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The Decay Ring
-Status-

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Summary

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- Decay ring “reference” parameters
- Constraints and variables
- The ring status
  - The injection
  - Optical functions
  - The magnets
  - Chromaticities correction
  - Decay products collection
- Effects of variable change
- Conclusions

Decay ring : reference parameters

Parameters of the radioactive ion beams

	$^{6}He^{2+}$	$^{18}Ne^{10+}$
γ	100	100
Energy (GeV)	555	1669
$B\rho$ (T.m)	931	559
τ (s) at rest	0.8	1.67
ε_{rms} (mm.mrad)	0.233	0.465
$N_{Injected}$ (ions/batch)	$0.9\ 10^{13}$	$4.9\ 10^{11}$
N_{Stored} (ions/batch)	$1.3\ 10^{14}$	$1.5\ 10^{13}$

Ring parameters

Circumference (m)	6935
Arc length (m)	1068
Straight section (m)	2399
Bend field (T) [$^{6}He^{2+}$]	6
Injection repetition rate (s)	8

- Two period lattice.
- The arcs are 2π insertions.
- The injection is located in the arc.
- Chromaticities correction with 2 sextupoles families.
- Free straight sections enable decay products collection.

Constraints and variables

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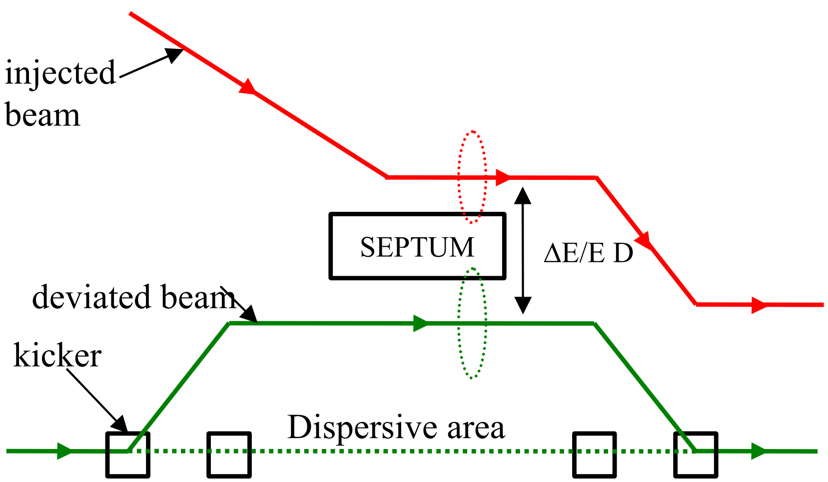
- Constraints :
  - the useful neutrino rate : constant
  - the maximum bend field
  - the admissible losses
    - in the arc bends
    - at the injection
  - the irradiation level : ?
  - the admissible cost : ?

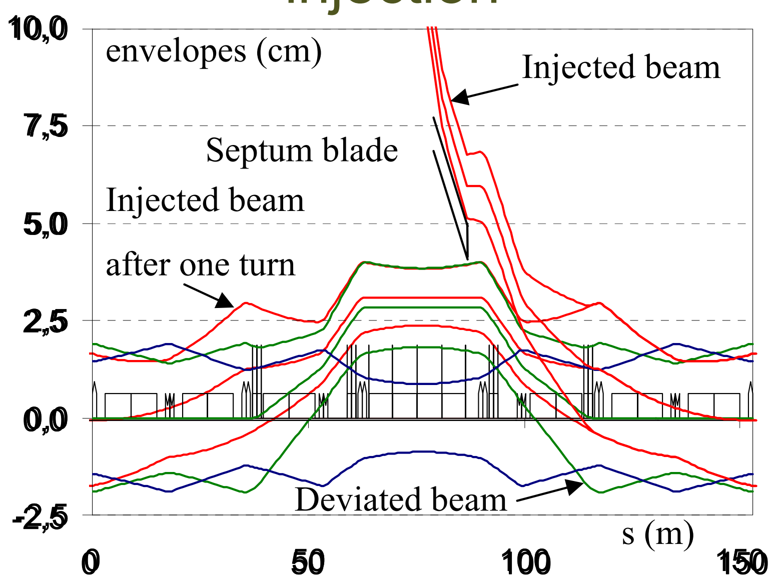
- Variables :
  - the injection repetition rate
  - the injected intensity : neutrino flux variable
  - the energy
  - the ring length
  - the particle

Injection : general

Layout



Horizontal envelopes at injection



- Injection is located in a dispersive area
- The stored beam is pushed near the septum blade with 4 “kickers”. At each injection, a part of the beam is lost in the septum
- Fresh beam is injected off momentum on its chromatic orbit. “Kickers” are switched off before injected beam comes back
- During the first turn, the injected beam stays on its chromatic orbit and passes near the septum blade
- Injection energy depends on the distance between the deviated stored beam and the fresh beam axis

Injection : parameters

The injected beam have to compensate the beta decay, and the losses when the stored beam is pushed near the septum blade.

Stored beam intensity limit :

$$N_S(t\to\infty)=\frac{N_I}{1-a\,2^{-\frac{T}{\gamma\tau}}}$$

Number of neutrino between two injection :

$$\Delta N_\nu(t\to\infty)=\frac{N_I\left(1-2^{-\frac{T}{\gamma\tau}}\right)}{1-a\,2^{-\frac{T}{\gamma\tau}}}\frac{1}{T}$$

Deposit power on the septum blade, at each injection :

$$P_{losses}=\frac{1-a}{1-a\,2^{-\frac{T}{\gamma\tau}}}N_I\,2^{-\frac{T}{\gamma\tau}}(\gamma-1)E_0\frac{1}{T}$$

Where :

- T : repetition rate
- τ : half-life of the ion at rest
- N_I : injected ions number at each injection
- a : transmission coefficient of the stored beam through the septum blade

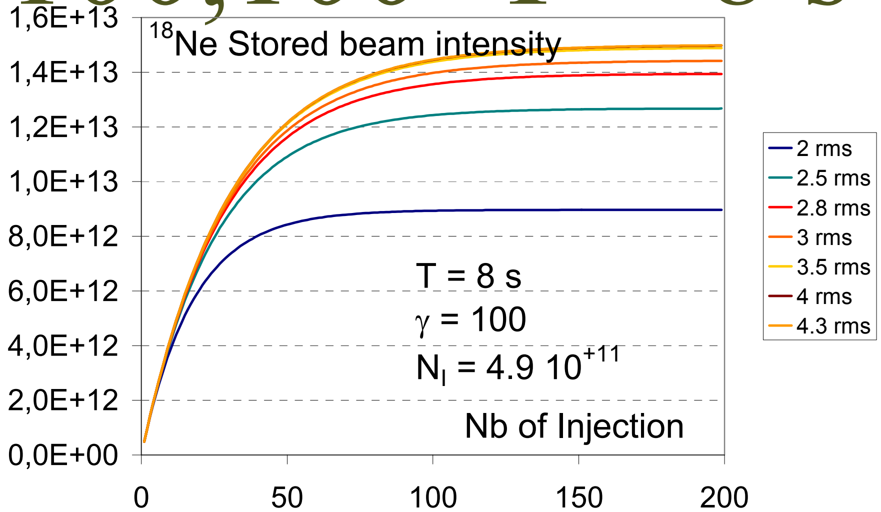
$$a=\int_{-\infty}^{n_m\sigma} f_\sigma(x)\,dx$$

