Status of the beta-beam study

Mats Lindroos on behalf of the
EURISOL beta-beam task

The beta-beam options

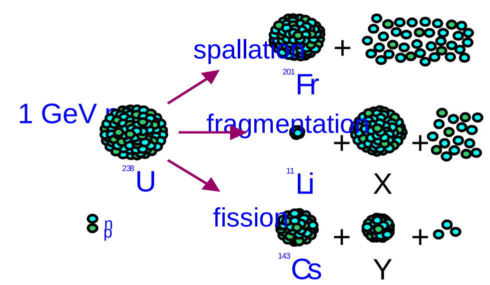
- Low energy beta-beams
  - Nuclear physics, double beta-decay nuclear matrix elements, neutrino magnetic moments
- The medium energy beta-beams or the EURISOL beta-beam
  - Lorenz gamma approx. 100 and average neutrino energy at rest approx. 1.5 MeV (P. Zucchelli, 2002)
- The high energy beta-beam
  - Lorenz gamma 300-500 and average neutrino energy at rest approx. 1.5 MeV
- The very high energy beta-beam
  - Lorenz gamma >1000
- The high Q-value beta-beam
  - Lorenz gamma 100-500 and average neutrino energy at rest 6-7 MeV
- The Electron capture beta-beam

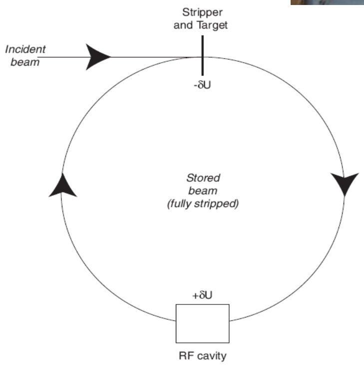
Production of beta-beam isotopes

- 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!

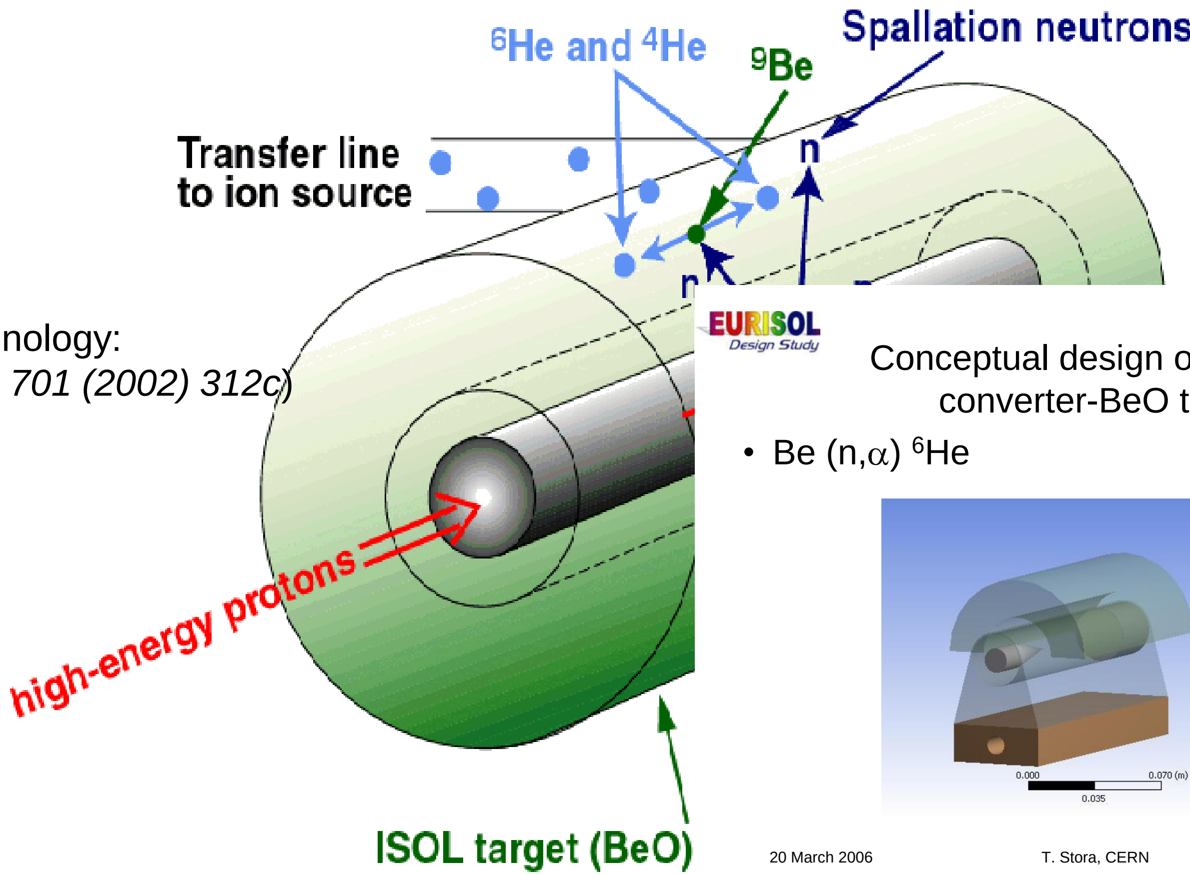
Options for production

- ISOL method at 1-2 GeV (200 kW)
  - >1 10^{13} ^{6}He per second
  - <8 10^{11} ^{18}Ne per second
  - ^{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 the future





