Beta Beams

Elena Wildner, CERN
Outline

- Beta Beam Concepts
- A Beta Beam Scenario
- Ion Production
- Other challenges
- Conclusion
Beta-beams, recall

Aim: production of (anti-)neutrino beams from the beta decay of radioactive 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 the 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!
  - Depending on $\beta^+$- or $\beta^-$- decay we get a neutrino or anti-neutrino
  - 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
**Choice of radioactive ion species**

- **Beta-active isotopes**
  - Production rates
  - Life time
  - Dangerous rest products
  - Reactivity (Noble gases are good)

- **Reasonable lifetime at rest**
  - If too short: decay during acceleration
  - If too long: low neutrino production
  - Optimum life time given by acceleration scenario
  - In the order of a second

- **Low Z preferred**
  - Minimize ratio of accelerated mass/charges per neutrino produced
  - One ion produces one neutrino.
  - Reduce space charge problems

<table>
<thead>
<tr>
<th>Isootope</th>
<th>A/Z</th>
<th>$t_{1/2}$ (s)</th>
<th>Q$_{eff}$ (MeV)</th>
<th>$Q_{av}$ (MeV)</th>
<th>$E_{av}$ (MeV)</th>
<th>$E_{av}$ (MeV)</th>
<th>Ions/bunch</th>
<th>Decay rate ($\sec^{-1}$)</th>
<th>rate / $E_{av}$ ($\sec^{-1}$)</th>
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<tbody>
<tr>
<td>$^6\text{He}$</td>
<td>3.0</td>
<td>0.80</td>
<td>3.5</td>
<td>3.5</td>
<td>1.57</td>
<td>1.94</td>
<td>5×10$^{-12}$</td>
<td>6He and 18Ne</td>
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<td>$^8\text{He}$</td>
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<td>0.11</td>
<td>10.7</td>
<td>9.1</td>
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<td>4.80</td>
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<td>8Li and 8B</td>
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<tr>
<td>$^6\text{Li}$</td>
<td>2.7</td>
<td>0.83</td>
<td>16.0</td>
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<td>11.5</td>
<td>9.8</td>
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<td></td>
<td></td>
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<tr>
<td>$^1\text{C}$</td>
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<td>24.4</td>
<td>9.8</td>
<td>6.4</td>
<td>2.87</td>
<td>3.55</td>
<td>2×10$^{-12}$</td>
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<td>$^1\text{O}$</td>
<td>2.7</td>
<td>0.74</td>
<td>8.0</td>
<td>4.5</td>
<td>2.05</td>
<td>2.46</td>
<td>2×10$^{-12}$</td>
<td></td>
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<td>$^1\text{Ne}$</td>
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<td>19.1</td>
<td>10.4</td>
<td>5.9</td>
<td>4.59</td>
<td>1.33</td>
<td>1×10$^{-12}$</td>
<td></td>
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<td>$^1\text{Na}$</td>
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<td>4.17</td>
<td>8.7</td>
<td>3.8</td>
<td>1.71</td>
<td>2.10</td>
<td>1×10$^{-12}$</td>
<td></td>
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</table>
The EURISOL scenario\(^(*)\) boundaries

- 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 Cherenkov detector with a CERN super-beam, proton decay studies and a neutrino observatory

**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 Eurov we will study \(^8\)Li and \(^8\)B

\(^*)\ FP6 "Structuring the European Research Area" programme (CARE, contract number RII3-CT-2003-506395)
Some scaling

- Accelerators can accelerate ions up to $Z/A \times \text{the proton energy.}$

- $L \sim E_v / \Delta m^2 \sim \gamma Q$, $\text{Flux} \sim L^{-2} \Rightarrow \text{Flux} \sim Q^{-2}$

- Cross section $\sim E_v \sim \gamma Q$

- Merit factor for an experiment at the atmospheric oscillation maximum: $M = \gamma / Q$

- Decay ring length scales $\sim \gamma$ (ion lifetime)
The EURISOL scenario

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

$^6$He: $\gamma = 100$
$^{18}$Ne: $\gamma = 100$

Decay ring
$B_\rho = 1500$ Tm
$B = \approx 6$ T
$C = \approx 6900$ m
$L_{ss} = \approx 2500$ m

