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
- **Challenges for the Beta-beam R&D**
  - The EURISOL DS
- **Trend curves as a tool in accelerator design**
  - Target values for EURISOL DS beta-beam facility
- **Conclusions**

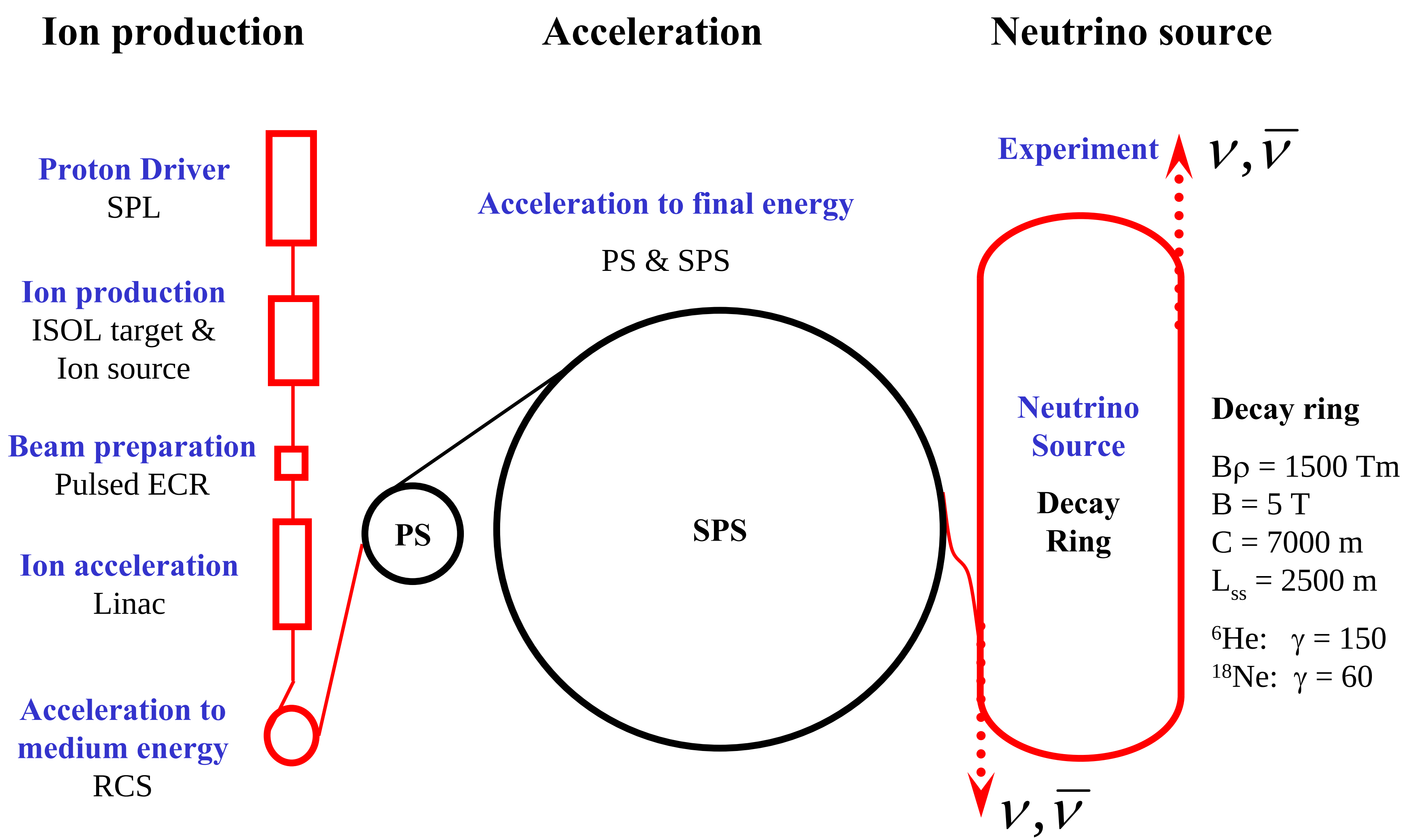
Introduction to beta-beams

- **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 for the first study**
  - **Make maximum use of the existing infrastructure.**

Beta-beam at CERN



FLUX

- The first "Beta-beam" was aiming for:
  - A beta-beam facility that will run for a "normalized" year of 10^7 seconds
  - An annual rate of 2.9 10^{18} anti-neutrinos (^6He) and 1.1 10^{18} neutrinos (^{18}Ne) at γ=100

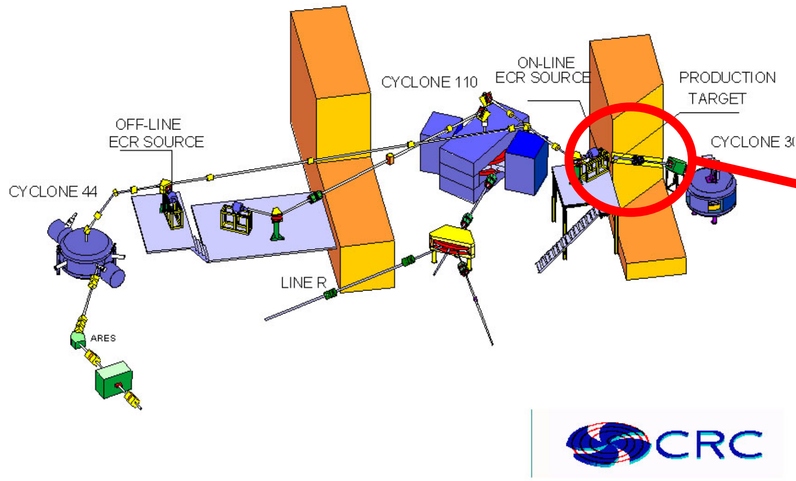
with an Ion production in the target to the ECR source:

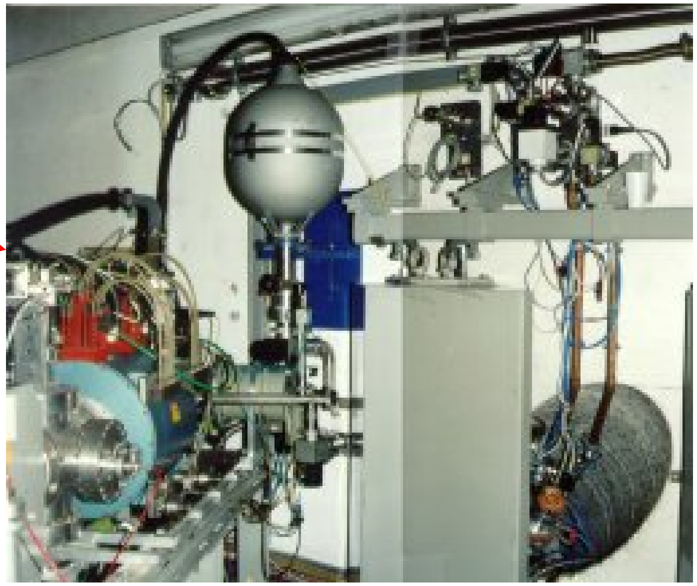
- ^6He= 2 10^{13} atoms per second
- ^{18}Ne= 8 10^{11} atoms per second

