A BASELINE BETA-BEAM

Mats Lindroos
AB Department, CERN

on behalf of the
Beta-beam Study Group

http://cern.ch/beta-beam/

Outline

- **Beta-beam baseline design**
  - **A baseline scenario, ion choice, main parameters**
  - **Ion production**
  - **Decay ring design issues**
- **Ongoing work and recent results**
  - **Asymmetric bunch merging for stacking in the decay ring**
  - **Decay ring optics design & injection**
- **Future R&D within EURISOL**
  - **The Beta-beam Task**
- **Conclusions**

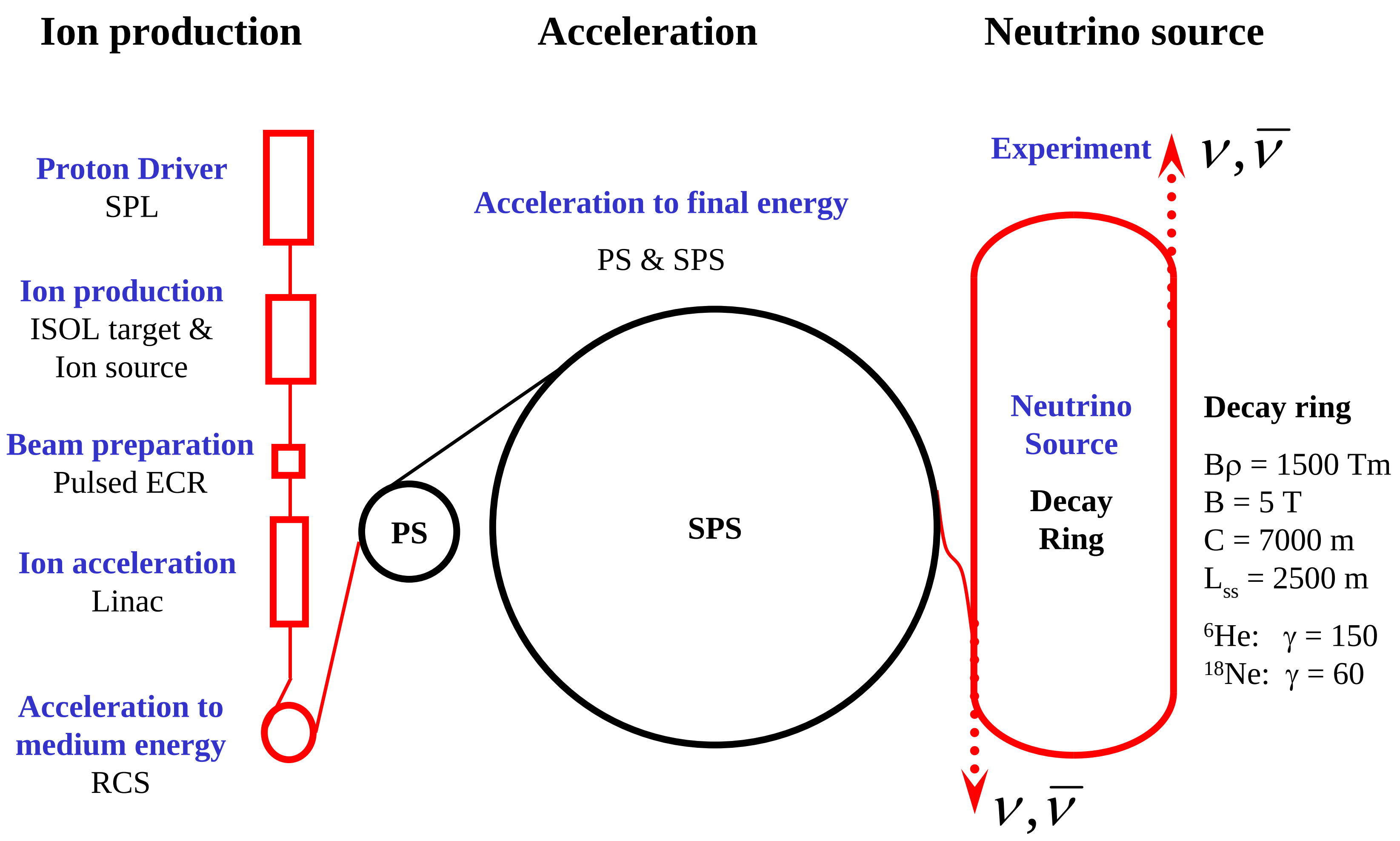
Introduction to beta-beams

- **Beta-beam proposal by Piero Zucchelli**
  - ***A novel concept for a neutrino factory: the beta-beam*, Phys. Let. B, 532 (2002) 166-172.**

- **AIM: production of a pure beam of electron neutrinos (or antineutrinos) through the beta decay of radioactive ions circulating in a high-energy (γ~100) storage ring.**

- **Baseline scenario**
  - **Avoid anything that requires a "technology jump" which would cost time and money (and be risky).**
  - **Make maximum use of the existing infrastructure.**

Beta-beam baseline design



Main parameters (1)

- **Factors influencing ion choice**
  - **Need to produce reasonable amounts of ions.**
  - **Noble gases preferred - simple diffusion out of target, gaseous at room temperature.**
  - **Not too short half-life to get reasonable intensities.**
  - **Not too long half-life as otherwise no decay at high energy.**
  - **Avoid potentially dangerous and long-lived decay products.**

- **Best compromise**
  - **Helium-6 to produce antineutrinos:** $^{6}_{2}He \rightarrow {}^{6}_{3}Li\ e^{-}\ \overline{\nu}$

    Average $E_{cms} = 1.937$ MeV
  - **Neon-18 to produce neutrinos:** $^{18}_{10}Ne \rightarrow {}^{18}_{9}F\ e^{+}\ \nu$

