The 9th
ICFA
Seminar

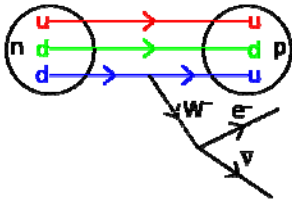
Concepts and R&D for beta beam facilities

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

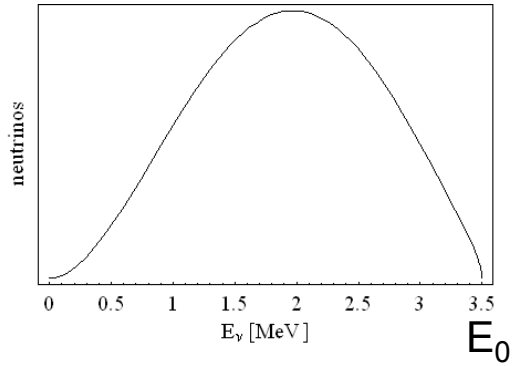
Outline

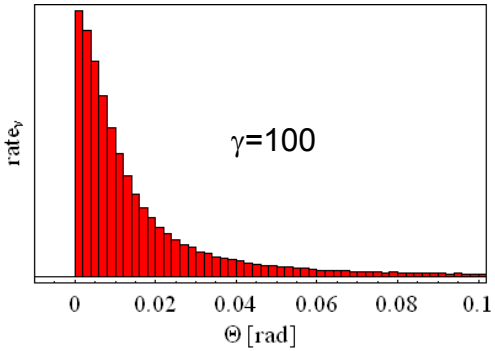
- Beta Beam Concepts and Options
- The EURISOL Beta Beam Scenario
- Ion Production
- Loss Management
- Improvements
- Continuation

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
  - ν–spectrum well known from electron spectrum
  - Reaction energy Q typically of a few MeV
- Accelerate parent ion to relativistic γ_{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





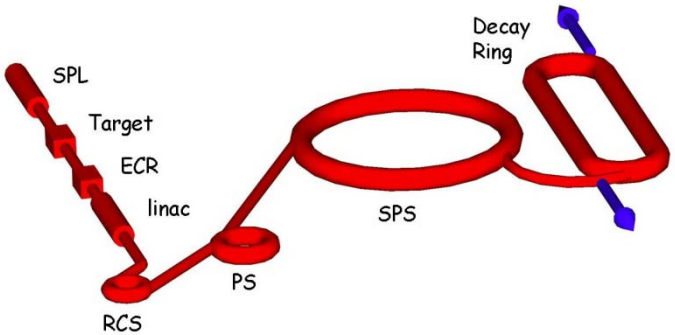
The beta-beam options

- 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 ν_μ in detector
  - Merit factor M ~ γ / E_0 ;
- Long Baselines
  - Higher γ or higher ion Q, needs more decays
- The Electron capture beta-beam
  - Monochromatic neutrino beam (interest expressed in recent paper by J. Barnabéu and C. Espinosa: arXiv:0712.1034[hep-ph])
- 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)

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

top-down approach

- 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 compex

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

Existing!!!

SPS
93 GeV

PS

8.7 GeV

Neutrino source

Beam to experiment

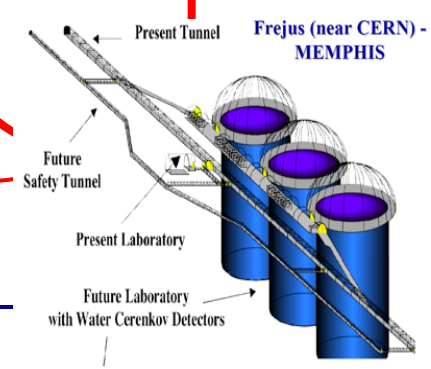
Neutrino
Source

Decay
Ring

Decay ring

$B\rho$ = 1500 Tm
B = ~6 T
C = ~6900 m
L_{ss} = ~2500 m

^{6}He: γ = 100
^{18}Ne: γ = 100



Detector in the Frejus tunnel

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
- 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
  - Will be studied within EUROν

Aimed:

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

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

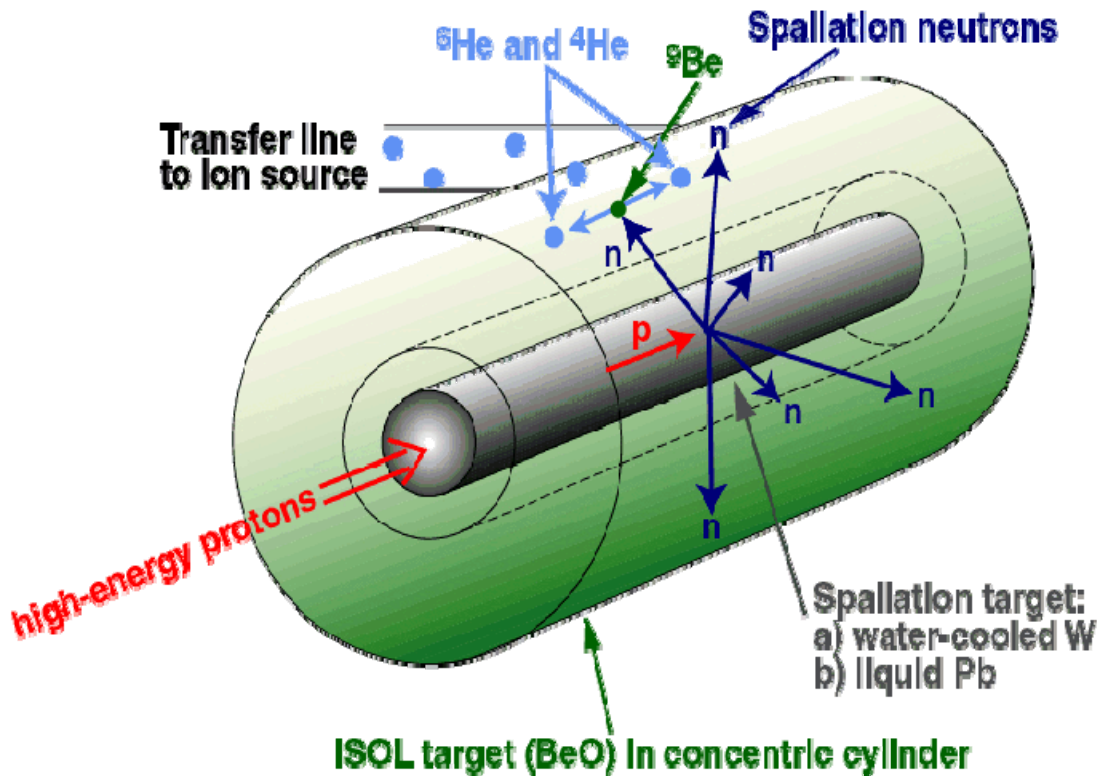
Courtesy M. Lindroos

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

^{6}He (ISOL)

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

T. Stora, N. Thollieres, CERN

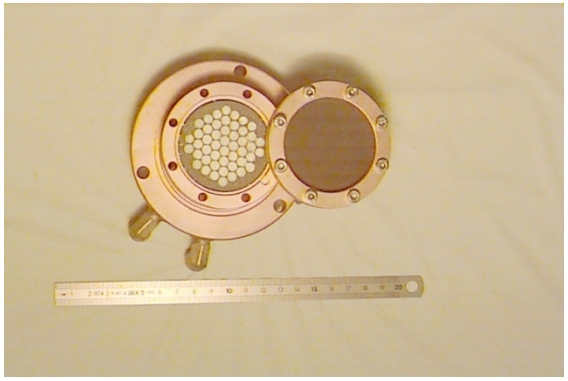


- Converter technology preferred to direct irradiation (heat transfer and efficient cooling allows higher power compared to insulating BeO).
- ^{6}He production rate is ~2x10^{13} ions/s (dc) for ~200 kW on target.

Projected values, known x-sections!

