Beta-beams

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On behalf of the
Beta-beam study group

http://cern.ch/beta-beam

Outline

- Introduction
  - History
  - EURISOL design study

- Beta-beam baseline design

  Layout envisaged within EURISOL DS (task 12)
    - The baseline layout
    - Ion production
    - RCS layout
    - Bunch merging for stacking in the decay ring
    - Decay ring design issues

- Challenges
  - Target and source
  - Decay losses in the accelerator chain

- Non-baseline options beyond the EURISOL design study
  - High gamma beta beam
  - EC beta beam

- Conclusions

History of 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 pure beams of electron neutrinos (or antineutrinos) from the beta decay of radioactive ions, circulating in a decay ring
- First ideas on conceptual design of the accelerator complex presented at NuFact'02 ("The Beta-beam working group").
- From 2005: Conceptual design study for a Beta-beam complex within the EURISOL DS
- Upcoming ideas for different concepts: low energy, high energy, EC beams, …

Design study

- EURISOL Design Study
  - Within the 6th framework program of EU
  - Running 2005-2008
  - Technical Design Report for EURISOL.
  - Conceptual Design Report for Beta-Beam (first study).
- The baseline scenario
  - Avoid anything that requires a "technology jump"
    - Reduce time effort
    - Minimize costs
  - Make use of a maximum of known technology and existing infrastructure
    - ISOL technique
    - Based at CERN: PS and SPS machines
- The Beta-beam Design Study is 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 and $1.1*10^{18}$ neutrinos (^{18}Ne) at $\gamma=100$

Neutrino beam "layout"

- 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 peak number of ions/nanosecond (background suppression).
- Aim for a duty factor of 10^{-3} → this is a major design challenge!

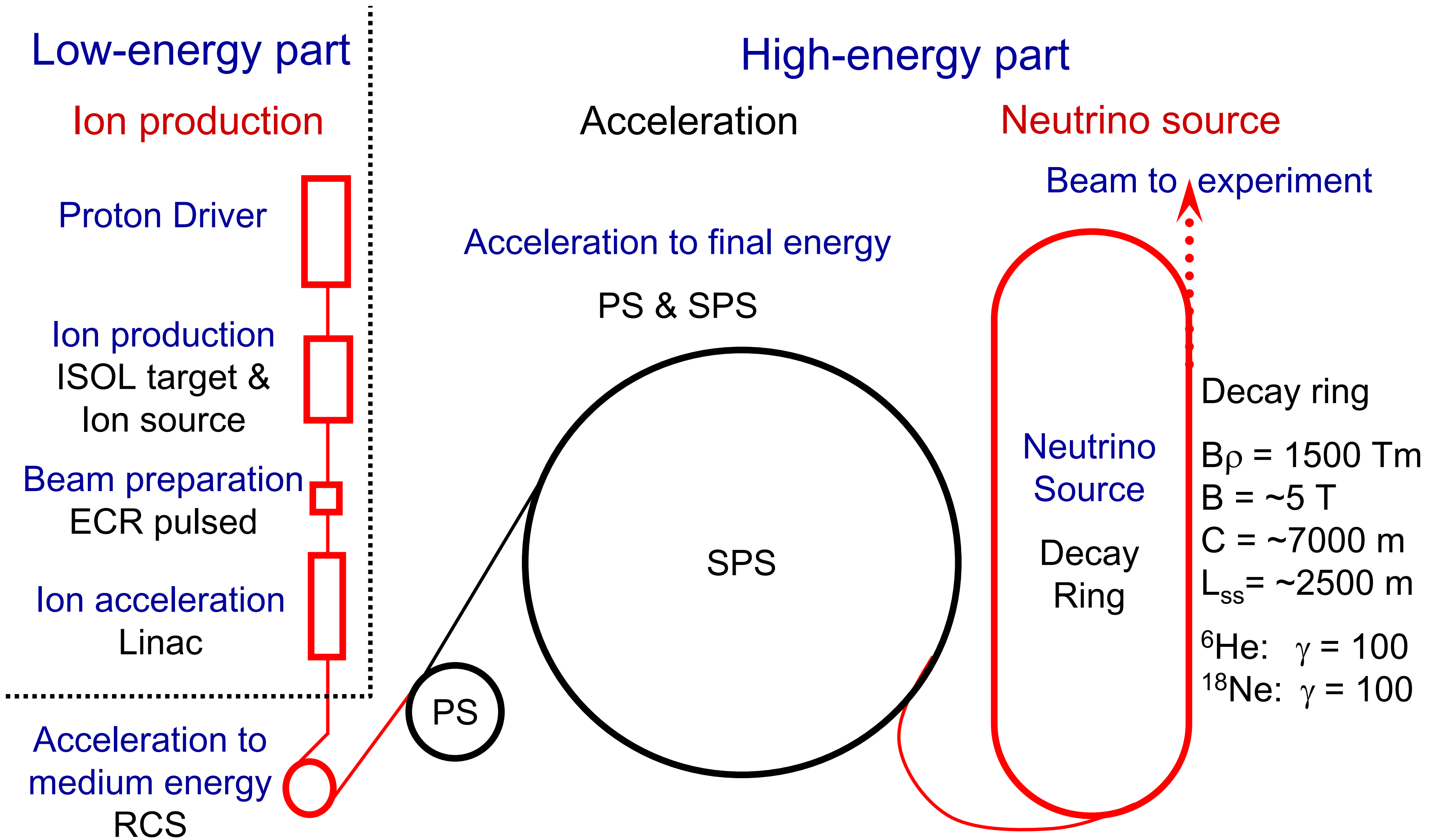
- Intensity design values in the decay ring