^{6}He production from ^{9}Be(n,α)



Converter technology:
(*J. Nolen, NPA 701 (2002) 312c*)

EURISOL Design Study

Conceptual design of the dual converter-BeO target

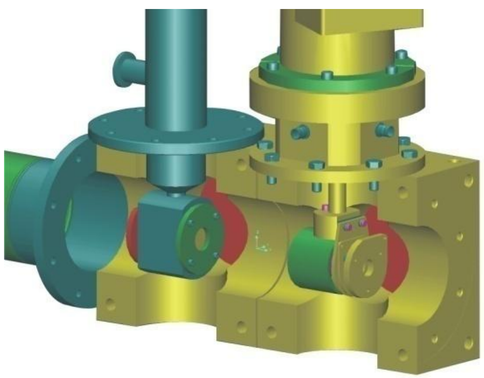
- Be (n,α) ^{6}He

20 March 2006 T. Stora, CERN EURISOL – Task #3

- **Converter technology preferred to direct irradiation (heat transfer and efficient cooling allows higher power compared to insulating BeO).**
- **^{6}He production rate is ~2x10^{13} ions/s (dc) for ~200 kW on target.**

Direct production: $^{16}O(^{3}He,n)^{18}Ne$

- Measurements at Louvain-La-Neuve (CRC) of cross section



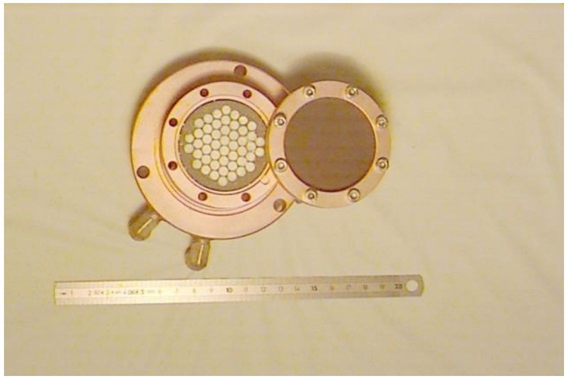
Courtesy to Semen Mitrofanov and Marc Loislet at CRC, Belgium

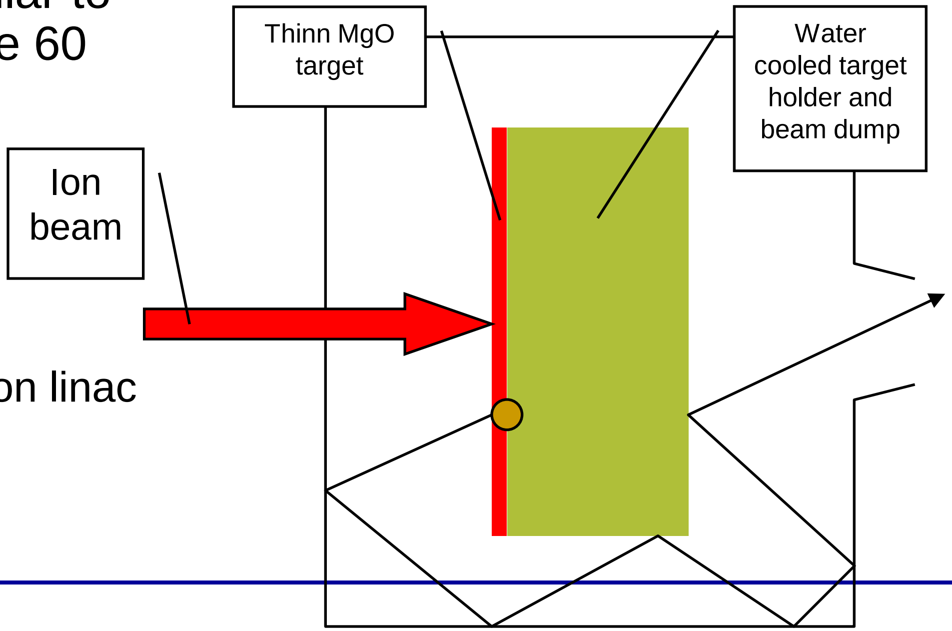
- The gas target was constructed like a cell with thin entrance foils
- In experiment the target pressure and the ^{3}He beam energy was changed

Beam energy, MeV	Target pressure, mbar (torr).	E_{loss},MeV
13	900 (675)	2
14.8	1200 (900)	2.4

Preliminary results from CRC

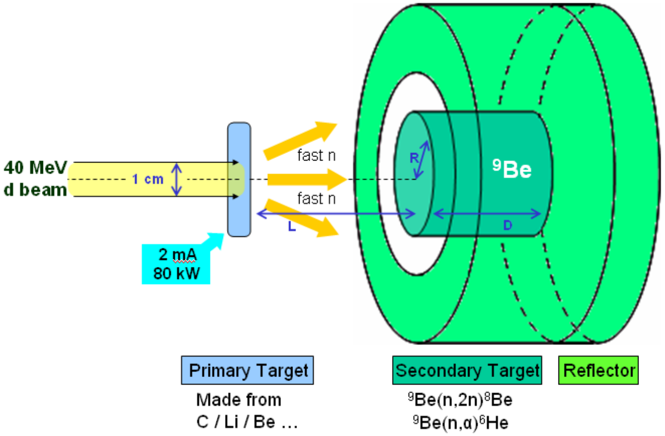
- Production of 10^{12} ^{18}Ne in a MgO target:
  - At 13 MeV, 17 mA of ^{3}He
  - At 14.8 MeV, 13 mA of ^{3}He
- Producing 10^{13} ^{18}Ne could be possible with a beam power (at low energy) of 1 MW (or some 130 mA ^{3}He beam).
- To keep the power density similar to LLN (today) the target has to be 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