- 1D Gaussian beam distribution assumed

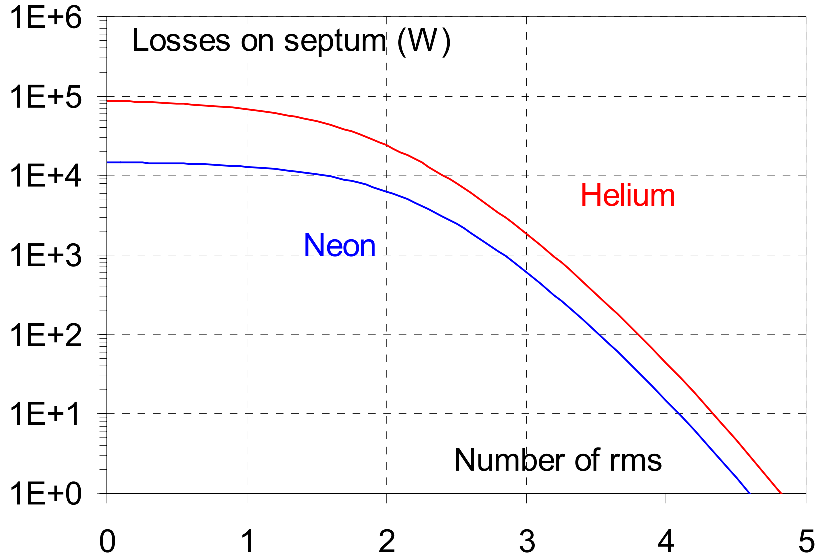
Four parameters : T, γ ,N_I, τ

Keep the Neutrino flux constant, if possible.

Injection : reference, γ = 100,100 T = 8 s



	$^6He^{2+}$	$^{18}Ne^{10+}$
γ	100	100
Injected intensity	0.9 10^{+13}	4.9 10^{+11}
ε_{rms} (mm.mrad)	0.233	0.465
Stored Intensity	1.34 10^{+14}	1.5 10^{+13}
Losses < 10 W	4.4 rms	4.1 rms
(Nb ν)/T	1.12 10^{+12}	6.12 10^{+10}



Injection apertures driven by Neon.

Decay losses power driven by Helium.

Magnetic field driven by Helium.

Optical functions

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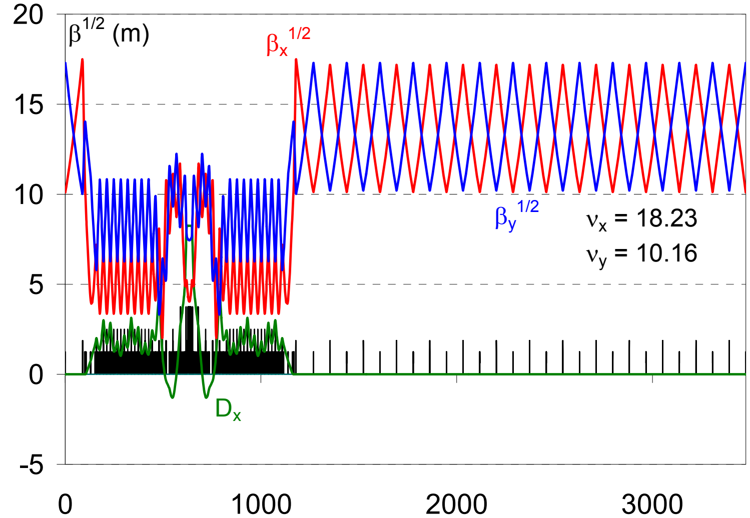
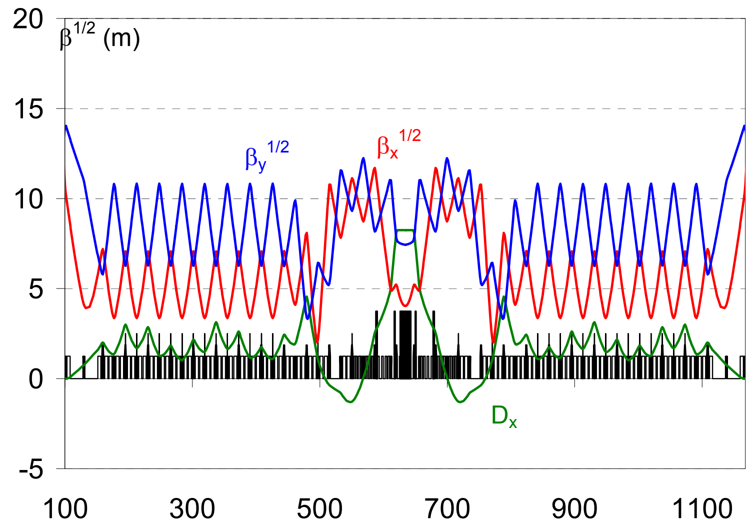
Half ring optical functions



The arc is a 2π insertion. Optical functions in the arc are smaller to reduce magnet apertures.

By arc, there are 489 m of 6 T field bend with 5 cm radius aperture.

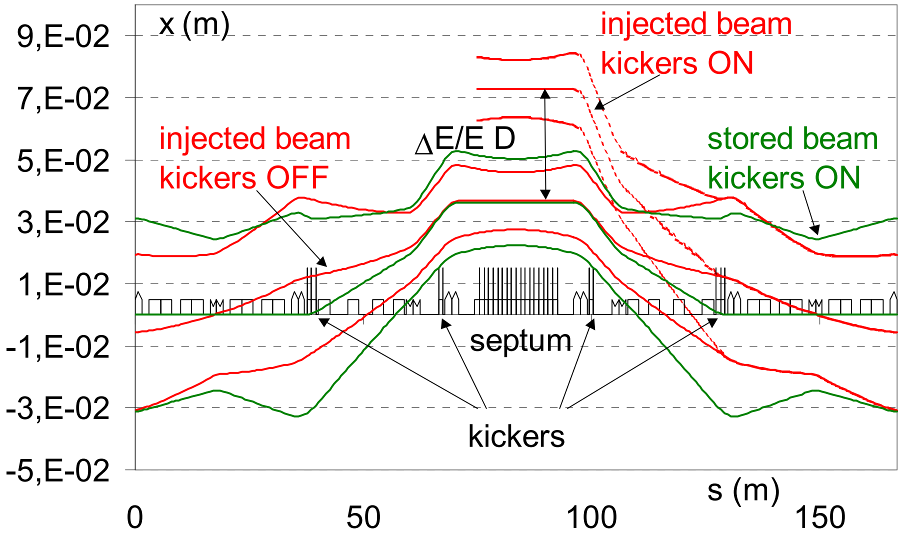
Arc optical functions



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

Injection : envelopes

Horizontal envelopes at injection



The injection septum is 18 m long and its field is 1 T.

The “kicker” deviations are 0.9 mrad (0.84 T.m) and 0.26 mrad (0.24 T.m)

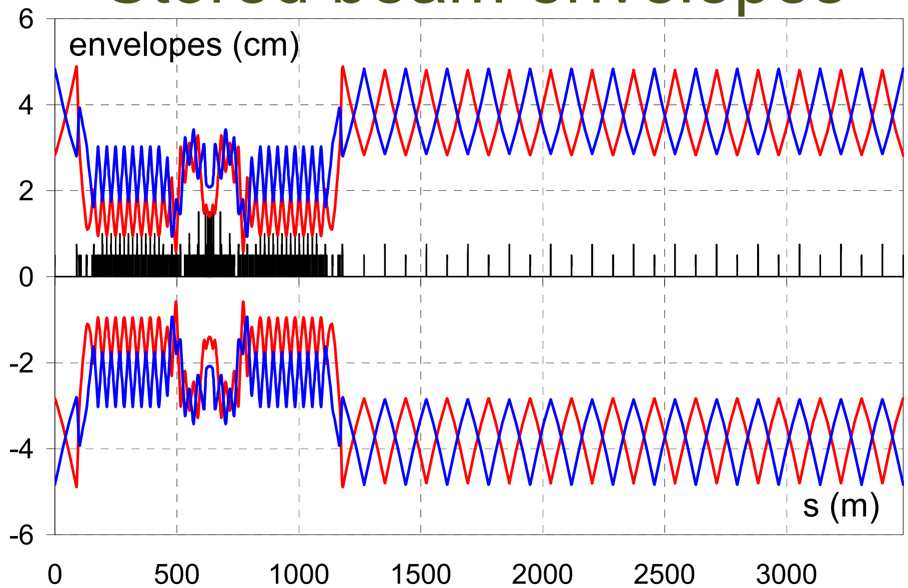
The difference between the envelopes of the stored beam and the returned injected beam take into account the injection dispersion mismatching.