    Average $E_{cms} = 1.86$ MeV

FLUX

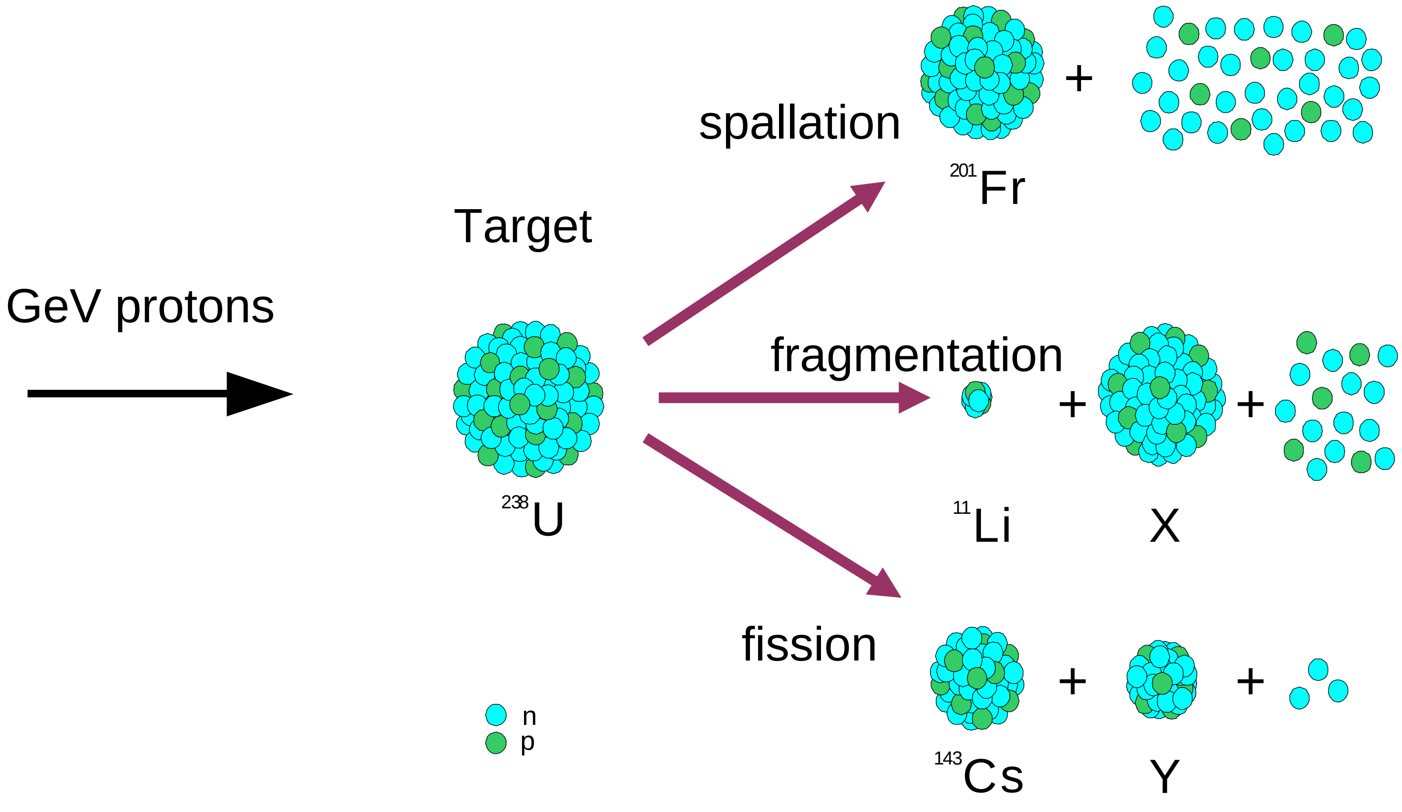
- The Design Study is aiming for:
  - A beta-beam facility that will run for a "normalized" year of 10^7 seconds
  - An integrated flux of 10 10^{18} anti-neutrinos (^6He) and 5 10^{18} neutrinos (^{18}Ne) in ten years running at γ=100

With an Ion production in the target to the ECR source:

- ^6He= 2 10^{13} atoms per second
- ^{18}Ne= 8 10^{11} atoms per second

Ion production - ISOL method

- **Isotope Separation OnLine method.**
- **Few GeV proton beam onto fixed target.**

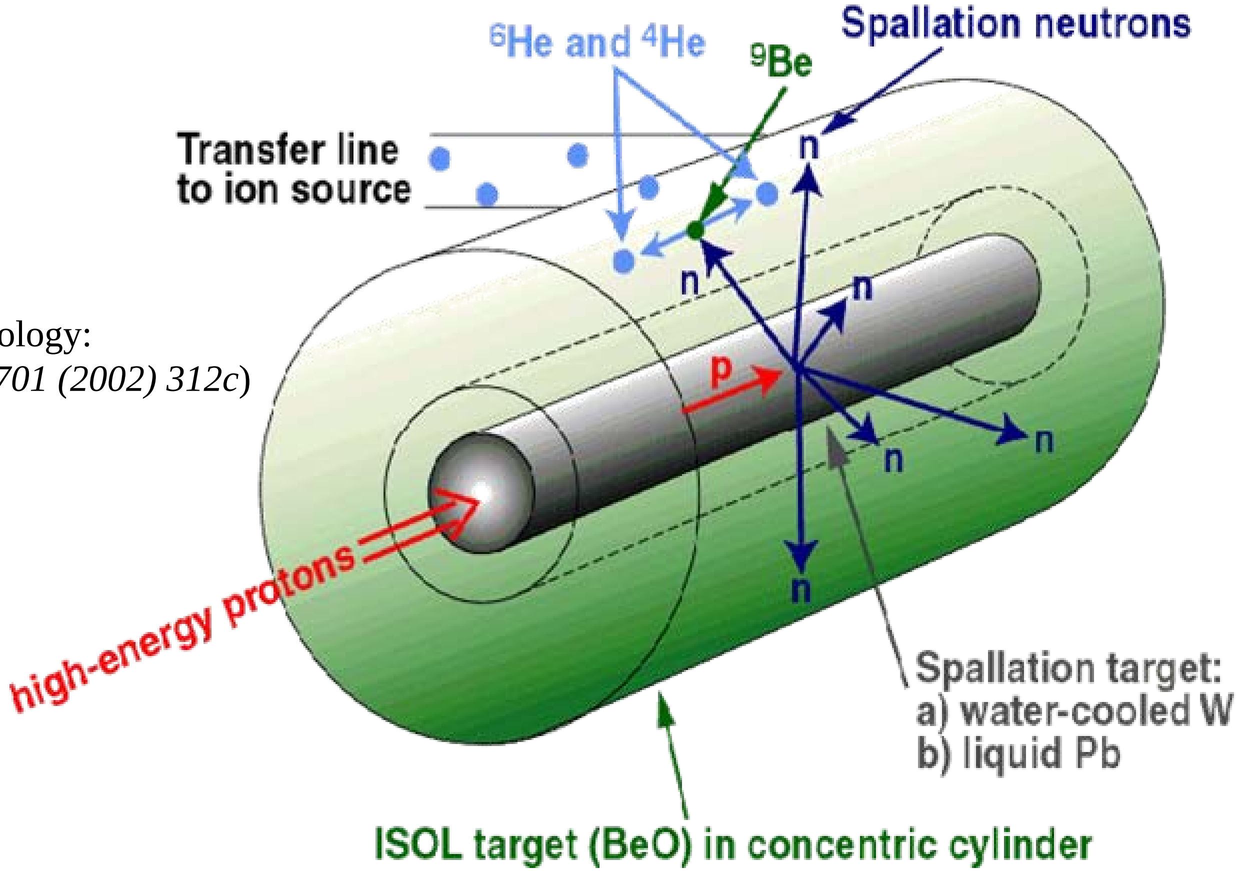


^{6}He via spallation n

^{18}Ne directly

^{6}He production from ^{9}Be(n,α)