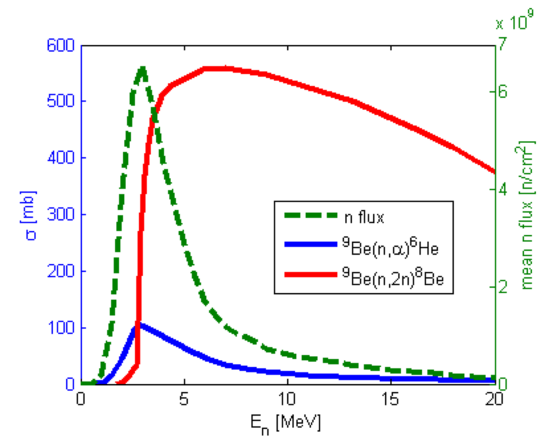




Light RIB Production with a 40 MeV Deuteron Beam

- T.Y.Hirsh, D.Berkovits, M.Hass (Soreq, Weizmann I.)
- 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 ~$6\cdot10^{13}$ atoms per second.

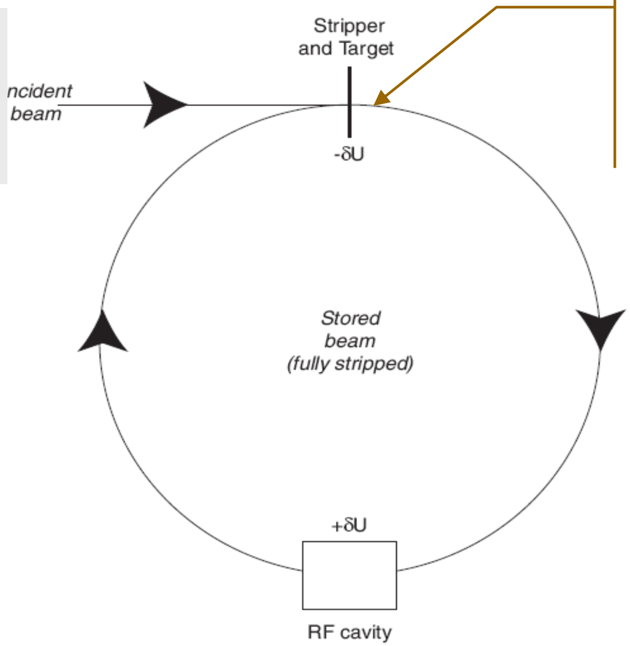




A new approach for the production

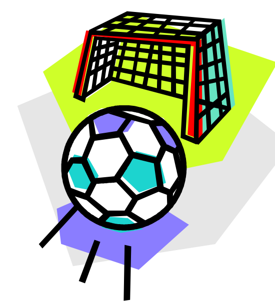
Beam cooling with ionisation losses – C. Rubbia, A Ferrari, Y. Kadi and V. Vlachoudis in NIM A 568 (2006) 475–487

^{7}Li
^{6}Li



$^{7}Li(d,p)^{8}Li$
$^{6}Li(^{3}He,n)^{8}B$

Missed opportunities



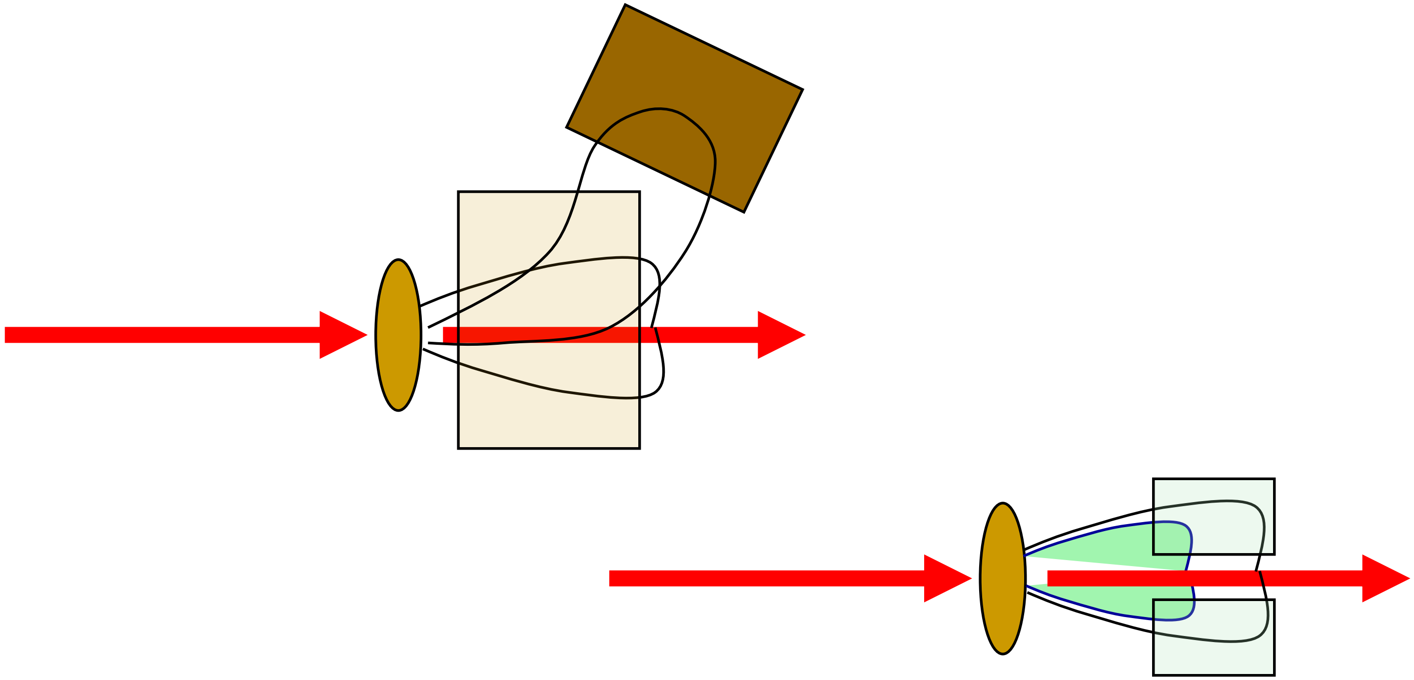
See also: Development of FFAG accelerators and their applications for intense secondary particle production, Y. Mori, NIM A562(2006)591