Distance between the axis of the injected beam and the deviated stored beam gives injection off-momentum, 0.46 %.

The first kicker after the septum needs a large horizontal aperture, ≈ 9 cm .

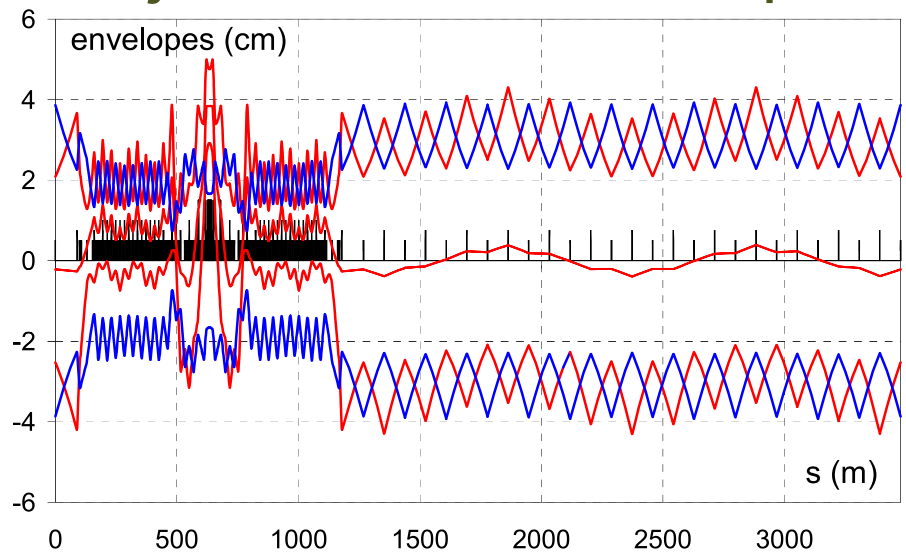
Magnet apertures

Stored beam envelopes



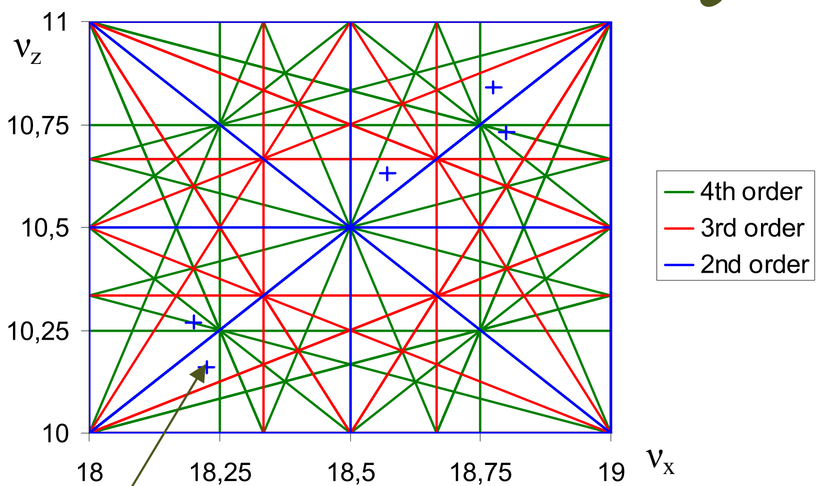
- In the long straight sections, the apertures are defined by the stored beam sizes.
- The sizes decrease when the energy increases.

Injected beam envelopes



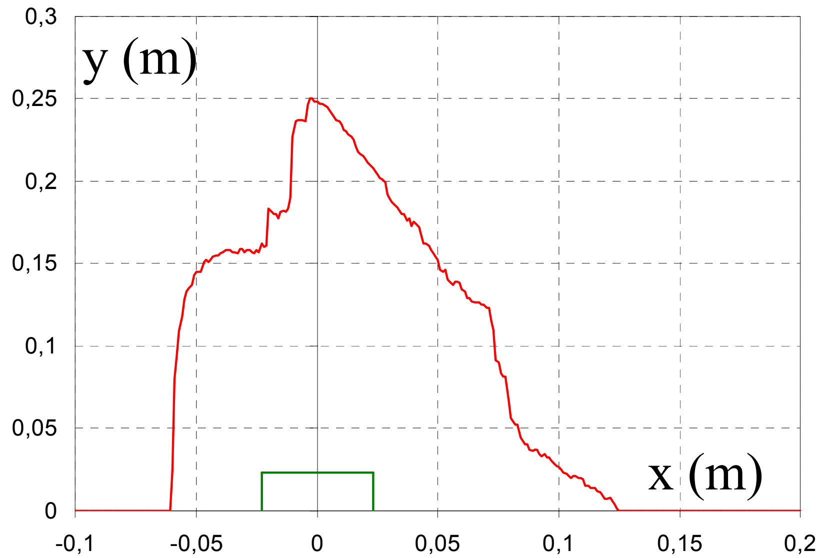
- In the arc, the horizontal aperture is defined by the injected beam off-momentum.
- The needed apertures decrease when the injected beam off-momentum decreases

2^{nd} order study



Best point

Dynamic aperture at the injection point



Chromaticities (ζ_x=-1.3, ζ_z=-1.8) corrected by 2 families of sextupoles.

Arcs are 2π insertions.

⇒ The tunes are given by the straight sections phase advances.

⇒ It is quite easy to optimize the tunes.

The working point is chosen according to :

