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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

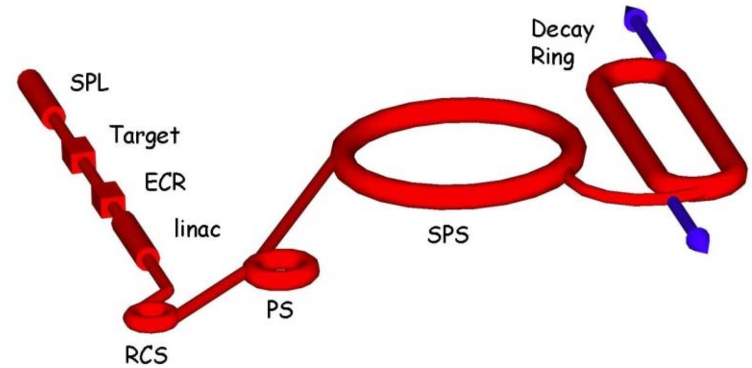
The beta-beam options

- 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
  - Monochromatic neutrino beam (interest expressed in recent paper by J. Barnabéu and C. Espinosa: arXiv:0712.1034[hep-ph])

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

EURISOL scenario



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

Aimed:

He 2.9 10^{18} (2.0 10^{13}/s)

Ne 1.1 10^{18} (2.0 10^{13}/s)

More on production:

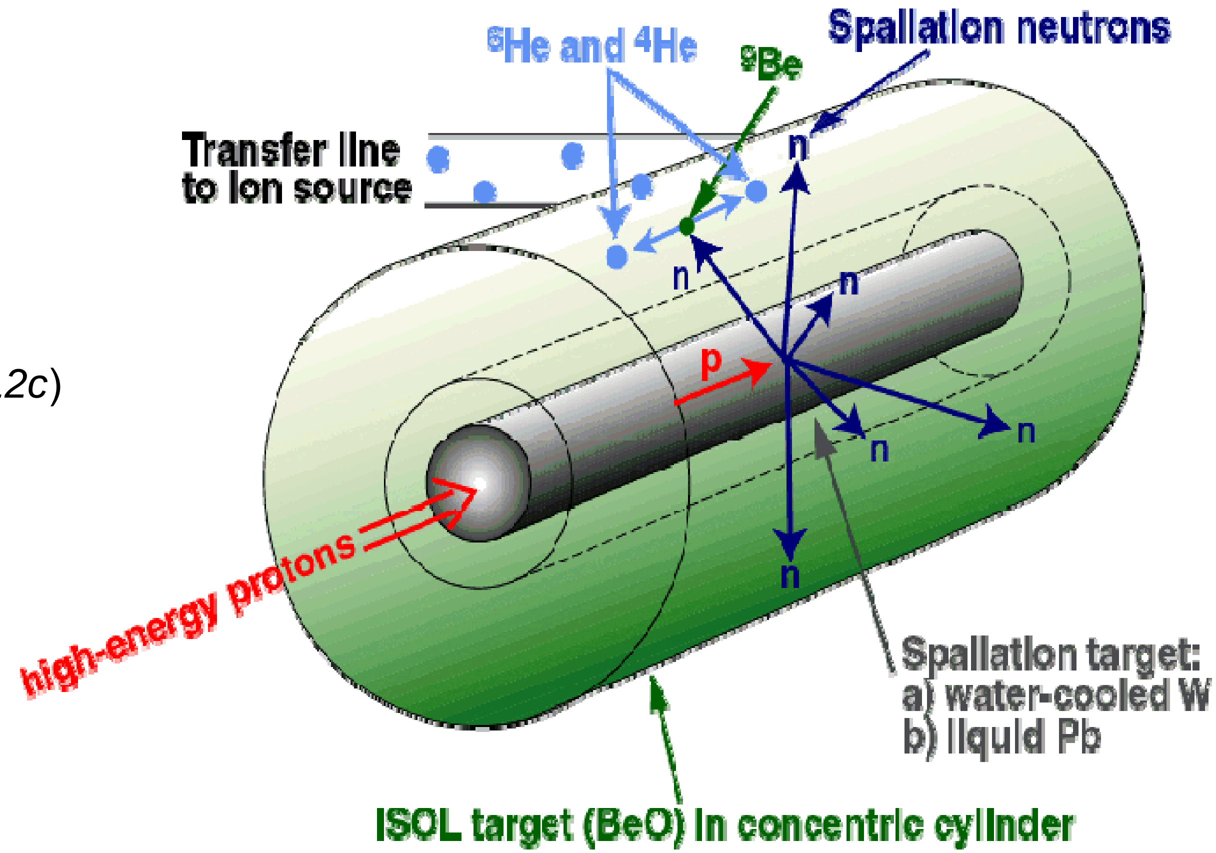
see talks by

M. Lindroos

and

P. Delahaye, FP7

^{6}He production from ^{9}Be(n,α)



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

T. Stora

N. Thollieres

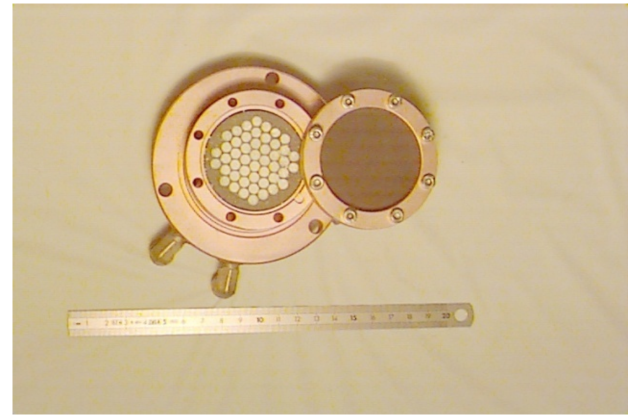
- Converter technology preferred to direct irradiation (heat transfer and efficient cooling allows higher power compared to insulating BeO).
- ^{6}He production rate is ~2x10^{13} ions/s (dc) for ~200 kW on target.