^{6}Helium^{2+}
- Stored ions: 9.7×10^{13} ions
- Rel. gamma: 100

^{18}Neon^{10+} (single target)
- Stored ions: 7.8×10^{13} ions/s
- Rel. gamma: 100

Translates to design values for the (anti-)neutrino rate with the stated layout of the decay ring

Beta-beam baseline design



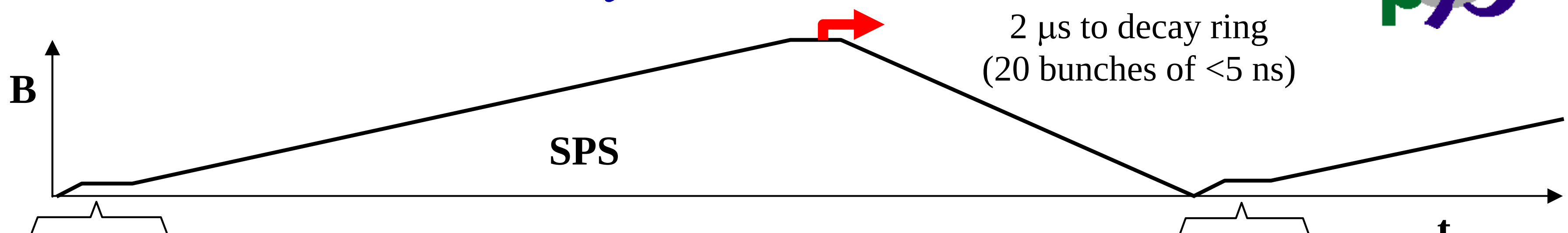
Isotopes

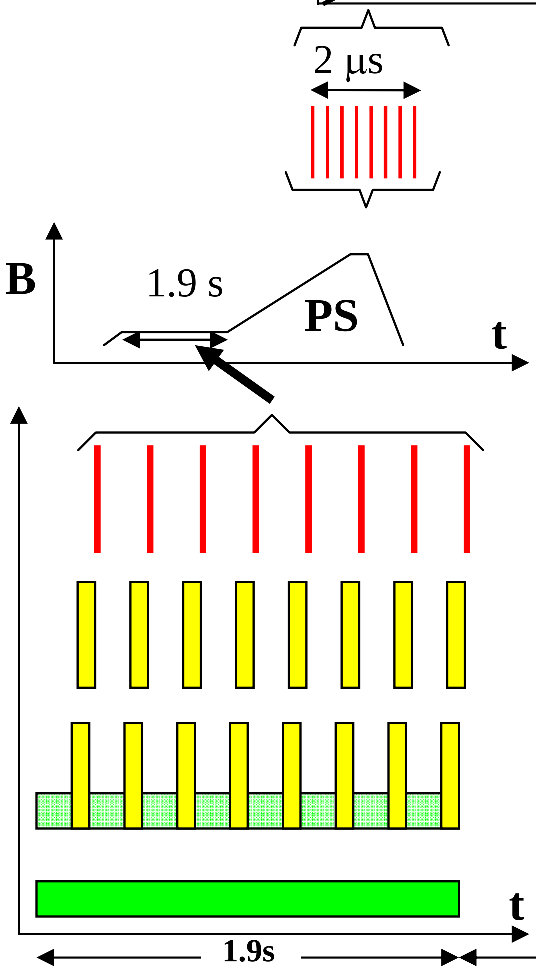
- Ion choice
  - Possibility to produce reasonable amounts of ions
  - Noble gases preferred - simple diffusion out of target, gas phase at room temperature
  - Not too short half-life to get reasonable intensities
  - Not too long half-life as otherwise no decay at high energy
  - Avoid potentially dangerous and long-lived decay products
- Best compromise
  - ^{6}Helium^{2+} to produce antineutrinos: $^{6}_{2}He \rightarrow ^{6}_{3}Li\, e^{-} \overline{\nu}$

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

    $\text{Average}\, E_{cms} = 1.86\ \text{MeV}$

From dc to very short bunches





SPS: injection of 20 bunches from PS.
Acceleration to decay ring energy and ejection.
Repetition time 6 s (^{6}He) and 3.6 s (^{18}Ne).