Critical review of the production ring concept

- Low-energy Ionization cooling of ions for Beta Beam sources – D. Neufer (To be submitted)
  - Mixing of longitudinal and horizontal motion necessary
  - Less cooling than predcited
  - Beam larger but that relaxes space charge issues
  - If collection done with separator after target, a Li curtain target with ^{3}He and Deutron beam would be preferable
    - Separation larger in rigidity

Problems with 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% !).

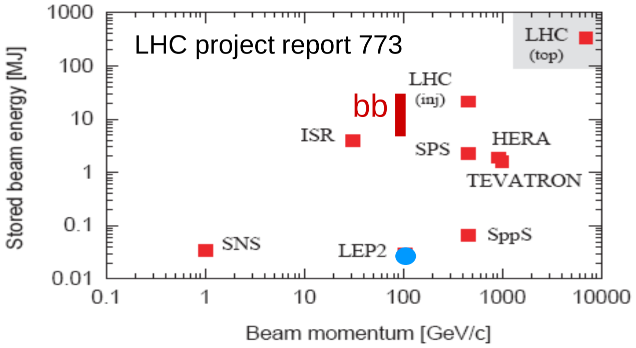


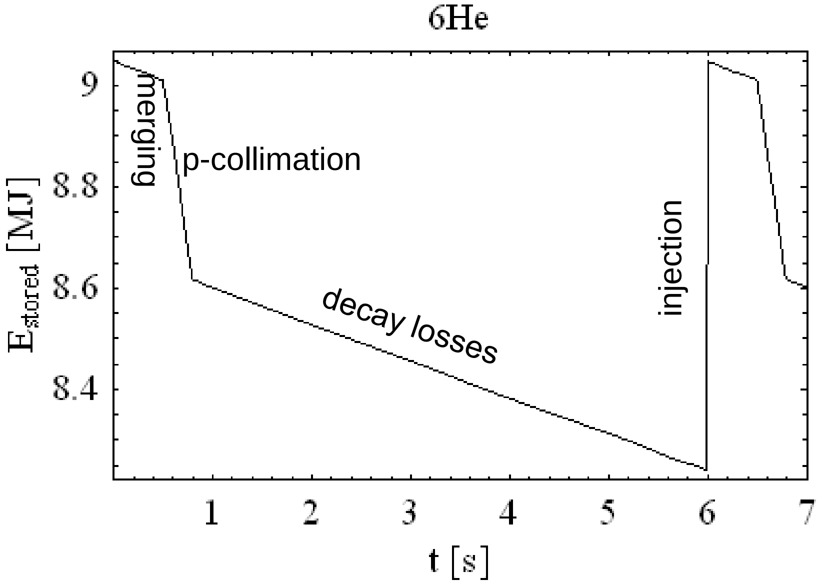
Radiation protection issues

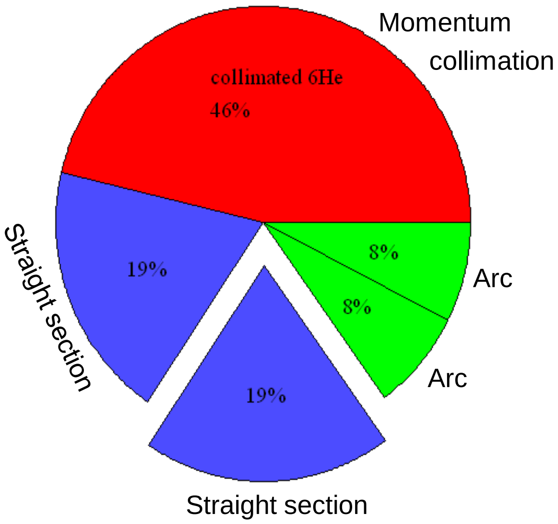
- Radiation safety for staff making interventions and maintenance at the target, bunching stage, accelerators and decay ring
  - 88% of ^{18}Ne and 75% of ^{6}He ions are lost between source and injection into the Decay ring
- Safe collimation of “lost” ions during stacking
  - ~1 MJ beam energy/cycle 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