- The often quoted beta-beam facility flux is for anti-neutrinos 29 10^{18} and for neutrinos 11 10^{18} in ten years running

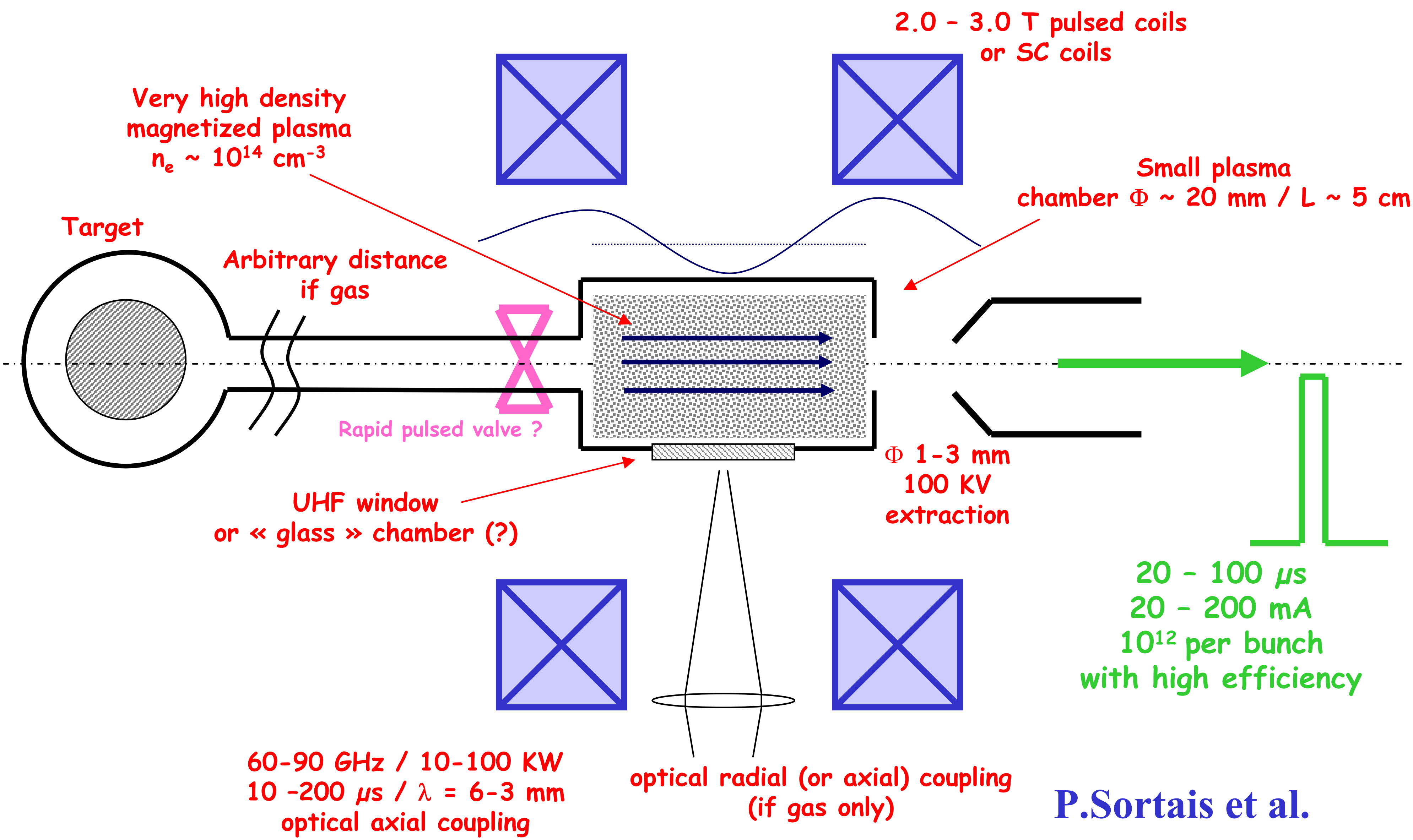
Producing 18Ne and 6He at 100 MeV

- Work within EURISOL task 2 to investigate production rate with "medical cyclotron"
  - Louvain-La-Neuve, M. Loislet



