Beta beam R&D status

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

- Recall, EURISOL
- Ion Production
- Loss Management
- Improvements
- New Program, EuroNu
The beta-beam options

- Low energy beta-beams
  - Lorentz gamma < 20, nuclear physics, double beta-decay nuclear matrix elements, neutrino magnetic moments

- The medium energy beta-beams or the EURISOL beta-beam
  - Lorentz gamma approx. 100 and average neutrino energy at rest approx. 1.5 MeV (P. Zucchelli, 2002), choice for first study

- The high energy beta-beam
  - Lorentz gamma 300-500, average neutrino energy at rest approx. 1.5 MeV

- The very high energy beta-beam
  - Lorentz gamma >1000

- The high Q-value beta-beam
  - Lorentz gamma 100-500 and average neutrino energy at rest 6-7 MeV

- The Electron capture beta-beam
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=100/100
  - 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 EuroNu we will study $^8$Li and $^8$B
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
  - $^8$Li and $^8$B not studied
  - Studied within EURISOL

- Direct production
  - $>1 \times 10^{13}$ (?) $^6$He per second
  - $1 \times 10^{13}$ $^{18}$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 the future

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

More on production:
see talks by
M. Lindroos and
P. Delahaye, FP7
$^6$He production from $^9$Be(n,α)

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.

Projected values, known x-sections!
Preliminary results from Louvain la Neuve, CRC

- Production of $10^{12}$ $^{18}$Ne in a MgO target:
  - At 13 MeV, 17 mA of $^3$He
  - At 14.8 MeV, 13 mA of $^3$He
- 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).
- 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
Light RIB Production with a 40 MeV Deuteron Beam

- T.Y. Hirsh, D. Berkovits, M. Hass (Soreq, Weizmann I.)
- Studied $^9$Be(n,α)$^6$He, $^{11}$B(n,α)$^8$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.
New approaches for the production


Will be studied in Euronu FP7
The production ring concept: review

- Low-energy Ionization cooling of ions for Beta Beam sources –
  D. Neuffer (To be submitted)

  - Mixing of longitudinal and horizontal motion necessary
  - Less cooling than predicted
  - Beam larger but that relaxes space charge issues
  - If collection done with separator after target, a Li curtain target with \(^3\)He and Deuteron beam would be preferable
  - Separation larger in rigidity
Challenge: collection device

- A large proportion of beam particles ($^6$Li) will be scattered into the collection device.
- The scattered primary beam intensity could be up to a factor of 100 larger than the RI intensity for 5-13 degree using a Rutherford scattering approximation for the scattered primary beam particles (M. Loislet, UCL)
- The $^8$B ions are produced in a cone of 13 degree with 20 MeV $^6$Li ions with an energy of 12 MeV±4 MeV (33%!).

![Diagram showing collection off axis (Wien Filter) and collection on axis with Rutherford scattered particles and $^8$B-ions.]

8B-ions
Rutherford scattered particles
Collection off axis (Wien Filter)
Collection on axis
8B-ions

Nufact 2008
The Beta Beam WP
Ongoing work on Radiation 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
  - Detailed studies on RCS
  - PS preliminary results available
- 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** (PS and Decay ring)
- Dynamic **vacuum**
- First study (Magistri and Silari, 2002) shows that Tritium and Sodium production in the **ground water** around the decay needs to be studied
Loss management

- Losses during acceleration

- Preliminary results:
  - Manageable in low-energy part.
  - PS heavily activated (1 s flat bottom).
    - Collimation? New machine?
  - SPS ok.
  - Decay ring losses:
    - Tritium and sodium production in rock is well below national limits.
    - Reasonable requirements for tunnel wall thickness to enable decommissioning of the tunnel and fixation of tritium and sodium.
    - Heat load should be ok for superconductor (E. Wildner, CERN, F. Jones, TRIUMF, PAC07).
Radioprotection: Detailed study for RCS

Stefania Trovati, CERN

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

- Shielding
- Airborne activity (in tunnel/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”

RCS design: See talk by A. Lachaize,
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: \(~5 \times 10^{12} \) \(^{6}\)He ions to be collimated per cycle
- Decay: \(~5 \times 10^{12} \) \(^{6}\)Li ions to be removed per cycle per meter
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, *A proof of principle of asymmetric bunch pair merging, AB-Note-2003-080 MD*
Decay Ring Collimation

A. Chancé and J. Payet, CEA Saclay, IRFU/SACM

- Momentum collimation: A first design has been realized for a collimation in one of the long straight sections. Only warm magnets are used in this part.
- A dedicated extraction section for the decay products at the arc entries is designed.

P. Delahaye, CERN

- Collimation system studies ongoing
Heat Deposition study in Decay Ring

- Need to reduce a factor 5 on midplane
  - Liners
  - Open Midplane magnets

Lattice design: A. Chancé and J. Payet, CEA Saclay, IRFU/SACM
We give the midplane opening, the field and the needed aperture: design routines have been developed to produce a magnet with good field quality.

Aluminum spacers possible on midplane to retain forces: gives transparency to the decay products. Special cooling and radiation dumps may be needed.
Neutrino flux from a beta-beam

- EURISOL beta-beam study
  - Aiming for $10^{18}$ (anti-)neutrinos per year

- Can it be increased to $10^{19}$ (anti-) neutrinos per year? This can only be clarified by detailed and site specific studies of:
  - Production
  - Bunching
  - Radiation protection issues
    - Cooling down times for interventions
    - Tritium and Sodium production in ground water
For 15 effective stacking cycles, 54% of ultimate intensity is reached for $^6$He and for 20 stacking cycles 26% is reached for $^{18}$Ne.
- Left: Cycle without accumulation
- Right: Cycle with accumulation. Note that we always produce ions in this case!
Alternatives

- We have to be open to new technologies: shortfall in production from targets can be remedied by stepwise implementation of new ideas
- We have to be open to new ideas: Monochromatic beta beams
- Follow development and ideas from other laboratories (FNAL)
- Follow detector choices and implantation regions
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
  - 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

See talk by P. Delahaye
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)
  - Duty cycle revised
  - Collimation design
  - See talk by A. Chancé

- A new PS?
  - Magnet protection system
  - Intensity limitations?

- Overall radiation & radioprotection studies
Improvements of the EURISOL beta-beam

- Increase production, improve bunching efficiency, accelerate more than one charge state and shorten acceleration
  - Improves performance linearly
- Accumulation
  - Improves to saturation
- Improve the stacking: sacrifice duty factor, add cooling or increase longitudinal bunch size
  - Improves to saturation
- Magnet R&D: shorter arcs, open midplane for transparency to decay
  - Improves to saturation
Conclusions

- The EURISOL beta-beam conceptual design report will be presented in second half of 2009
- First coherent study of a beta-beam facility
- A beta-beam facility using $^8\text{Li}$ and $^8\text{B}$
- Experience from EURISOL
- First results will come from Euronu DS WP (starting fall 2008)
Acknowledgements

Particular thanks to
M. Lindroos,
M. Benedikt,
A. Fabich,
P. Delahaye
for contributions to the material presented.