A BASELINE BETA-BEAM

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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

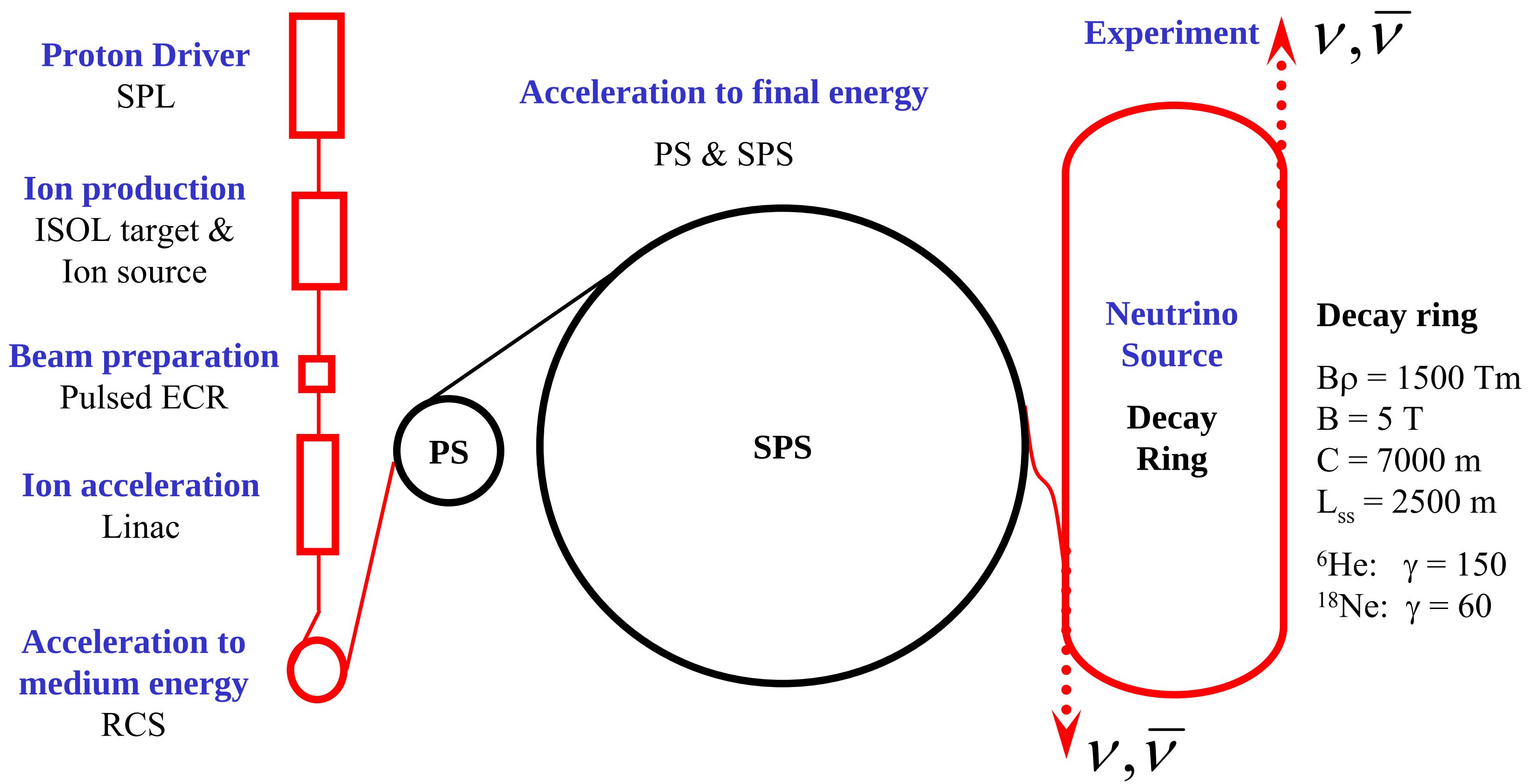
- **Beta-beam proposal by Piero Zucchelli**
  - ***A novel concept for a neutrino factory: the beta-beam,*** **Phys. Let. B, 532 (2002) 166-172.**

- **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

Ion production | **Acceleration** | **Neutrino source**



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

Main parameters (2)