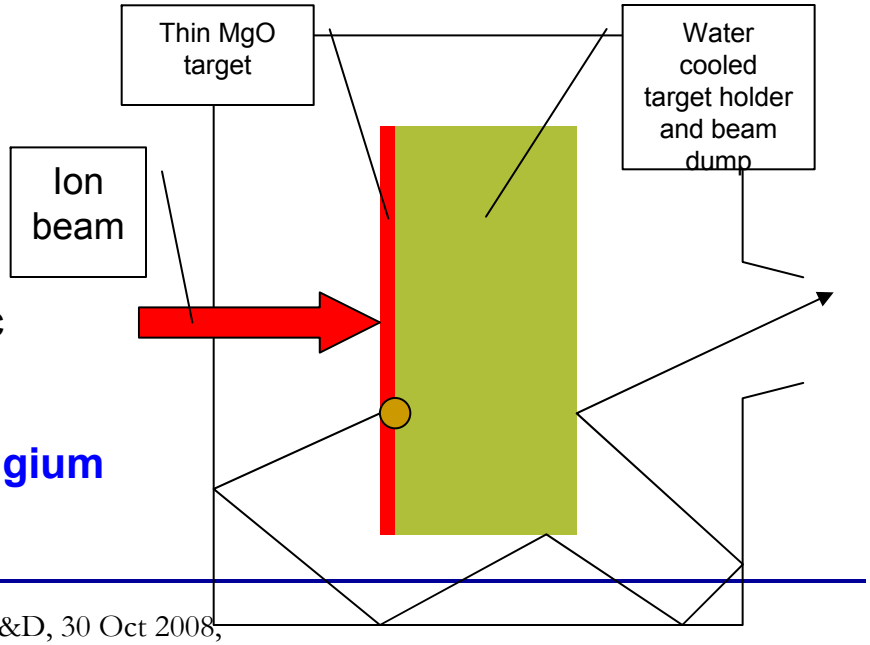
^{18}Ne (Direct Production)

Geometric scaling



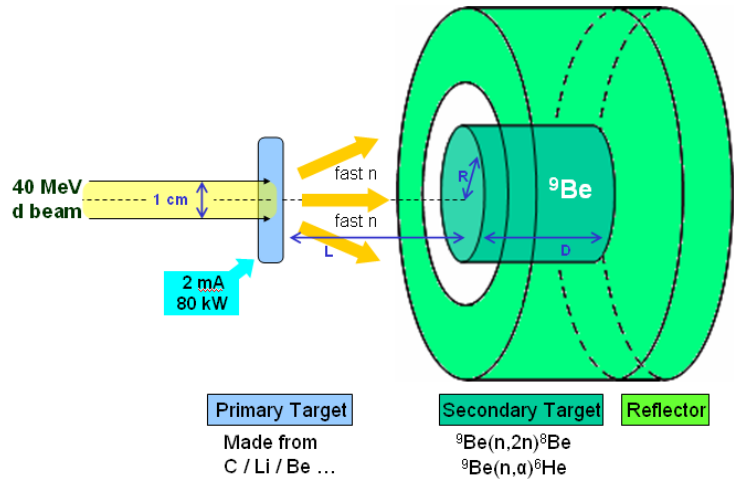
- Producing 10^{13} ^{18}Ne could be possible with a beam power (at low energy) of 2 MW (or some 130 mA ^{3}He beam on MgO).
- To keep the power density similar to LLN (today) the target has to be 60 cm in diameter.
- To be studied:
  - Extraction efficiency
  - Optimum energy
  - Cooling of target unit
  - High intensity and low energy ion linac
  - High intensity ion source

S. Mitrofanov and M. Loislet at CRC, Belgium



^{6}He (Two Stage ISOL)

- 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 ~6·10^{13} atoms per second.



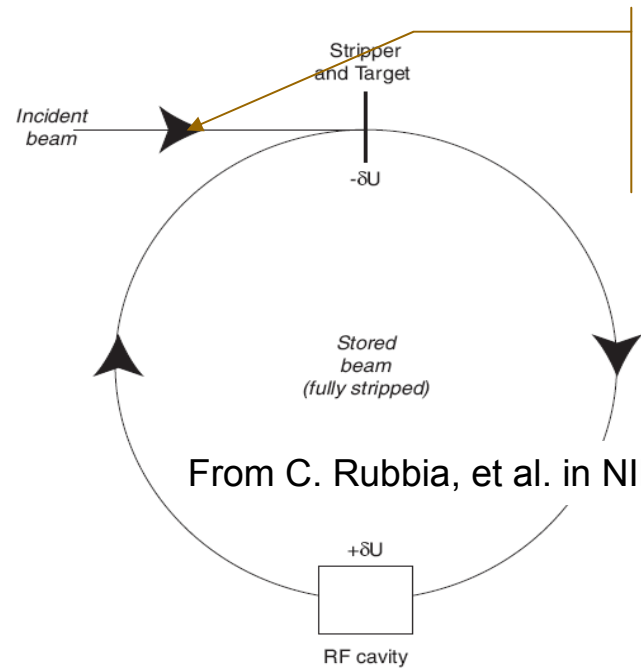
T.Y.Hirsh, D.Berkovits, M.Hass
(Soreq, Weizmann I.)