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

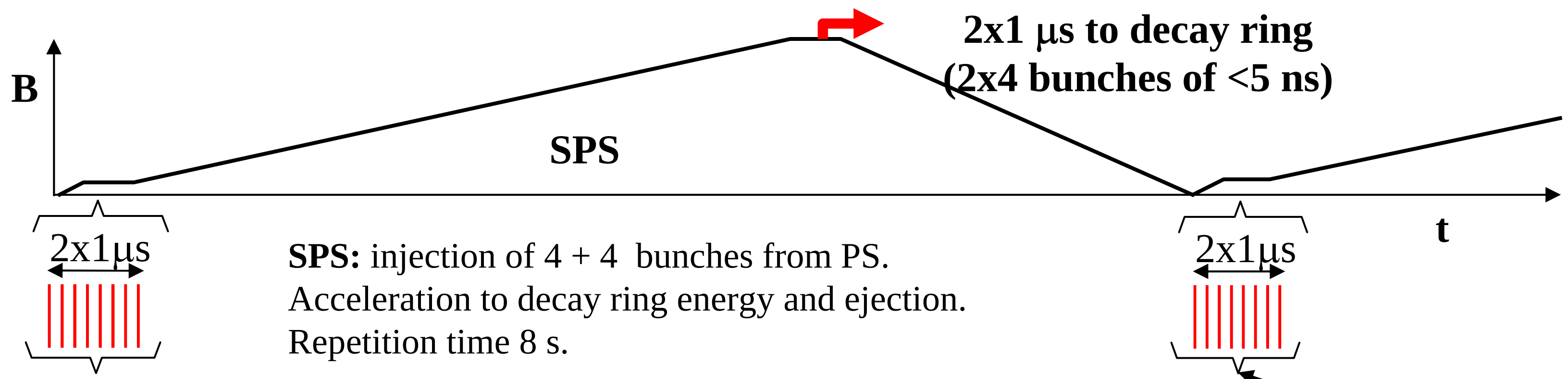


- **Converter technology preferred to direct irradiation (heat transfer and efficient cooling allows higher power compared to insulating BeO).**
- **^{6}He production rate is ~2x10^{13} ions/s (dc) for ~200 kW on target.**

^{18}Ne production

- Spallation of close-by target nuclides
  - $^{24}Mg^{12}$ (p, p_3 n_4) $^{18}Ne^{10}$.
  - Converter technology cannot be used; the beam hits directly the magnesium oxide target.
  - Production rate for ^{18}Ne is ~ 1x10^{12} ions/s (dc) for ~200 kW on target.
  - ^{19}Ne can be produced with one order of magnitude higher intensity but the half-life is 17 seconds!

From dc to very short bunches



SPS: injection of 4 + 4 bunches from PS.
Acceleration to decay ring energy and ejection.
Repetition time 8 s.

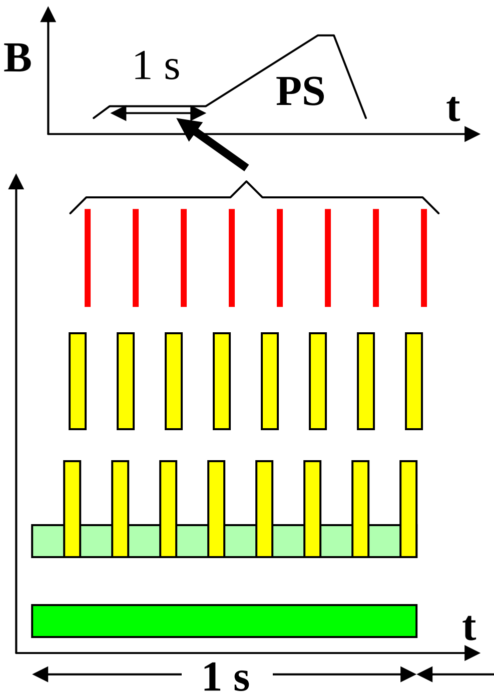
PS: 1 s flat bottom with 8 (16) injections. Acceleration in ~1 s to top PS energy.

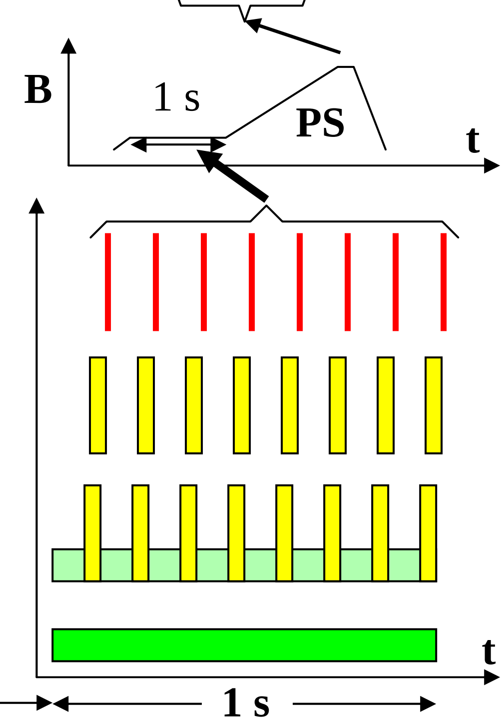
RCS: further bunching to ~100 ns
Acceleration to ~300 MeV/u.
8 (16) repetitions during 1 s.

Post accelerator linac:
acceleration to ~100 MeV/u.
8 (16) repetitions during 1 s.