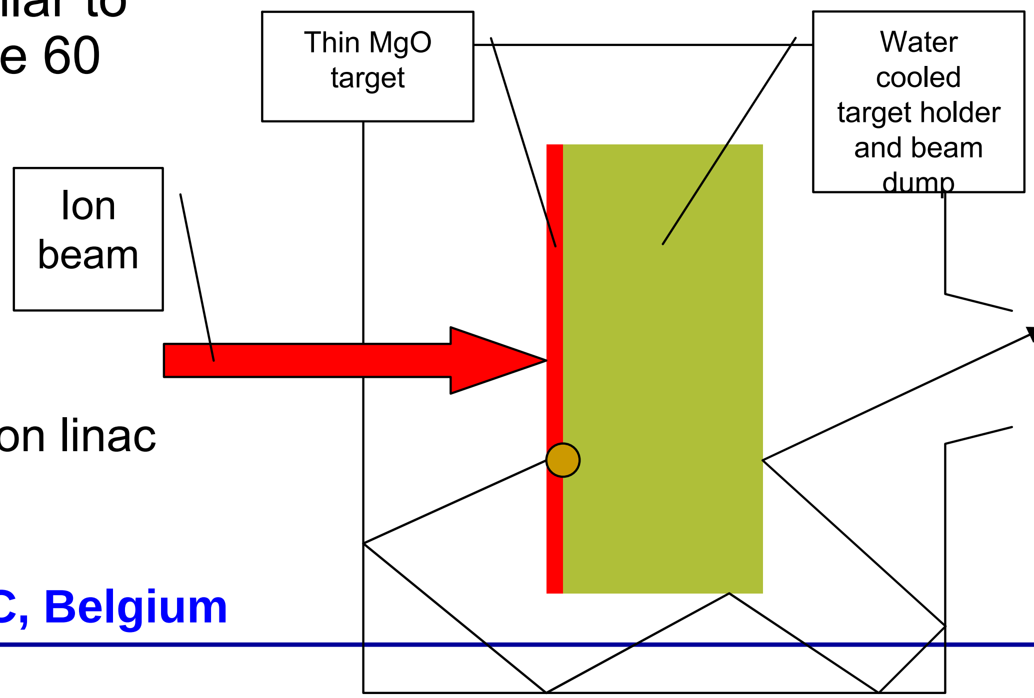
Projected values, known x-sections!

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

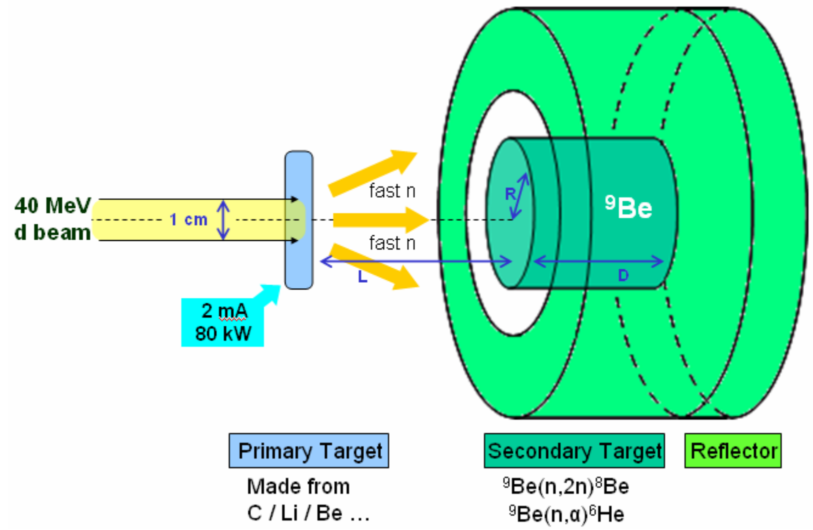
Geometric scaling



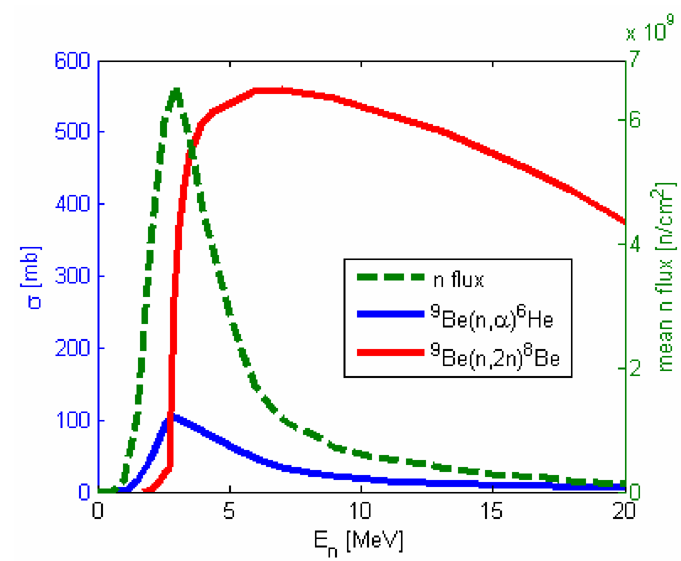


S. Mitrofanov and M. Loislet at CRC, Belgium

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 ~$6 \cdot 10^{13}$ atoms per second.