New approaches for ion 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

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

Will be studied in Euroν FP7:

- Design of ring
- Cooling in ring
- Collection device
- ECR Source

Overview, production

Illustration	METHOD	Advantage	Drawback
	Production ring	-"Re-use" of driver beam thanks to cooling -Huge cross sections for compound nucleus	-Challenging gas target design -Collection device efficiency
	Converter target, with low and high energy driver	Can accept very high intensity driver beam (>1 MW)	Limited to neutron produced isotopes such as ^{6}He and ^{8}Li
	ISOL with >1 GeV protons	Universal, any non-refractory isotope can be produced at high intensity with good beam quality	Can only accepted up to some 100 kW of driver beam
	Direct production	-Low energy and high intensity driver -Huge cross sections for compound nucleus	-Challenging very high intensity driver design -Extraction efficiency

Courtesy M. Lindroos

Work on Radiation Issues

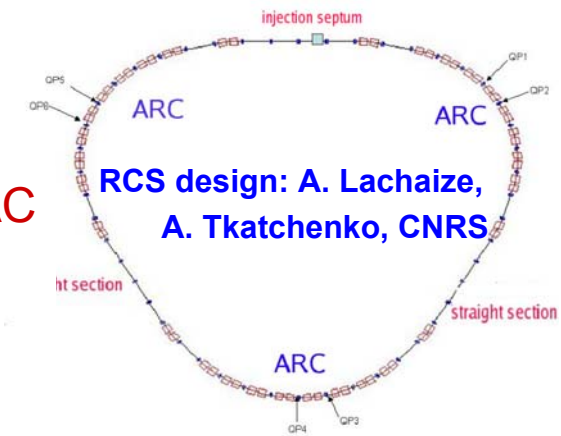
- Radiation safety
  - 88% of ^{18}Ne and 75% of ^{6}He ions are lost between source and injection into the Decay Ring
  - Detailed studies on RCS (manageable)
  - PS preliminary results available (heavily activated, 1 s flat bottom)
  - SPS and Decay Ring studies ongoing
- Safe collimation of ions during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