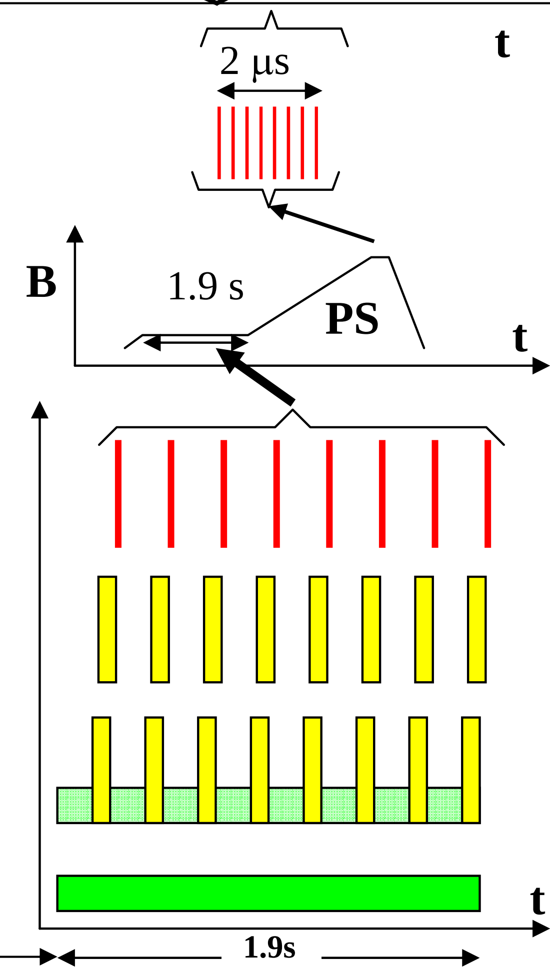
PS: 1.9 s flat bottom with 20 injections. Acceleration in 0.8 s to top energy.

RCS: further bunching to ~100 ns.
Acceleration to ~500 MeV/u.
10 Hz repetition rate.

Post accelerator linac:
acceleration to ~100 MeV/u.
20 repetitions during 1.9 s.

60 GHz ECR: accumulation for 0.1 s.
Ejection of fully stripped ~20 μs pulse.
20 batches during 1.9 s.

Target: dc production during 1.9 s.

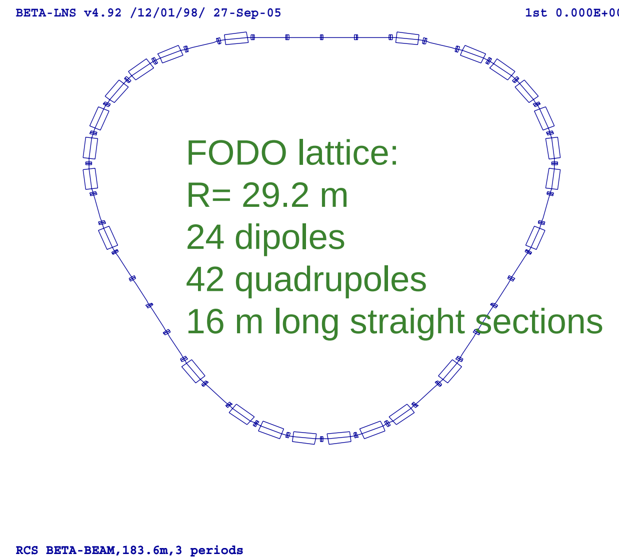


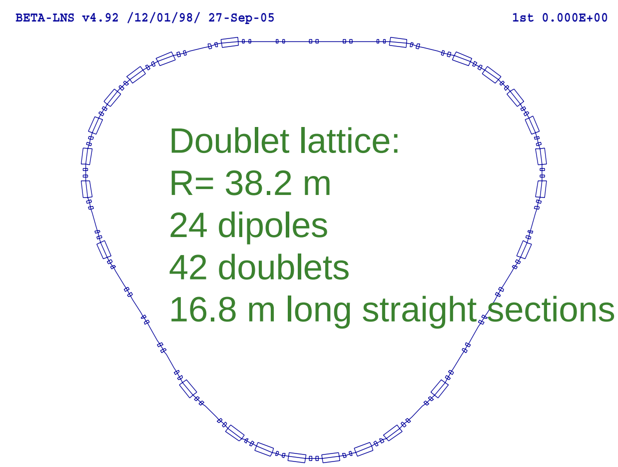
4.1s

Rapid Cycling Synchrotron

- Fast cycle to reduce decay losses at low energy
- High(er) top energy desired
  - relax space charge problems
  - reduce decay losses during accumulation in the PS
- $B\rho$ = 1 T * 11 m

	f [Hz]	B_{min} [T]	B_{max} [T]
bb $^{6}He^{2+}$	10	0.404	1.0
bb $^{18}Ne^{10+}$	10	0.242	1.0
ISIS	50	0.18	0.7
AUSTRON	25 (50)	0.204	0.94
JPARC	25	0.253	1.01