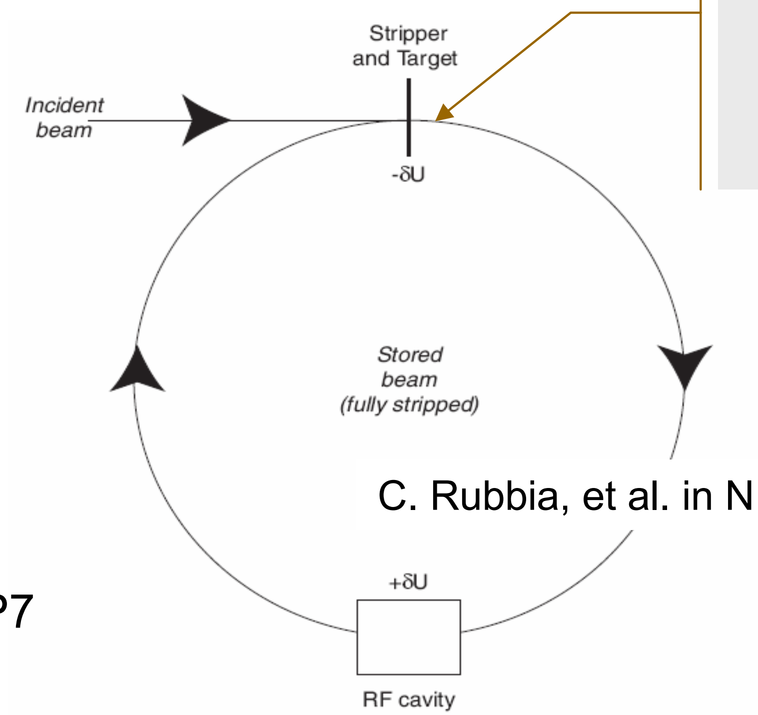


New approaches for the production

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

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

^{7}Li
^{6}Li



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

C. Rubbia, et al. in NIM A 568 (2006) 475–487

Will be studied in Euronu FP7

The production ring concept: review

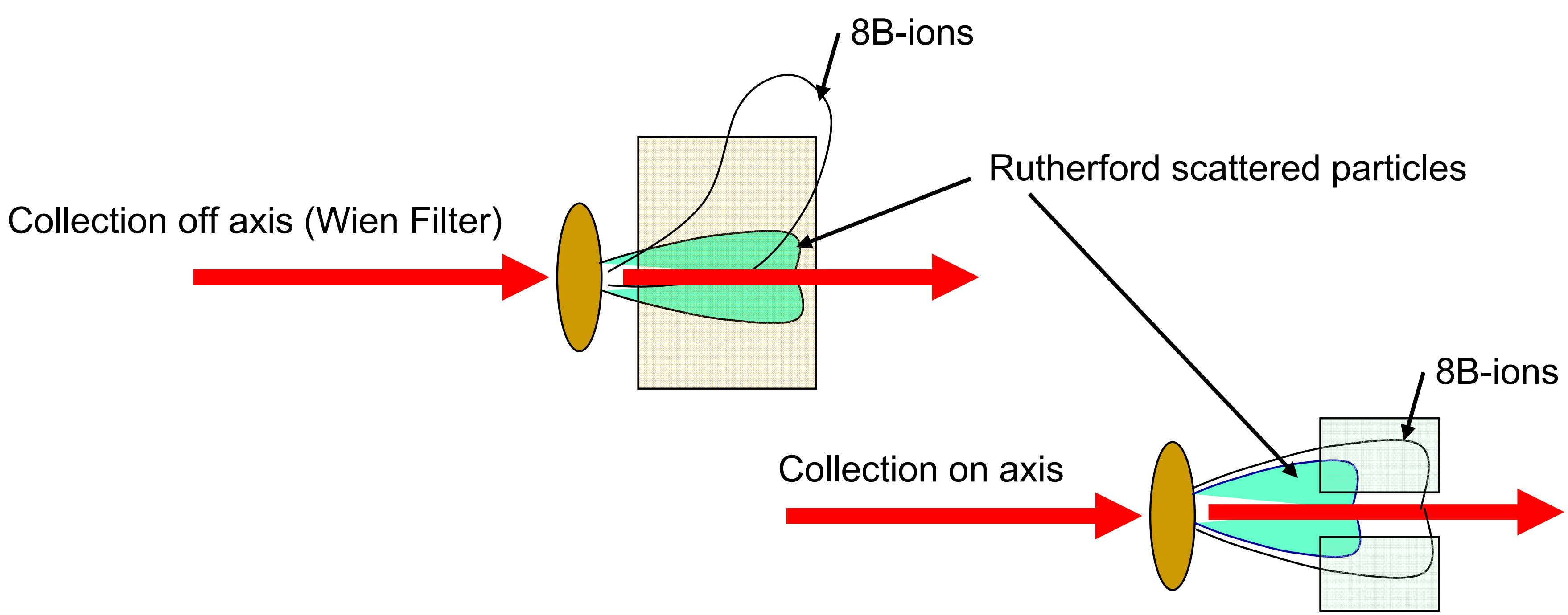
- Low-energy Ionization cooling of ions for Beta Beam sources –

  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 ^3He 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% !).