Radioprotection: Detailed study for RCS

Radio protection: Stefania Trovati, CERN

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

Avoided if chopping in LINAC



- 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

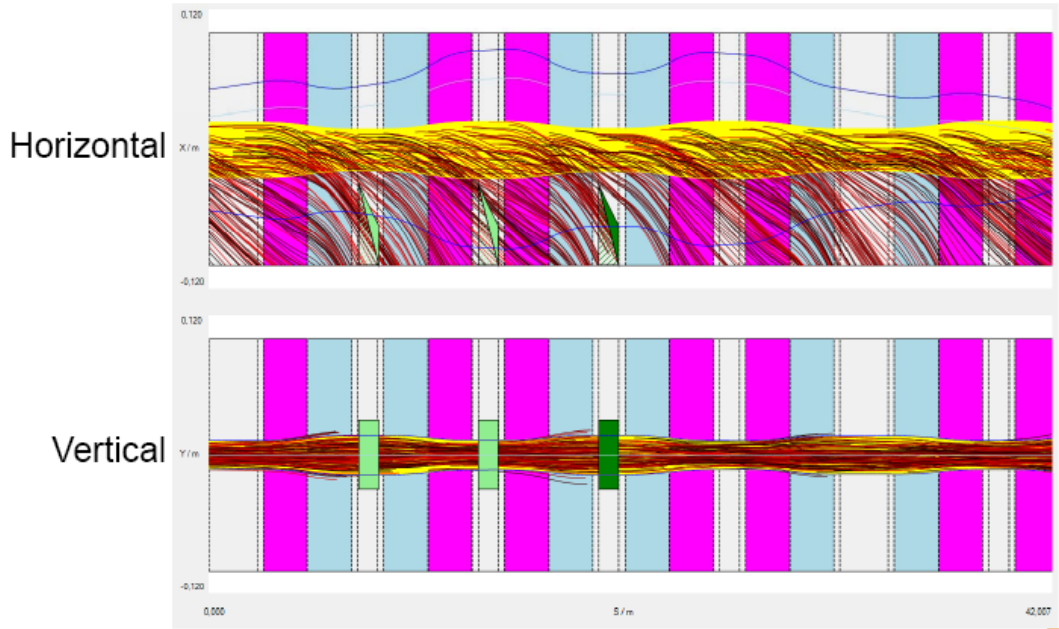
*** "Controlled area"**

Activation and coil damage in the PS

StrahlSim: Losses

Beta Beams in EURISOL

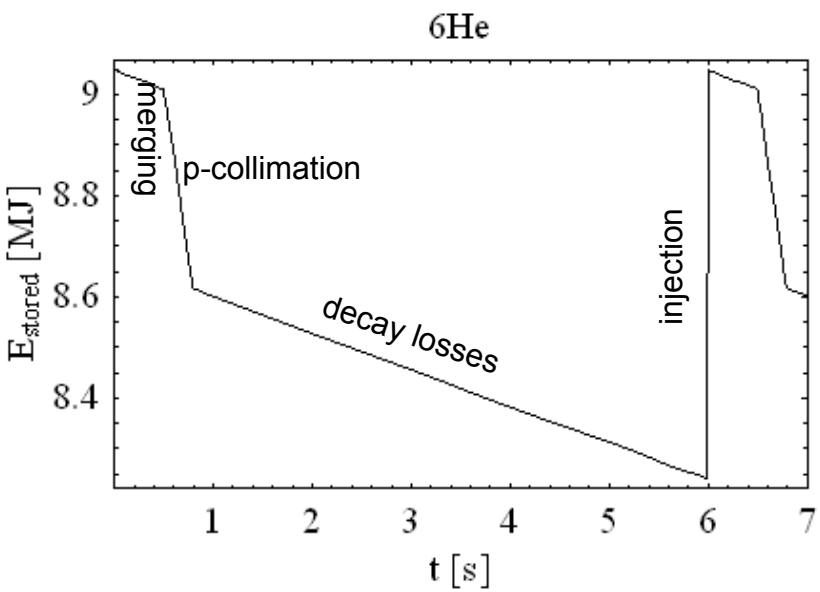
He-beam. Decay products tracked to the collimator and beampipe (red & black curves).