A. Tkatchenko, IPN Orsay

RCS BETA-BEAM, C=154m, 3 periods

Decay ring design aspects

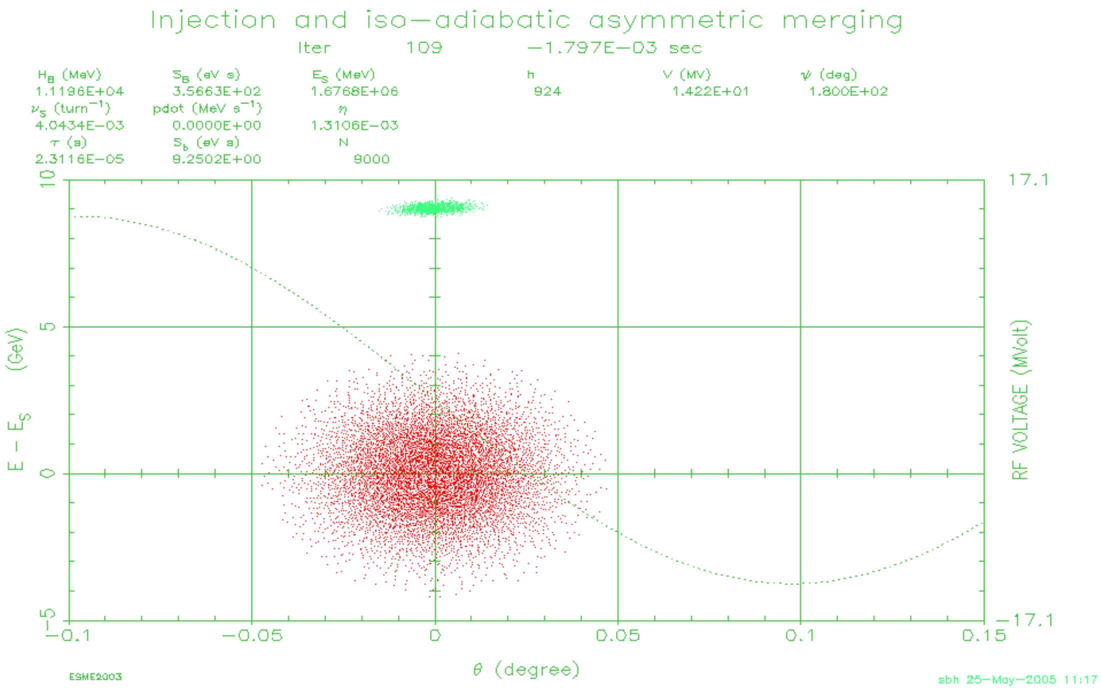
- The ions have to be concentrated in very few, very short bunches.
  - Suppression of atmospheric background via time structure.

- There is an absolute need for stacking in the decay ring.
  - Not enough flux from source and injection chain.
  - Life time is an order of magnitude larger than injector cycling
    - 80 s (167 s) as compared to 6 s (3.6 s) SPS cycling
  - We need to stack at least over 10 to 15 injector cycles.

- Stacking with a new injection/merging technique was developed (asymmetric bunch merging in longitudinal phase space)

Asymmetric bunch pair merging

- Moves the fresh bunch into the centre of the stack and pushes less dense phase space areas to larger amplitudes until these are cut by the momentum collimation system.



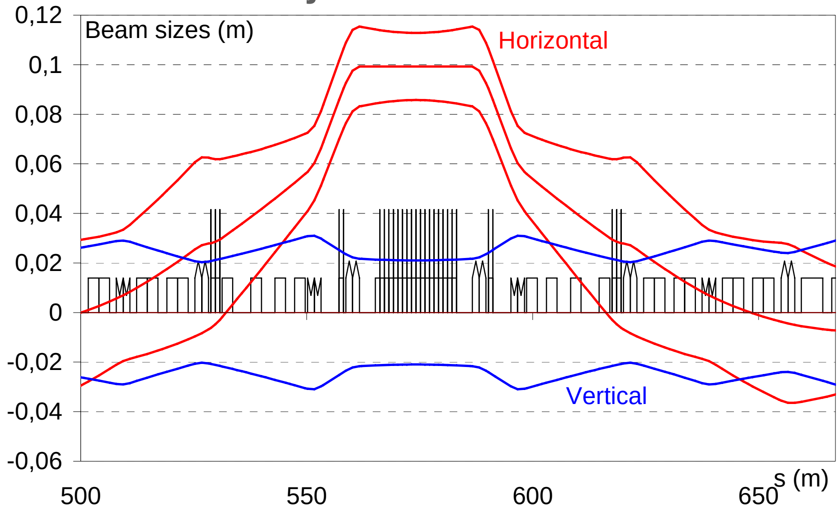
S. Hancock, CERN

- Stack and fresh bunch need to be positioned in adjacent “buckets” of the dual harmonic system (12.5 ns distance!)

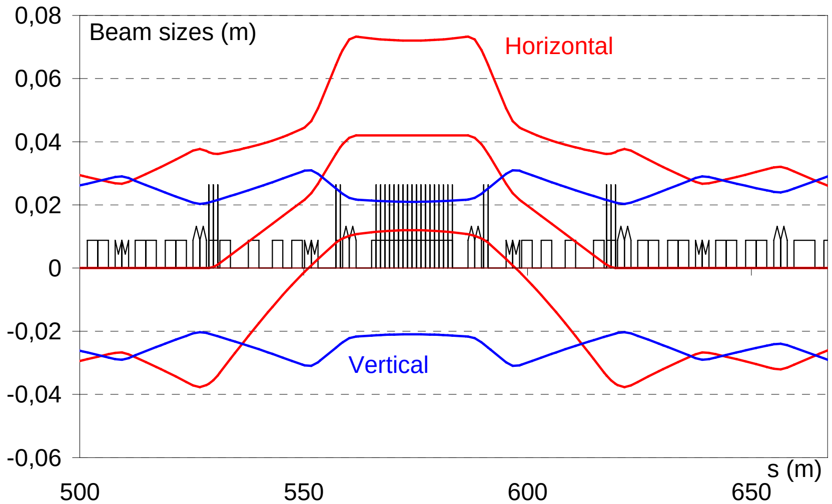
Injection section

A. Chance, CEA-Saclay (F)

Injected beam



Stored beam



The beam bump is about 4.2 mm

Kicker half-apertures enlarged: 11 cm. Their field has increased (0.3 T)

Some magnet apertures are quite large : we need a 8 cm half-aperture just after the injection section. Special magnet at this point?