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 (Magistris 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
  - Full FLUKA simulations in progress for all stages (M. Magistris and M. Silari, TIS-2003-017-RP-TN, Stefania Trovati, EURISOL Design Study:
    7th Beta-beam Task Meeting, 19th May 2008).

- 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).

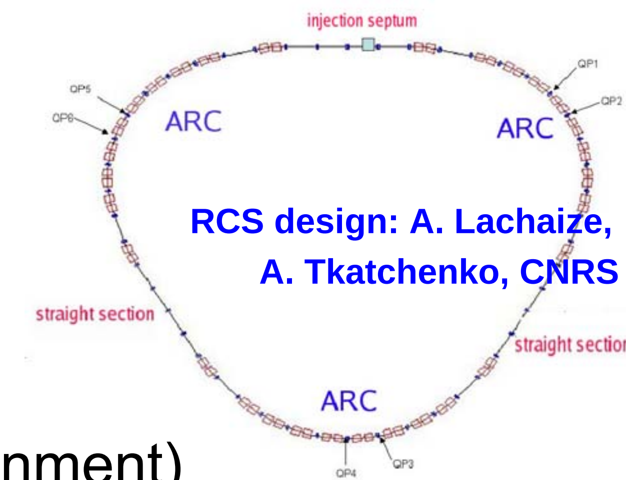
Radioprotection: Detailed study for RCS

Stefania Trovati, CERN

RCS design: See talk by A. Lachaize

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

} 50% of injected particles



RCS design: A. Lachaize,
A. Tkatchenko, CNRS / IN2P3

- 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”