Particle turnover

- ~1 MJ beam energy/cycle injected
  → equivalent ion number to be removed
  ~25 W/m average



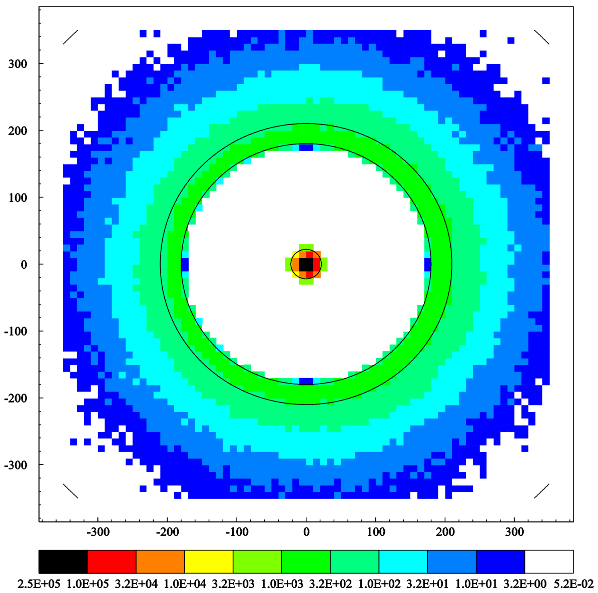




- Momentum collimation: ~5*10^{12} ^{6}He ions to be collimated per cycle
- Decay: ~5*10^{12} ^{6}Li ions to be removed per cycle per meter

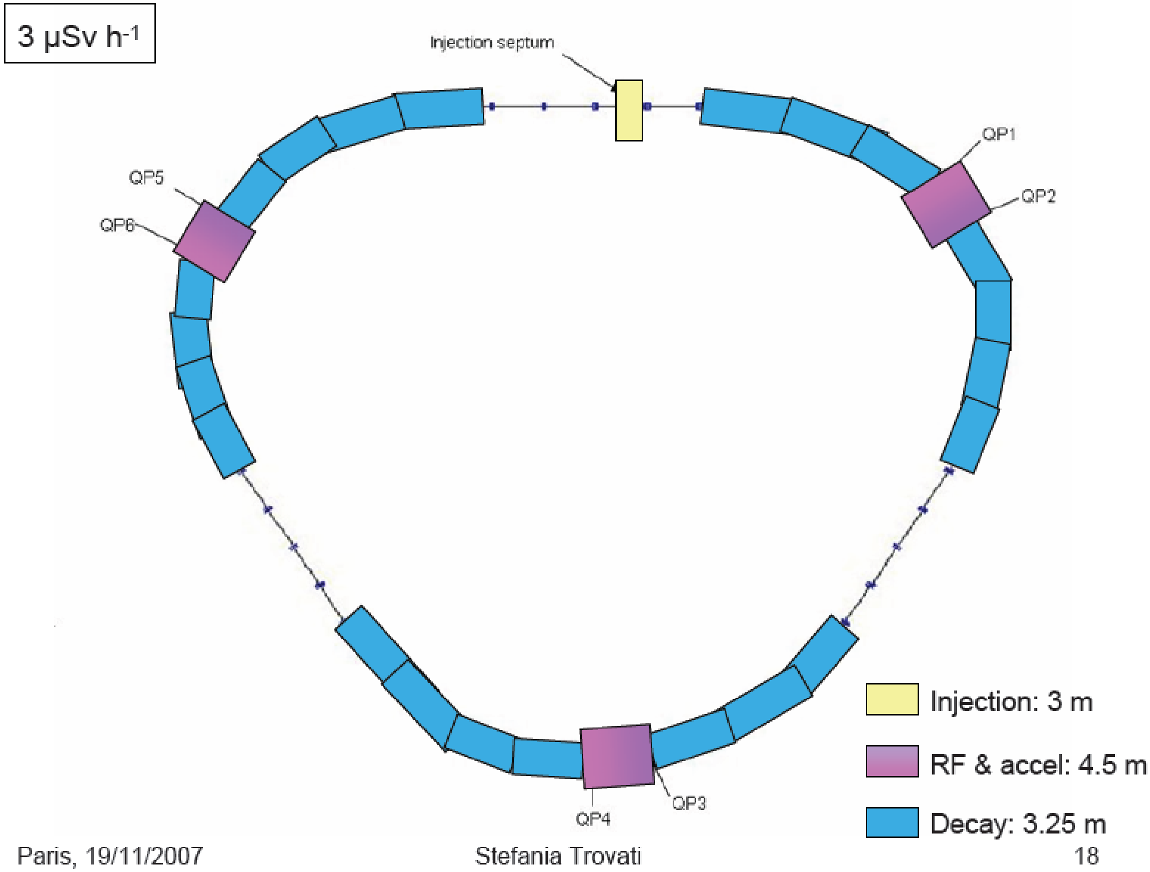
Decay losses

- Losses during acceleration
  - Full FLUKA simulations in progress for all stages (M. Magistris and M. Silari, *Parameters of radiological interest for a beta-beam decay ring*, TIS-2003-017-RP-TN).
- 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.