60 GHz ECR: accumulation for 1/8 (1/16) s
ejection of fully stripped ~20 μs pulse.
8 (16) batches during 1 s.

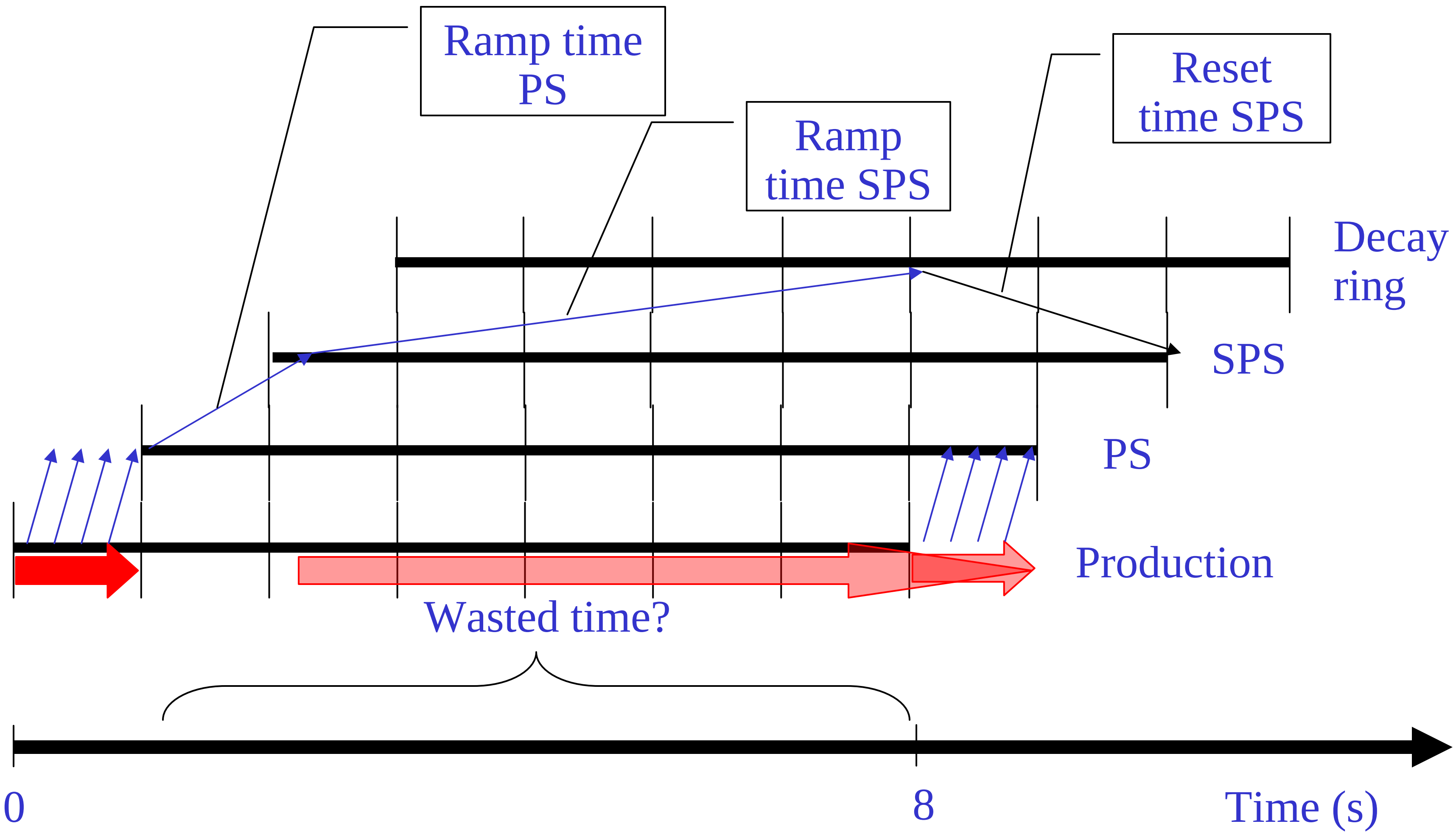
Target: dc production during 1 s.





7 s

Wasted time or accumulation time?



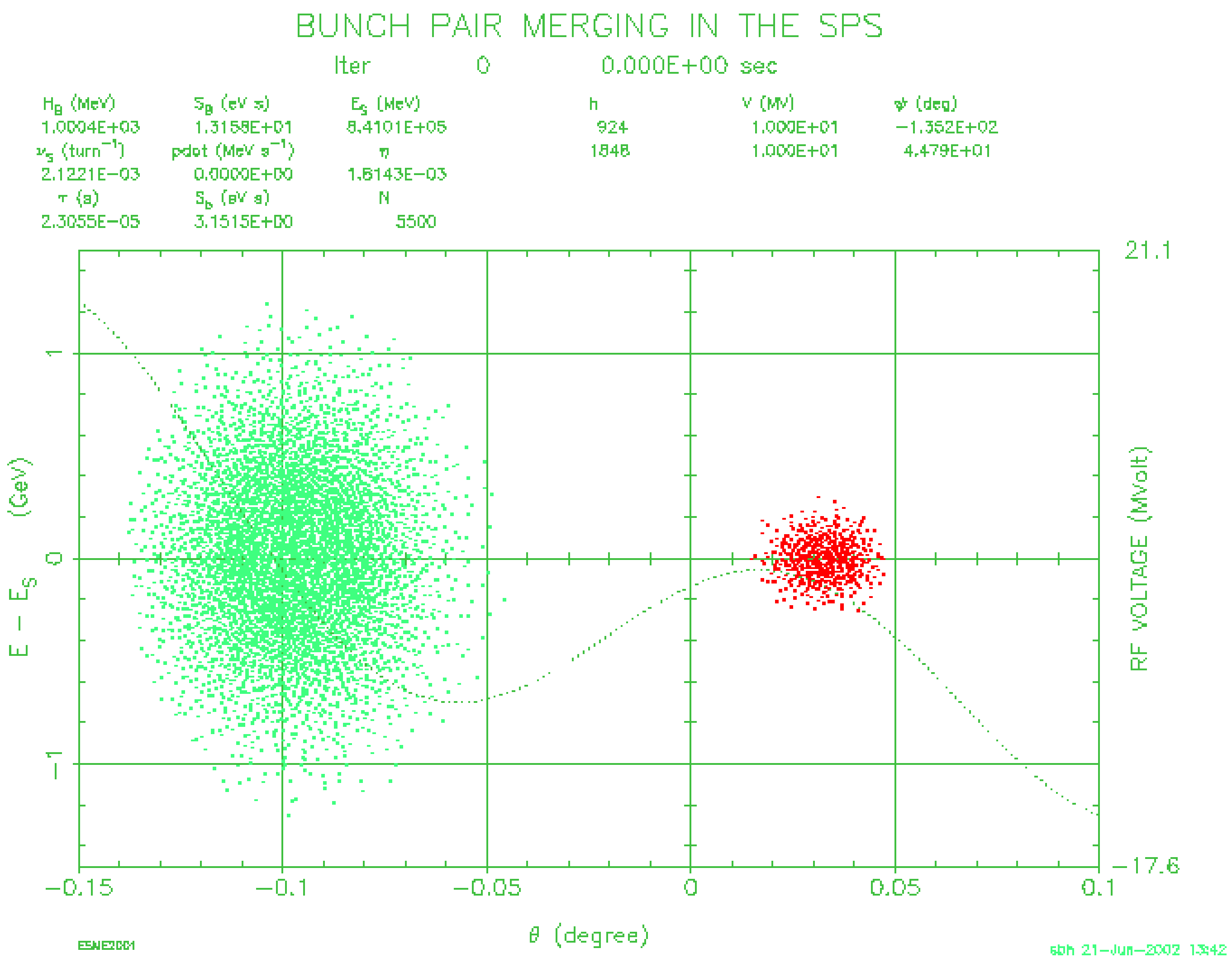
Decay ring design aspects

- The ions have to be concentrated in a few very short bunches
  - Suppression of atmospheric background via time structure.
- There is an essential need for stacking in the decay ring
  - Not enough flux from source and injector chain.
  - Lifetime is an order of magnitude larger than injector cycling (120 s compared with 8 s SPS cycle).
  - Need to stack for at least 10 to 15 injector cycles.
- Cooling is not an option for the stacking process
  - Electron cooling is excluded because of the high electron beam energy and, in any case, the cooling time is far too long.
  - Stochastic cooling is excluded by the high bunch intensities.
- Stacking without cooling "conflicts" with Liouville