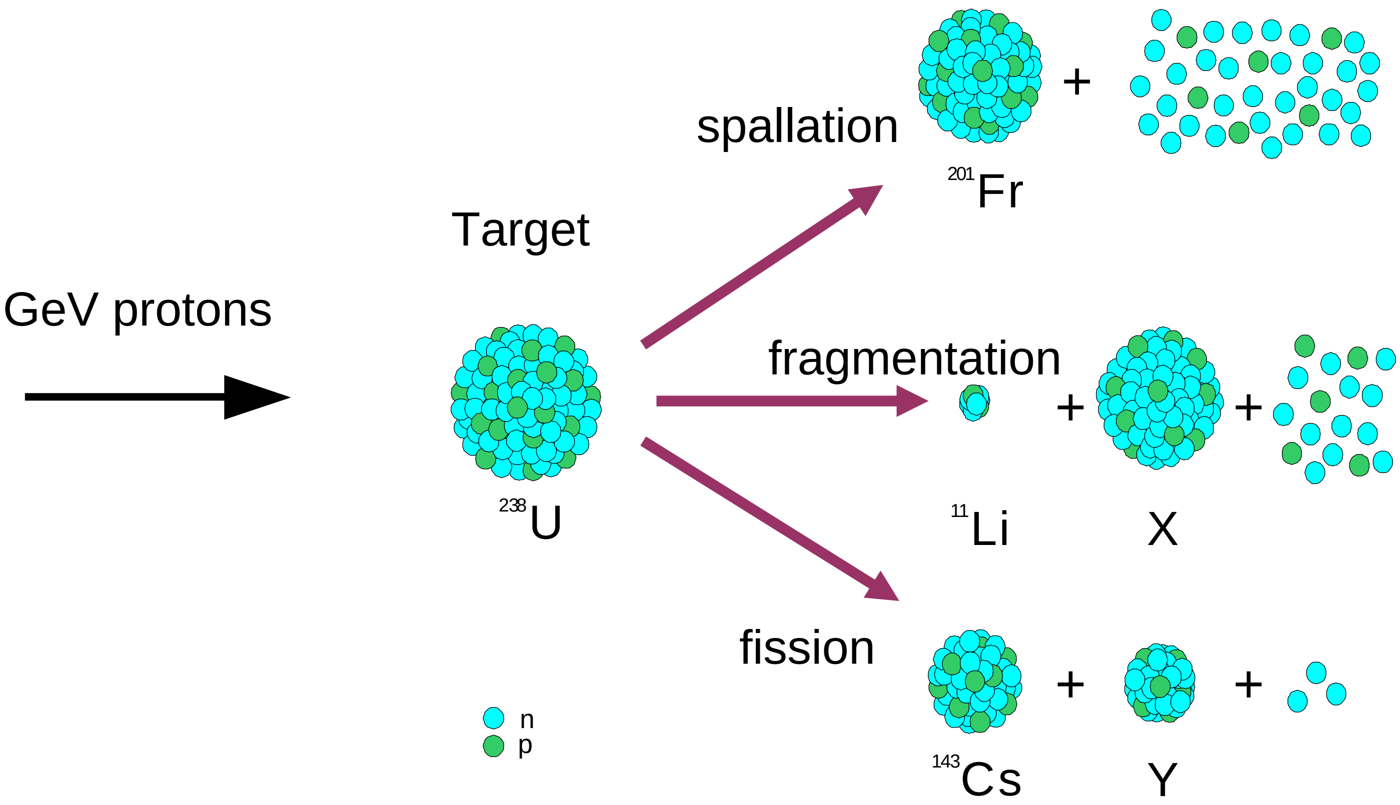
- **Target values in the decay ring**

^{6}Helium^{2+}		^{18}Neon^{10+}	
– Inj. flux	9×10^{12} ions/batch	– Inj. flux	0.5×10^{12} ions/batch
– Energy	139 GeV/u	– Energy	55 GeV/u
– Gamma	150	– Gamma	60
– Rigidity	1500 Tm	– Rigidity	335 Tm

- **The neutrino beam at the experiment has the "time stamp" of the circulating beam in the decay ring.**
- **The beam has to be concentrated in as few and as short bunches as possible to maximize the number of ions/nanosecond for background suppression.**
- **Aim for a duty factor of 10^{-4} . This is a major design challenge!**

Ion production - ISOL method

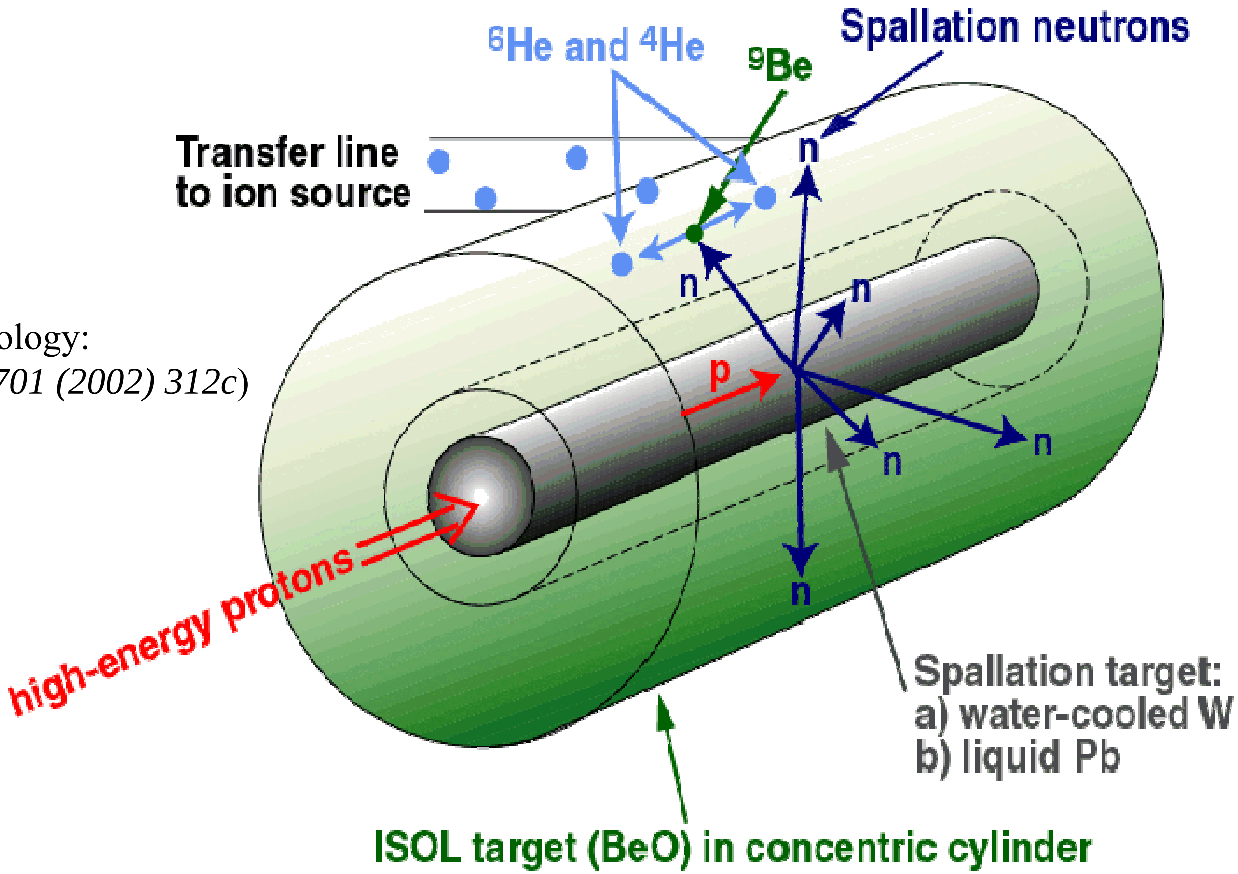
- **Isotope Separation OnLine method.**
- **Few GeV proton beam onto fixed target.**