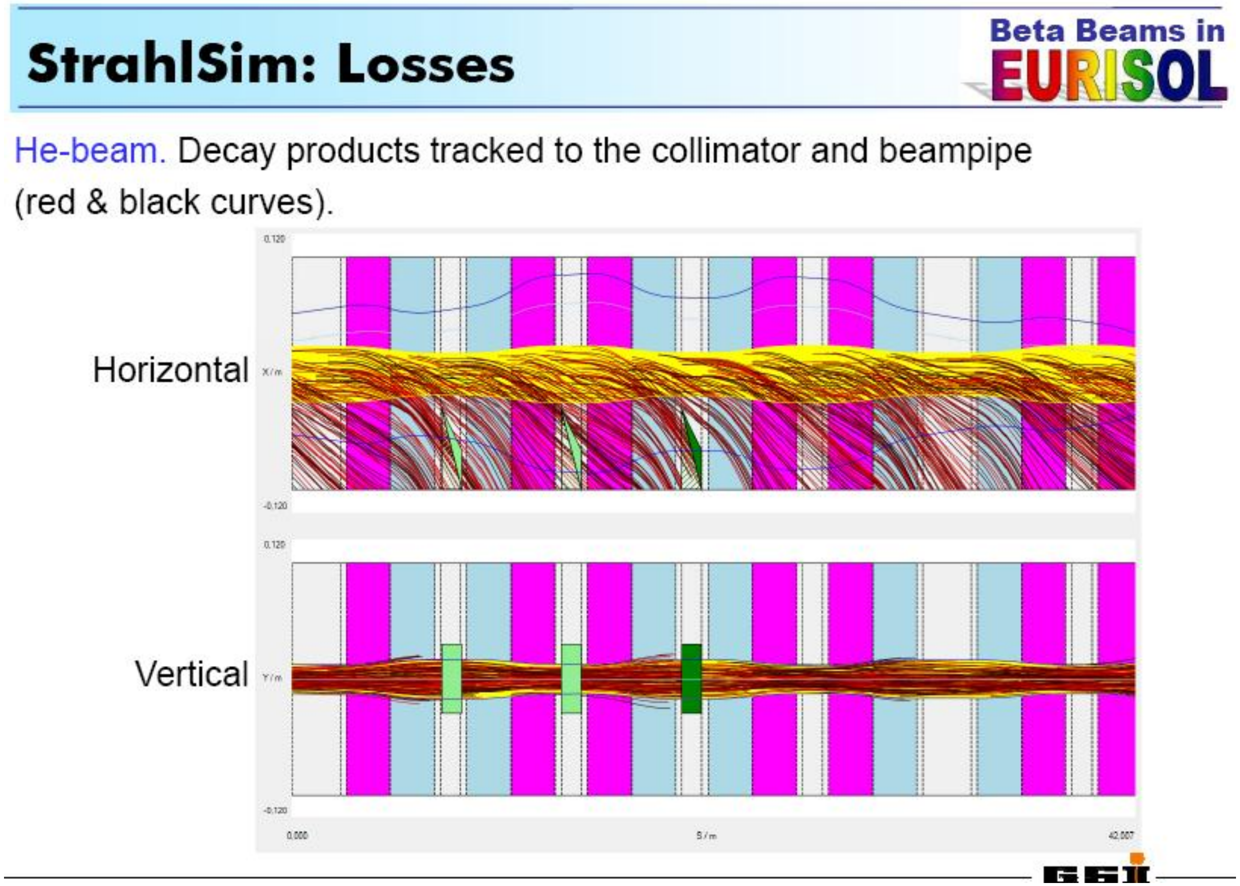
FLUKA simulated losses in surrounding rock (no public health implications)

Shielding: requirements for RCS



- Shielding thickness for different parts of the RCS within realistic limits

Activation and coil damage in the PS

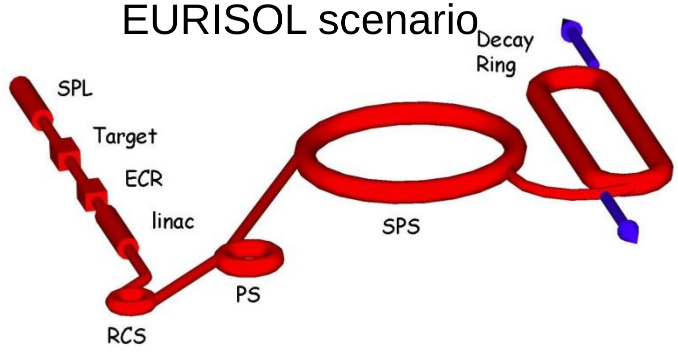


- The coils could support 60 years operation with a EURISOL type beta-beam

The EURISOL scenario

- Based on CERN boundaries
- Ion choice: ^{6}He and ^{18}Ne
- Relativistic gamma=100/100
  - SPS allows maximum of 150 (^{6}He) or 250 (^{18}Ne)
  - Gamma choice optimized for physics reach
- 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

EURISOL scenario



- Opportunity to share a Mton Water Cerenkov detector with a CERN superbeam, proton decay studies and a neutrino observatory

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

- Once we have thoroughly studied the EURISOL scenario, we can “easily” extrapolate to other cases. EURISOL study could serve as a reference.