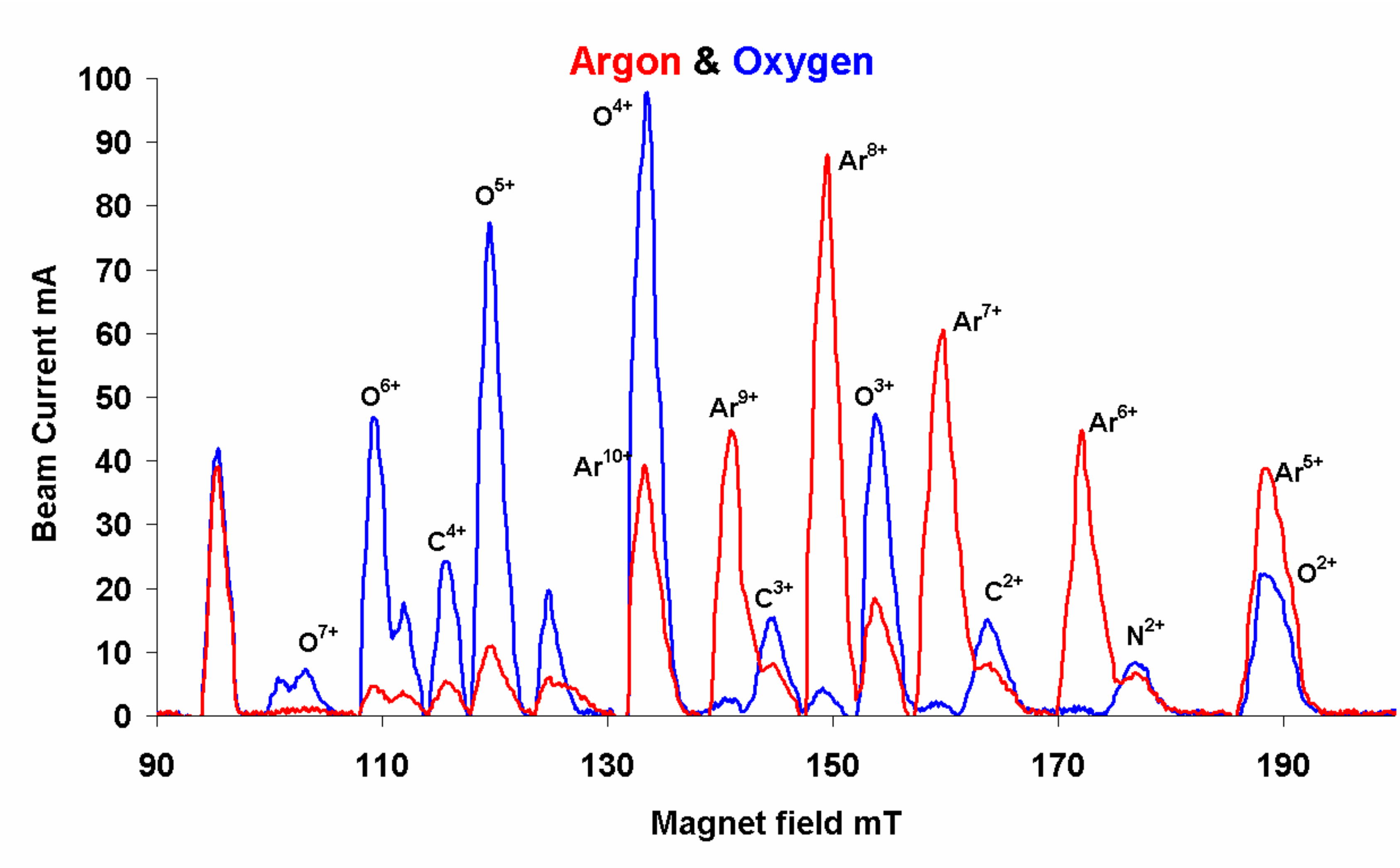


60 GHz « ECR Duoplasmatron » for gaseous RIB

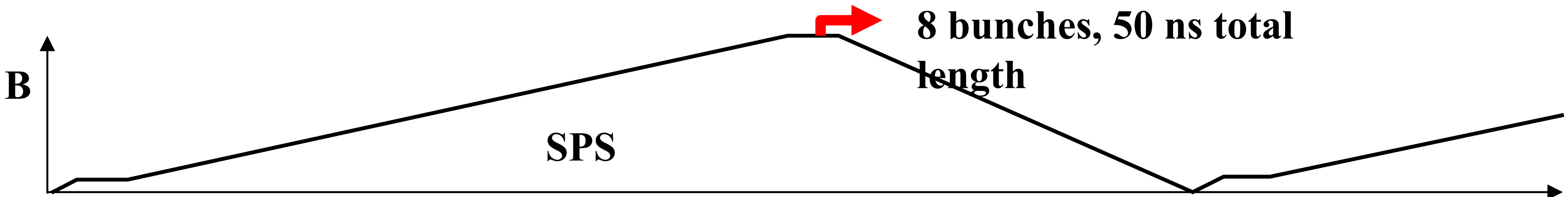


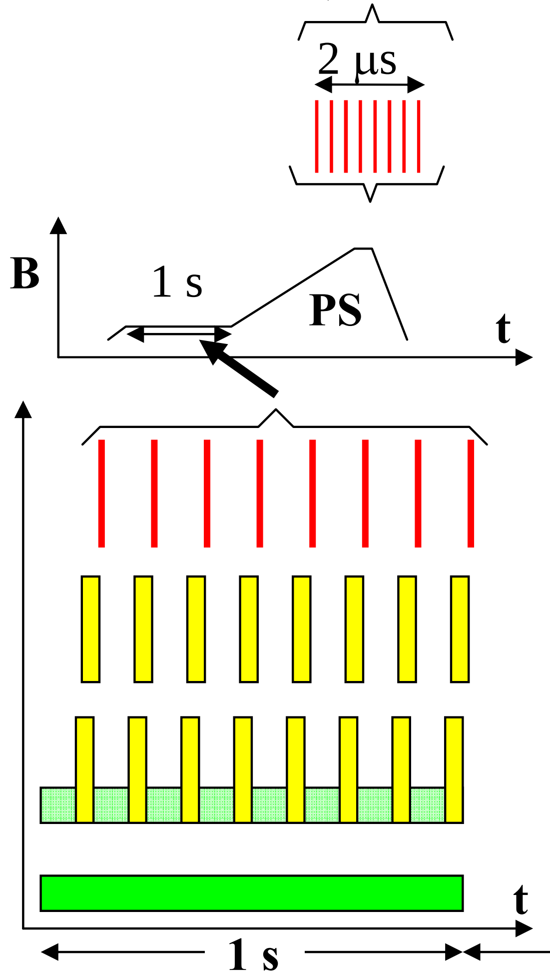
P.Sortais et al.

Charge state distribution!



From dc to very short bunches, v1





SPS: injection of 8 bunches from PS.
Acceleration to decay ring energy and ejection.

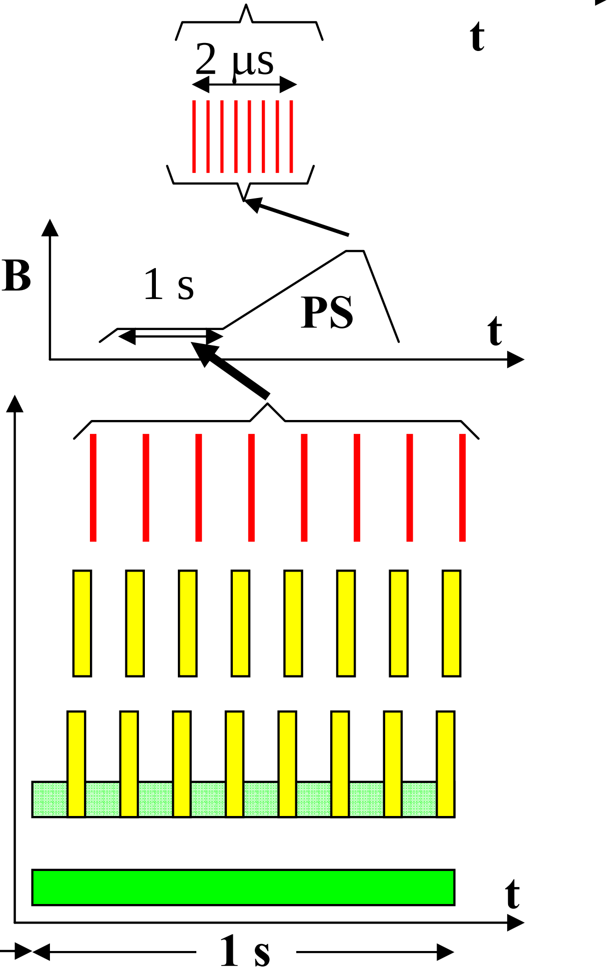
PS: 1 s flat bottom with 16 injections. Acceleration in ~1 s to ~86.7 Tm..

RCS: further bunching to ~100 ns
Acceleration to ~ 8 Tm.
16 repetitions during 1 s.

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

60 GHz ECR: accumulation for 1/16 s ejection of fully stripped ~50 μs pulse.
16 batches during 1 s.

Target: dc production during 1 s.



