Ion accumulation and cooling at low energy

Ansgar Simonsson and Anders Källberg
Manne Siegbahn Laboratory, Stockholm

Mats Lindroos
AB Department, CERN

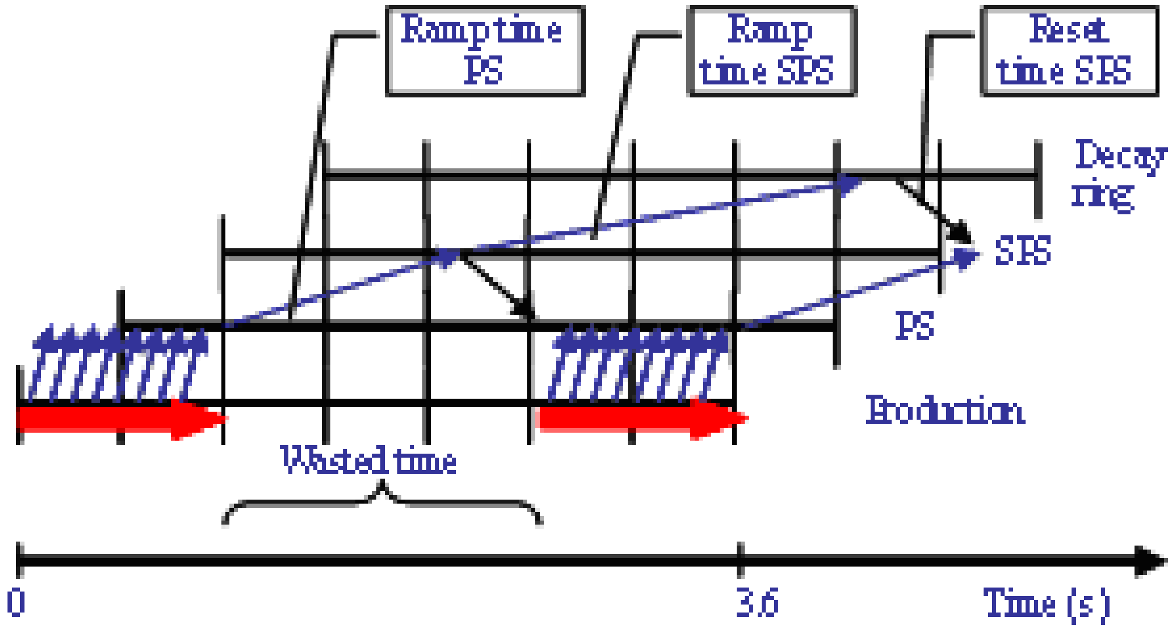
Basic Idea

Make use of all the ions produced in the ion source by accumulating ions in a cooler ring before the RCS, also while PS is ramping

Principle

- Accumulation of ions before the RCS
  - Electron cooling of the ions in the cooler ring makes accumulation possible
  - The ions are continuously cooled in all dimensions which gives space for the injection of more ions
  - This can continue while PS is ramping, thus making use of all the ions produced.