^{6}He via spallation n

^{18}Ne directly

^{6}He production from ^{9}Be(n,α)



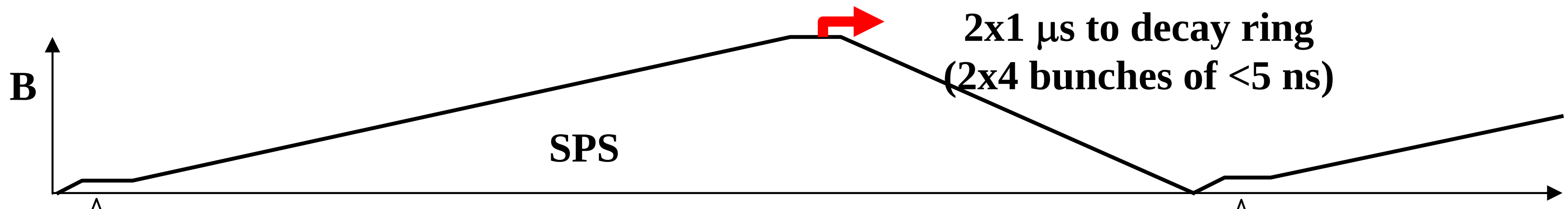
Converter technology:
(*J. Nolen, NPA 701 (2002) 312c*)

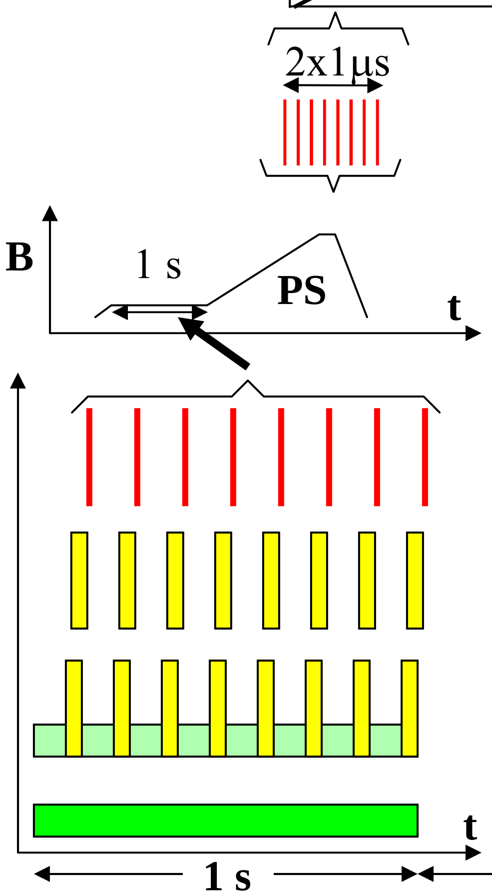
- **Converter technology preferred to direct irradiation (heat transfer and efficient cooling allows higher power compared to insulating BeO).**
- **^{6}He production rate is ~2x10^{13} ions/s (dc) for ~200 kW on target.**

^{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 ~ 1×10^{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.

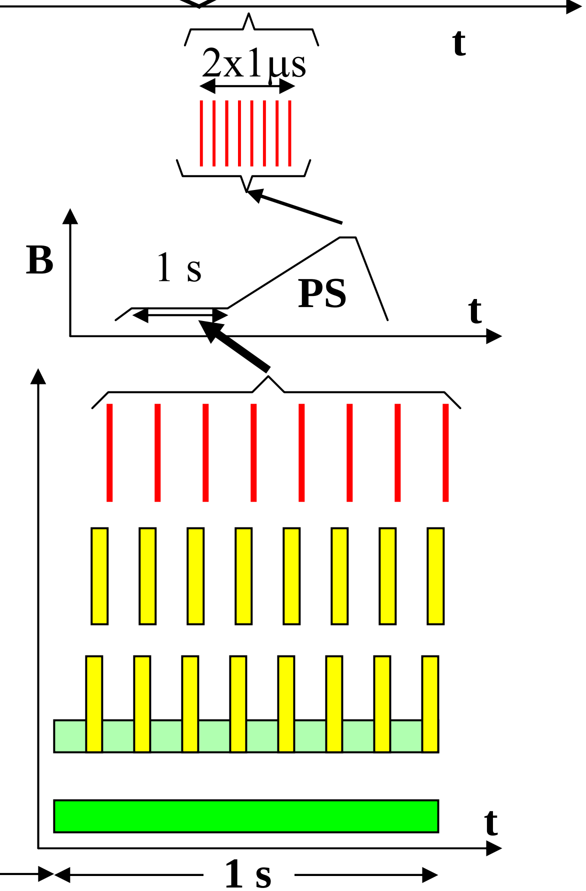
PS: 1 s flat bottom with 8 (16) injections. Acceleration in ~1 s to top PS energy.

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.