Intensities, ^{6}He, v1

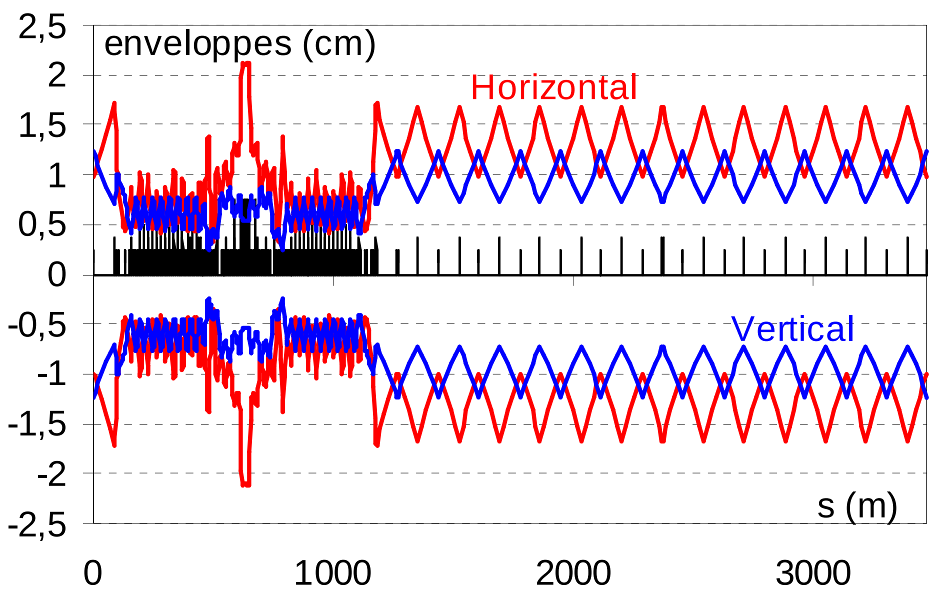
Machine	Total Intensity out (10^{12})	Comment
Source	20	DC pulse, Ions extracted for 1 second
ECR	1.16934	Ions accumulated for 60 ms, 99% of all 6He ions in highest charge state, 50 microseconds pulse length
RCS inj	0.582144	Multi-turn injection with 50% efficiency
RCS	0.570254	Acceleration in 1/32 seconds to top magnetic rigidity of 8 Tm
PS inj	6.82254	Accumulation of 16 bunches during 1 second
PS	5.75908	Acceleration in 0.8 seconds to top magnetic rigidity of 86.7 Tm and merging to 8 bunches.
SPS	5.43662	Acceleration to gamma=100 in 2.54 seconds and ejection to decay ring of all 8 bunches (total cycle time 6 seconds)
Decay ring	58.1137	Total intensity in 8 bunches of 50/8 ns length each at gamma=100 will result in a duty cycle of 0.0022. Maximum number of merges = 15.

Intensities, ^{18}Ne, v1

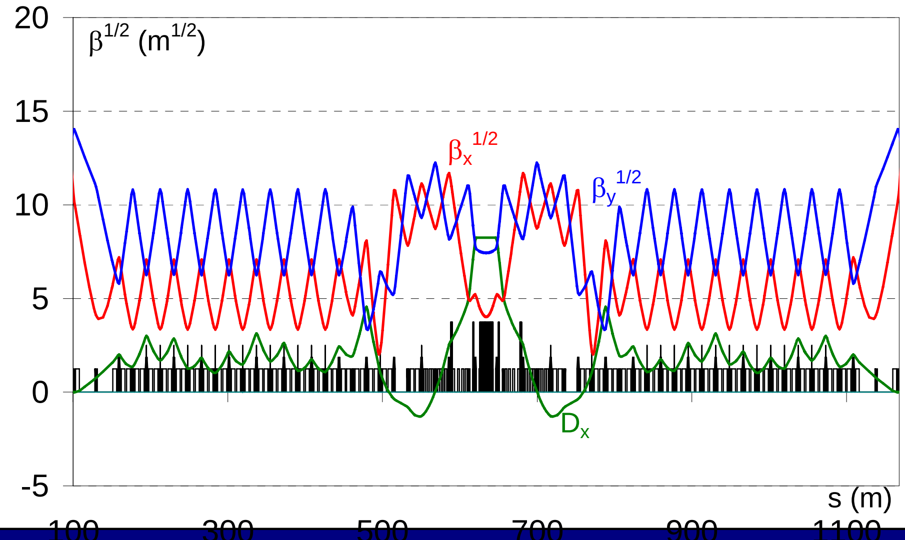
Machine	Total Intensity out (10^{10})	Comment
Source	80	DC pulse, Ions extracted for 1 second
ECR	1.42222	Ions accumulated for 60 ms, 30% of all 18Ne ions in one dominant charge state, 50 microseconds pulse length
RCS inj	0.709635	Multi-turn injection with 50% efficiency
RCS	0.703569	Acceleration in 1/32 seconds to top magnetic rigidity of 8 Tm
PS inj	10.093	Accumulation of 16 bunches during 1 second.
PS	9.57532	Acceleration in 0.8 seconds to top magnetic rigidity of 86.7 Tm and merging to 8 bunches.
SPS	9.45197	Acceleration to gamma=100 in 1.42 seconds and ejection to decay ring of all 8 bunches (total cycle time 3.6 seconds)
Decay ring	277.284	8 bunches of 50/8 ns length each will at gamma=100 result in a duty cycle of 0.0022. Maximum number of merges = 40.

Ring optics

Beam envelopes



Arc optics



In the straight sections, we use FODO cells. The apertures are ±2 cm in the both plans

The arc is a 2π insertion composed of regular cells and an insertion for the injection.

There are 489 m of 6 T bends with a 5 cm half-aperture.