Activation and coil damage in the PS

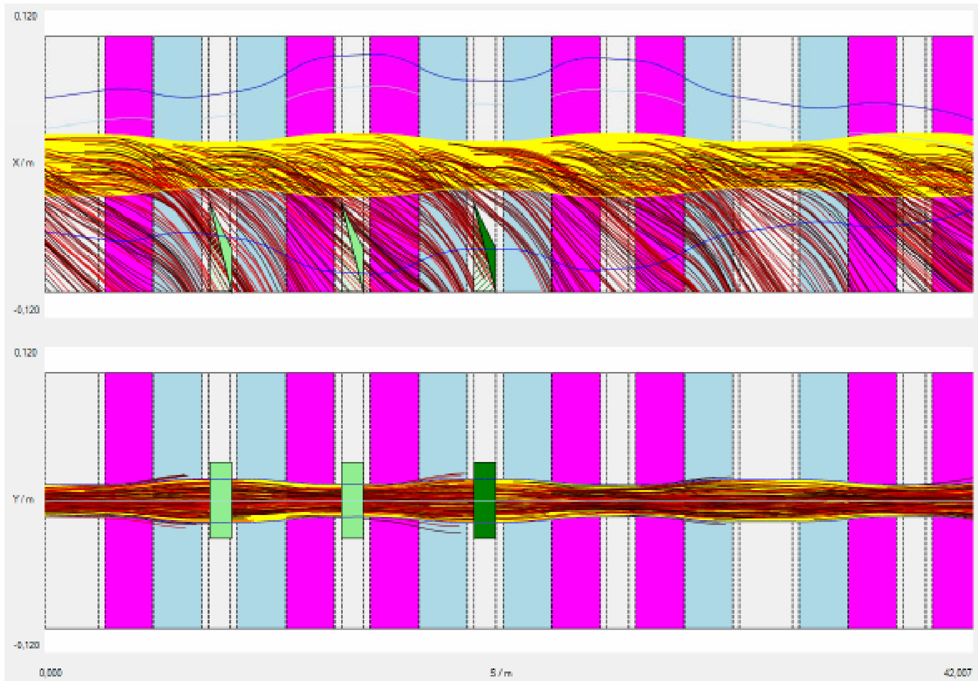
StrahlSim: Losses

Beta Beams in EURISOL

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

Horizontal

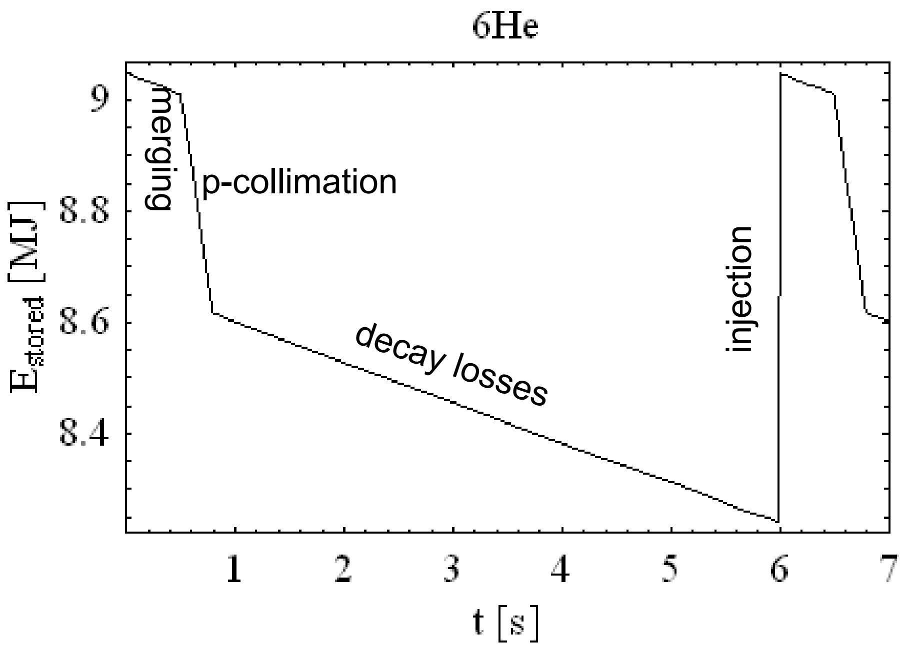
Vertical

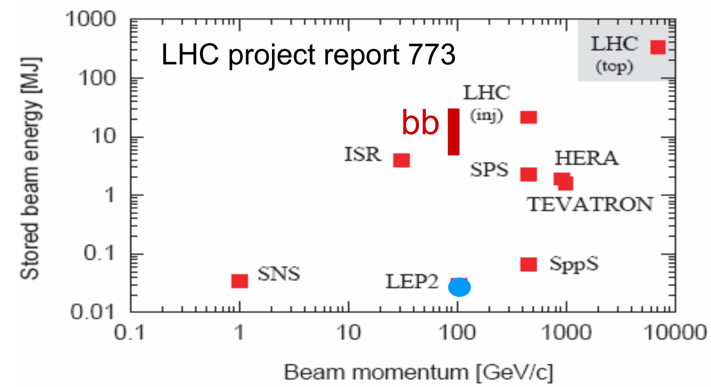


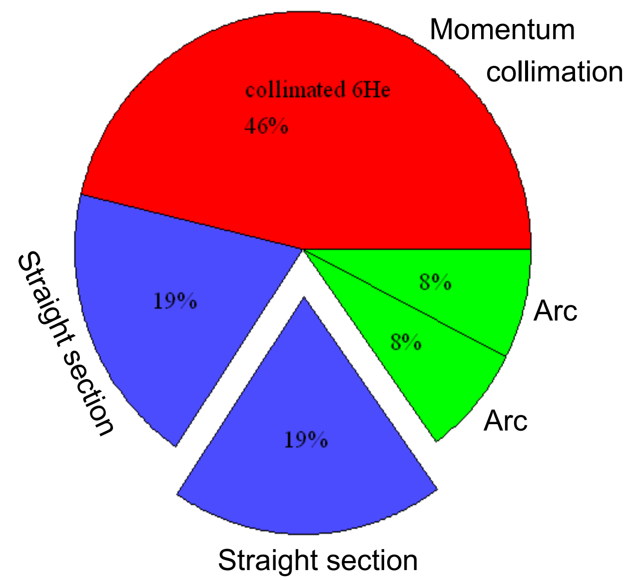
M. Kirk et. al GSI

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

Particle turnover in decay ring

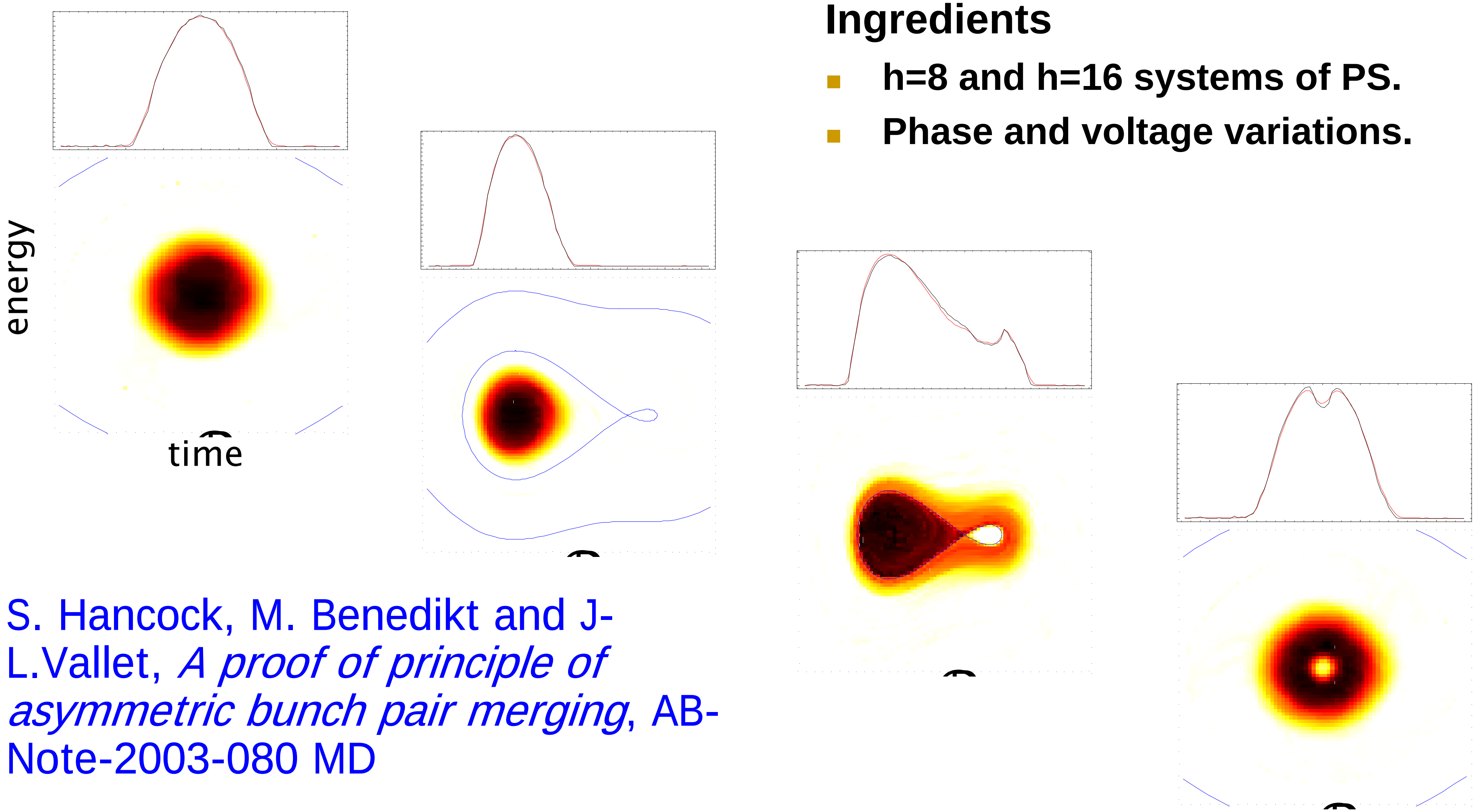






