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ANALYSIS OF THE IH-STRUCTURE FOR THE ACCELERATION OF MULTI CHARGE STATE BEAMS

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1) CEN/SACLAY

CONTENTS

1. PRINCIPLES AND DEFINITIONS CONCERNING THE IH STRUCTURE

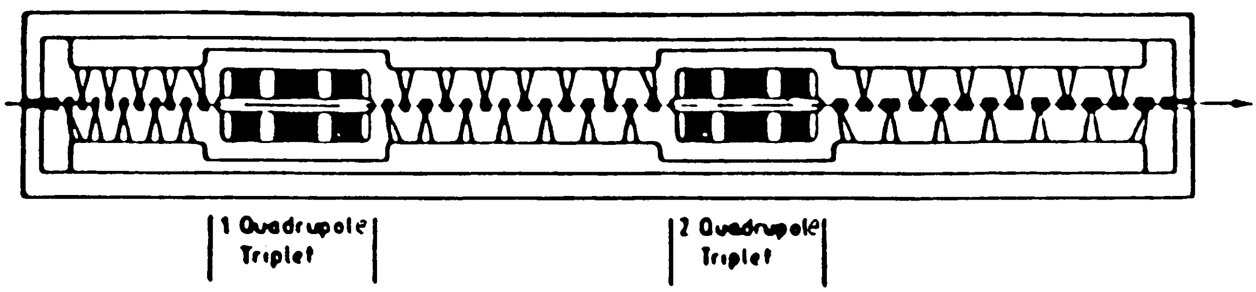
1.1 The structure as proposed by U.Ratzinger[1]

The input beam has the following charateristics :

Particle :	Pb^{25+}
Input energy :	300 keV/n
Emittance (longitudinal) :	95π keV.degr/n
Emittance (transverse) :	1.25π mm.mrad (normalized)

The characteristics of the structure are :

Working point (at entrance) :	290 keV/n
Final energy :	1.6 MeV/n
Frequency :	101 MHz
Length :	3.5 m
ϕ :	0.65 m
# gaps :	41
# quadrupoles :	6 (2 triplets)



1) GSI,DARMSTADT (FRG)

1.2 Definitions

1.2.1 Cell length

The length of a cell is defined as :

$$CL_i = gap_i /2 + drift + gap_{i+1} /2$$

1.2.2 Cell length at triplet

The cell length at the triplet is defined as :

$$CL_t = gap_i /2 + triplet + gap_{i+1} /2$$

1.2.3 Optimum phase ϕ_c for a gap

This phase gives the maximum possible energy gain to a particle in a gap.

1.2.4 Concentration ellipse

In the longitudinal phase space are defined :

$$D_{22}x^2 - 2D_{12}xy + D_{11}y^2 = 4\Delta$$

$$D_{11} = \frac{1}{n}\sum_{i=1}^{n} \delta W_i^2$$

$$D_{22} = \frac{1}{n}\sum_{i=1}^{n} \delta \phi_i^2$$

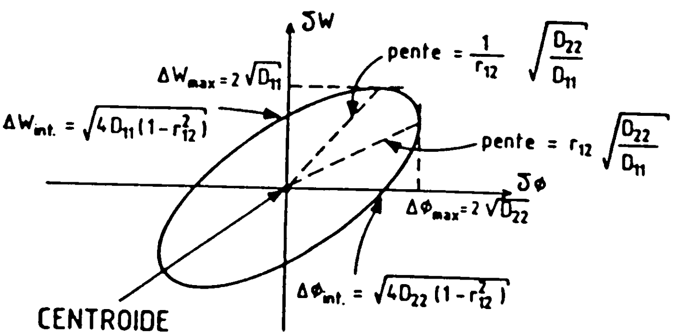
$$D_{12} = \frac{1}{n}\sum_{i=1}^{n} \delta W_i \delta \phi_i$$

$$\Delta = D_{11}D_{22} - D_{12}^2$$

$$r_{12} = \frac{D_{12}}{(D_{11}\ D_{22})^{1/2}}$$

surface of the concentration ellipse:

$$S = 4\pi\sqrt{\Delta}$$



2. ACCELERATION PRINCIPLE (FOR CHARGE STATE 25+)

Figure 1 shows the position of the beam relative to the working point of the structure.