Neutrino flux from a beta-beam

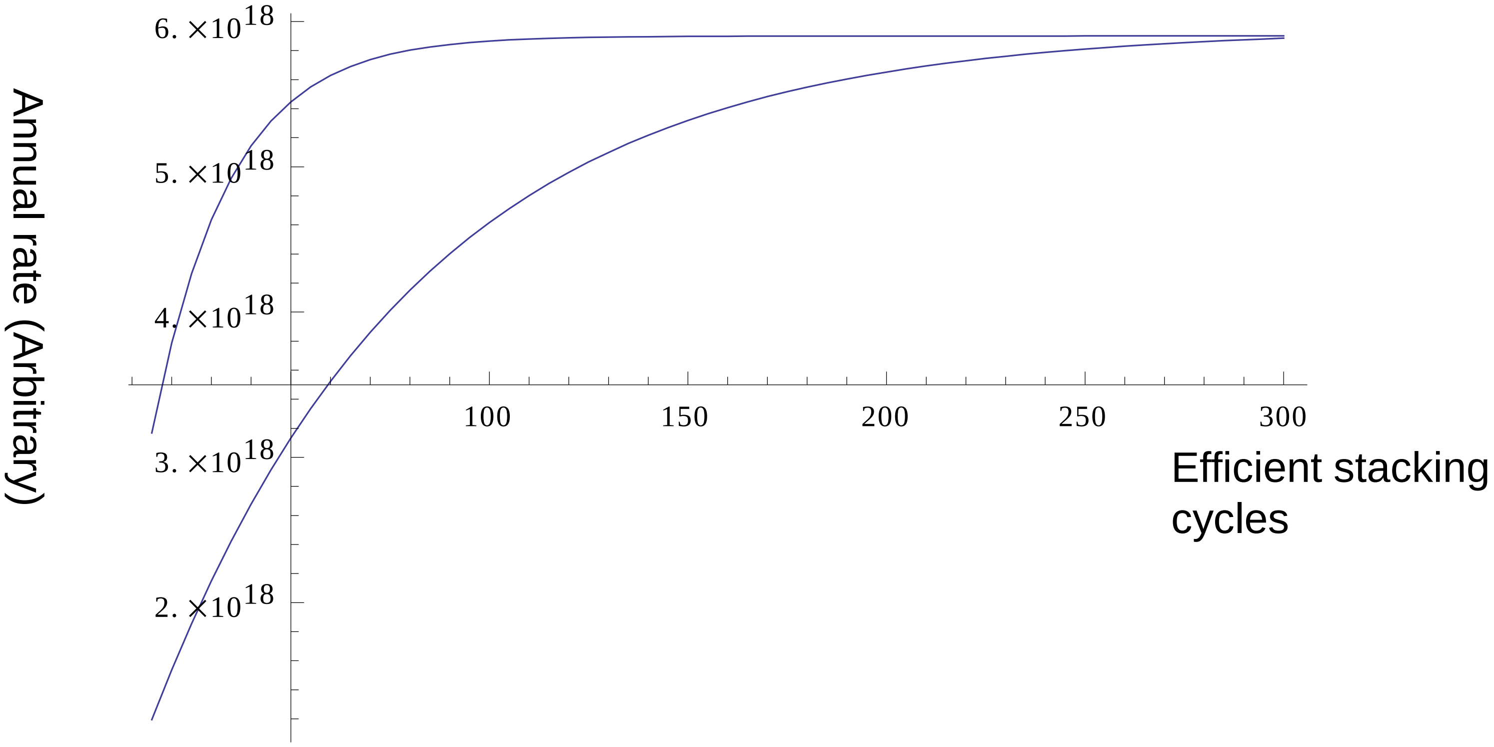
- EURISOL beta-beam study
  - Aiming for 10^{18} (anti-)neutrinos per year

- It is possible that it could be increased to some10^{19} (anti-) neutrinos per year. However, this 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

How can we improve the beta-beam?