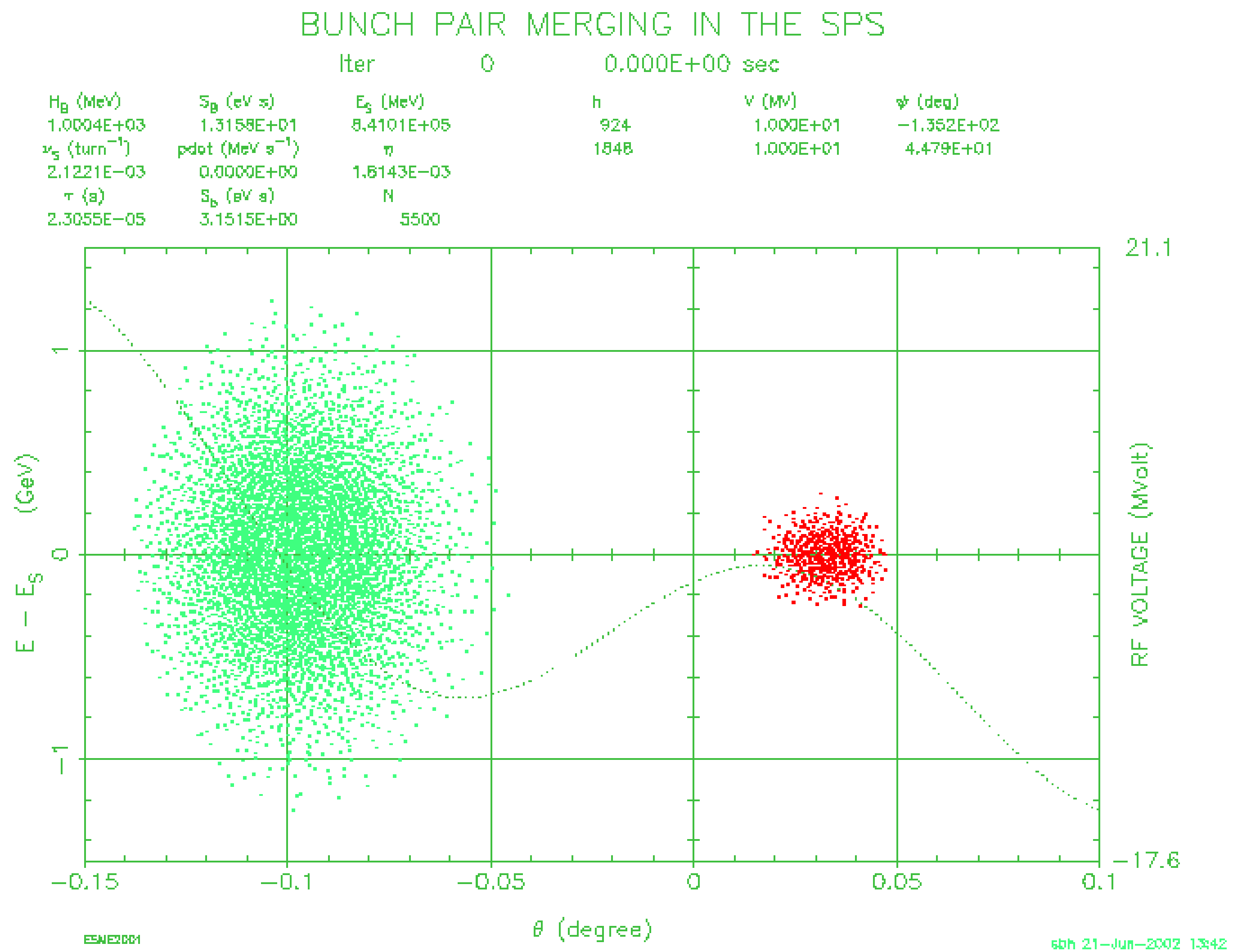
Decay ring design aspects

- 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

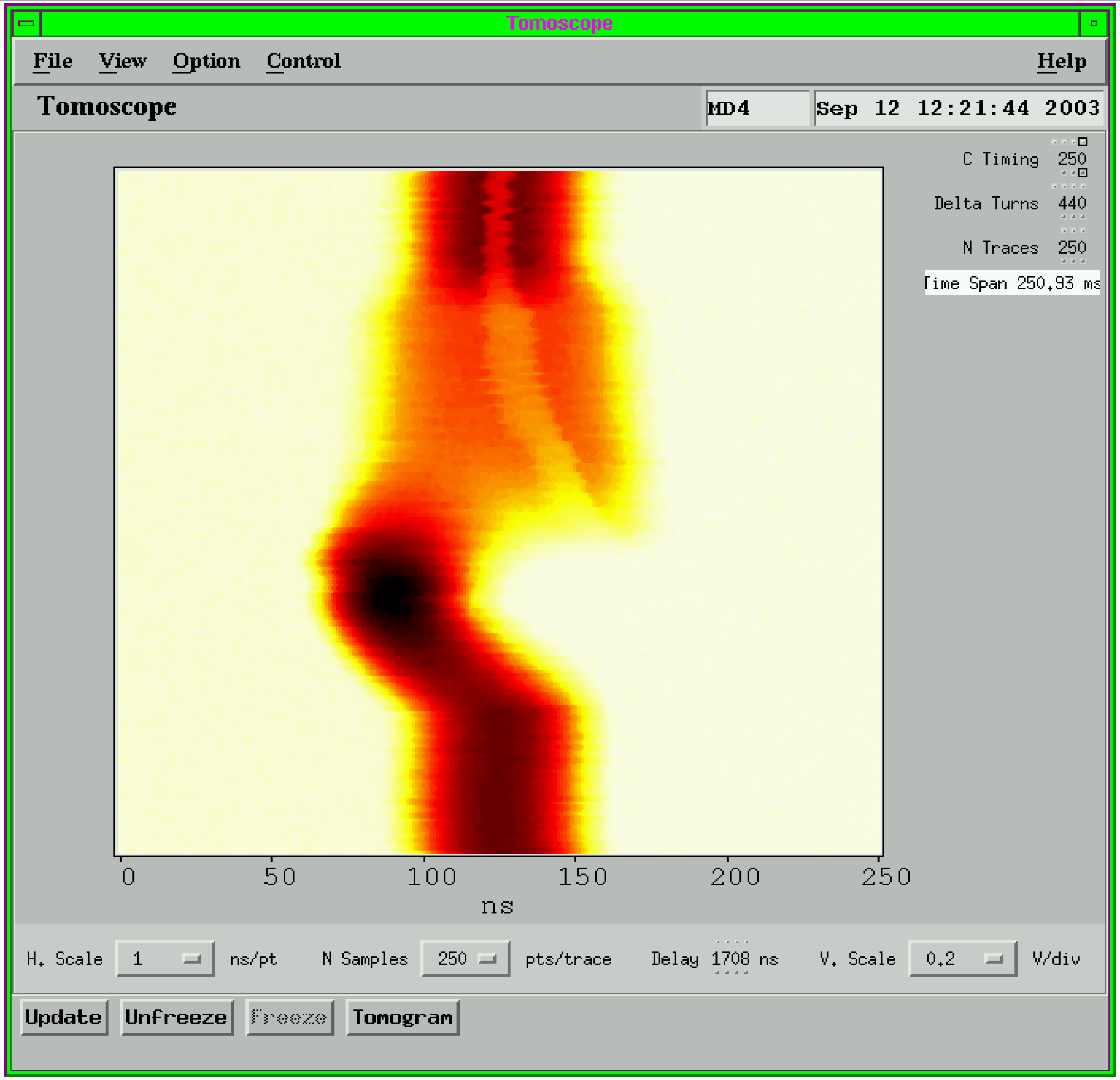
Asymmetric bunch pair merging