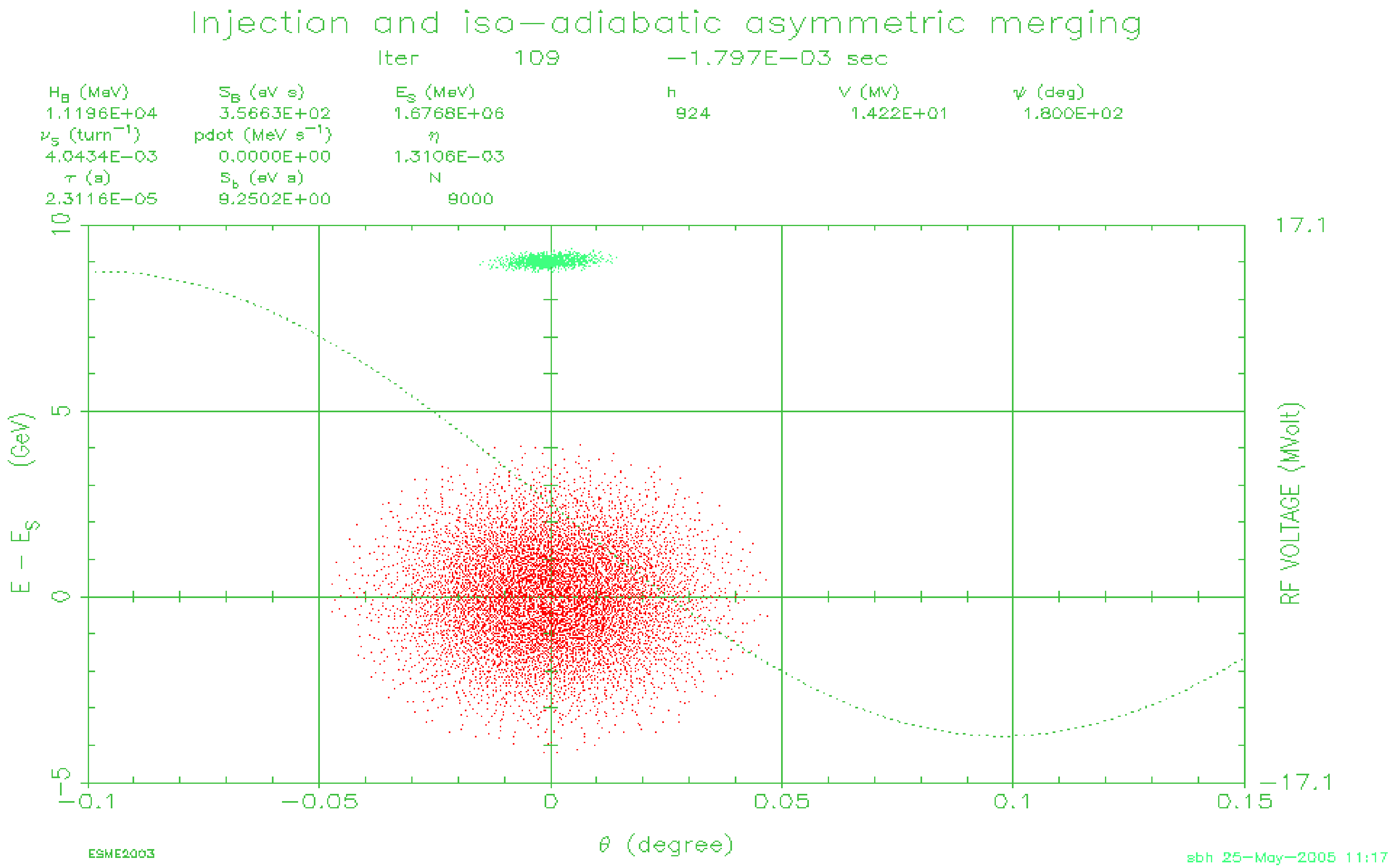
At the injection point, dispersion is as high as possible (8.25 m) while the horizontal beta function is as low as possible (21.2 m).

The injection septum is 18 m long with a 1 T field.

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!).**
  - **For 6He at γ=100 in the version 1 beta-beam design up to 15 merges can be done.**
  - **For 18Ne (version 2) up to 40 merges can be done thanks to a better mass-to-charge ratio**

Simulation (in the SPS)



Design study objectives

- Establish the limits of the first study based on existing CERN accelerators (PS and SPS)
- Freeze target values for annual rate at the EURISOL beta-beam facility
  - Close cooperation with nowg
- Freeze a baseline for the EURISOL beta-beam facility
- Produce a Conceptual Design Report (CDR) for a credible beta-beam facility
- Produce a first cost estimate for the facility

Challenges for the study

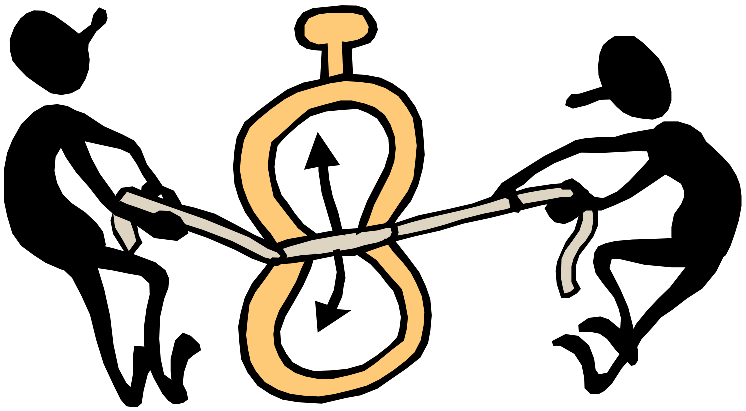
- The self-imposed requirement to re-use a maximum of existing infrastructure
  - Cycling time, aperture limitations etc.
- The small duty factor
- The activation from decay losses
- The high intensity ion bunches in the accelerator chain and decay ring

Baseline, version 1

- PS and SPS with small modifications
- Only one charge state from ECR
- 8 bunches in the decay ring
  - Duty factor 2.1 10^{-3}
- Merging ratio 15 for both ion types
- For 10 years running (5+5):
  - Anti neutrinos: 8.82 10^{18}
  - Neutrinos: 9.49 10^{16}

Duty factor

- A small duty factor does not only require short bunches in the decay ring but also in the accelerator chain
  - Space charge limitations



Baseline, version 2

- ECR source operates at 15 Hz
- PS receives 20 bunches
- No merging in PS and SPS
  - Tune shift respected
- Merging ratio for ^{18}Ne=40
- 2.5 times higher duty factor
- With version 1 input for all other parameters, for 10 years running (5+5):
  - Anti-neutrinos: 1.07 10^{19}
  - Neutrinos: 2.65 10^{17}

Using existing PS and SPS, version 2
Space charge limitations at the "right flux"

[μm]	^{6}He	^{18}Ne
RCS inj	16.4, 8.8	16.4, 8.8
PS inj	6.6, 3.5	4.0, 2.1
SPS inj	0.8, 0.4	0.5, 0.3

- Transverse emittance normalized to PS acceptance at injection for an annual rate of 10^{18} (anti-) neutrinos