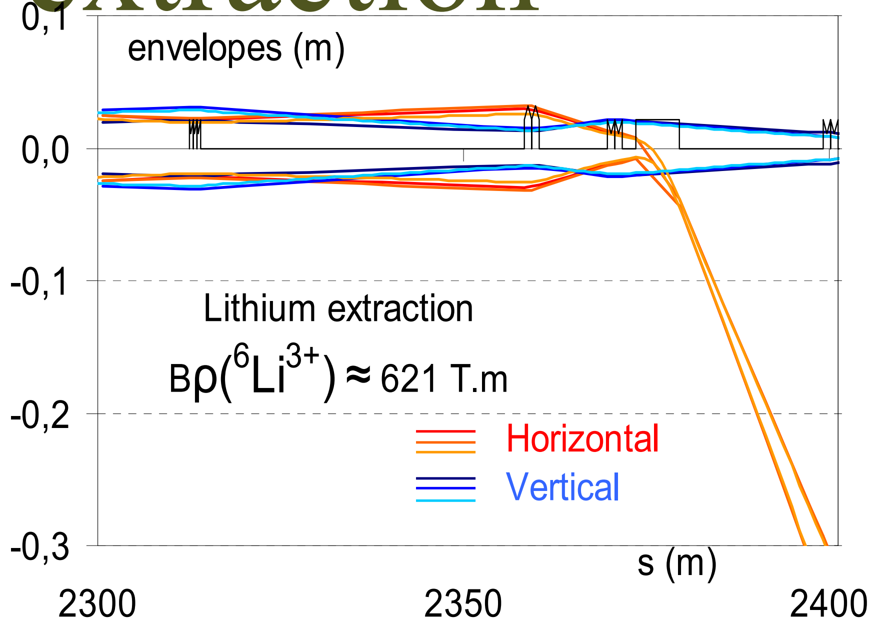
⇒ the dynamic aperture

⇒ the momentum acceptance

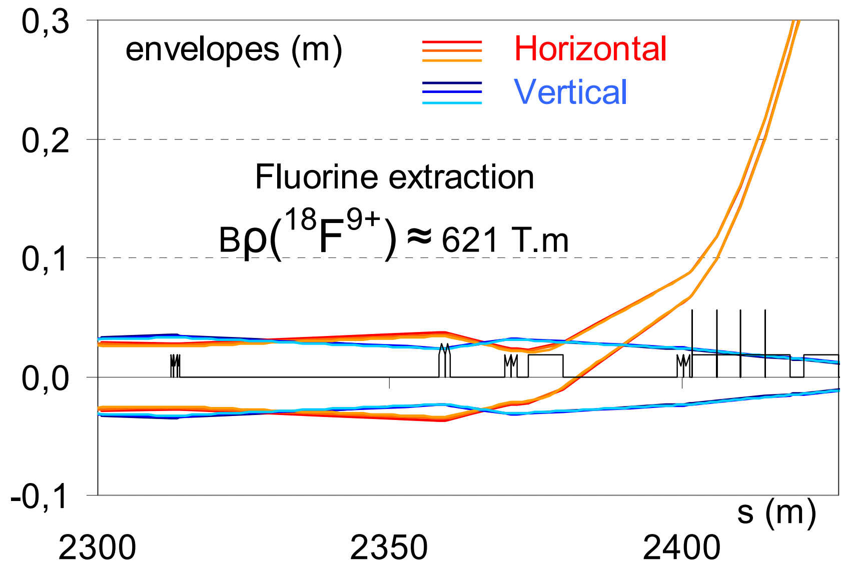
Physically, the momentum acceptance is limited by the septum position.

Straight section decay products extraction

Lithium extraction



Fluorine extraction



Two free straight sections after the first arc dipole enable the extraction of decay products coming from long straight sections.

This is ≈35% of the total losses and needs a particular treatment.

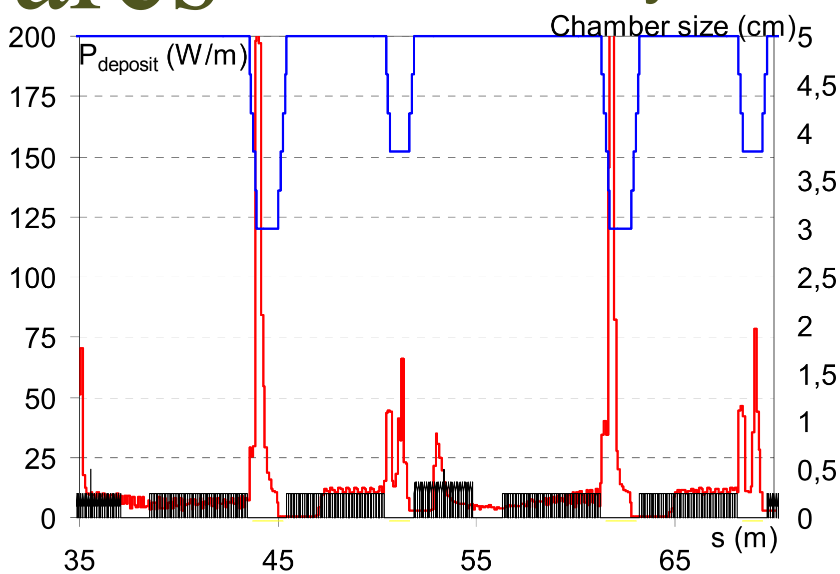
Lithium extraction can be made without a septum.

Fluorine extraction needs an additional septum.

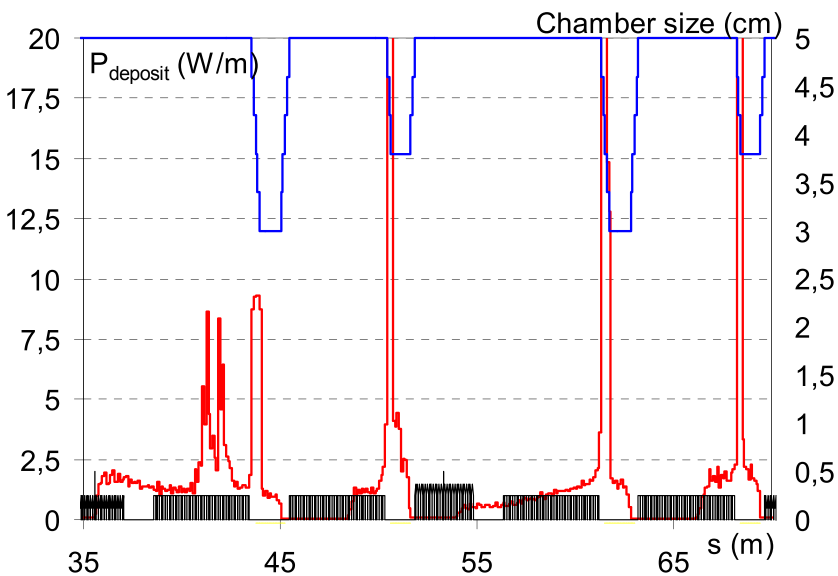
The permanent septum for Fluorine extraction is 22.5 m long and its field is 0.6 T.

Decay products collection in the arcs

Helium decay



Neon decay



Most of Lithium is deposited at the middle of dipoles

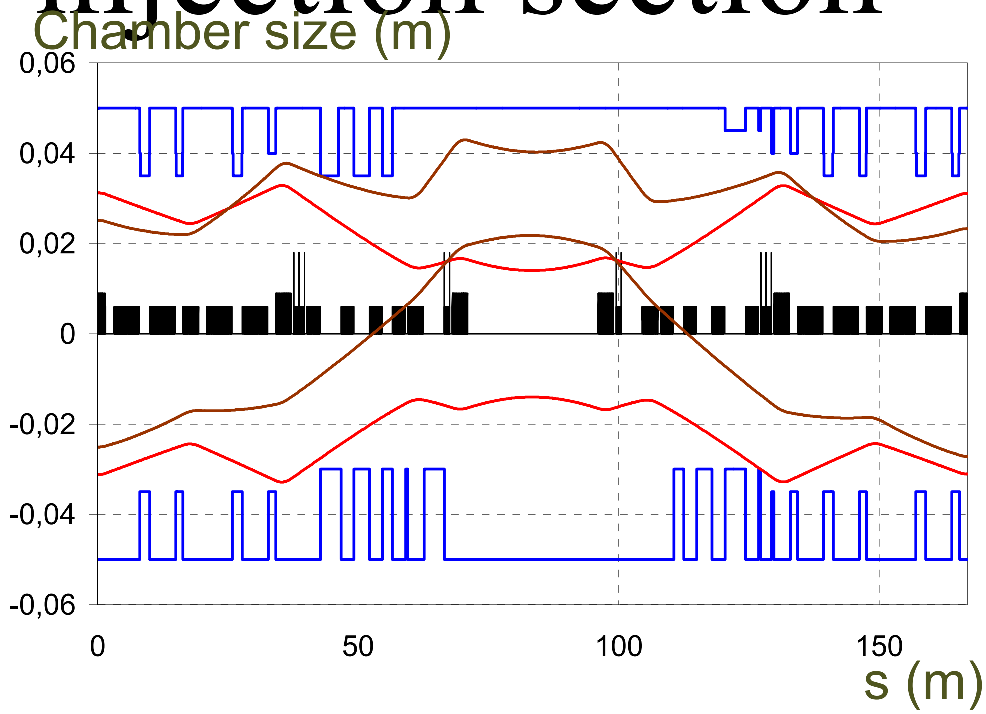
⇒ we have divided the dipoles in two 6T bends and separated them with a drift.

The chamber sizes between the two dipoles are small to maximize the deposition here.

⇒ Problem of radioprotection

⇒ Fewer problems in the dipoles, the deposit power is < 15 W/m.