Concerning the quadripoles in the injection section, the fields are quite reasonable (less than 1.5 T with a 6 cm radius)

All ions in the decay ring are “lost”:

- decay losses
  - Simulated 10 W/m maximum
- collimated

Challenges for the study

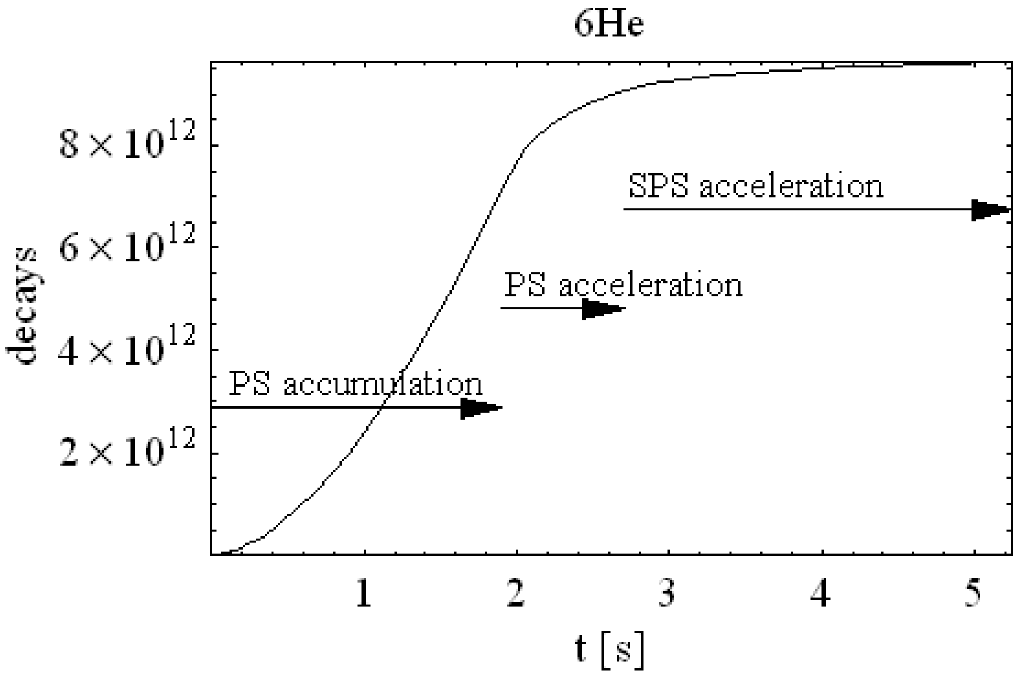
- Isotope production
- Efficiency of ECR source for single charge states
  - Development of 60 GHz source required
- The self-imposed requirement to re-use a maximum of existing infrastructure
  - Cycling time, aperture limitations, collimation systems etc.
- The high intensity ion bunches in the accelerator chain and decay ring
- The small duty factor
- Excessive space charge at PS injection.
- Decay losses

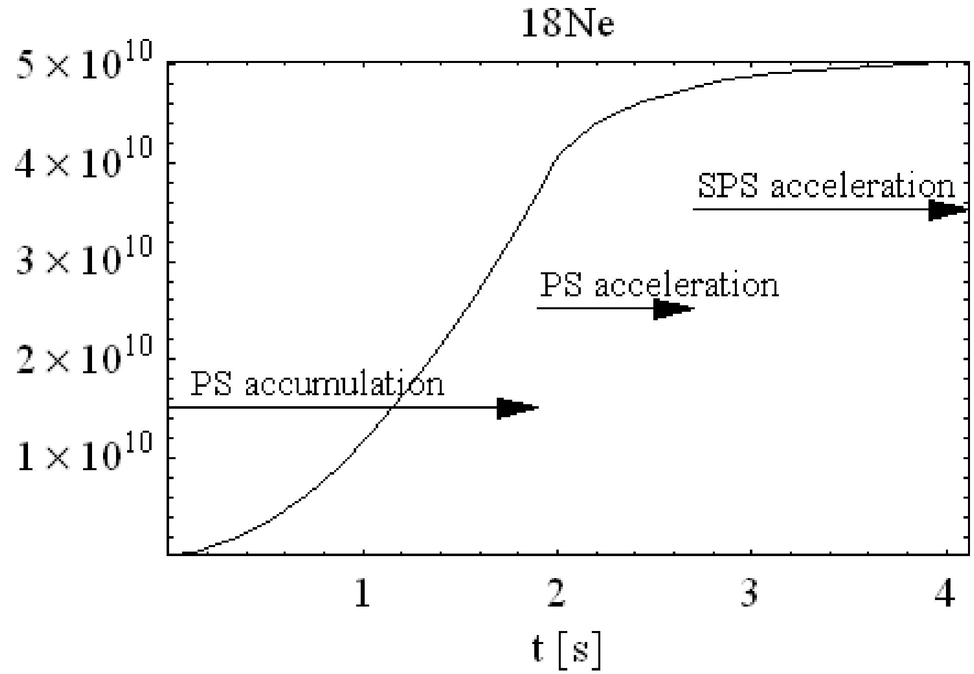
Ion production

The present status is (after 9 months of the 4-year design study):