- 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

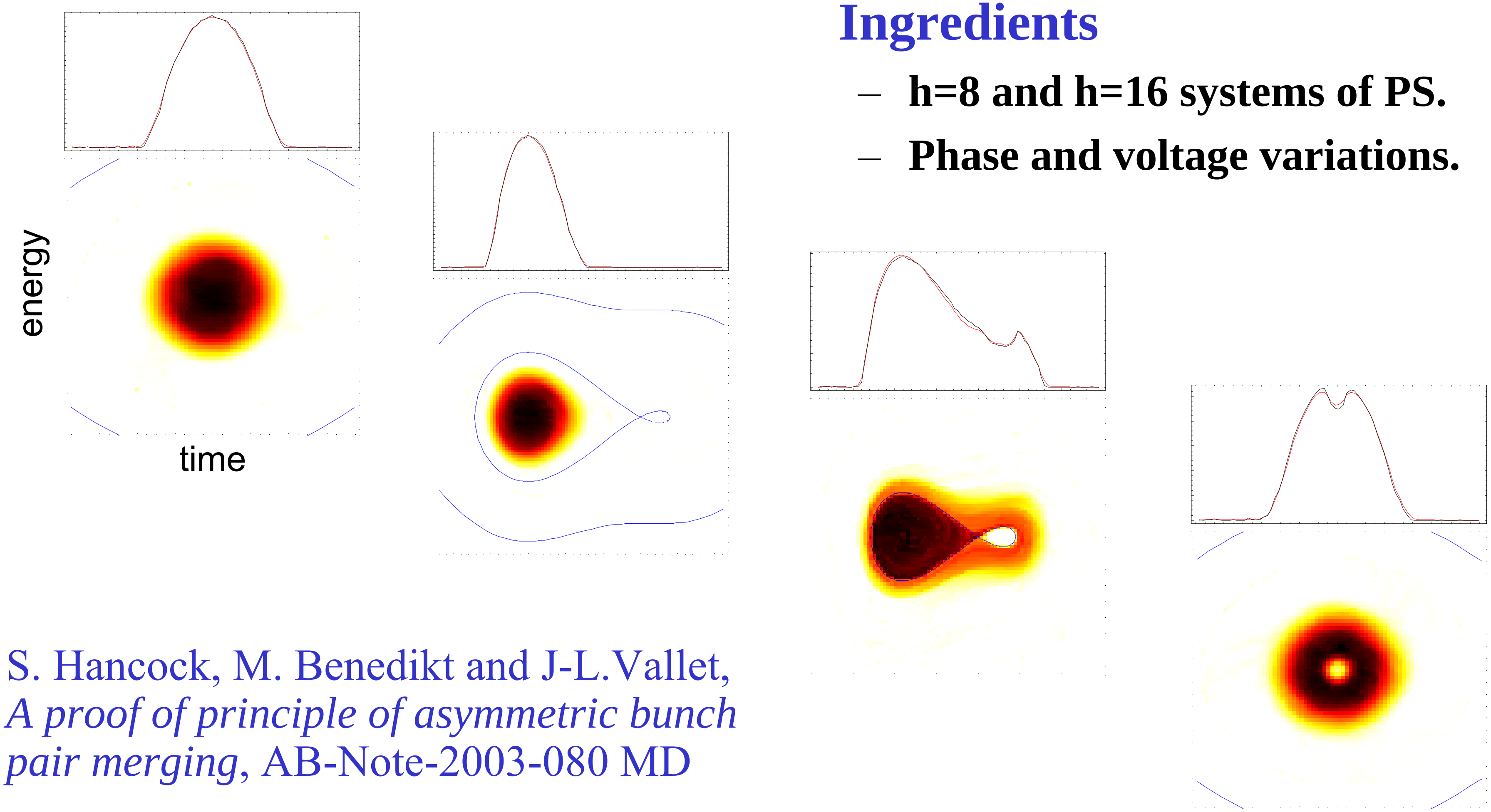


A large bunch is merged with a small amount of empty phase space.