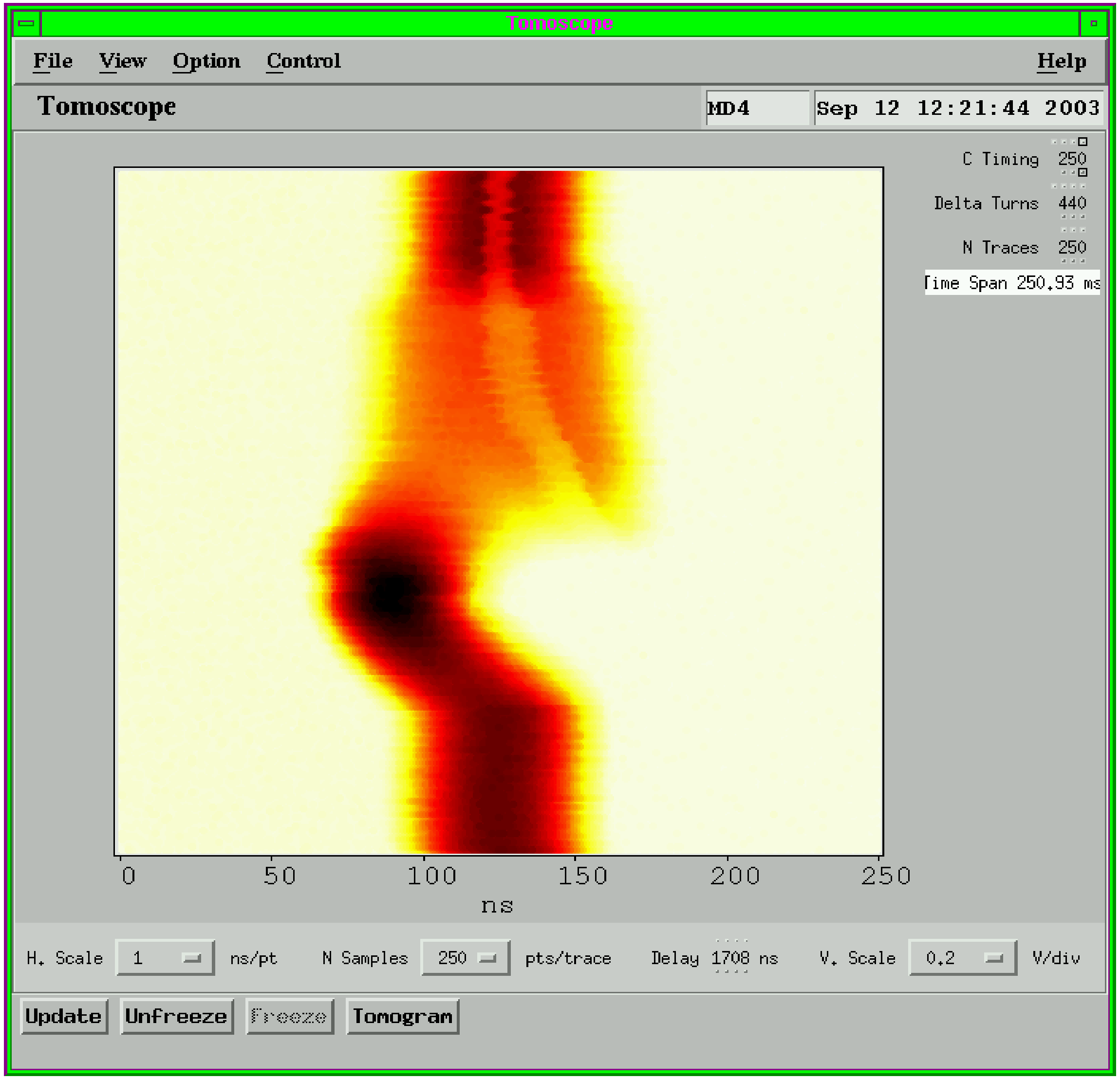
Asymmetric bunch pair merging

- **Moves a fresh dense bunch into the core of the much larger stack and pushes less dense phase space areas to larger amplitudes until these are cut by the momentum collimation system.**
- **Central density is increased with minimal emittance dilution.**
- **Requirements:**
  - **Dual harmonic rf system. The decay ring will be equipped with 40 and 80 MHz systems (to give required bunch length of ~10 ns for physics).**
  - **Incoming bunch needs to be positioned in adjacent rf "bucket" to the stack (i.e., ~10 ns separation!).**

Simulation (in the SPS)



Test experiment in the PS

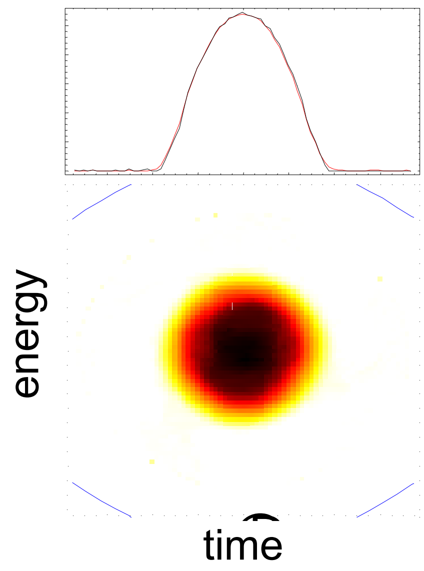


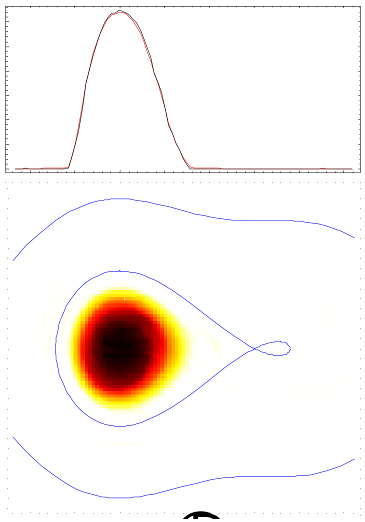
A large bunch is merged with a small amount of empty phase space.

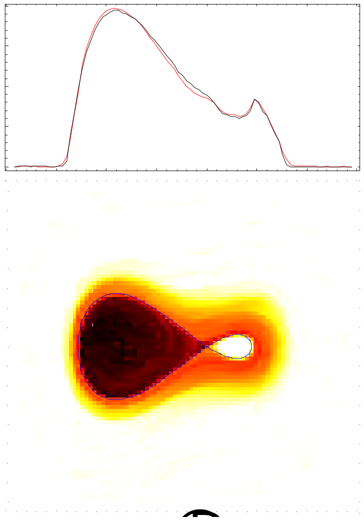
Longitudinal emittances are combined.

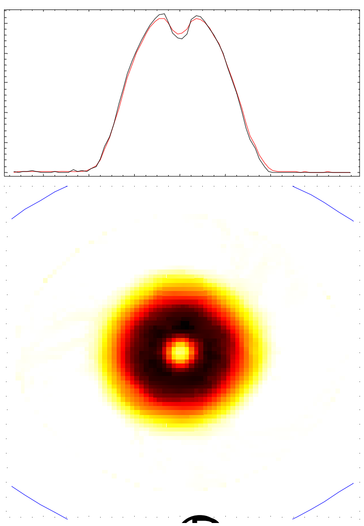
Minimal blow-up.