Decay products losses in the injection section



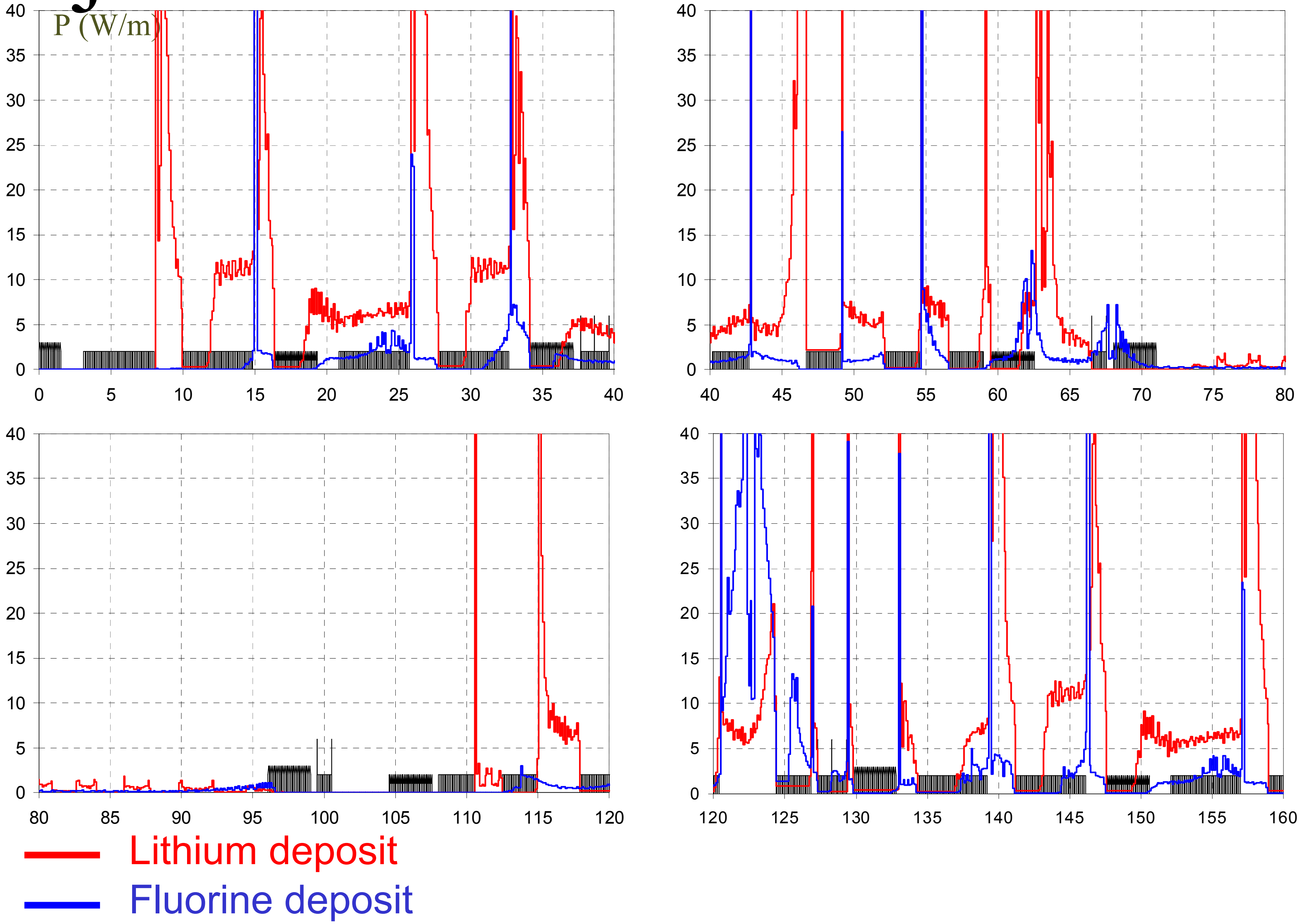
Asymmetric chamber.

Problem of the straight section for the injection : the integrated deposit is very high.

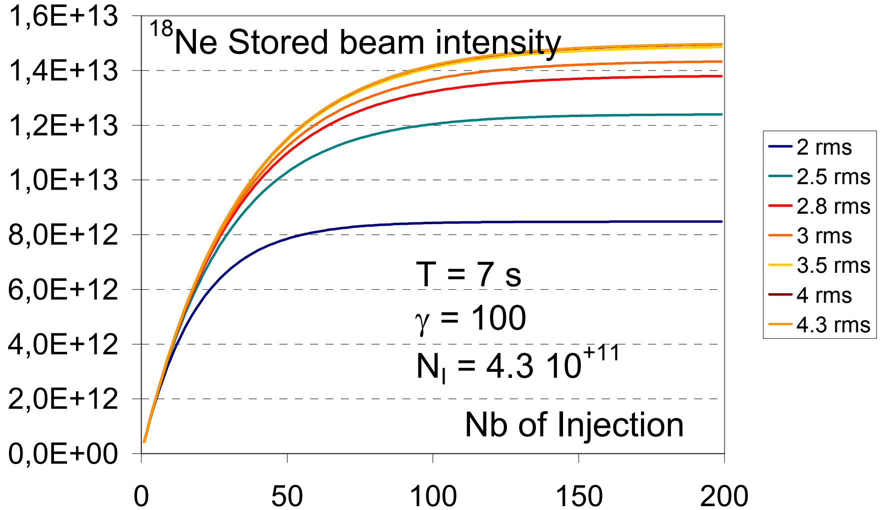
⇒The Lithium AND Fluorine deposits are not negligible

⇒We had to divide the dipoles in two dipoles again.

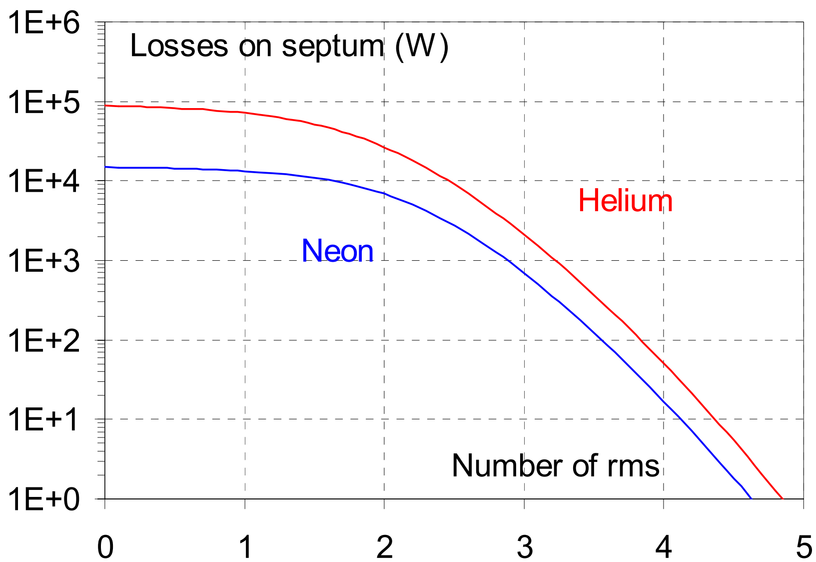
Decay products losses in the injection section



Repetition rate T = 7 s (green site)



	$^6He^{2+}$	$^{18}Ne^{10+}$
γ	100	100
Injected intensity	$0.8\ 10^{+13}$	$4.3\ 10^{+11}$
ε_{rms} (mm.mrad)	0.233	0.465
Stored Intensity	$1.34\ 10^{+14}$	$1.5\ 10^{+13}$
Losses < 10 W	4.4 rms	4.2 rms
(Nb ν)/T	$1.12\ 10^{+12}$	$6.12\ 10^{+10}$



Less demanding on sources, by pulse. But, the integrated intensity is the same.

No other change.