Cycle

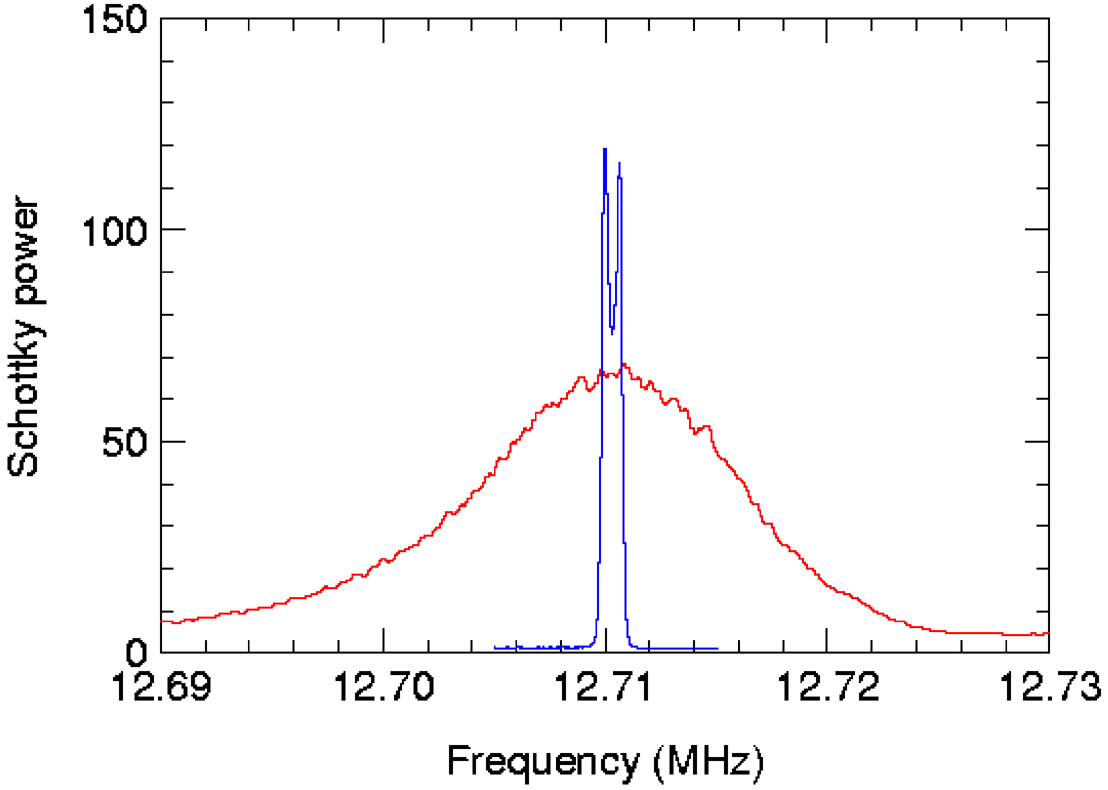


Ramp time PS
Ramp time SPS
Reset time SPS
Decay ring
SPS
PS
Production
Wasted time
0
3.6
Time (s)