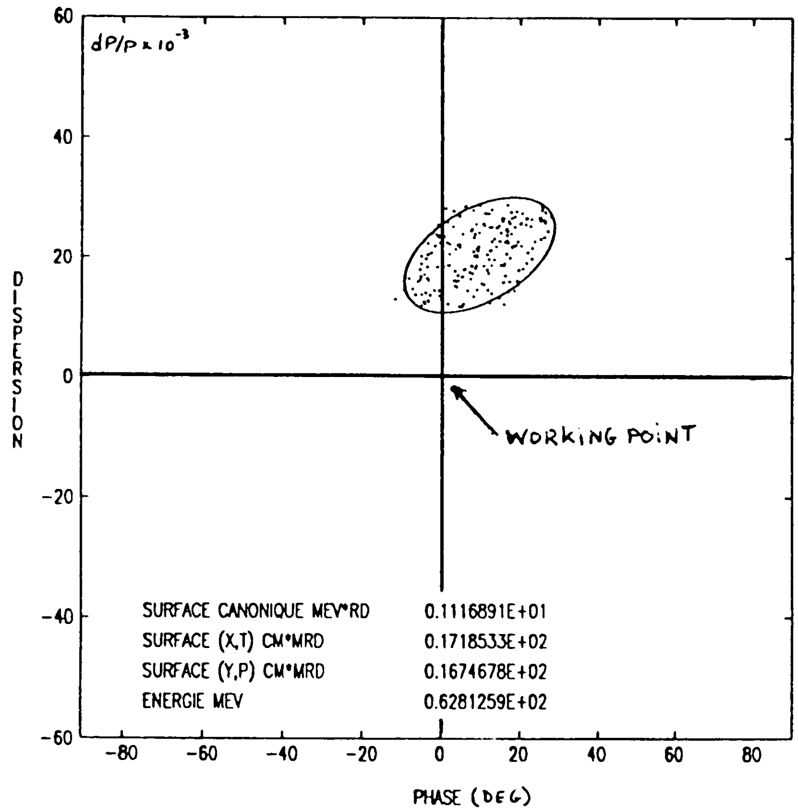


Figure 1: Input beam in (dP/P , dΦ) phase plane

Given a fictitious particle with a starting energy identical to the working point at the entrance of the structure , one takes the first 10 cell lengths (i.e. 11 gaps) such that this particle will enter each of these gaps with the phase ϕ_c .

The 11th cell comprises a triplet. Its length is adjusted in order to have the centre of gravity of the concentration ellipse at a phase angle of $\simeq \phi_c - 30°$ at the entrance of the 12th, 13th and 14th accelerating gap. The following cell length (i.e. comprising the 15th gap) shifts the phase angle back to $\simeq \phi_c$ (see figure 2). A similar adjustment is made with the cell length comprising the second triplet.

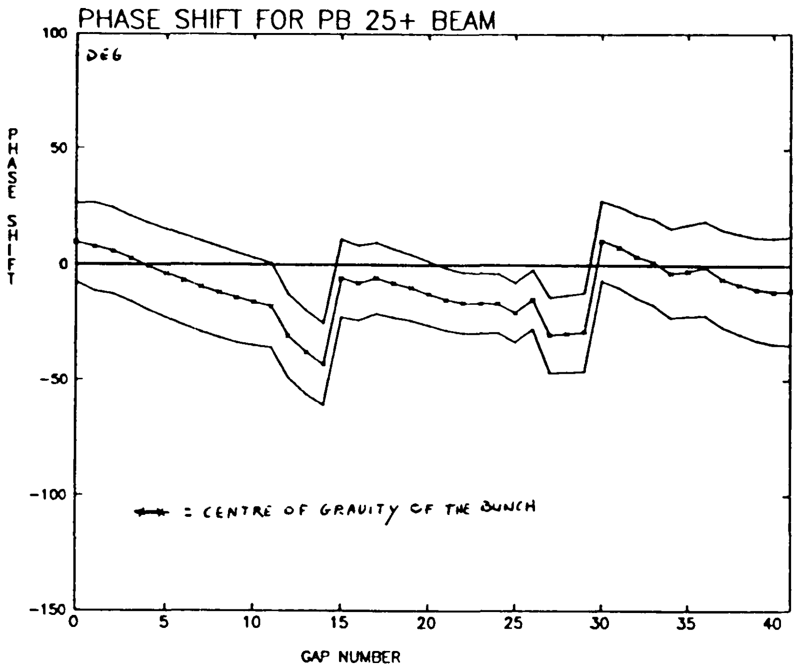


Figure 2: Phase shift of the concentration ellipse

3. BEAM SIMULATION

3.1 Simulation of a Pb^{25+} beam

Using a Monte-Carlo method a bunch of 200 particles is obtained. Table 1 shows the evolution of the canonical surface and the concentration of the bunch in the (dP/P , dΦ) phase plane as calculated by the programme.