Injected intensity change

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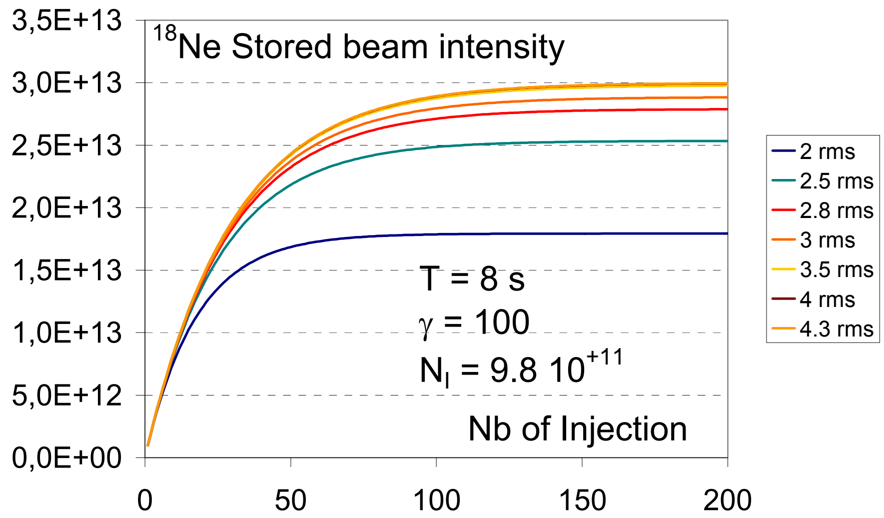
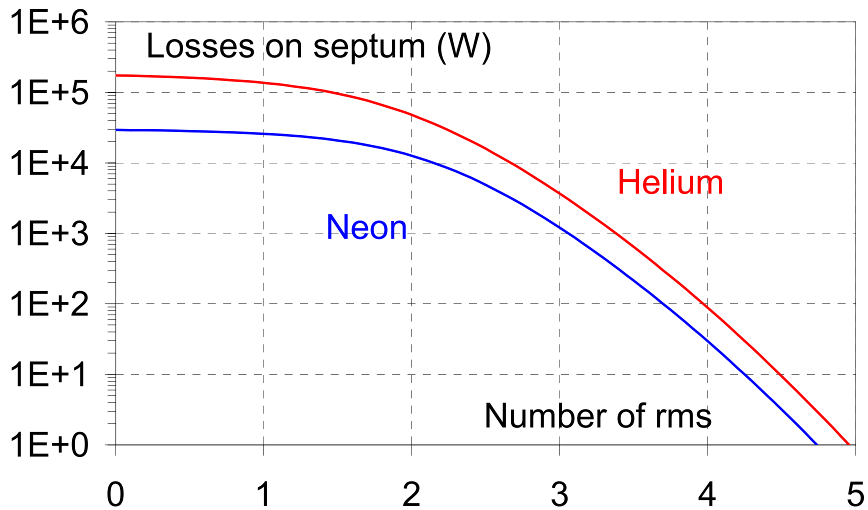


	$^6He^{2+}$	$^{18}Ne^{10+}$
γ	100	100
Injected intensity	1.8 10^{+13}	9.8 10^{+11}
ε_{rms} (mm.mrad)	0.233	0.465
Stored Intensity	2.69 10^{+14}	3.0 10^{+13}
Losses < 10 W	4.5 rms	4.3 rms
(Nb ν)/T	2.25 10^{+12}	1.22 10^{+11}



Neutrino production changes with N_I.

Injection apertures change with N_I.

Injection off-momentum changes with N_I.

Decay losses power changes with N_I.

Stored beam intensity changes with N_I.

Energy change : γ = 60, 60, T = 8 s

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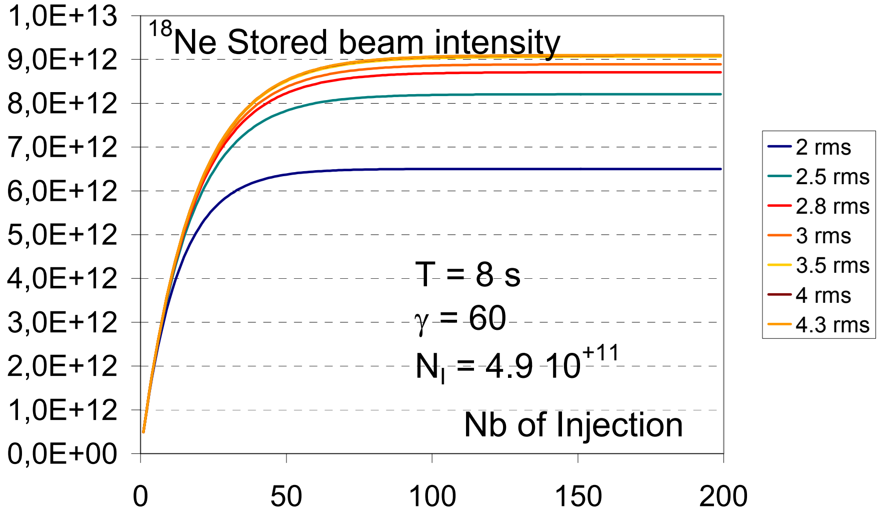
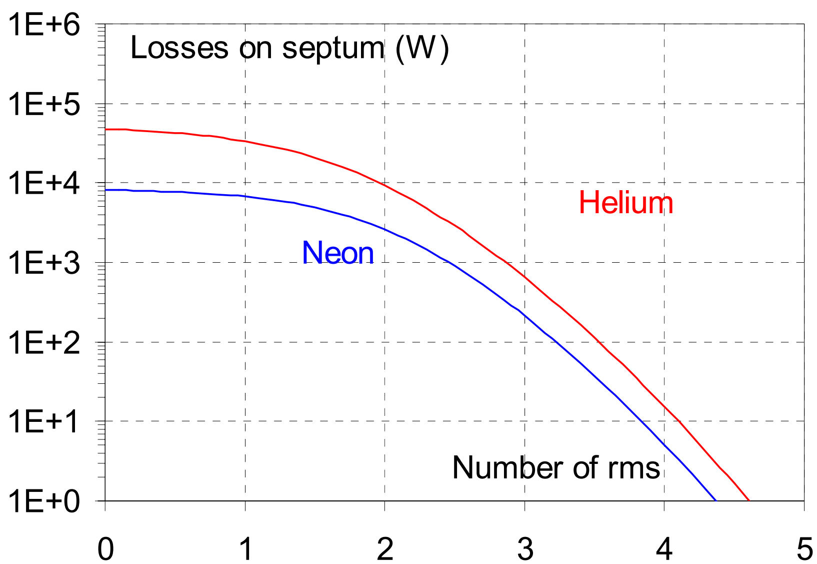


	$^{6}He^{2+}$	$^{18}Ne^{10+}$
γ	60	60
Injected intensity	0.9 10^{+13}	4.9 10^{+11}
ε_{rms} (mm.mrad)	0.384	0.776
Stored Intensity	0.91 10^{+14}	0.82 10^{+13}
Losses < 10 W	4.1 rms	3.9 rms
(Nb ν)/T	1.12 10^{+12}	6.12 10^{+10}



Injection apertures increase with ε.

Injection off-momentum increases.