	^{6}He	^{18}Ne
RCS inj	-0.019	-0.078
PS inj	-0.11	-0.20
SPS inj	-0.090	-0.15

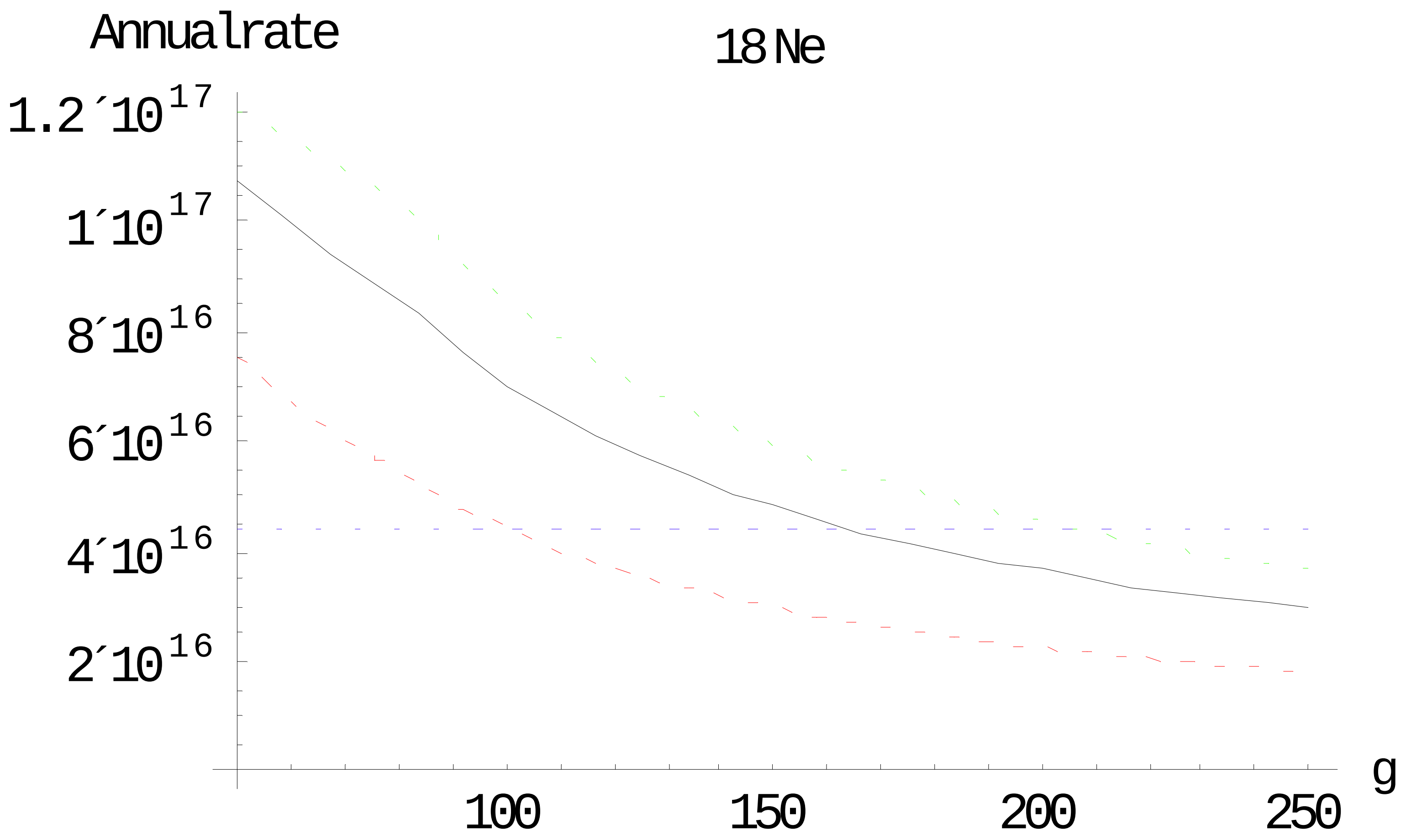
- Space charge tune shift
  - Note that for LHC the corresponding values are -0.078 and -0.34

Trend curves

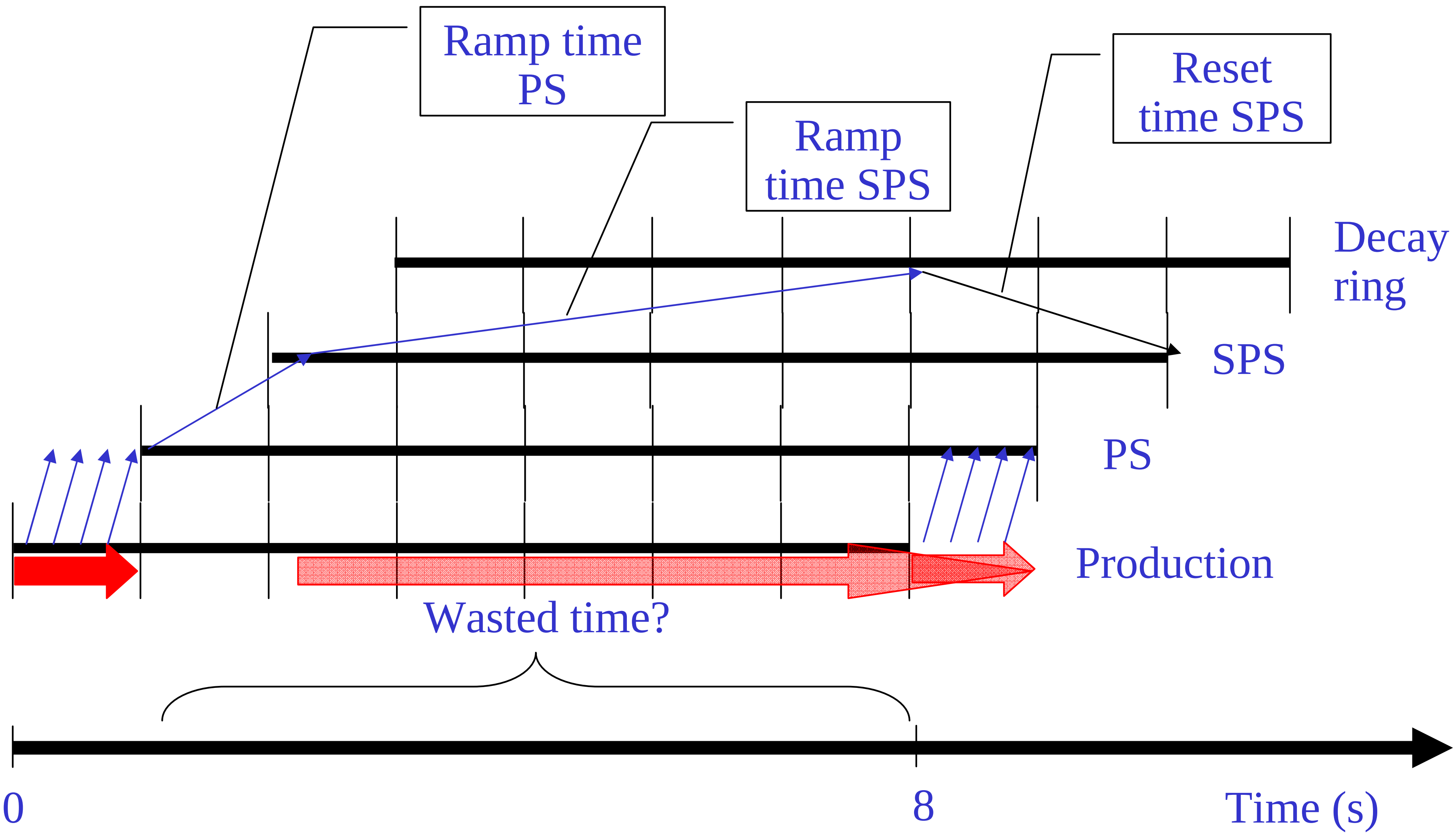
- *A tool to identify the right parameters for a design study*
- Does not in themselves guarantee that a solution can be found!
- Requires a tool to express the annual rate as a function of all relevant machine parameters

```
psacceleration := (ClearAll[n];
  psTpern[t_] := psinjTpern +
   (spsinjTpern - psinjTpern) t/psaccelerationtime;
  gamma[t_] := 1 + psTpern[t] / Epern;
  decayrate[t_] := Log[2] n[t] / (gamma[t] thalf);
  eqns = {D[n[t], t] == -decayrate[t], n[0]==nout3};
  n[t_] = n[t] /. DSolve[eqns, n[t], t] //First;
  nout4 = n[psaccelerationtime]
)
```

