per cycle per meter
Longitudinal Merging

Mandatory for success of the $\gamma=100$ beta-beam concept
Lifetime of ions (minutes) is much longer than cycle time (seconds) of a beta-beam complex

1) Injection

Merging: “oldest” particles pushed outside longitudinal acceptance $\rightarrow$ momentum collimation

2) Rotation

3a) Single merge

3b) Repeated merging

Courtesy Steven Hancock, CERN
Decay Ring Stacking: experiment in CERN PS

Ingredients
- h=8 and h=16 systems of PS.
- Phase and voltage variations.

S. Hancock, M. Benedikt and J.-L. Vallet, CERN
Decay Ring Lattice design: A. Chancé and J. Payet, CEA Saclay

Peak Power Deposition in cable along magnet (FLUKA)

- Need to reduce a factor 5 on midplane
  - Liners with cooling
  - Open Midplane magnets
**Open Midplane Dipole for Decay Ring**

**Cos2\(\theta\) design open midplane magnet**

Manageable (7 T operational) with Nb - Ti at 1.9 K

Aluminum spacers possible on midplane to retain forces: gives transparency to the decay products

Special cooling and radiation dumps may be needed inside yoke.

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J. Bruer, E. Todesco, CERN
The study will focus on production issues for $^{8}\text{Li}$ and $^{8}\text{B}$

- $^{8}\text{B}$ is highly reactive and has never been produced as an ISOL beam
- Production ring: enhanced direct production
  - Ring lattice design
  - Cooling
  - Collection of the produced ions (UCL, INFN, ANL), release efficiencies and cross sections for the reactions
  - Sources ECR (LPSC, GHMFL)
  - Supersonic Gas injector (PPPL)

Parallel studies

- Multiple Charge State Linacs (P Ostroumov, ANL)
- Intensity limitations
The beta-beam in EURONU DS (II)

- Optimization of the Decay Ring (CERN, CEA, TRIUMF)
  - Lattice design for new ions
  - Open midplane superconducting magnets
  - R&D superconductors, higher field magnets
  - Field quality, beam dynamics
  - Injection process revised (merging, collimation)
- A new PS?
  - Magnet protection system
  - Intensity limitations?
- Overall radiation & radioprotection studies
Summary

- The EURISOL beta-beam conceptual design report will be presented in second half of 2009
  - First coherent study of a beta-beam facility
- Continuation of the work: a beta-beam facility using $^8\text{Li}$ and $^8\text{B}$
  - Experience from EURISOL
  - First results will come from Eurov DS beta beam WP started 1 Sept. 2008 (4 year study)
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