- Antineutrino rate (and ^{6}He figures) have reached the design values but no safety margin is yet provided.
- Neutrino rate (and ^{18}Ne figures) are more than one order of magnitude below the desired performance.
  - Still missing factor (~25) for ^{18}Ne production
  - Without change of base-line scenario: asks for improvement of isotope production/preparation
  - First step beyond current baseline could be an accumulation scenario at low energy
- ^{19}Ne no immediate solution (for baseline scenario)
  - Production rate much higher, but ife time 10 times higher
  - Needs acceleration and storage of a much higher number of ions
    - Limited by space charge in the PS and SPS

Decay losses





- ~90% of all “unwanted” decays occur in the PS
- Can be translated into power losses and compared with “existing” high intensity operation …

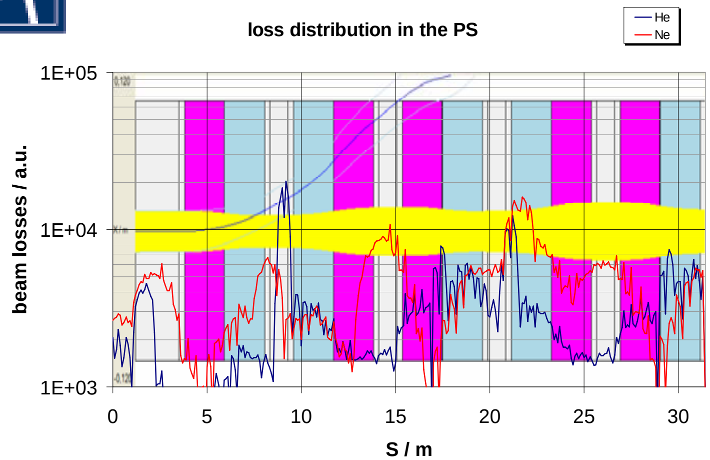
Power losses

machine		CNGS [5]	Beta-beam	
			^{6}He	^{18}Ne
RCS	loss/cycle [ions]	-	$6.4 * 10^{11}$	$0.3 * 10^{10}$
	loss/cycle/l [ions/m]	-	$1.1 * 10^{10}$	$5 * 10^{7}$
	E_{loss}/cycle[kJ]	-	0.184	0.005
	$P_{loss,average}$[1] [W/m]	-	0.5	0.
PS	loss/cycle [ions]	$7.6 * 10^{12}$	$8.48 * 10^{12}$	$4.5 * 10^{10}$
	loss/cycle/l [ions/m]	$1.2 * 10^{10}$	$1.4 * 10^{10}$	$7.2 * 10^{7}$
	E_{loss}/cycle[kJ]	12.4	8	0.25
	$P_{loss,average}$ [W/m]	3.3	2.2	0.12
SPS	loss/cycle [ions]	$3.8 * 10^{12}$	$0.53 * 10^{12}$	$0.2 * 10^{10}$
	loss/cycle/l [ions/m]	$5..4 * 10^{8}$	$7.6 * 10^{7}$	$3 * 10^{5}$
	E_{lost}/cycle[kJ]	10.3	16.9	0.27
	$P_{loss,average}$ [W/m]	0.25	0.4	0.01
Total	loss/cycle [ions]	$11.4 * 10^{12}$	$9.7 * 10^{12}$	$5 * 10^{10}$
	E_{lost}/cycle [kJ]	22.7	25.0	0.52

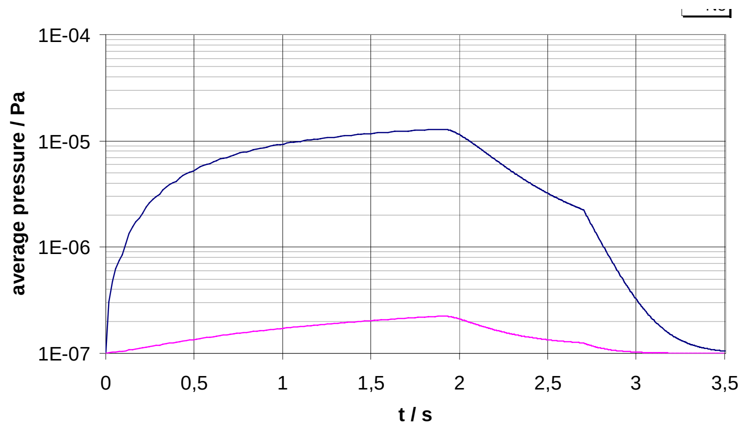
- **18Ne case given for bottom-up analysis**
- **Deficiency factor ~25**

- PS and SPS comparable for CNGS and Beta-beam operation at design values
- PS exposed to highest power losses overall