Table 1

Position in the structure	Canonical surface (MeV.rad)	Concentration $(dP/P.deg)^{-1}$
Entrance	1.33	1.96
Triplet 1	2.34	1.92
Triplet 2	2.99	2.69
Exit	5.34	2.15

The canonical surface increased with a factor ≈ 4 , but the concentration of the bunch improved with 10 % . From this one can conclude that the beam at the exit is still well bunched even though the canonical surface has increased. Figure 3 shows the dispersion dP/P along the structure.

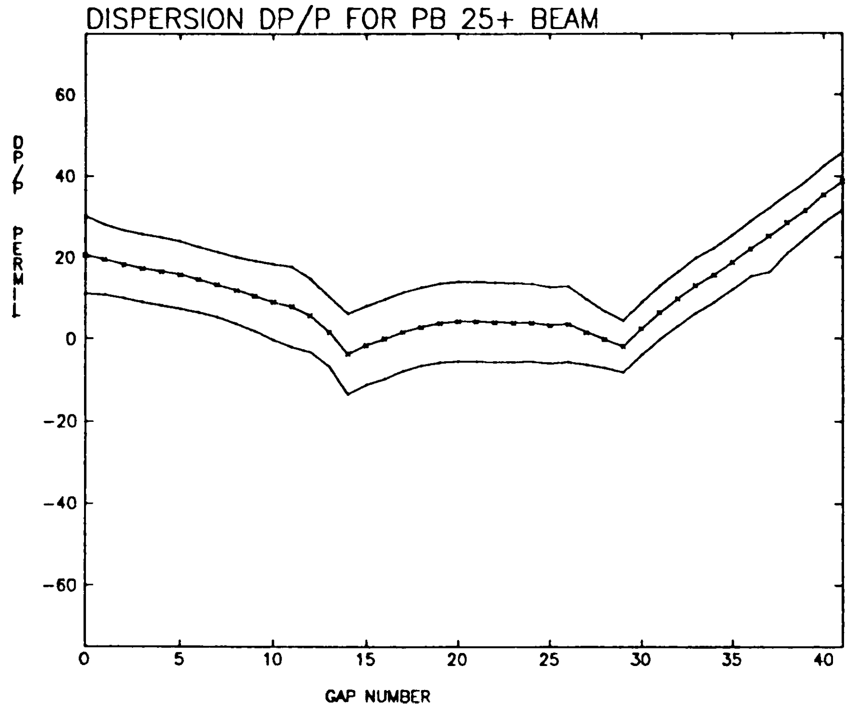


Figure 3

3.2 Simulation of a beam with several charge states

The structure given by U.Ratzinger is one optimized for Pb^{25+} . To make this structure work with different charge states we have found the following :

3.2.1 Adjustment concerning the longitudinal phase space

The cell length of the first triplet has to be adjusted such that the lowest charge state sees a phase of $\phi_c - 30^0$ at the entrance of the 12th gap.

The cell length of the second triplet has to be adjusted such that the highest charge state sees a phase of $\phi_c - 30^0$ at the entrance of the 27th gap.

3.2.2 Adjustment concerning the transverse phase space

The force of both triplets has to be optimized for the highest charge state.

3.3 Results of beam simulations with 3 charge states

The three charge states are 25+ (50%) , 26+ (25%) and 27+ (25%). Apart from having different charge states , the bunch simulated has got similar characteristics as the single charged bunch mentioned before. After having made the necessary adjustments (see section 3.2) the programme gave us the following results :

Table 2 shows the evolution of the canonical surface and the concentration of the bunch in the (dP/P , dΦ) phase plane as calculated by the programme. It also shows how many particles are retained if one would reject particles outside a phase window of ± 40 degr. around the centre of gravity of the bunch.

Table 2

Position in the structure	Canonical surface (MeV.rad)	Concentration $(dP/P.deg)^{-1}$	Particles kept
Entrance	1.11	1.95	200
Triplet 1	5.33	0.85	200
Triplet 2	4.90	1.63	198
Exit	8.61	1.31	190

Although the canonical surface has increased with a factor ≈ 7.7, the concentration of the particles in the bunch has only degraded by some 30% . Again one can conclude that the particles stay well bunched.