Design report July 2009
ECR, Linac, RCS, Decay Ring (Nufact08)

T. Thuillier, L. Latrasse, T. Lamy, C. Fourel, J. Giraud, LPSC, CNRS/IN2P3-UJF-INP Grenoble, Trophime, P. Sala, J. Dumas, F. Debray, LCMI, CNRS, Grenoble

LINAC Design: A. Bechtholt, Frankfurt am Main

RCS design: A. Lachaize, A. Tkatchenko, IPNO, CNRS

Antoine CHANCÉ, Jacques Payet, CEA Saclay IRFU/SACM

22/07/09  Beta Beams, Nufact09, Elena Wildner
Intensity evolution during acceleration

Cycle optimized for neutrino rate towards the detector

30% of first $^6$He bunch injected are reaching decay ring
Overall only 50% ($^6$He) and 80% ($^{18}$Ne) reach decay ring

Normalization
Single bunch intensity to maximum/bunch
Total intensity to total number accumulated in RCS
Radioprotection

Residual Ambient Dose Equivalent Rate at 1 m distance from the beam line (mSv h⁻¹)

<table>
<thead>
<tr>
<th></th>
<th>RCS (quad - ¹⁸Ne)</th>
<th>PS (dip - ⁶He)</th>
<th>SPS</th>
<th>DR (arc - ¹⁸Ne)</th>
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</thead>
<tbody>
<tr>
<td>1 hour</td>
<td>15</td>
<td>10</td>
<td>-</td>
<td>5.4</td>
</tr>
<tr>
<td>1 day</td>
<td>3</td>
<td>6</td>
<td>-</td>
<td>2.6</td>
</tr>
<tr>
<td>1 week</td>
<td>2</td>
<td>2</td>
<td>-</td>
<td>1.4</td>
</tr>
</tbody>
</table>

Annual Effective Dose to the Reference Population (µSv)

<table>
<thead>
<tr>
<th></th>
<th>RCS</th>
<th>PS</th>
<th>SPS</th>
<th>DR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.67</td>
<td>0.64</td>
<td>-</td>
<td>5.6 (only decay losses)</td>
</tr>
</tbody>
</table>

Stefania Trovati, Matteo Magistris, CERN

22/07/09  Beta Beams, Nufact09, Elena Wildner
Activation and coil damage in the PS

StrahlSim: Losses

He-beam. Decay products tracked to the collimator and beampipe (red & black curves).

The coils could support 60 years operation with a EURISOL type beta-beam

M. Kirk et. al GSI
Particle turnover in decay ring

- Momentum collimation (study ongoing):
  - $\sim 5 \times 10^{12}$ $^6$He ions to be collimated per cycle
  - Decay: $\sim 5 \times 10^{12}$ $^6$Li ions to be removed per cycle per meter
Duty factor and Cavities for He/Ne

$10^{14}$ ions, 2% !!!

20 bunches, 10 ns long, distance 23*4 nanoseconds
filling 1/11 of the Decay Ring, repeated every 23
microseconds

Erk Jensen, CERN

- Not conclusive yet - only first ideas - more work is needed!
- The heavy transient beam loading is unprecedented.
- Since there is no net energy transfer to the beam, the problem might be solved using a linear phase modulation in the absence of the beam, mimicking detuning - this could reduce gap transients.
- A high Q cavity (S.C.?) would be preferable.
Open Midplane Dipole for Decay Ring

Cos$2\theta$ 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.

J. Bruer, E. Todesco, CERN
Open mid-plane Quadrupole

Acknowledgments (magnet design):
F Borgnolutti, E. Todesco (CERN)
Open mid-plane Quadrupole

Acknowledgments (magnet design):
F Borgnolotti, E. Todesco (CERN)
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 EURO

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

**Try to get resources to pursue ideas how to produce Ne!**
Options for production

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

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

- **Production ring**
  - $10^{14} \text{ } ^8\text{Li}$
  - $>10^{13} \text{ } ^8\text{B}$
  - Will be studied Within EUROv

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

  *Courtesy M. Lindroos*

N.B. Nuclear Physics has limited interest in those elements => Production rates not pushed!
Try to get ressources to persue ideas to produce Ne!
Converter technology preferred to direct irradiation (heat transfer and efficient cooling allows higher power compared to insulating BeO).