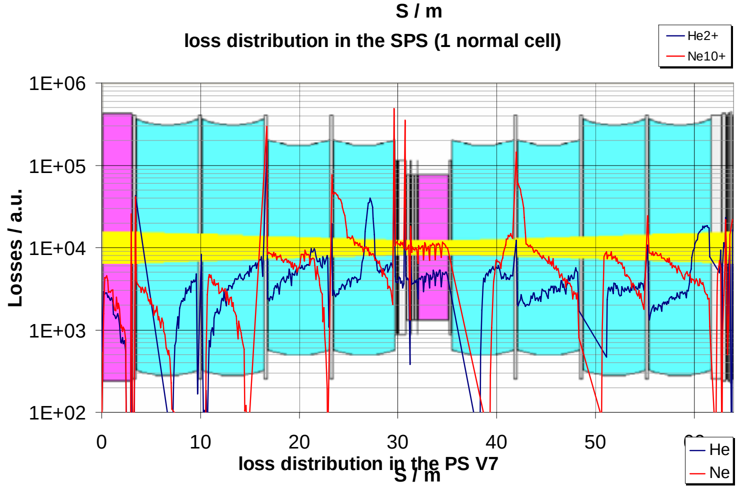
Loss distribution and dyn. vacuum

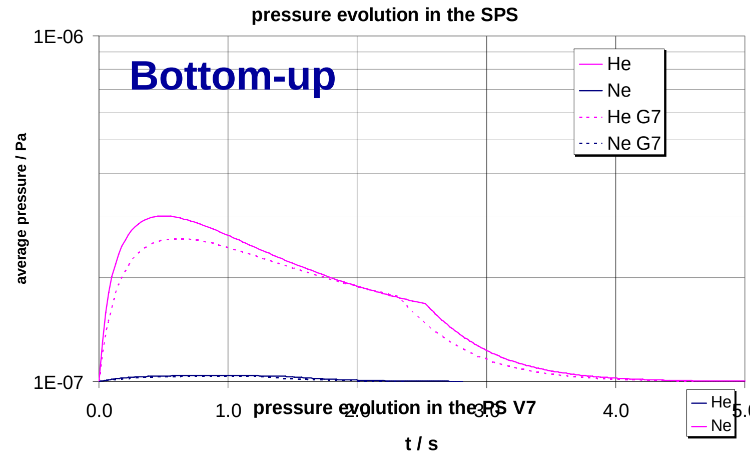


Pressure evolution due to desorption

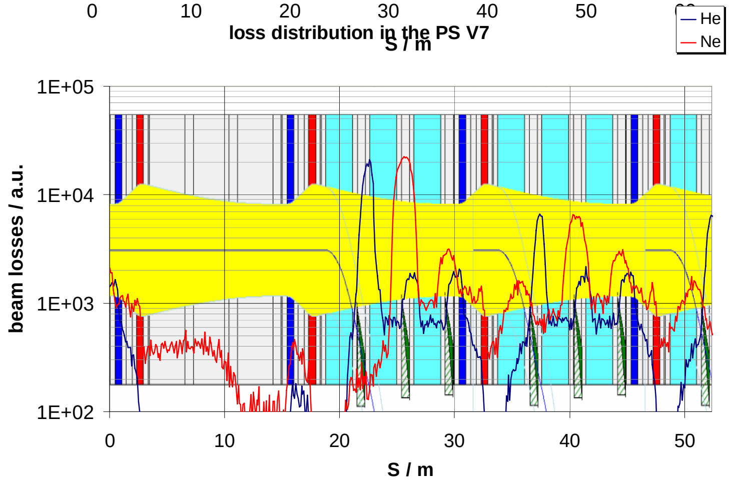


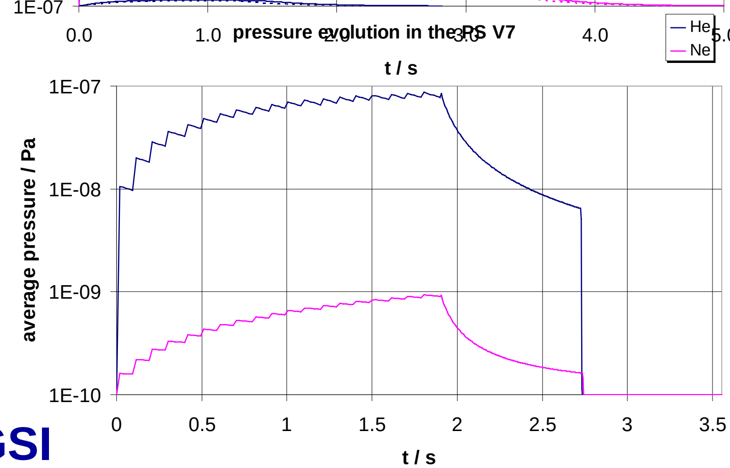
PS





SPS





New "PS"