Test 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

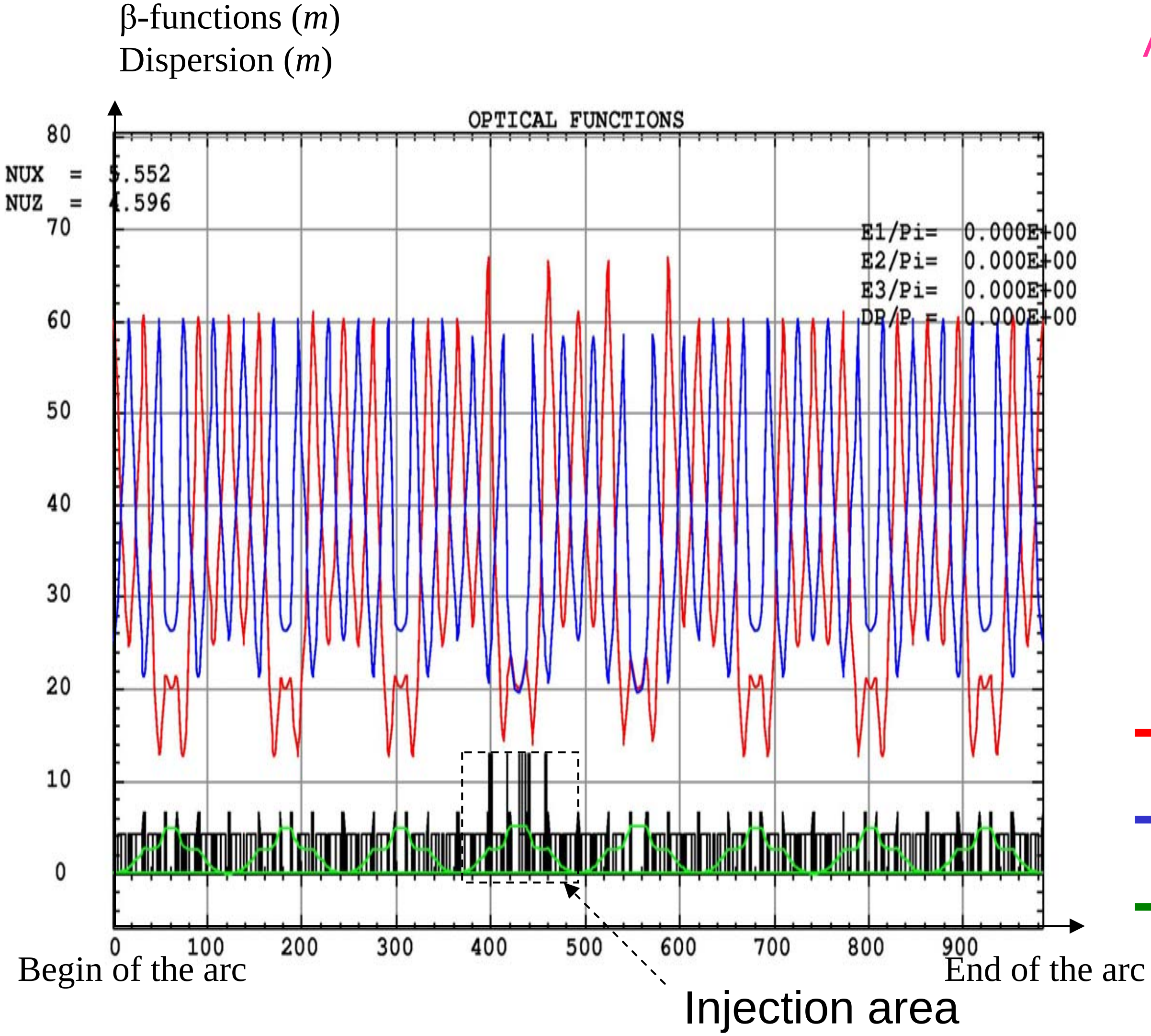
Decay ring injection design aspects

- **Asymmetric merging requires fresh bunch injected very close longitudinally to existing stack. Conventional injection with fast elements (septa and kickers) is excluded.**

- **Alternative injection scheme**
  - **Inject an off-momentum beam on matched dispersion trajectory.**
  - **No fast elements required (bumper rise and fall ~10 μs).**
  - **Requires large normalized dispersion at injection point (small beam size and large separation due to momentum difference).**
  - **Price to be paid is larger magnet apertures in decay ring.**

Decay ring arc lattice design

A. Chance, CEA-Saclay (F)



- FODO structure
- Central cells detuned for injection
- Arc length ~984m
- Bending 3.9 T, ~480 m L_{eff}
- 5 quadrupole families