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

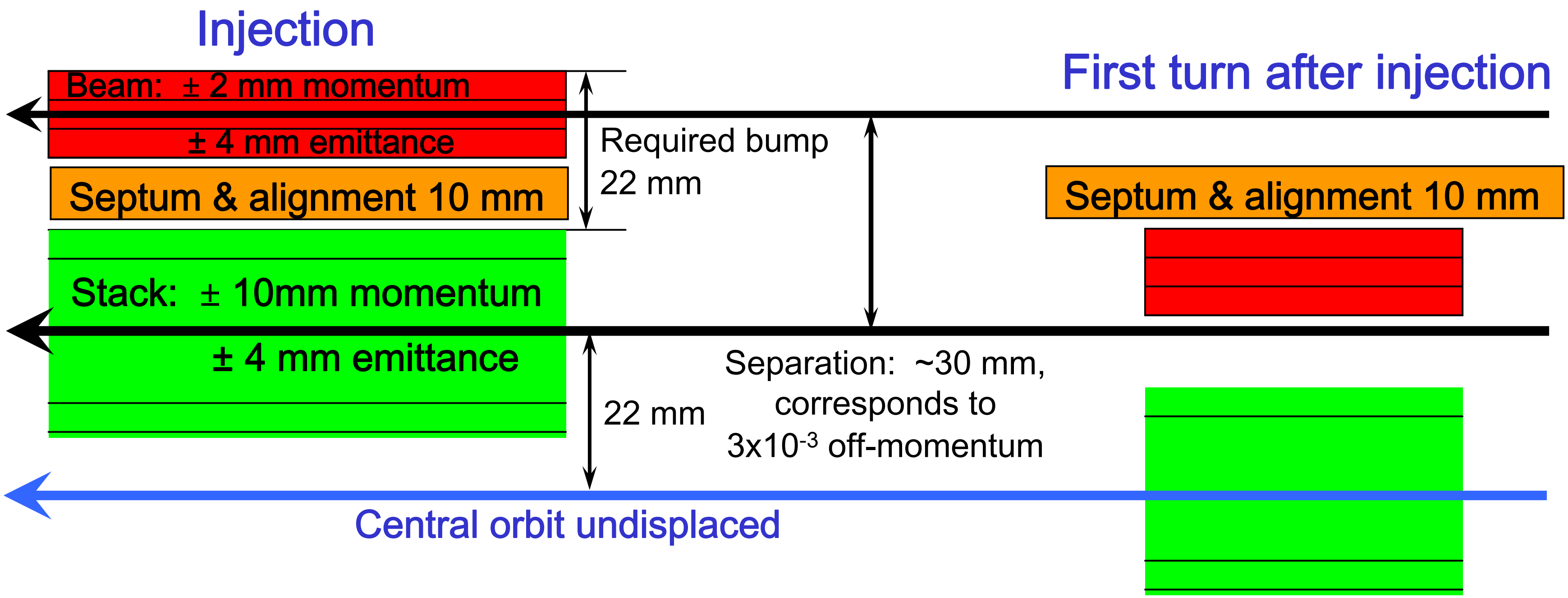
Decay ring injection design aspects

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

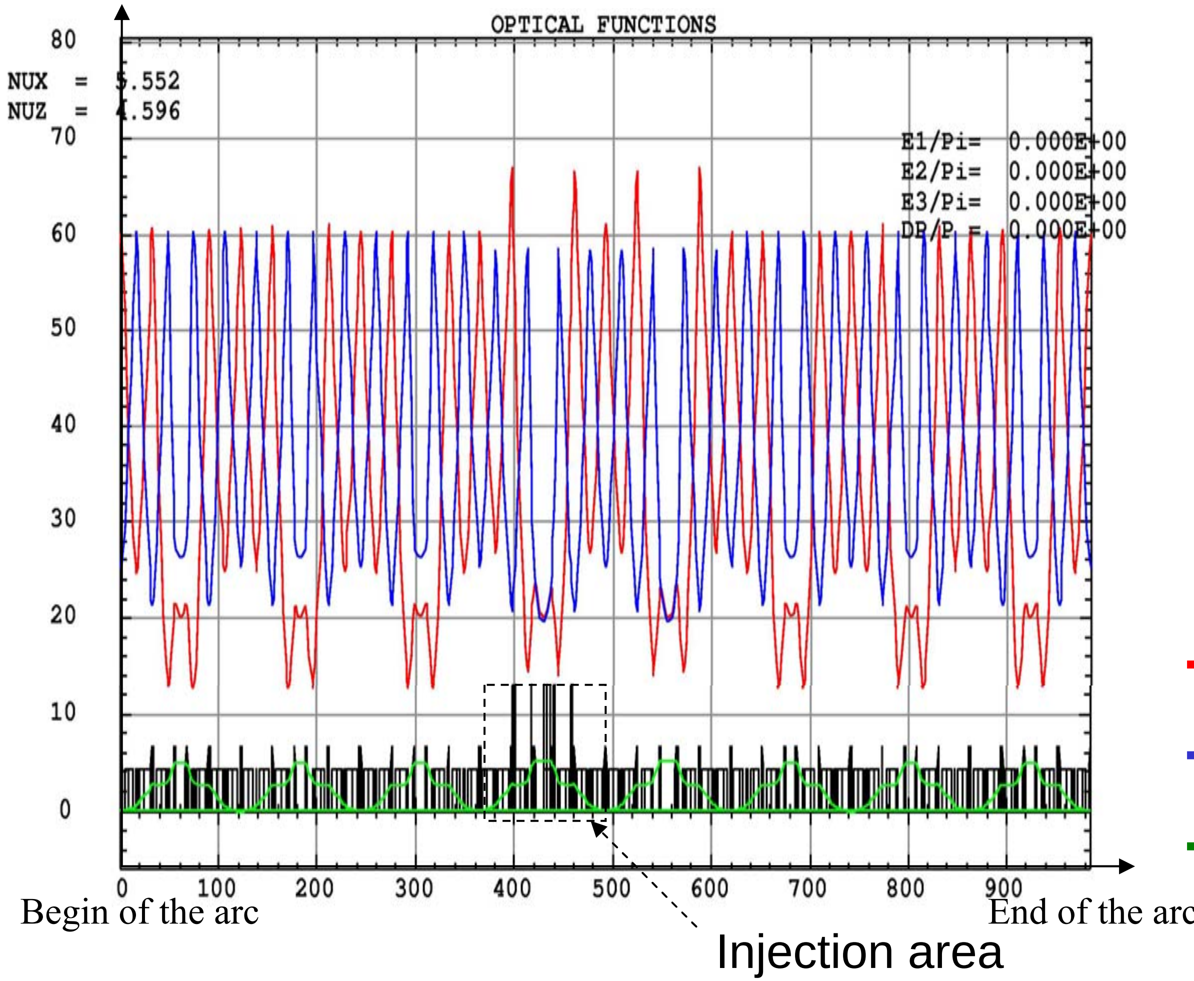
- **Alternative injection scheme**
  - **Inject an off-momentum beam on matched dispersion trajectory.**
  - **No fast elements required (bumper rise and fall ~10 μs).**
  - **Requires large normalized dispersion at injection point (small beam size and large separation due to momentum difference).**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