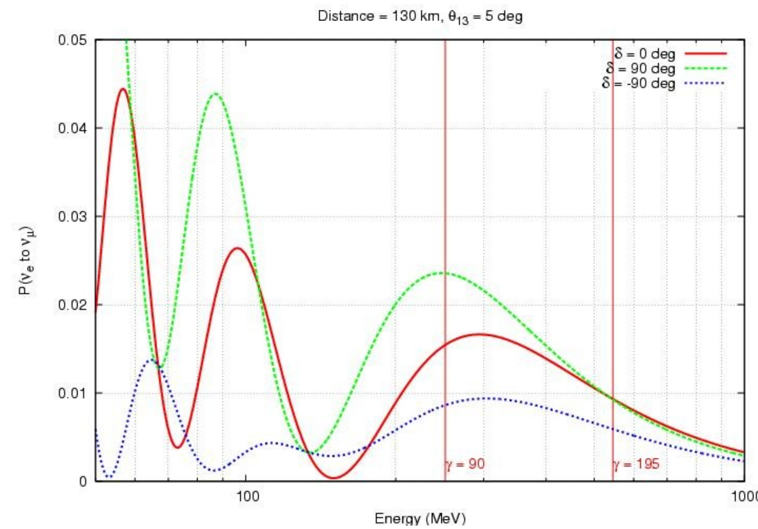
P. Spiller, GSI

Beyond baseline

- Each a comment on a
  - EC beta beam
  - High gamma facility

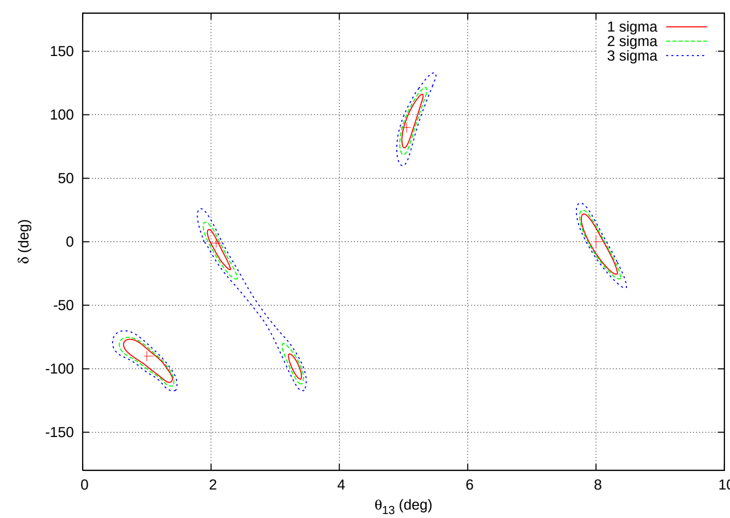
EC: A monochromatic neutrino beam

Decay	$T_{1/2}$	BR_ν	EC/ν	I^{β}_{EC}	B(GT)	E_{GR}	Γ_{GR}	Q_{EC}	E_ν	ΔE_ν
$^{148}Dy \rightarrow {}^{148}Tb^*$	3.1 m	1	0.96	0.96	0.46	620		2682	2062	
$^{150}Dy \rightarrow {}^{150}Tb^*$	7.2 m	0.64	1	1	0.32	397		1794	1397	
$^{152}Tm2^- \rightarrow {}^{152}E_T^*$	8.0 s	1	0.45	0.50	0.48	4300	520	8700	4400	520
$^{150}Ho2^- \rightarrow {}^{150}Dy^*$	72 s	1	0.77	0.56	0.25	4400	400	7400	3000	400



Possible isotope for EC: Dysprosium

- It creates a excellent neutrino beam, but …
  - Production rate feasible and sufficient?
  - Effective beam preparation of not-fully stripped ions
  - Acceleration of partly stripped ions
    - Charge-state change during acceleration

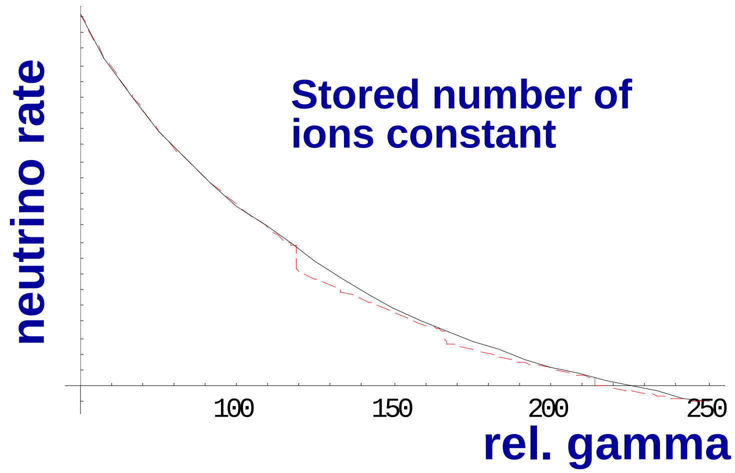


- Beyond EURISOL DS: Who will do the design?
- Is ^{150}Dy the best isotope?

M. Lindroos et al.

High gamma facility

SPS acceleration is limited to γ=150 (250) for ^{6}He (^{18}Ne)



- High gamma facility would need more ions stored to reach same neutrino rate
- Acceleration to higher gamma implies longer cycle
  - baseline scenario at limit of space charge and tune shift

Conclusions

- Beta-beam design study is advancing well, encouraging results already obtained.
- Main efforts will now focus on ^{18}Ne shortfall.
  - Improvements on production side required
- Baseline parameters fixed
  - Study goes now into detail of different machines and aspects
- Going beyond the base line design at a later stage with additional accumulation rings, and other new machines (green-field) may open the way to important performance enhancements.