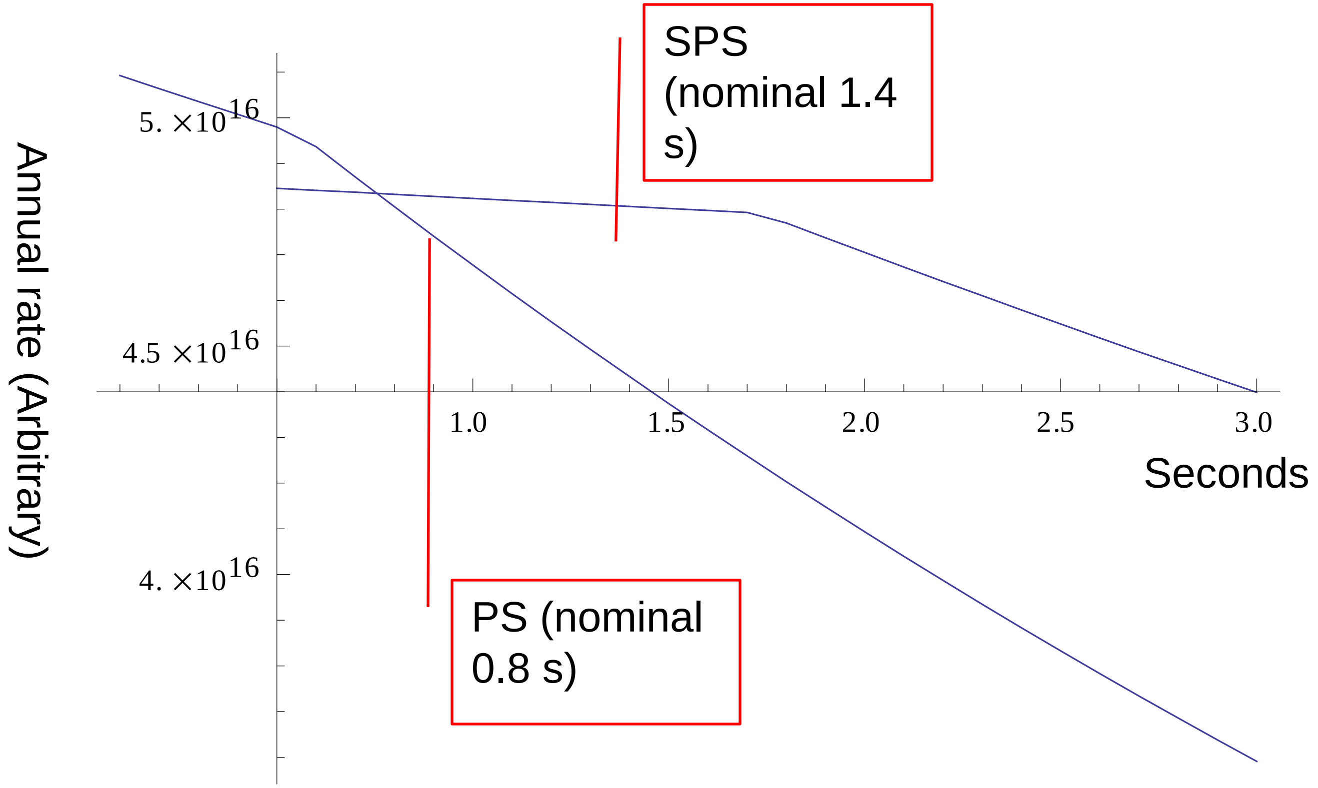
- Increase production, improve bunching efficiency, accelerate more than one charge state and shorten acceleration
  - Improves performance linearly
- Accumulation
  - Improves to saturation
- Improve the stacking; sacrifice duty factor, add cooling or increase longitudinal bunch size
  - Improves to saturation

Stacking efficiency and low duty factor



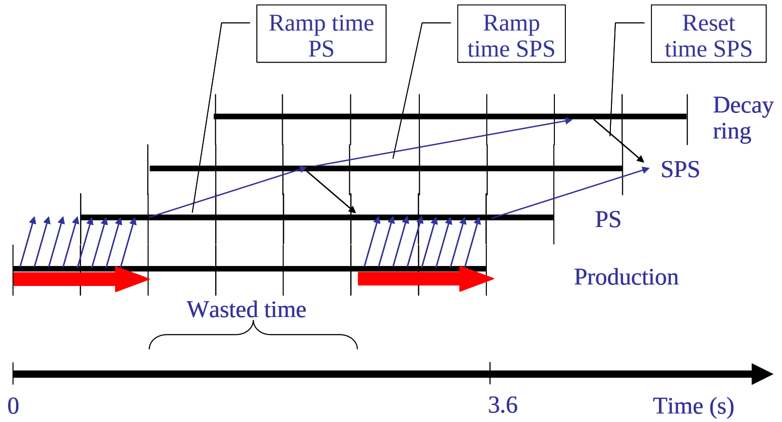
- For 15 effective stacking cycles, 54% of ultimate intensity is reached for ^{6}He and for 20 stacking cycles 26% is reached for ^{18}Ne

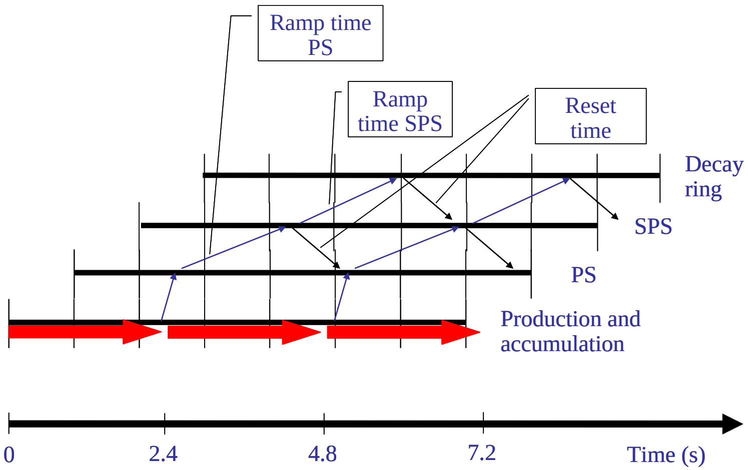
Acceleration time PS and SPS



- The complete "chain" must be optimized to gain from faster acceleration

Why do we gain with such an accumulation ring?





- Left: Cycle without accumulation
- Right: Cycle with accumulation. Note that we always produce ions in this case!

The beta-beam in EURONU DS

- The study will focus on production issues for ^{8}Li and ^{8}B
  - ^{8}B is highly reactive and has never been produced as on ISOL beam
  - Production ring enhanced direct production
    - Which is the best ring lattice?
    - How to collect the produced ions?
    - What are the “real” cross sections for the reactions?
- How can the accelerator chain and decay ring be adapted to ^{8}Li and ^{8}B
  - Magnet protection system
  - Intensity limitations

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}Li and ^{8}B
  - First result from Euronu DS WP
- A beta-beam facility at DESY (Hamburg) or at FNAL?
  - For DESY contact Prof. Achim Stahl, Aachen