Horizontal β_x

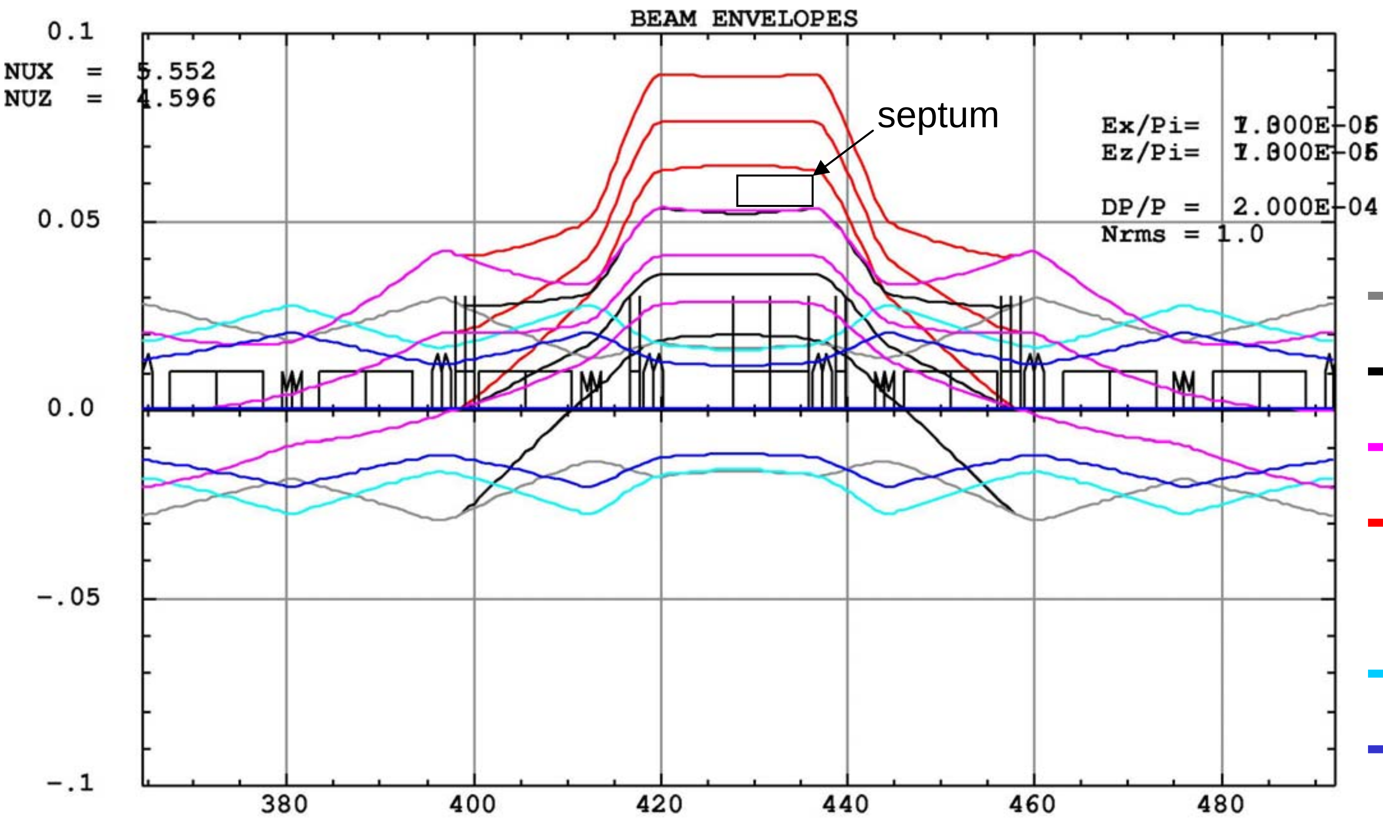
Vertical β_y

Horizontal Dispersion D_x

Decay ring injection envelopes

A. Chance, CEA-Saclay (F)

Envelope (*m*)



Horizontal envelopes :

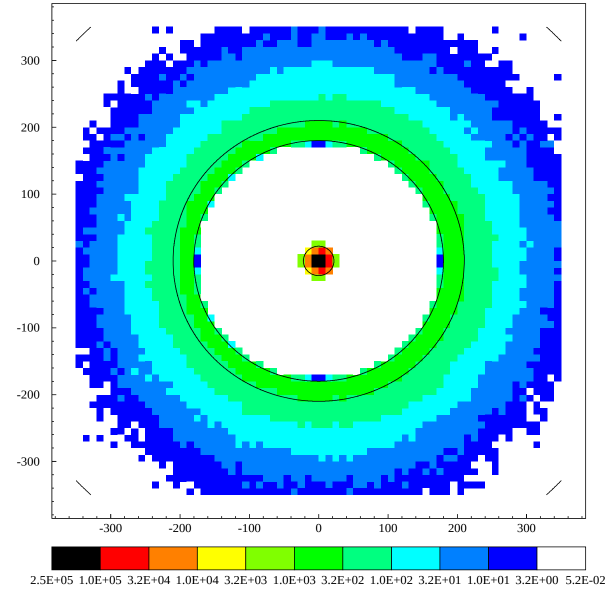
- Δp/p = 0 bumps off
- Δp/p = 0 bumps on
- Δp/p = 0.8% bumps off
- Δp/p = 0.8% bumps on

Vertical envelopes :

- stored beam
- injected beam

- **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)

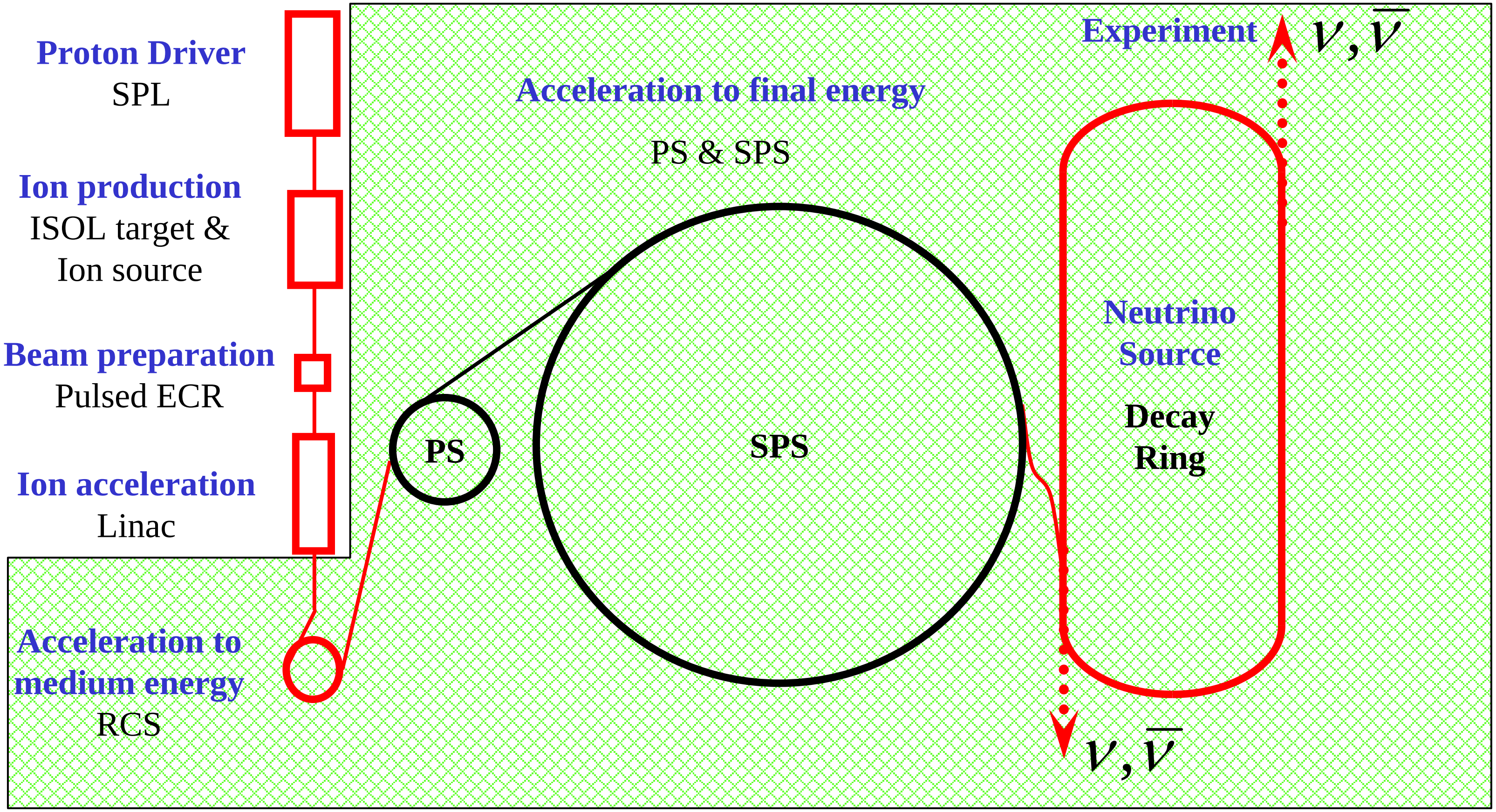
Future R&D

- Future beta-beam R&D together with EURISOL project
- Design Study in the 6th Framework Programme of the EU

- The EURISOL Project
  - Design of an ISOL type (nuclear physics) facility.
  - Performance three orders of magnitude above existing facilities.
  - A first feasibility / conceptual design study was done within FP5.
  - Strong synergies with the low-energy part of the beta-beam:
    - Ion production (proton driver, high power targets).
    - Beam preparation (cleaning, ionization, bunching).
    - First stage acceleration (post accelerator ~100 MeV/u).
    - Radiation protection and safety issues.