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

Recent measurements at ISOLDE

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T. Stora, N. Thollieres, CERN
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 EUROv

**N.B.** Nuclear Physics has limited interest in those elements => Production rates not pushed!
Try to get resources to pursue ideas to produce Ne!
18Ne (Direct Production)

Geometric scaling

- 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

T. Stora, CERN, 2009 -> ?
6He (Two Stage ISOL)

- 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.

- Interesting also for $^8$Li

T.Y.Hirsh, D.Berkovits, M.Hass
(Soreq, Weizmann I.)

It seems we can produce plenty of antineutrinos…
Options for production

- ISOL method at 1-2 GeV (200 kW)
  - >1 $10^{13}$ $^6$He per second
  - <8 $10^{11}$ $^{18}$Ne per second
  - Studied within EURISOL
  - 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)
- Direct production
  - >1 $10^{13}$ (?) $^6$He per second
  - 1 $10^{13}$ $^{18}$Ne per second
  - Studied at LLN, Soreq, WI and GANIL
- Production ring
  - $10^{14}$ (?) $^8$Li
  - >$10^{13}$ (?) $^8$B
  - Difficult Chemistry
  - Will be studied Within EURO

N.B. Nuclear Physics has limited interest in those elements => Production rates not pushed!
Try to get resources to pursue ideas to produce Ne!
New approaches for ion production


Supersonic gas jet target, stripper and absorber


Studied within Eurov FP7 (*)

(*) FP7 “Design Studies” (Research Infrastructures) EUROOnu (Grant agreement no.: 212372)
Beta Beam scenario EUROnu, FP7

- Ion Linac 20 MeV
- Ion production
- ISOL target, Collection
- 60 GHz pulsed ECR
- Linac, 0.4 GeV
- RCS, 5 GeV
- PR 8B/8Li

Existing!!!

SPS 92 GeV

Decay ring
B_p ~ 500 Tm
B = ~6 T
C = ~6900 m
L_{ss} = ~2500 m

8 Li: \( \gamma = 100 \)
18 B: \( \gamma = 100 \)

Detector Gran Sasso (~ 5 times higher Q)

22/07/09
Beta Beams, Nufact09, Elena Wildner
The beta-beam in EURONU DS (I)

- The study will focus on production issues for $^8$Li and $^8$B
  - $^8$B is highly reactive and has never been produced as an ISOL beam
- Production ring: enhanced direct production
  - Ring lattice design (CERN)
  - Cooling (CERN +)
  - Collection of the produced ions, release efficiencies and cross sections for the reactions (UCL, INFN, ANL)
  - Sources ECR (LPSC, GHMFL)
  - Supersonic Gas injector (PPPL +)

- CERN Complex
  - All machines to be simulated with B and Li (CERN, CEA)
  - PS2 presently under design (apertures!)
  - Multiple Charge State Linacs (P Ostroumov, ANL)
Associated partners in EURONU DS

Possible realization with one detector only (price)

$\nu_\mu$-beam:

SPL: $<E_\nu> = 260$ MeV  
$L_{opt} = 134$ km

CERN – Frejus: 130 km

$\nu_e$-beam:

$\gamma = 150$ Lopt = 130 km  
$\gamma = 500$ Lopt = 1000 km

CERN – Frejus: 130 km  
DESY – Frejus: 960 km

3-Flavor Oscillation needs two significantly different baselines to disentangle CP and matter effects
The production Ring: Ion Source for Beta Beams

- 12m circumference
- mirror symmetrical structure
- 1.5T dipoles
- 5 quadrupole-families
- $Dx = 0$ in cavity-section
- best choice of $Dx$ in target-section depends on wedge angle of the target

Michaela Schaumann, Aachen/CERN, 2009
Simulations, Production Ring (ion source)