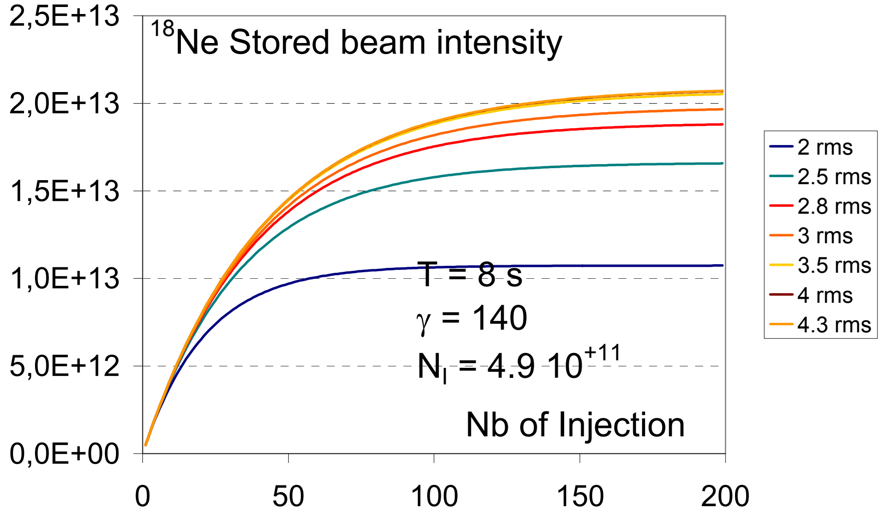
Decay losses power decreases with γ.

Stored beam intensity decreases with γτ.

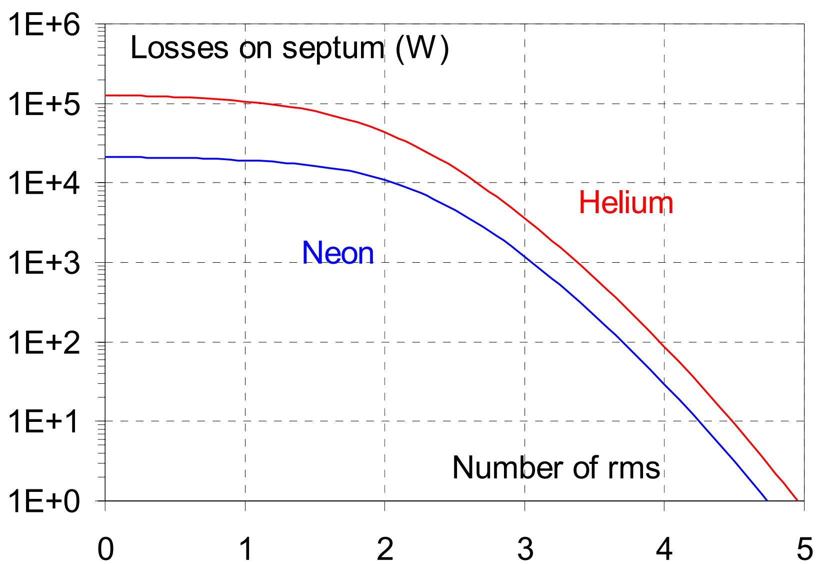
Magnetic fields decrease with γ.

Septum length decreases with γ.

Energy change : γ = 140, 140, T = 8 s



	$^{6}He^{2+}$	$^{18}Ne^{10+}$
γ	140	140
Injected intensity	$0.9\ 10^{+13}$	$4.9\ 10^{+11}$
ε_{rms} (mm.mrad)	0.165	0.332
Stored Intensity	$1.86\ 10^{+14}$	$2.09\ 10^{+13}$
Losses < 10 W	4.5 rms	4.3 rms
(Nb ν)/T	$1.12\ 10^{+12}$	$6.12\ 10^{+10}$



Injection apertures decrease with ε.

Injection off-momentum decreases.

Decay losses power increases with γ.

Stored beam intensity increases with $\gamma\tau$.

Magnetic fields increase with γ.

Septum length increases with γ.

Ring length change

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In all cases we keep the ratio (straight section / ring) constant.

Increase the ring length :

- The magnetic fields decrease.
- We have to verify the losses collection ability of the lattice.
- Number of neutrino by pulse increases, and the duty cycle is lower.

Decrease the ring length :

- The magnetic fields increase.
- We have also to verify the losses collection ability.
- Number of neutrino by pulse decreases, with a larger duty cycle.

Particle change

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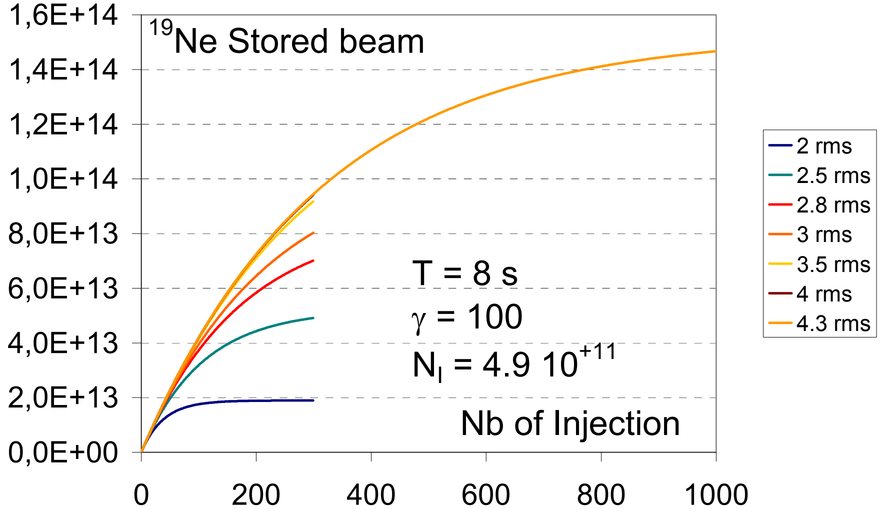
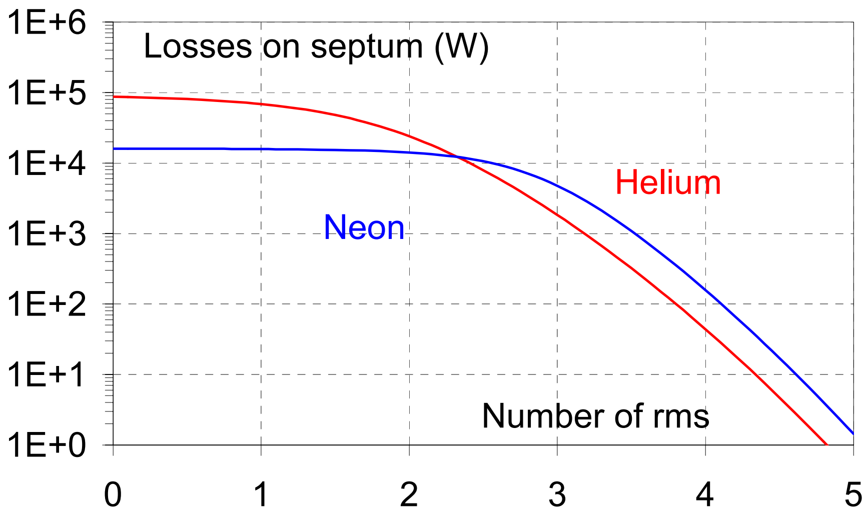


$^{19}Ne^{10+}$, τ =17.3 s

	$^{6}He^{2+}$	$^{19}Ne^{10+}$
γ	100	100
Injected intensity	$0.9\ 10^{+13}$	$4.9\ 10^{+11}$
ε_{rms} (mm.mrad)	0.233	0.465
Stored Intensity	$1.34\ 10^{+14}$	$1.53\ 10^{+14}$
Losses < 10 W	4.4 rms	4.6 rms
(Nb ν)/T	$1.12\ 10^{+12}$	$6.12\ 10^{+10}$



Injection apertures change with (γ-1)E0.

Injection off-momentum also.

Decay losses change with (γ-1)E0.

Stored beam intensity changes with $\gamma\tau$.

Magnetic fields change with γ A/Q.

Conclusions

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We have a first lattice for the ^{6}He, ^{18}Ne, γ=100 as reference case.

When varying parameter one by one, we have :

- if N_l increases, the neutrino flux increases, the stored intensity increases, the losses power increases.