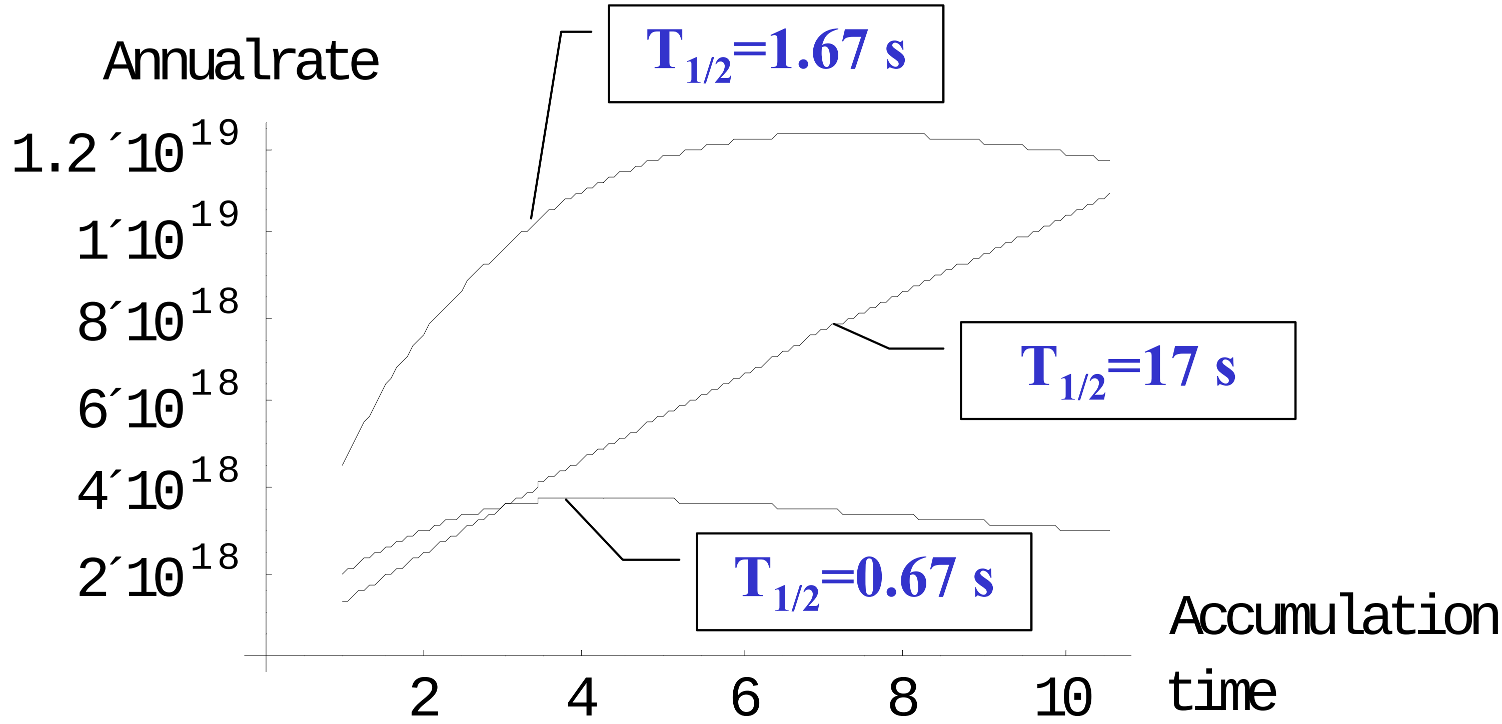
Gamma and duty cycle



The slow cycling time. What can we do?