- Momentum collimation: ~$5*10^{12}$ ^{6}He ions to be collimated per cycle
- Decay: ~$5*10^{12}$ ^{6}Li ions to be removed per cycle per meter

Decay 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

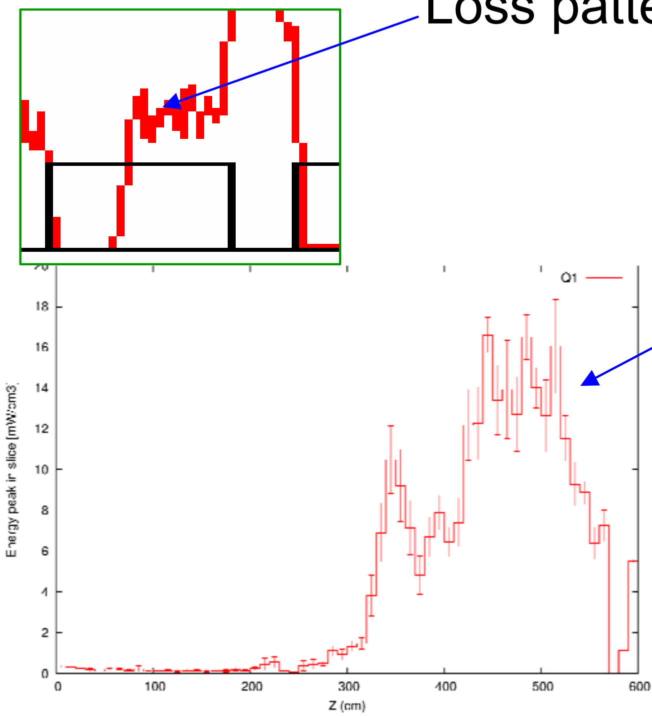
- Momentum collimation: A first design has been realized for a collimation in one of the long straight sections. Only warm magnets are used in this part.
- A dedicated extraction section for the decay products at the arc entries is designed.