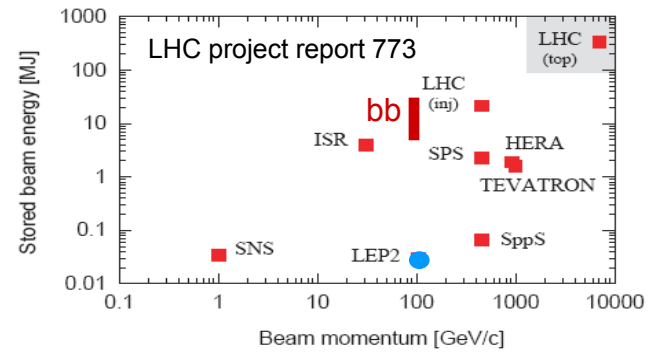


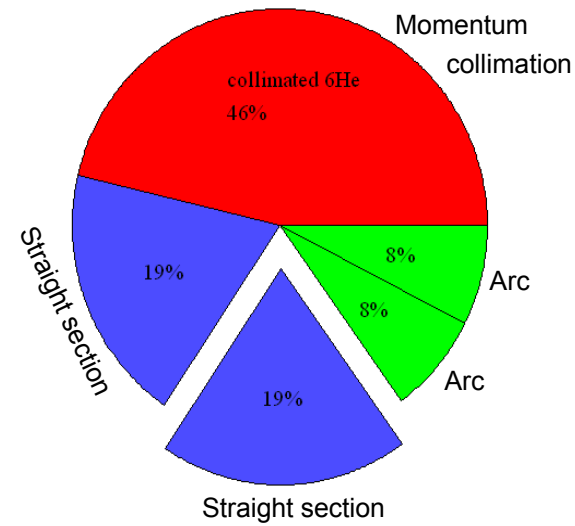
M. Kirk et. al GSI

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

Particle turnover in decay ring





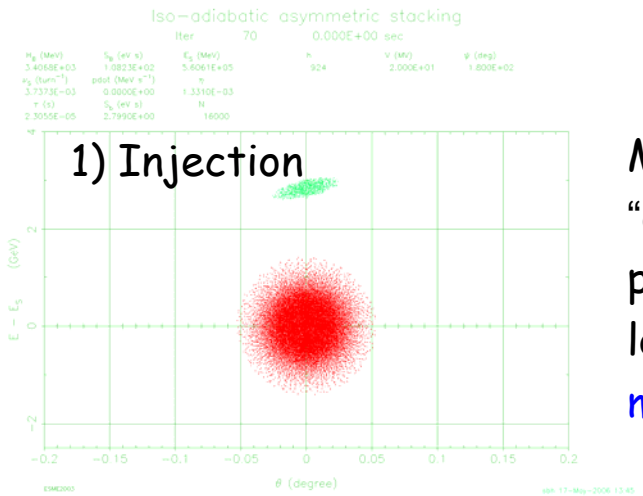


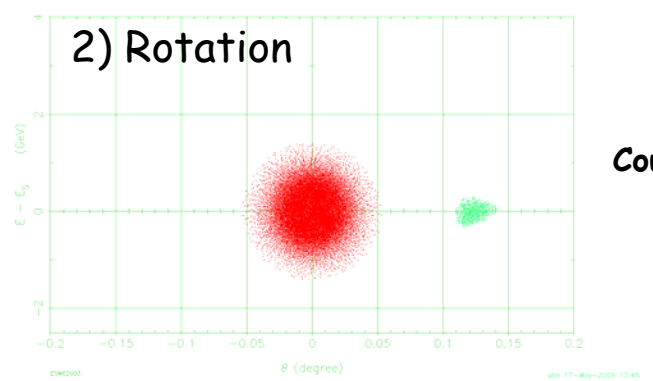
- Momentum collimation: ~5*10^{12} ^{6}He ions to be collimated per cycle
- Decay: ~5*10^{12} ^{6}Li ions to be removed per cycle per meter

Longitudinal Merging

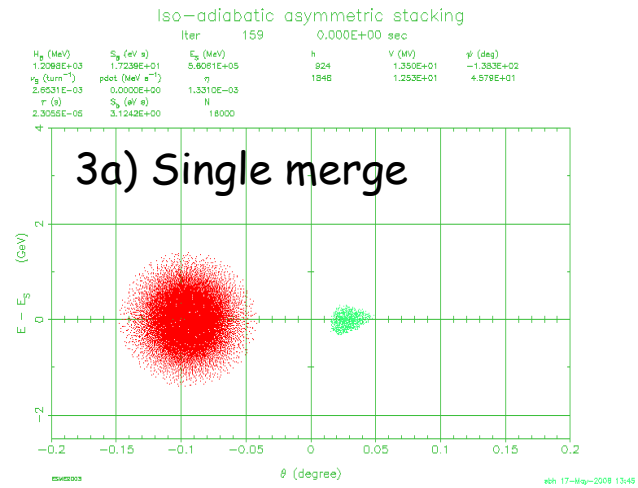
Mandatory for success of the γ=100 beta-beam concept

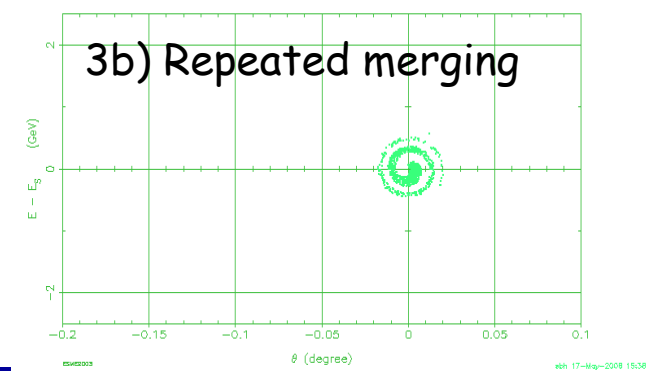
Lifetime of ions (minutes) is much longer than cycle time (seconds) of a beta-beam complex