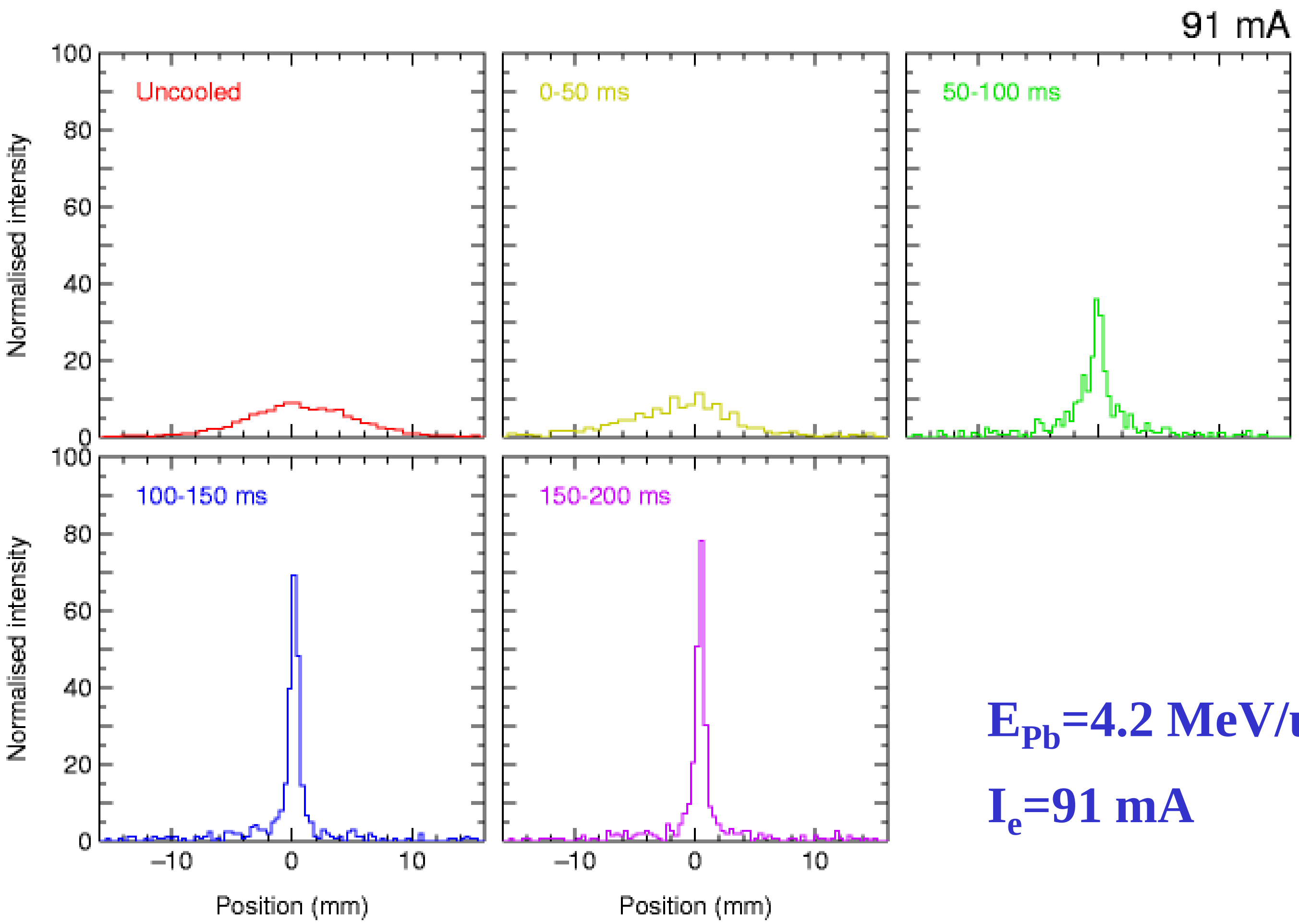
Further benefit from cooling

Due to the possibly smaller emittance of the cooled beam from the cooler ring, the efficiency of the multi-turn injection into the RCS might be improved.

Longitudinal cooling of d^+



Transverse cooling of Pb^{54+}



E_{Pb}=4.2 MeV/u

I_e=91 mA

Main challenge

- The electron cooling needs to be fast enough. The cooling time should be of the same order as the repetition time of the injected pulses (1/10 Hz).
- Transverse cooling is limiting, since it normally is slower than longitudinal
- Cooling time depends on the initial emittance
- @ 100 Mev/u: $U_e \approx 55$ kV, $I_e = 2\text{-}3$ A needed

Limitations

- Radioactive halflife of ^{18}Ne 1.67 s. Balance between accumulation and decay is achieved after ≈ 2-3*$t_{½}$
- Instabilities and space-charge limitations. (Not studied in detail, but tune shift in the cooler ring itself does not seem to be a limit)

Parameters to vary

- Number of pulses accumulated in the cooler ring
- Further accumulation in the PS or SPS? Or both?
- Number of accumulations in PS/SPS

Optimum found for 23 bunches from the ECR in the cooler ring and 10 bunches from PS in the SPS