P. Delahaye, CERN

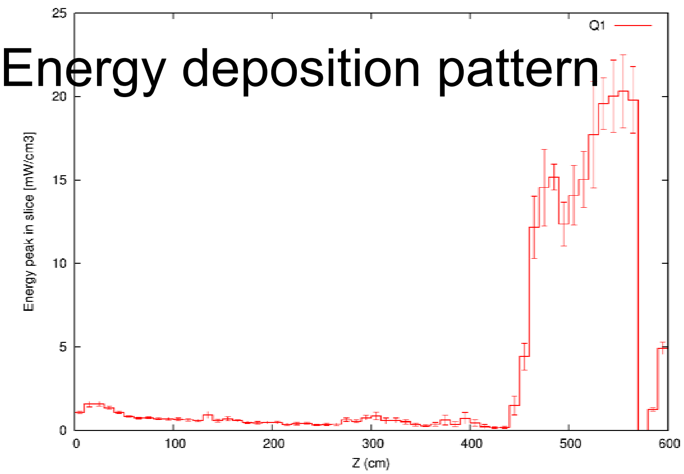
- Collimation system studies ongoing

Heat Depositon study in Decay Ring

Loss pattern

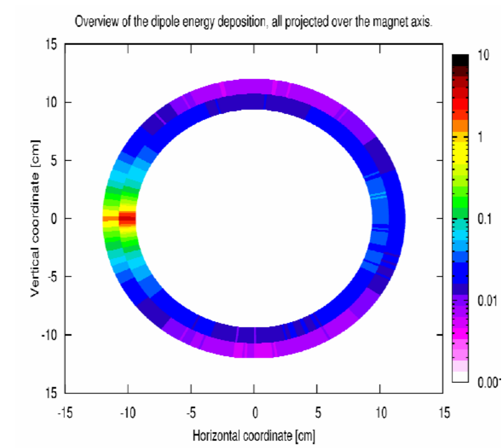


Energy deposition pattern



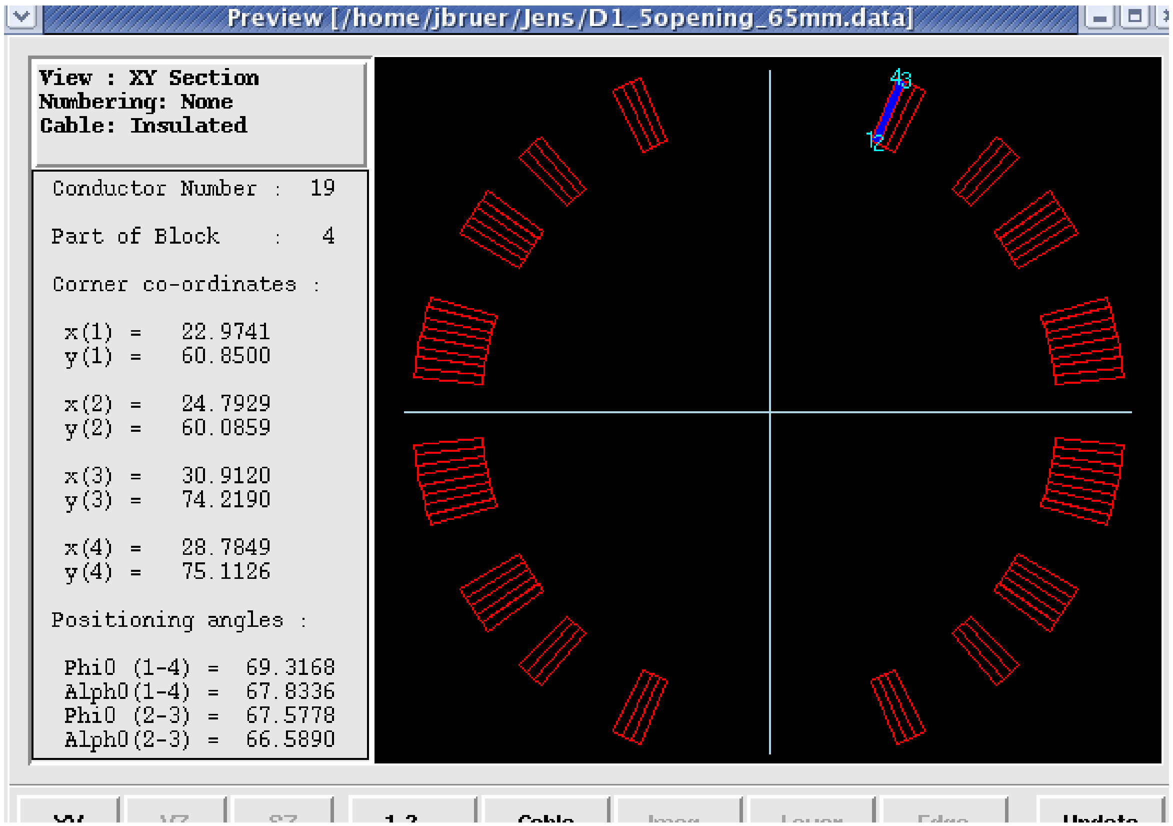
Lattice design: A. Chancé and J. Payet, CEA Saclay, IRFU/SACM

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



Open Midplane Dipole for Decay Ring

Cosθ design open midplane magnet



J. Bruer, E. Todesco, CERN

We give the midplane opening, the field and the needed aperture: design routines have been developed to produce a magnet with good field quality.