Decay ring injection layout

- Example machine and beam parameters:
  - Dispersion: D_{hor} = 10 m
  - Beta-function: β_{hor} = 20 m
  - Moment. spread stack: $\Delta p/p = \pm 1.0\text{x}10^{-3}$ (full)
  - Moment. spread bunch: $\delta p/p = \pm\ 2.0\text{x}10^{-4}$ (full)
  - Emit. (stack, bunch): ε_{geom} = 0.6 πmm



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

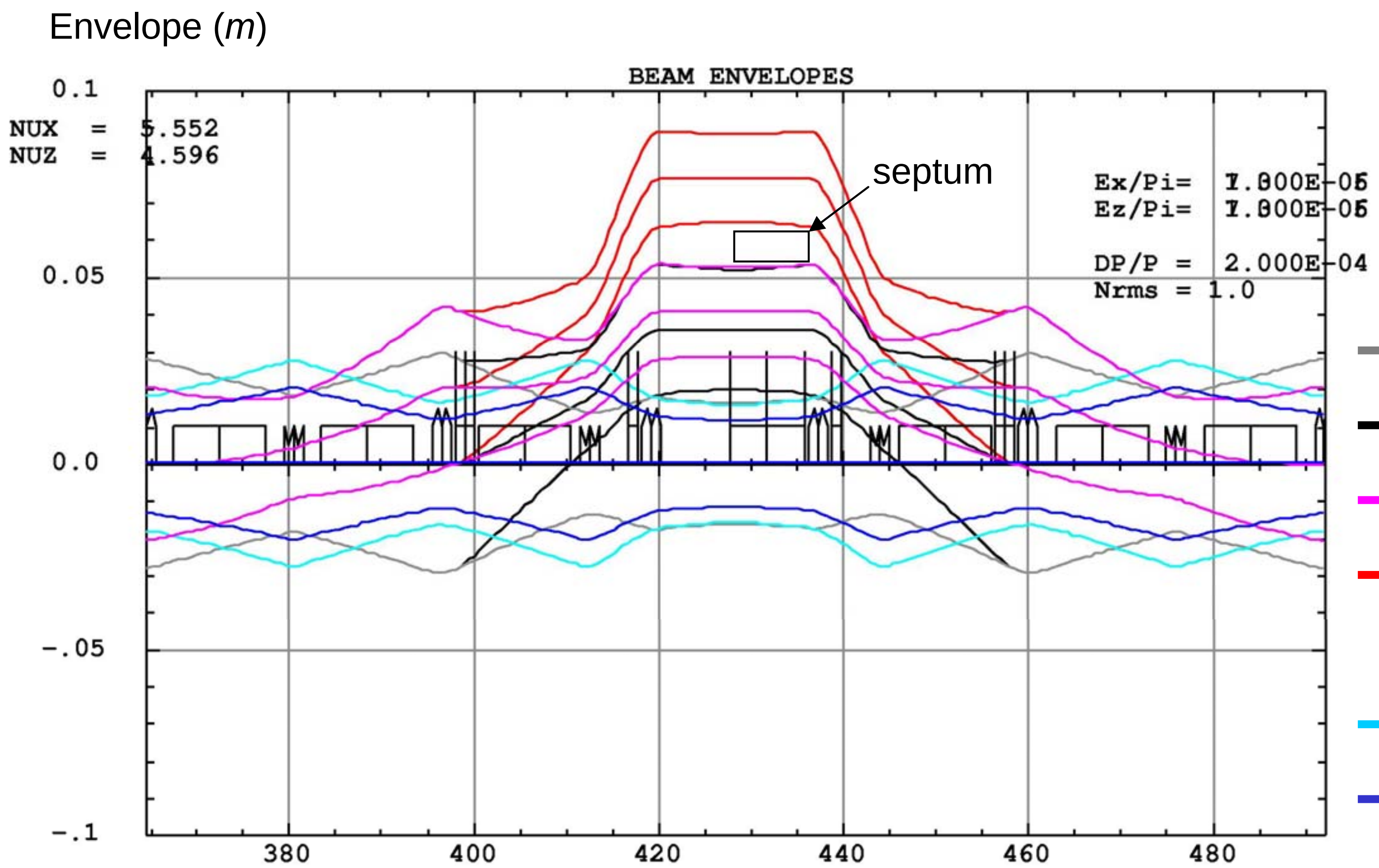
— Horizontal β_x

— Vertical β_y

— Horizontal Dispersion D_x

Decay ring injection envelopes

A. Chance, CEA-Saclay (F)



Horizontal envelopes :