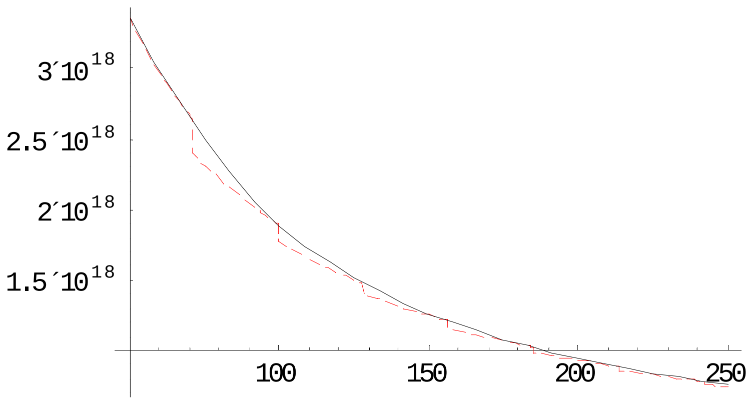


Accumulation at 400 MeV/u

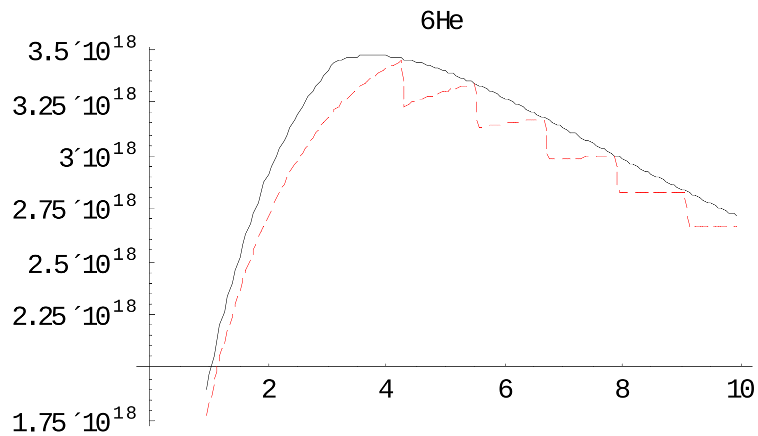


How to change the flux, ^6He

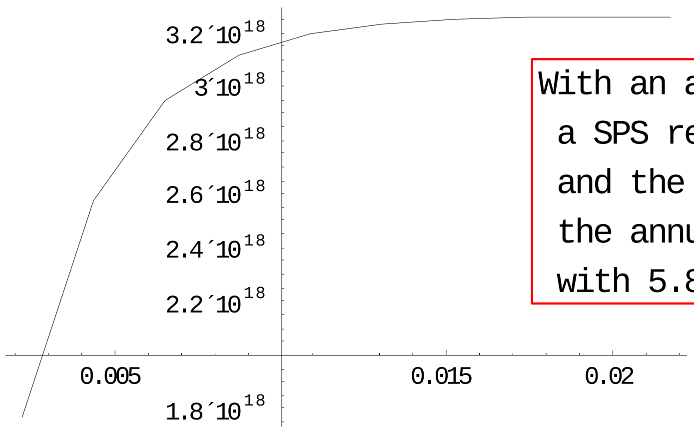
EURISOLDS/task12/3-2005



Flux as a function of gamma

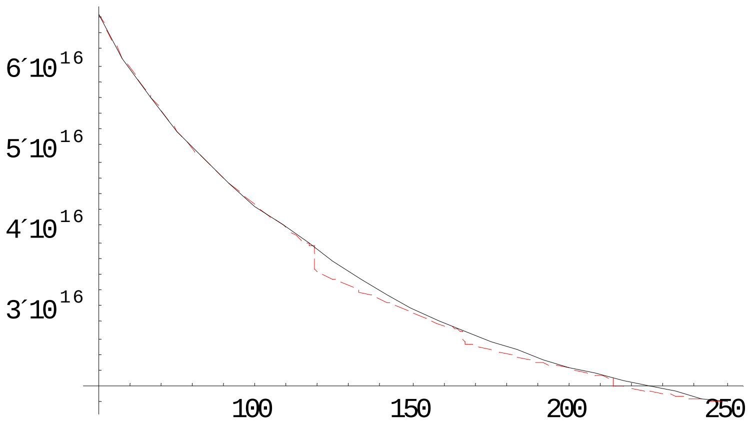


Flux as a function of accumulation time in PS

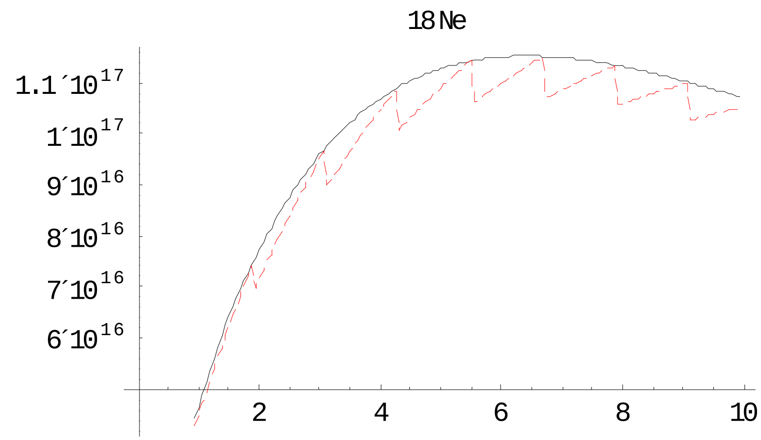


Flux as a function of duty cycle

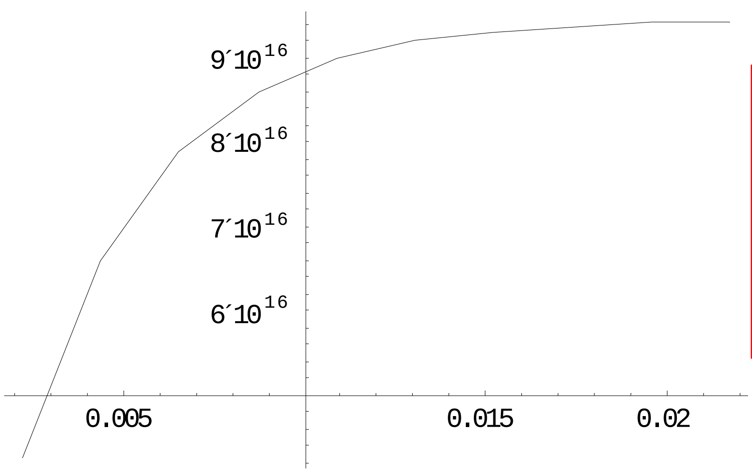
With an accumulation time in the PS of 4.3125 seconds,
a SPS repetitiontime of 6. seconds
and the standard dutycycle
the annual flux of 6He would be 3.44963´ 10^{18}
with 5.8138´ 10^{13} ions in the decay ring



Flux as a function of gamma



Flux as a function of accumulation time in PS



Flux as a function of duty cycle

With an accumulation time in the PS of 5.5625 seconds,
, a SPS repetitiontime of 7.2 seconds
, 3 charge states in the linac
and the standard dutycycle
the annual flux of 18Ne would be 3.42769×10^{17},
with 5.8138×10^{13} ions in the decay ring

N.B. 3 charge states through the linac!

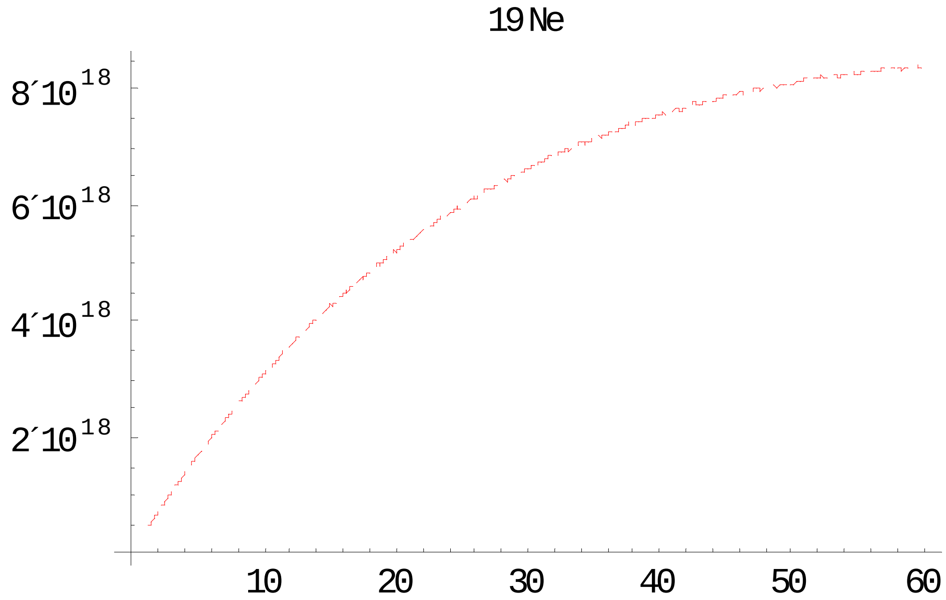
^{19}Ne?

- 19Ne:

$$^{19}_{10}Ne \rightarrow ^{19}_{9}F\ e^{+}\nu$$

$$Q_{\beta} = 2.2\ \mathrm{MeV}$$

$$t_{1/2} = 17.22\ \mathrm{s}$$



- With three linacs and accumulation
  - New PS
  - Accumulation ring
  - Three linacs
  - SPS tune shift?
  - IBS in SPS and Decay ring?

Conclusions

- **Beta-Beam Task well integrated in the EURISOL DS**
- **EURISOL study will result in a first conceptual design report for a beta-beam facility at CERN.**
  - **In close collaboration with the nowg establish target values for the EURISOL DS beta-beam study**
  - **We need a "STUDY 1 = EURISOL DS beta-beam" for the beta-beam to be considered a credible alternative to super beams and neutrino factories**
  - **We need a "green-field" study to establish true physics potential of the beta-beam concept (and cost).**
- Recent new ideas promise a fascinating continuation into further developments beyond the ongoing EURISOL DS
  - EC beta-beam, High gamma beta-beam, etc.