Main challenges

- Design of the electron cooler
  - length 14m
  - electron current 3 A

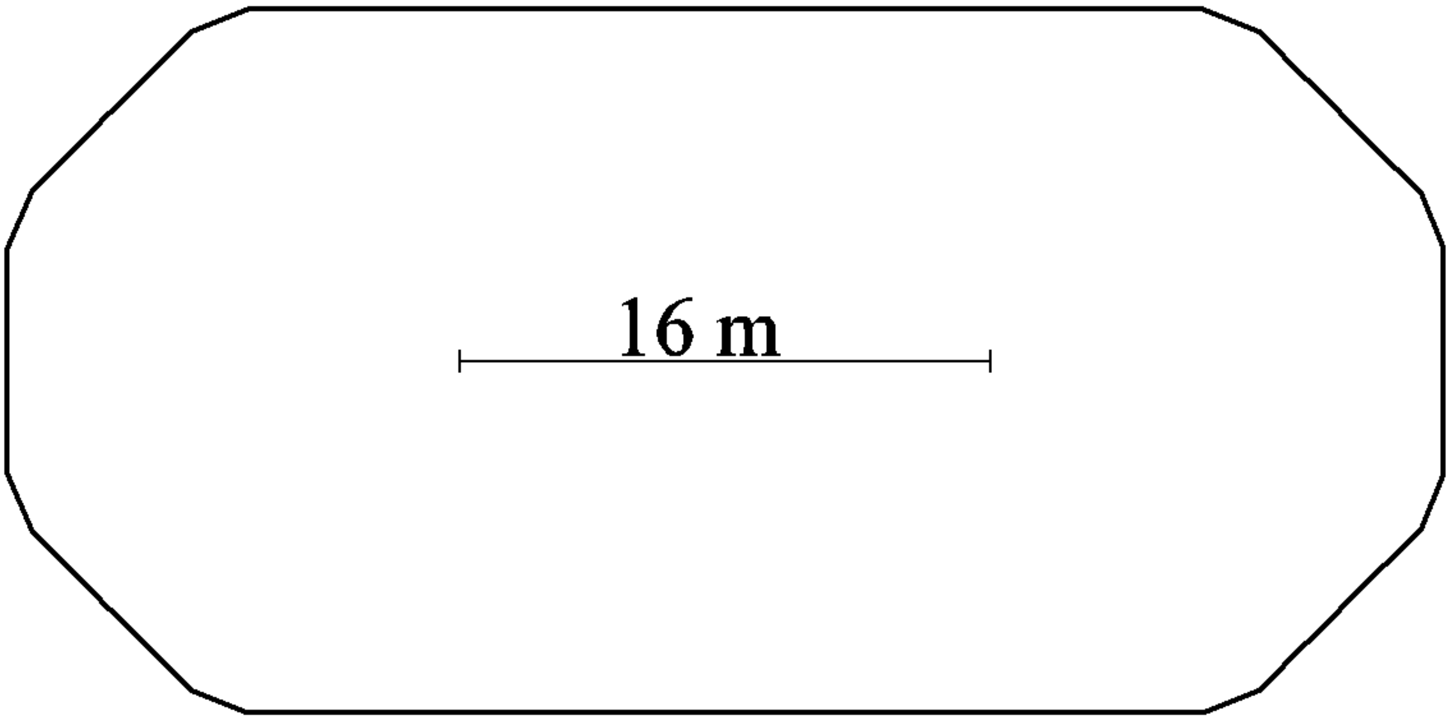
- Intensity limitations in the ring (and maybe further downstream)

Electron cooling

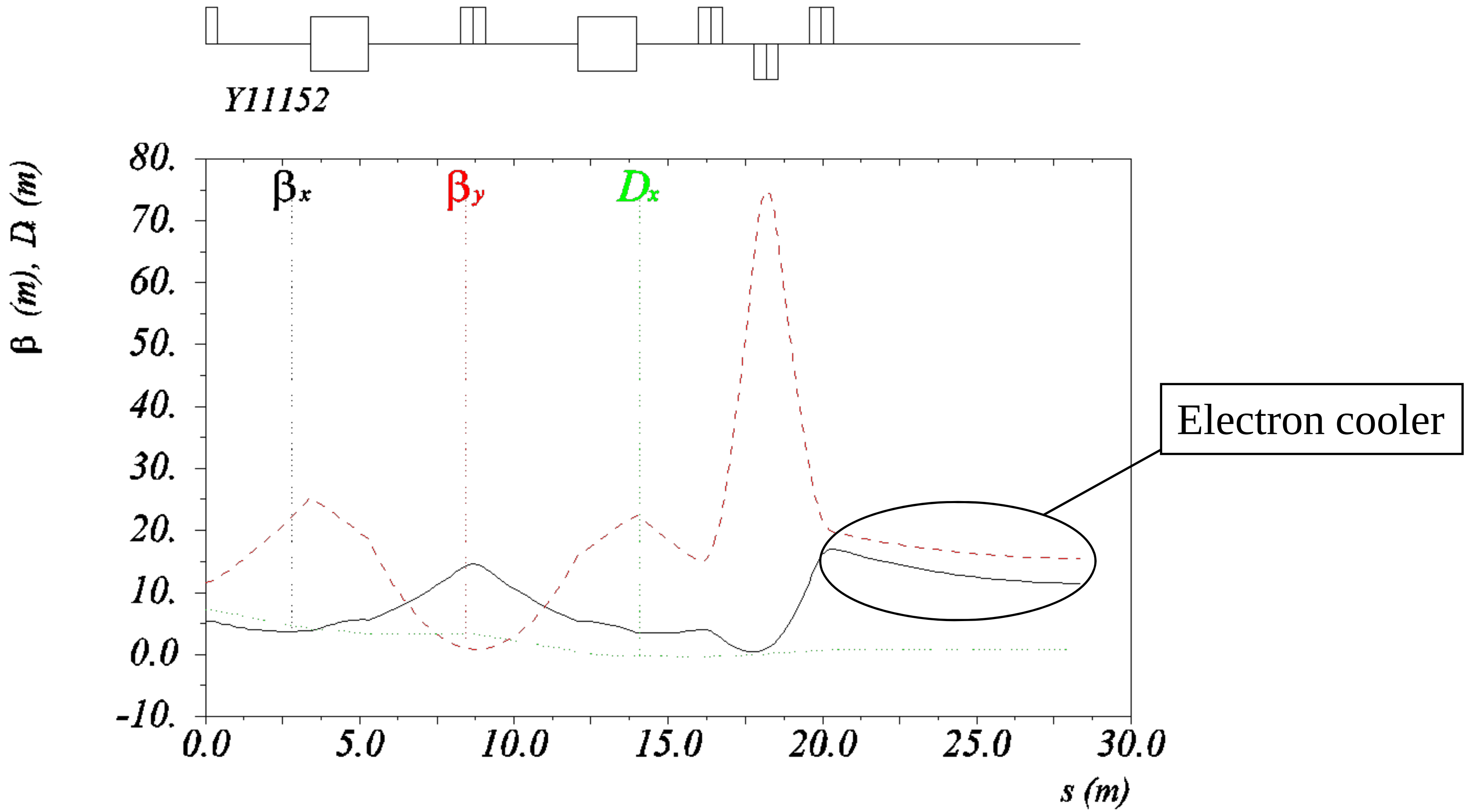
- fast for cold ions, slower when electron and ion velocities differ
- not dependent on ion current
- much faster longitudinally than transversely
- cooling speed ~ $q^2/A \times I_e/\Theta^3$, where Θ is the angle between ions and electrons – large ß-functions (smaller angles) are beneficial