- $\Delta p/p = 0$ bumps off
- $\Delta p/p = 0$ bumps on
- $\Delta p/p = 0.8\%$ bumps off
- $\Delta p/p = 0.8\%$ bumps on

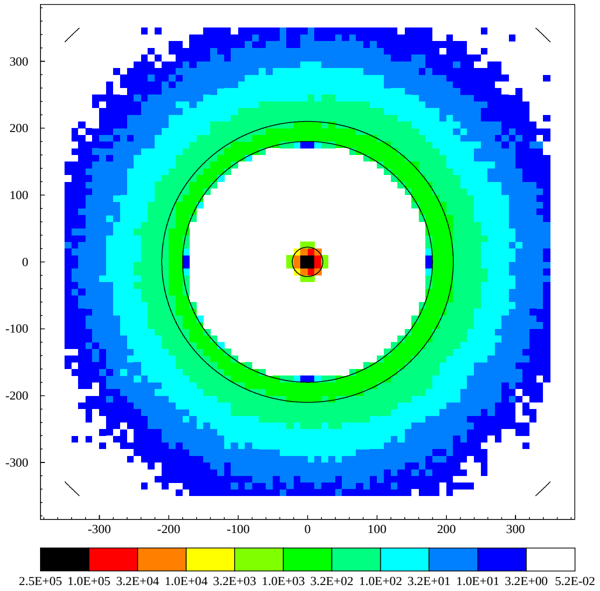
Vertical envelopes :

- stored beam
- injected beam

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)

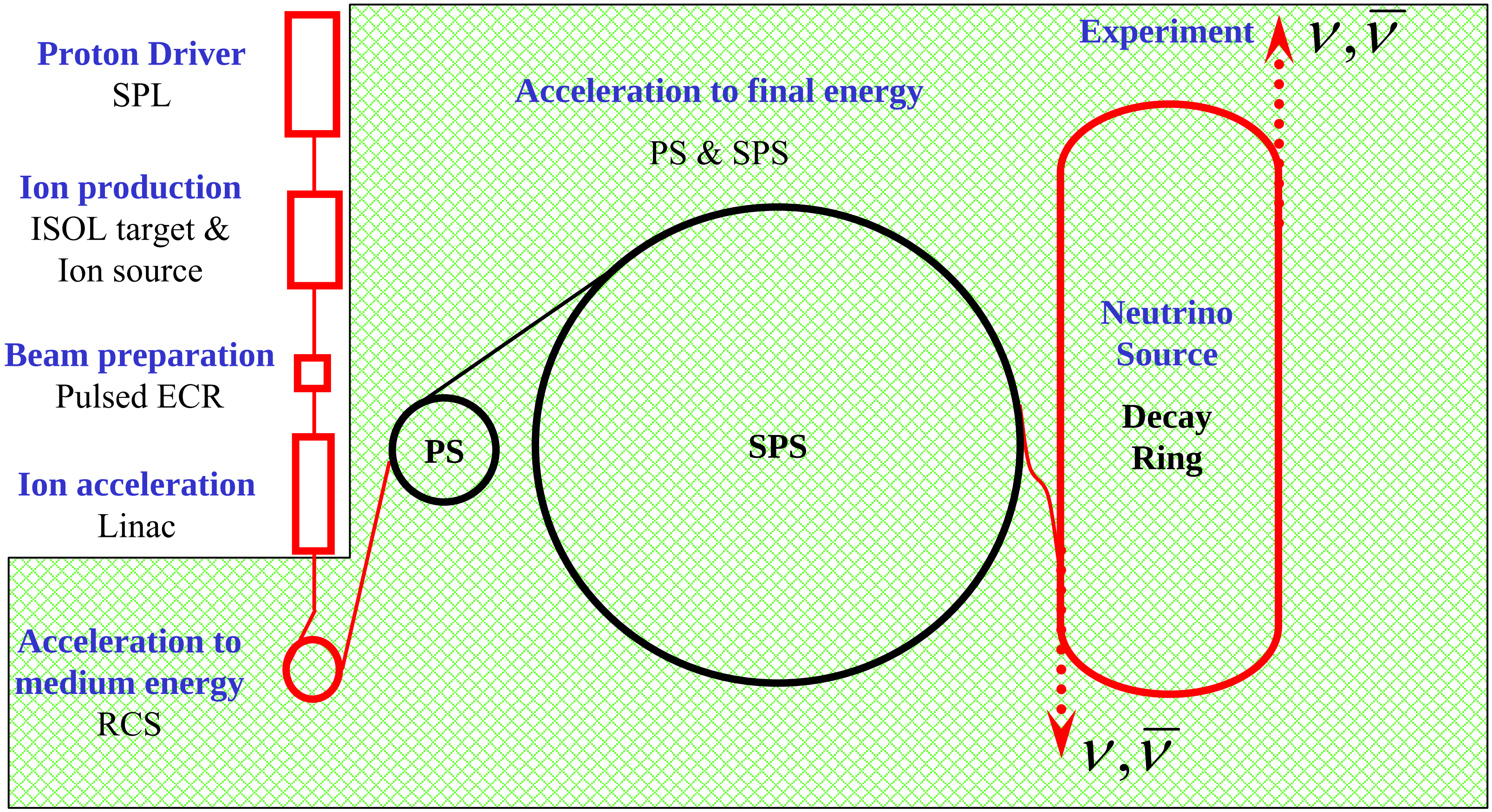
Future R&D

- **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).

Conclusions

- **Well-established beta-beam baseline scenario.**
- **R&D work has started on several critical aspects (mainly decay ring).**
- **Beta-Beam Task well integrated in the EURISOL DS.**
- **Strong synergies between Beta-beam and EURISOL.**
- **Definitive EU approval.**
- **Detailed planning for next 4 years under way.**