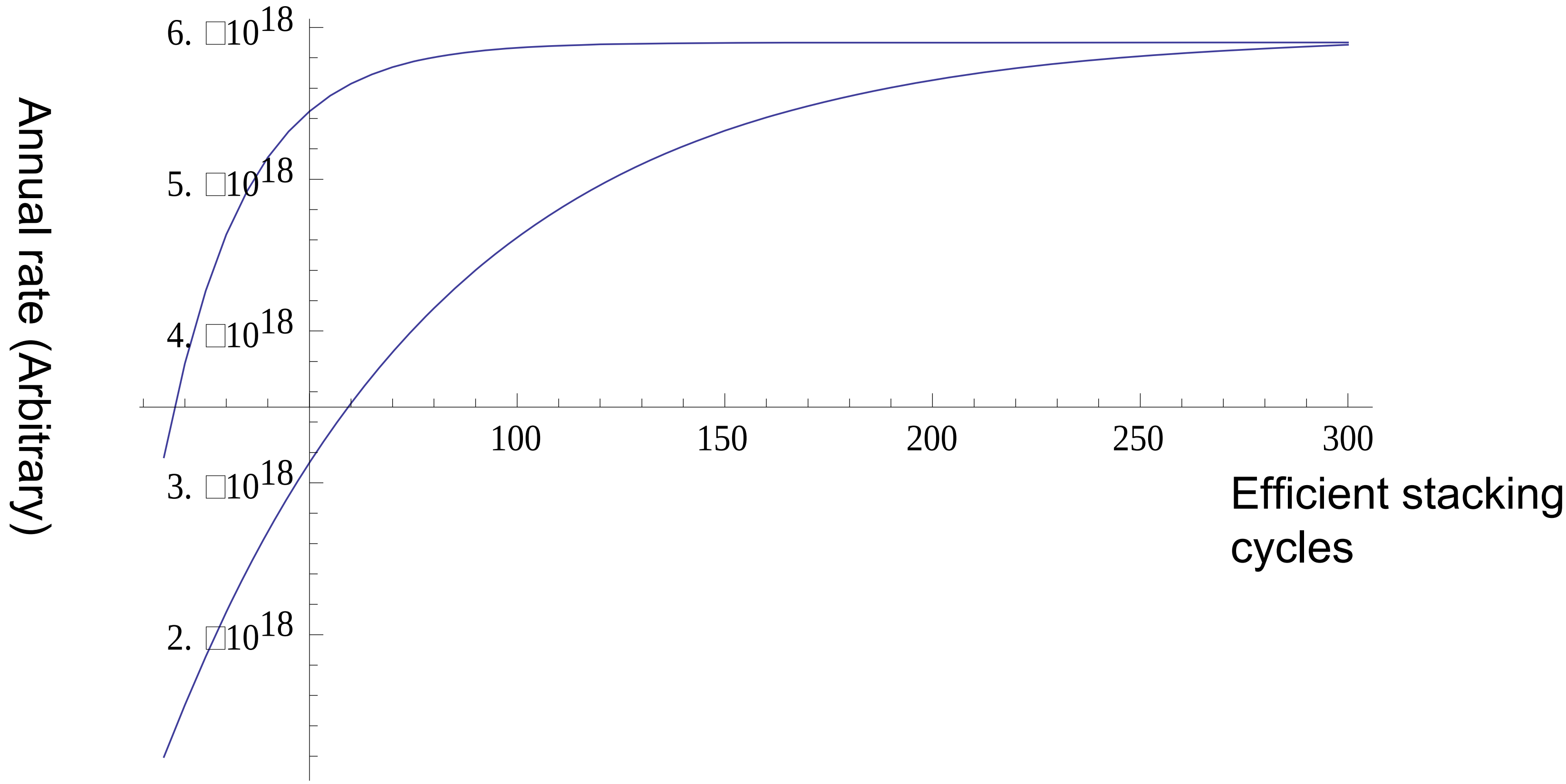
Aluminum spacers possible on midplane to retain forces: gives transparency to the decay products

Special cooling and radiation dumps may be needed.

Neutrino flux from a beta-beam

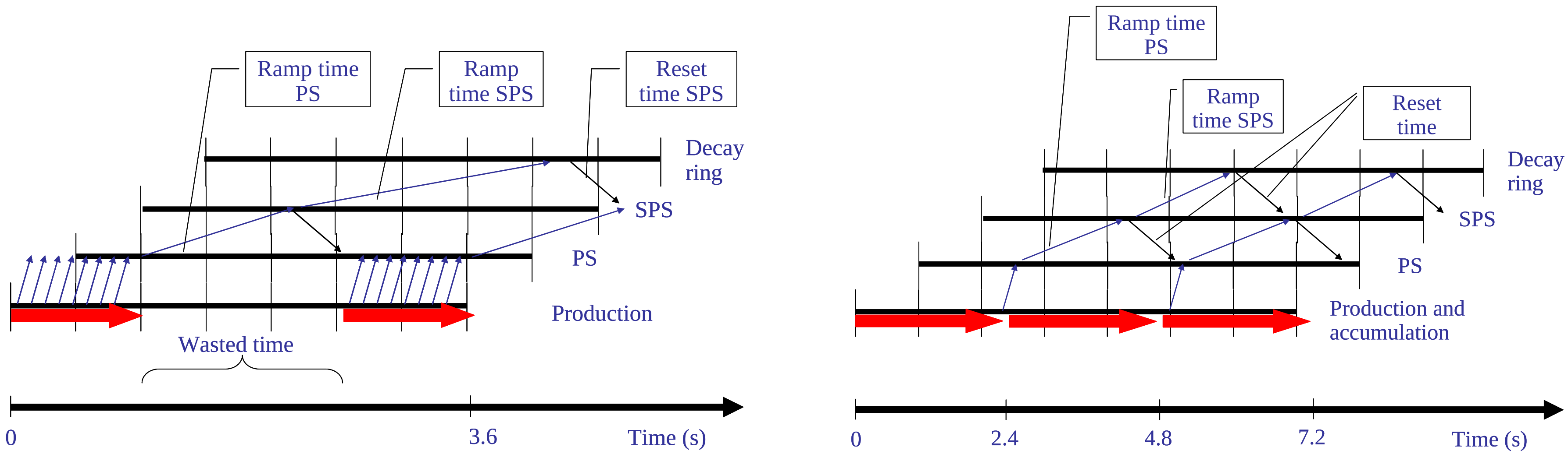
- EURISOL beta-beam study
  - Aiming for 10^{18} (anti-)neutrinos per year
- Can it be increased to10^{19} (anti-) neutrinos per year? This can only be clarified by detailed and site specific studies of:
  - Production
  - Bunching
  - Radiation protection issues
    - Cooling down times for interventions
    - Tritium and Sodium production in ground water

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

Benefit from an accumulation ring



- 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)

See talk by P. Delahaye

- 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)
  - Duty cycle revised
  - Collimation design
- A new PS?
  - Magnet protection system
  - Intensity limitations?
- Overall radiation & radioprotection studies

See talk by A. Chancé

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}Li and ^{8}B
  - Experience from EURISOL
  - First results will come from Euronu DS WP (starting fall 2008)

Acknowledgements

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