Electron cooler ring

- A birds-eye view of an 114 m circumference accumulator ring with two 16 m free straight sections and room for a 14 m long electron cooler.



Lattice functions of ¼ of the accumulator ring.



Electron cooling, to study

Electron cooling with high currents

Investigate how large current it is possible to obtain with the quality needed for efficient electron cooling

and verify that the simulations are valid. Since the cooling force is not linear also corrections can be quite important.

Cost estimate

- Circumference 114 m
- 8 bending magnets 2.7 Tm
- Fixed energy, no ramping needed
- 20 q-poles
- 14 m electron cooler 3 A
- Simple RF only for bunching (diagnostics)
- UHV vacuum to minimize losses
- ...

Cost estimate

	Estimated cost (kCHF)	Comment
Dipoles	400	Based on RCS estimate
Q-poles	740	Based on RCS estimate
Other magnets	670	Based on RCS estimate
Current supplies	830	5 MSEK
Installation, cabling	1000	6 MSEK
Civil engineering	830	5 MSEK
Vacuum	1900	Estimated as 100 kSEK/m
Injection	830	Including supplies

Cost estimate

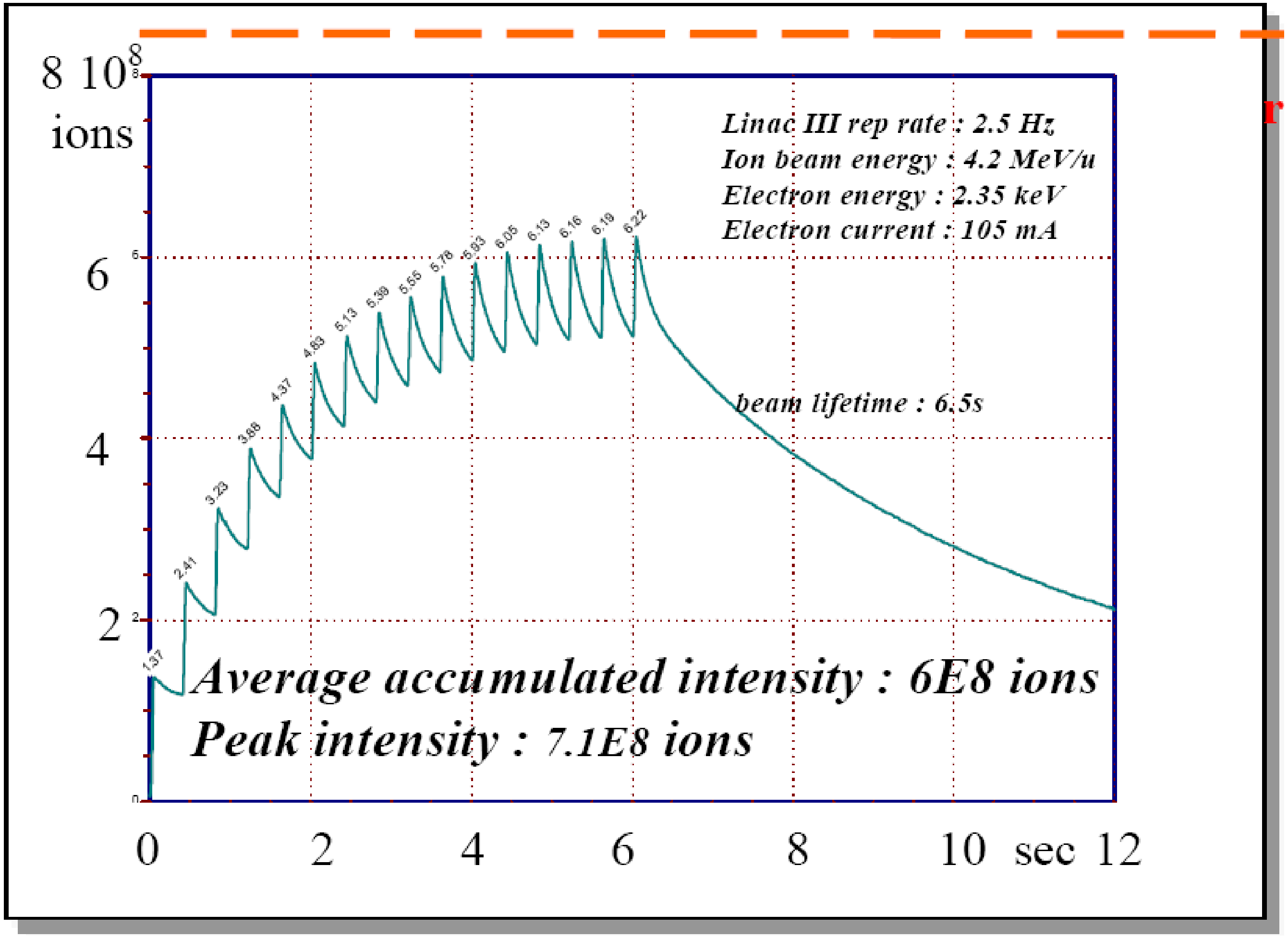
	Estimated cost (kCHF)	Comment
Extraction	830	Including supplies
Diagnostics	570	Estimated as 7% of the above
Control	500	
Contingencies	1830	20%
Sum without electron cooler	11000	
Electron cooler	4200	25MSEK (magnets 10 MSEK, supplies 5MSEK, vacuum 5 MSEK, smaller parts 5 MSEK)
Total	15200	

A 300 kV, 3 A cooler with a 4 m interaction region from Novosibirsk for the HIRFL-CSR project at INP, Lanzhou