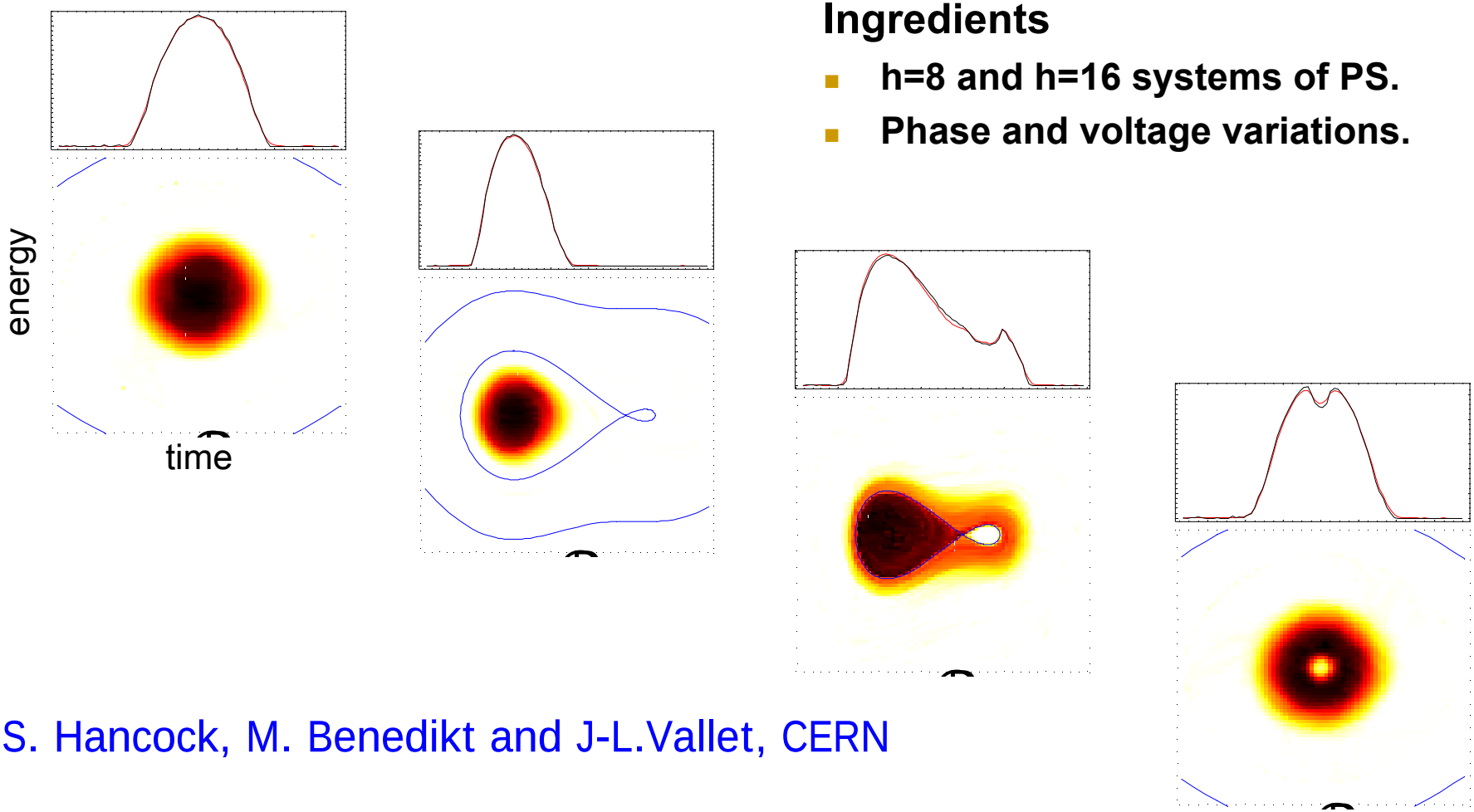
Merging:
"oldest" particles
pushed outside
longitudinal acceptance →
momentum collimation