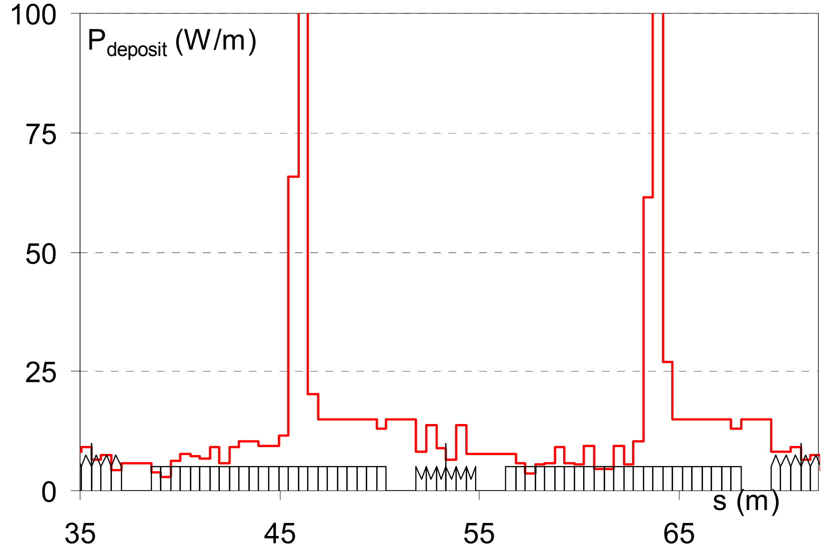
Keeping the neutrino production rate as constant

- if γ increases, the magnetic fields and the losses power increase
- if $\gamma\tau$ increases, the stored intensity increases
- if the injection repetition rate T decreases, the injected intensity decreases also
- if the ring length decreases, the magnetic fields increase and the neutrino beam properties are worse.

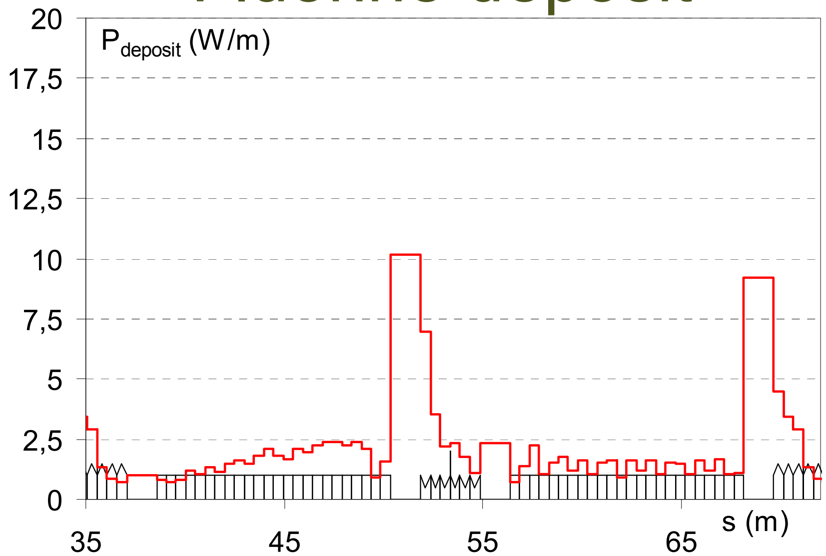
We could change also the straight section / ring length ratio, indeed the useful neutrino flux depends on it.

Decay products losses in the arcs

Lithium deposit



Fluorine deposit



We have begun studying the repartition of the disintegrations in the arcs.

Most of decay products deposits come into the dipoles.

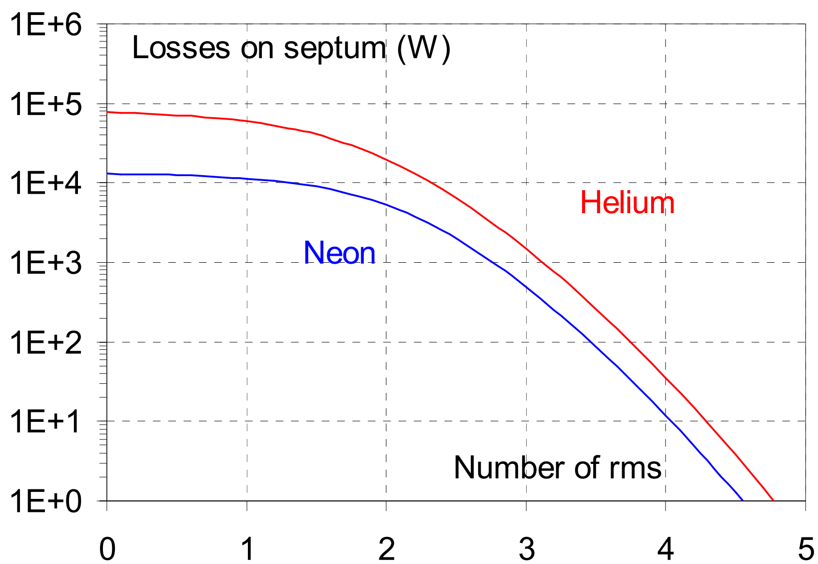
⇒Problem of radioprotection in the arc

⇒Problem of dipole cooling

⇒This design is not valuable due to this deposit level

Injection : γ = 90, 90, T = 8 s

	$^{6}He^{2+}$	$^{18}Ne^{10+}$
γ	90	90
Injected intensity	0.9 10^{+13}	4.9 10^{+11}
ε_{rms} (mm.mrad)	0.256	0.517
Stored Intensity	1.2110+14	1.35 10^{+13}
Losses < 10 W	4.3 rms	4.1 rms
(Nb ν)/T	1.12 10^{+12}	6.12 10^{+10}



Injection apertures increase.

Decay losses power decreases by 0.9.

Stored beam intensity decreases.

Magnetic fields decrease.

Injection : γ = 110, 110, T = 8 s

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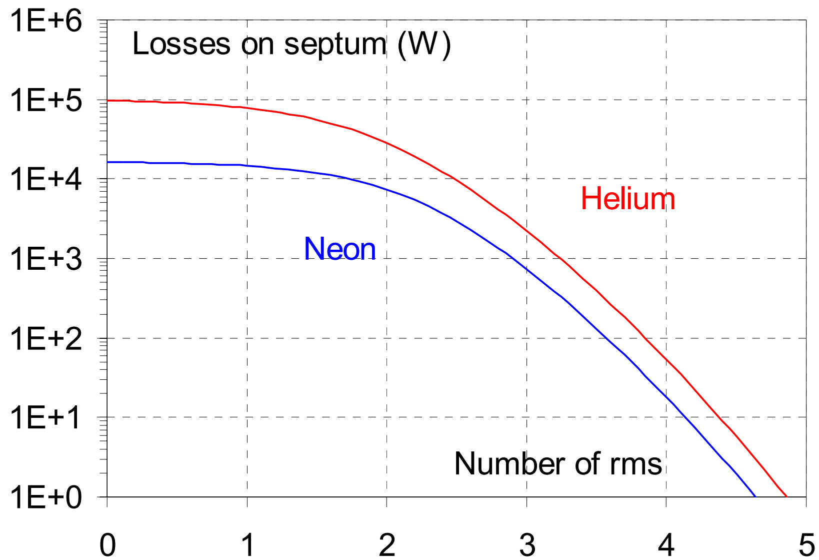
	$^{6}He^{2+}$	$^{18}Ne^{10+}$
γ	110	110
Injected intensity	0.9 10^{+13}	4.9 10^{+11}
ε_{rms} (mm.mrad)	0.212	0.423
Stored Intensity	1.4710+14	1.65 10^{+13}
Losses < 10 W	4.4 rms	4.2 rms
(Nb ν)/T	1.12 10^{+12}	6.12 10^{+10}



Injection apertures decrease.

Decay losses power increases by 1.1.

Stored beam intensity increases.

Magnetic fields increase.