Cooling rate

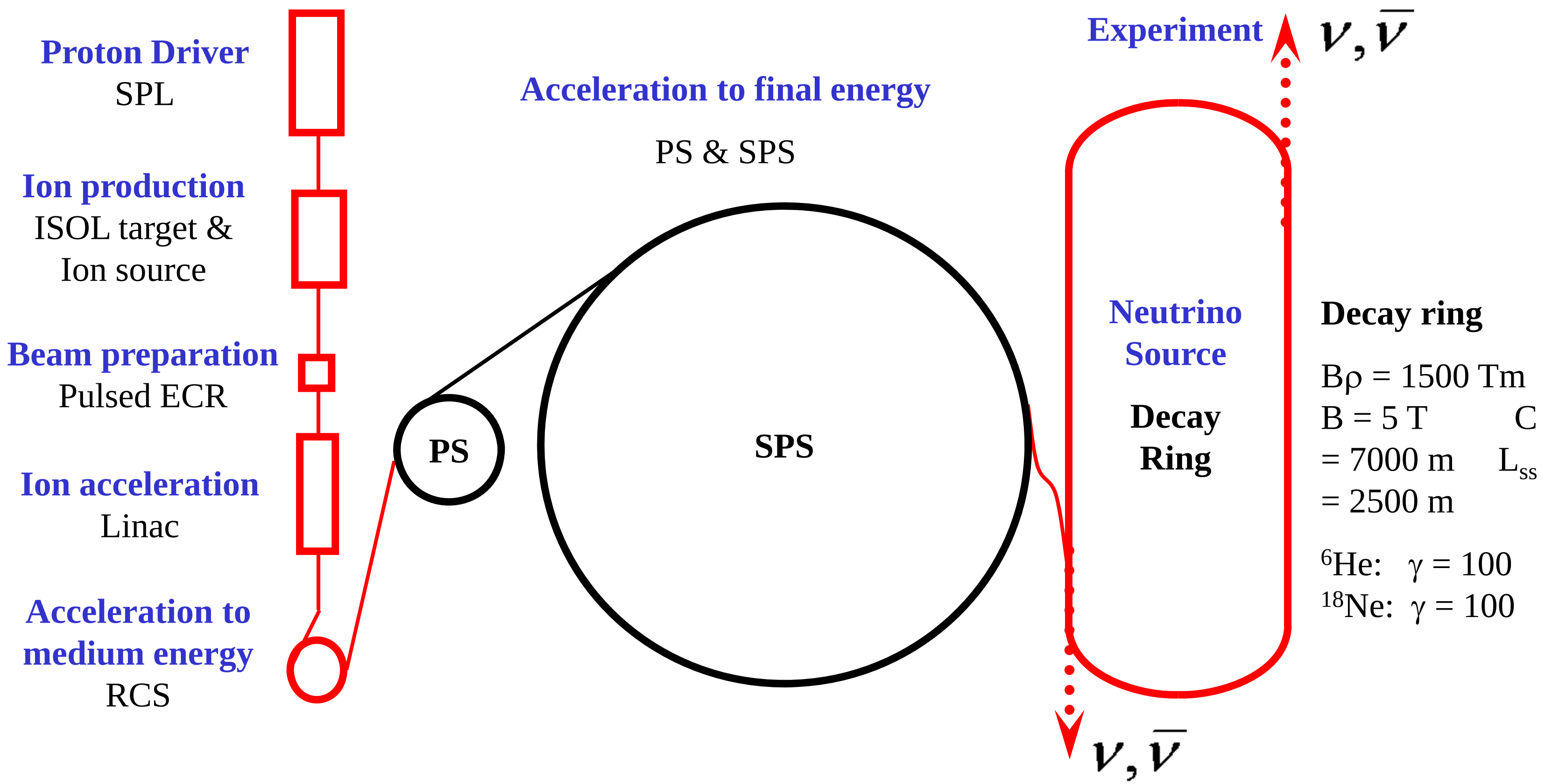
$$\frac{1}{\tau} \approx 2.5 \times 10^{-13}\ [\mathrm{Amp}^{-1}\ \mathrm{m}^2\ \mathrm{s}^{-1}] \times \left(\frac{1}{R} \frac{q^2}{A} \frac{1}{\beta^4 \gamma^5} \right) \times \ell_{\mathrm{c}} j_{\mathrm{e}} \frac{1}{\theta^3}$$

Accumulation of Pb ions in LEAR



Beta-beam baseline design

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



Intensities, ^{6}He

Machine	Total Intensity out (10^{12})	Comment
Source	20	DC pulse, Ions extracted for 1 second
ECR	1.2	Ions accumulated for 60 ms, 99% of all 6He ions in highest charge state, 50 microseconds pulse length
RCS inj	0.58	Multi-turn injection with 50% efficiency
RCS	0.57	Acceleration in 1/32 seconds to top magnetic rigidity of 8 Tm
PS inj	6.8	Accumulation of 16 bunches during 1 second
PS	5.8	Acceleration in 0.8 seconds to top magnetic rigidity of 86.7 Tm and merging to 8 bunches.
SPS	5.4	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	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

Machine	Total Intensity out (10^{10})	Comment
Source	80	DC pulse, Ions extracted for 1 second
ECR	1.4	Ions accumulated for 60 ms, 30% of all 18Ne ions in one dominant charge state, 50 microseconds pulse length
RCS inj	0.71	Multi-turn injection with 50% efficiency
RCS	0.70	Acceleration in 1/32 seconds to top magnetic rigidity of 8 Tm
PS inj	10.1	Accumulation of 16 bunches during 1 second.
PS	9.6	Acceleration in 0.8 seconds to top magnetic rigidity of 86.7 Tm and merging to 8 bunches.
SPS	9.5	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	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.