The dispersion in phase and in momentum of the bunch along the structure is shown in figures 4 and 5 respectively. Figure 6 shows the concentration ellipse at the exit of the structure.

Figure 7 shows the X-extension halved of the bunch. The Y-extension is not shown because the beam is more or less symmetrical along the structure (except for in the triplets). The extension in the triplets are not shown in this figure.

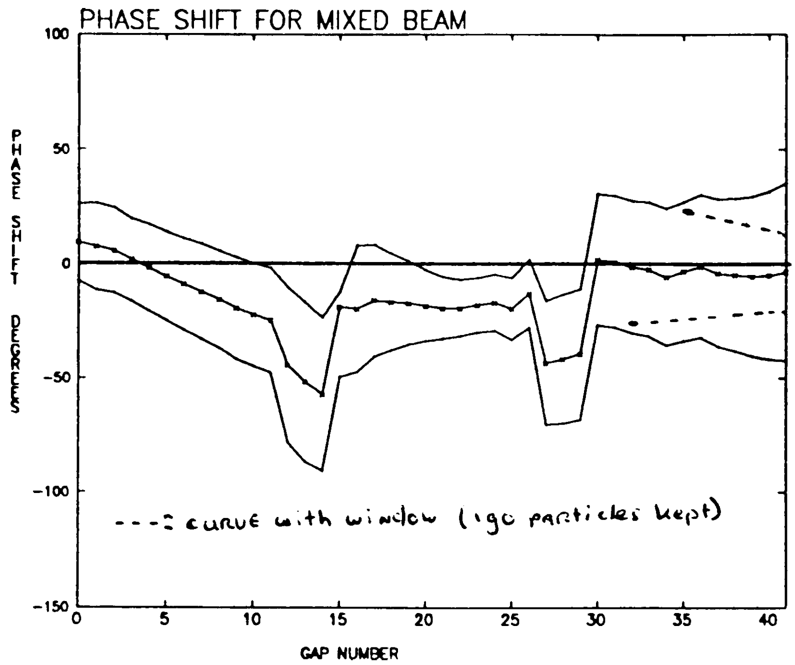


Figure 4

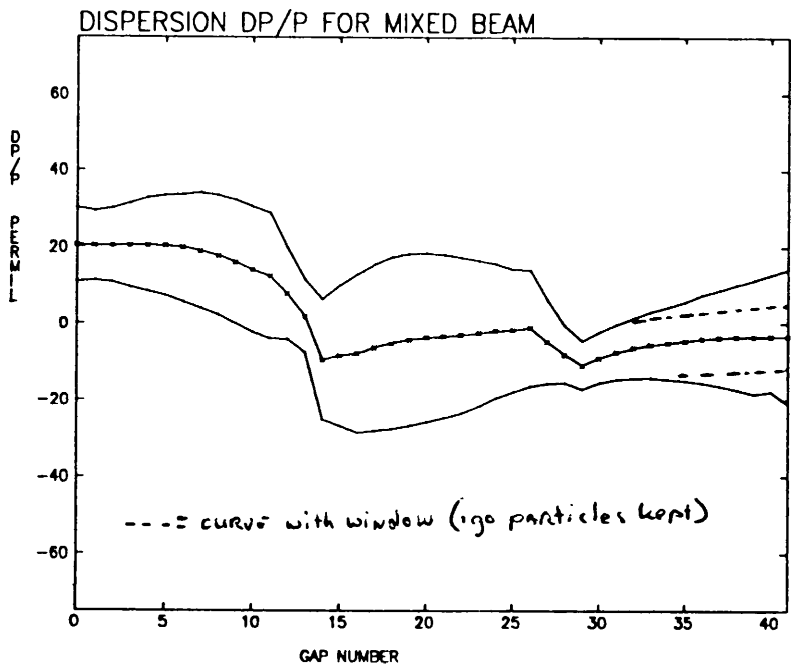


Figure 5

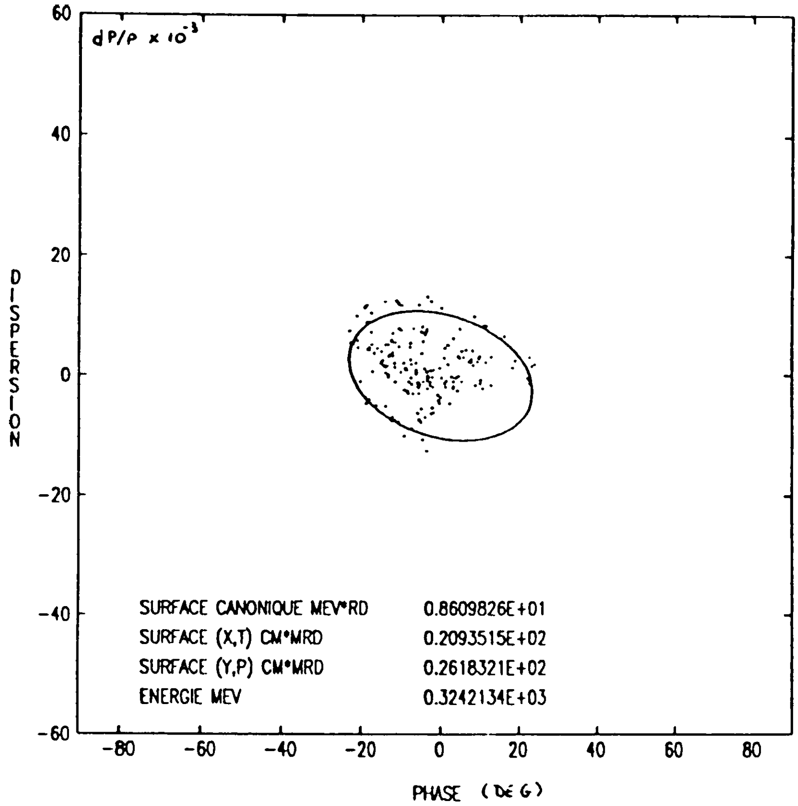


Figure 6: Concentration ellipse in the (dP/P , dΦ) phase plane

The transverse emittance growth due to the coupling between the longitudinal and transverse phase planes is of the order of 35% . This means that there is a weak coupling between the these phase planes.