Li-8 production

Energies of the incoming beam
- 100 MeV Li7 beam
- 90 MeV Li7 beam
- 80 MeV Li7 beam
- 70 MeV Li7 beam
- 60 MeV Li7 beam
- 50 MeV Li7 beam
- 40 MeV Li7 beam
- 30 MeV Li7 beam

GEANT4

Jokob Wehner, Aachen/CERN, 2009

Minimum angle of the wedge for different dispersions

Dispersion
- 60 cm
- 55 cm
- 50 cm
- 45 cm
- 40 cm

Jokob Wehner, Aachen/CERN, 2009
The production ring cooling: review

Low-energy Ionization cooling of ions for Beta Beam sources – D. Neuffer (FERMILAB-FN-0808-APC)

Mini-workshop Fermilab next week on Beta Beams, ionization cooling (David Neuffer)
Challenge: collection device

- A large proportion of beam particles ($^6$Li) will be scattered into the collection device.

- Production of $^8$Li and $^8$B:
  - $^7$Li(d,p) $^8$Li and $^6$Li($^3$He,n) $^8$B reactions using low energy and low intensity ~ 1nA beams of $^6$Li(4-15 MeV) and $^7$Li(10-25 MeV) hitting the deuteron or $^3$He target.

Collection on axis

Rutherford scattered particles

8B-ions

Semen Mitrofanov
Marc Loiselet
Thierry Delbar
Collection Device, Schedule

- Semen Mitrofanov
- Marc Loiselet
- Thierry Delbar

- First beam runs – November-December’09 – several two days runs
- Full-time beam tests - January-February’10

- End of the summer’10 - we hope we will finished with $^8$Li.

Terra Incognita:

“We have 1 years to discover how to produce $^8$B beam of necessary intensity and 1.5 year to develop the production technique »
Cross section measurements at Laboratori Nazionali di Legnaro

M. Mezzetto (INFN-Pd)
on behalf of
INFN-LNL: M. Cinausero, G. De Angelis, G. Prete

First Experiment performed in July 2008

Inverse kinematic reaction:
$^7$Li + Cd$_2$ target    $E=25$ MeV
Data reduction in progress
Future: reduce contamination
ECR Source

100 kV insulation

Ground
V=0

MW window

polyhelix

polyhelix

polyhelix

polyhelix

V= 100 kV

Multi electrode extraction

Ions extraction

insulator

Water cooled plasma chamber

60 GHz Microwaves

T. Lami

Beta Beams, Nufact09, Elena Wildner
How to get a 60 GHz Gyrotron and perform experiments?

Use any external resources possible (collaborate!!)  

T. Lami

ISTC project:
IAP Nizhny Novgorod (Plasma physics theory and experiments, gyrotron manufacturing)

LPSC in this programme will be responsible of the design and construction of various ECR ion sources with the help of LNCMI.

LNCMI has committed itself to the magnetic characterization (i.e. a permanent room for experiments + electrical Power!!)

As the leader of one of the work packages in the EUROnu collaboration, the “Beta Beam” work package, for which CERN is the leading institute, I can only encourage the mentioned ISTC project. The ion source is one of the crucial parts for the success of the EUROnu beta beam project.

| Estimated total cost of the project (US $) | 1 000 000 |
| Requested from the ISTC               | 710 000   |
| Other financial source 1: LPSC          | 290 000   |
Associates

- Weizmann Institute of Science, Revohot
  - Michael Hass
  - Partners: GANIL and Soreq
  - Collaboration with Aachen (exchange of students)

- Work Focus
  - produce light radioactive isotopes also for beta beams
  - secondary neutrons from an intense, 40 MeV d beam (6He and 8Li) and direct production with 3He or 4He beams (18Ne).
  - Use of superconducting LINACs such as SARAF at Soreq (Israel) and the driver for SPIRAL-II (GANIL).