Beta-beam task

From exit of the heavy ion Linac (~100 MeV/u) to the decay ring (~100 GeV/u).

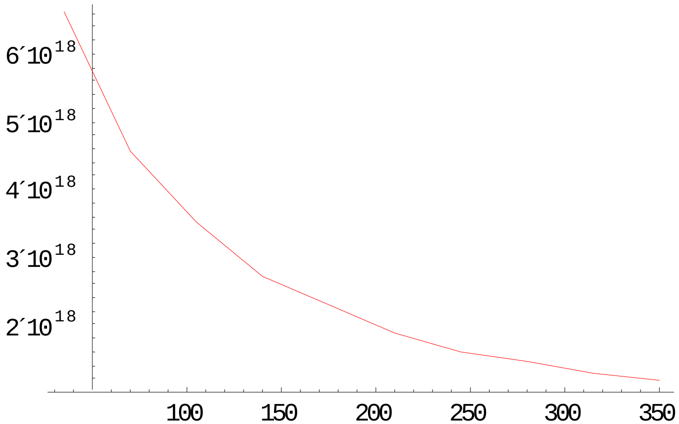


Beta-beam sub-tasks

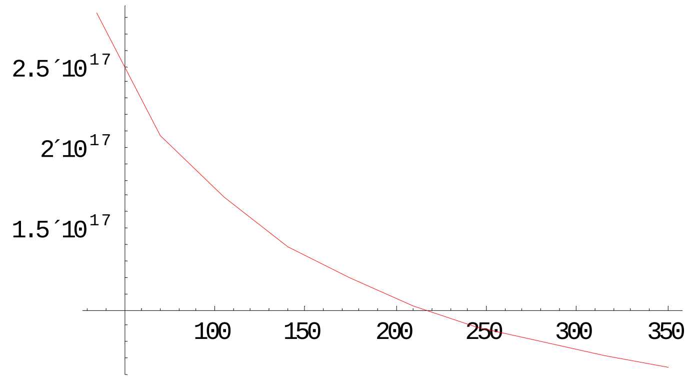
- **Beta-beam task starts at exit of EURISOL post accelerator and comprises the conceptual design of the complete chain up to the decay ring.**
- **Participating insitutes: CERN, CEA-Saclay, IN2P3, CLRC-RAL, GSI, MSL-Stockholm.**
- **Organized by a steering committee overseeing 3 sub-tasks.**
  - **ST 1: Design of the low-energy ring(s).**
  - **ST 2: Ion acceleration in PS/SPS and required upgrades of the existing machines including new designs to eventually replace PS/SPS.**
  - **ST 3: Design of the high-energy decay ring.**
  - **Detailed work and manpower planning is under way.**
  - **Around 38 (13 from EU) man-years for beta-beam R&D over next 4 years (only within beta-beam task, not including linked tasks).**

Can we reach the FLUX?

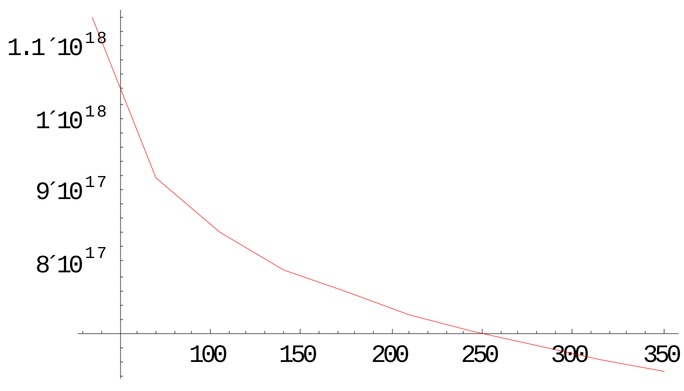
^{6}He



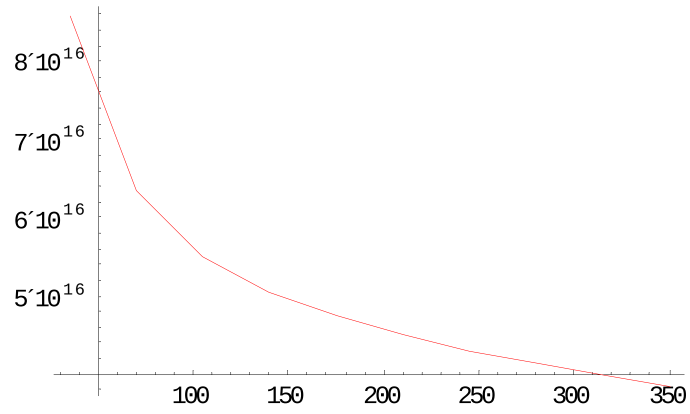
^{18}Ne



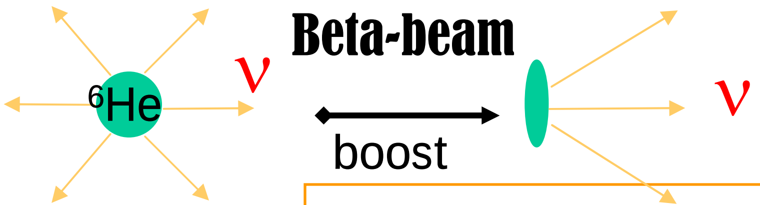
^{19}Ne



^{150}Dy



LOW-ENERGY BETA-BEAMS



C. Volpe, hep-ph/0303222
Journ. Phys. G. 30(2004)L1

THE PROPOSAL

To exploit the beta-beam concept to produce intense and pure low-energy neutrino beams.

PHYSICS POTENTIAL

- Neutrino-nucleus interaction studies for particle, nuclear physics, astrophysics (nucleosynthesis).

  Important for neutrinoless double-beta decay.

  C. Volpe, hep-ph/0501233

- Neutrino properties, like ν magnetic moment.

Conclusions

- Well-established beta-beam baseline scenario.
- Beta-Beam Task well integrated in the EURISOL DS.
  - Strong synergies between Beta-beam and EURISOL.
- Design study started for "base line" isotopes.
- Baseline study should result in a credible conceptual design report.
  - We need a "STUDY 1" for the beta-beam to be considered a credible alternative to super beams and neutrino factories
  - New ideas welcome but the design study cannot (and will not) deviate from the given flux target values and the chosen baseline
  - Parameter list to be frozen by end of 2005
- Recent new ideas promise a fascinating continuation into further developments beyond (but based on) the ongoing EURISOL (beta-beam) DS
  - Low energy beta-beam, EC beta-beam, High gamma beta-beam, etc.
- And this is only the beginning…