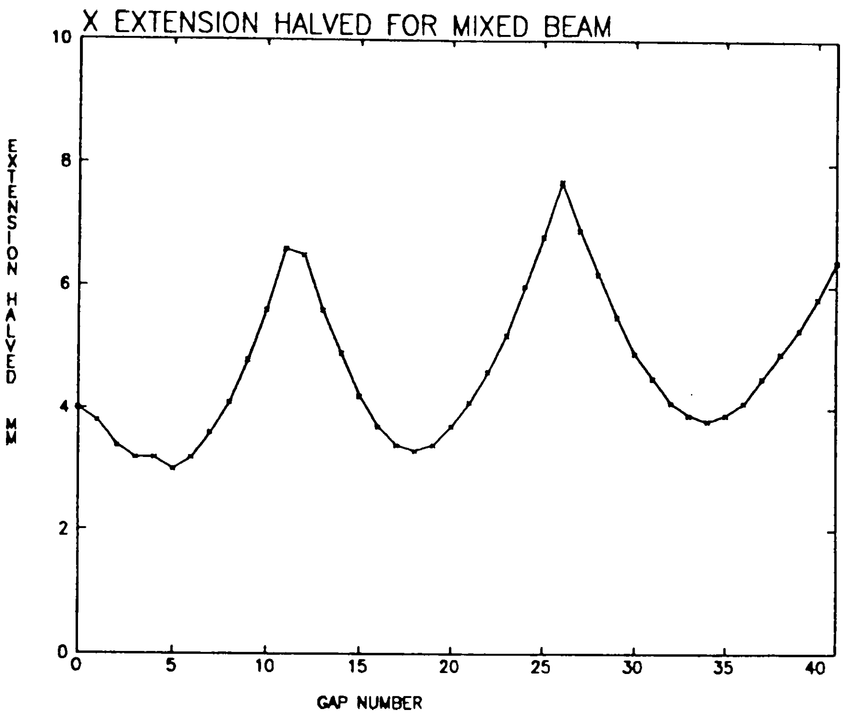


Figure 7

4. CONCLUSIONS

The results for charge state 25+ confirm those of U.Ratzinger. Higher charge states can also be accelerated by this structure. If one would like to accelerate a lower charge state, one must optimize the structure for this charge state.

A weak point of this machine might be the mechanical proximity of the gaps around the triplets. The cell lengths which include the triplets could be increased. However , this can only be done by a fixed amount and would cause an increase in phase dispersion of the bunch.

The acceptance of the structure with several charge states still needs further investigation.