- Added Value
  - To produce strong beta beam ion candidates or production methods not in EUROnu

Courtesy Micha Hass
## He/Ne & Li/B

### Bottom-up Exit Intensities

<table>
<thead>
<tr>
<th></th>
<th># 8B Ions</th>
<th># 8Li Ions</th>
<th># 18Ne Ions</th>
<th># 6He Ions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source rate</td>
<td>$2.10^{13}$</td>
<td>$2.10^{13}$</td>
<td>$8.10^{11}$</td>
<td>$2.10^{13}$</td>
</tr>
<tr>
<td>ECR</td>
<td>$5.610^{11}$</td>
<td>$1.6910^{12}$</td>
<td>$2.2210^{10}$</td>
<td>$1.8510^{12}$</td>
</tr>
<tr>
<td>RCS inj</td>
<td>$2.7910^{11}$</td>
<td>$8.410^{11}$</td>
<td>$1.1110^{10}$</td>
<td>$9.2310^{11}$</td>
</tr>
<tr>
<td>RCS</td>
<td>$2.7310^{11}$</td>
<td>$8.1810^{11}$</td>
<td>$1.0910^{10}$</td>
<td>$8.9710^{11}$</td>
</tr>
<tr>
<td>PS inj</td>
<td>$4.1810^{12}$</td>
<td>$1.1410^{13}$</td>
<td>$1.9110^{11}$</td>
<td>$1.210^{13}$</td>
</tr>
<tr>
<td>PS</td>
<td>$3.8410^{12}$</td>
<td>$1.10^{13}$</td>
<td>$1.8210^{11}$</td>
<td>$1.0310^{13}$</td>
</tr>
<tr>
<td>SPS</td>
<td>$3.7510^{12}$</td>
<td>$9.5510^{12}$</td>
<td>$1.810^{11}$</td>
<td>$9.7410^{12}$</td>
</tr>
<tr>
<td>Decay Ring</td>
<td>$1.1310^{14}$</td>
<td>$2.4110^{14}$</td>
<td>$3.1310^{12}$</td>
<td>$1.0410^{14}$</td>
</tr>
</tbody>
</table>

### Annual Neutrino Rates

<table>
<thead>
<tr>
<th></th>
<th># $\nu$ from 8B</th>
<th># anti-$\nu$ from 8Li</th>
<th># $\nu$ from 18Ne</th>
<th># anti-$\nu$ from 6He</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Rate</td>
<td>$3.7510^{18}$</td>
<td>$7.1610^{18}$</td>
<td>$4.6410^{16}$</td>
<td>$3.1410^{18}$</td>
</tr>
<tr>
<td>Required Annual Rate</td>
<td>$5.510^{18}$</td>
<td>$1.4510^{20}$</td>
<td>$1.110^{18}$</td>
<td>$2.910^{19}$</td>
</tr>
</tbody>
</table>

Courtesy Christian Hansen May 2009

\[ \frac{^7\text{Be}}{^4\text{Be}} \rightarrow e^+ + \nu_e \]
\[ \frac{^3\text{Li}}{^4\text{Be}} \rightarrow e^- + \bar{\nu}_e \]
\[ \frac{^{18}\text{Ne}}{^9\text{F}} \rightarrow e^+ + \nu_e \]
\[ \frac{^6\text{He}}{^6\text{Li}} \rightarrow e^- + \bar{\nu}_e \]
No dutycycle

- With RF Barrier Bucket gymnastics the DR could maybe be used till full saturation (investigations ongoing)

- For the 6He and 18Ne ions however bunching was needed and merging allowed for only 15 and 20 injections respectively
Barrier Buckets, relaxed duty factor

See Poster Session today: Christian Hansen (CERN)
## 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>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>938</td>
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Magnet R&D
Conclusions (i)

- The EURISOL beta-beam conceptual design report will be presented in second half of 2009
- First coherent study of a beta-beam facility
- Top down approach
- 18Ne shortfall
- Duty Factors are challenging: Collimation and RF in Decay Ring
Conclusions (ii)

- A beta-beam facility using $^8\text{Li}$ and $^8\text{B}$ (EUROnu)
  - Experience from EURISOL
  - Production issues (not to forget $^{18}\text{Ne}$)
  - Optimize chain
  - Revisit Duty Factors
  - Apertures of PS2
  - (Complete) simulation of beta beam complex
  - Costing (add what is not in EUROnu)
  - **First results will come from Euronu DS (2008-2012)**
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