Courtesy Steven Hancock, CERN

Decay Ring Stacking: experiment in CERN PS



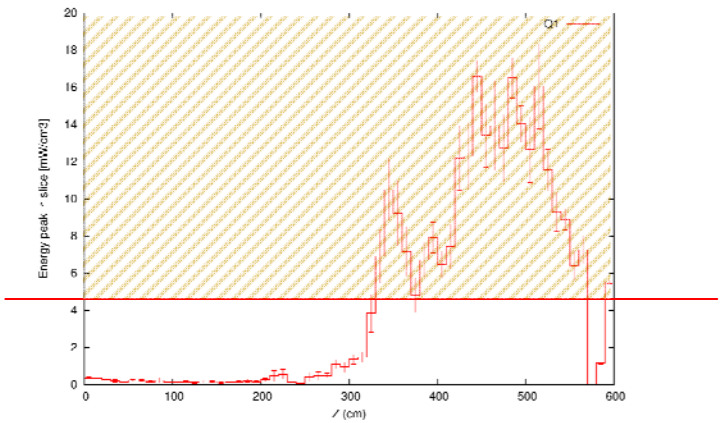
Ingredients

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

S. Hancock, M. Benedikt and J-L.Vallet, CERN

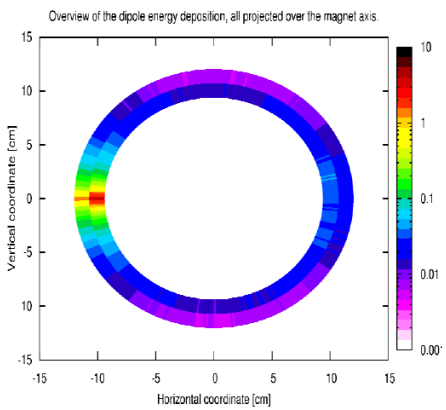
Heat Deposition study in Decay Ring

Peak Power Deposition in cable along magnet (FLUKA)



Decay Ring Lattice design: A. Chancé and J. Payet, CEA Saclay

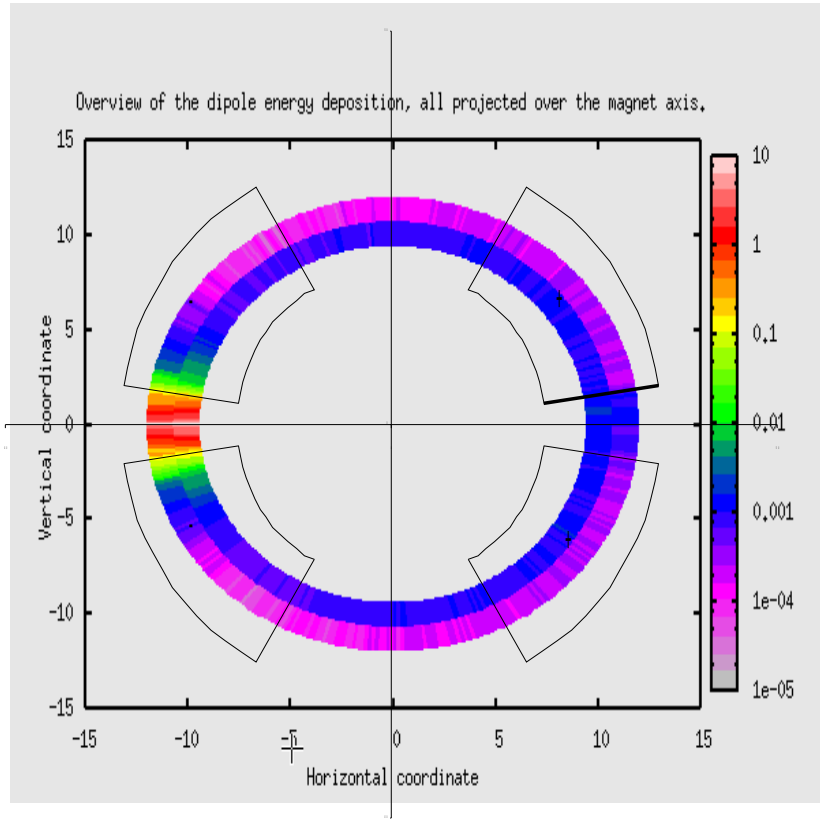
E. Wildner, CERN



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

Open Midplane Dipole for Decay Ring

Cos2θ design open midplane magnet



J. Bruer, E. Todesco, CERN

- 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.

The beta-beam in EUROν 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

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}Li and ^{8}B
  - Experience from EURISOL
  - First results will come from Euroν DS

    beta beam WP started 1 Sept. 2008 (4 year study)

Acknowledgements

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