

# Electron Trappings In RHIC From A Debunched Proton Beam

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Electron Trappings  
in RHIC  
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# Ion Trapping / Electron Trapping

Proton Beam Completely Debundled

Gas Composition as derived in RHIC-PG-51

Densities:

Molecules	<u>Z</u>	<u>A</u>	<u>warm</u>	<u>cold</u>
			25%	75%
H <sub>2</sub>	2	<del>2</del>	$2.1 \times 10^7 \text{ cm}^{-3}$	$2.3 \times 10^7 \text{ cm}^{-3}$
He	2	4	-	$2.3 \times 10^7 \text{ cm}^{-3}$
CO	14	28	$2.1 \times 10^7 \text{ cm}^{-3}$	-

Ionization cross-section  $\sigma_i$

$$\sigma_i = 1.8 \times 10^{-19} Z_i^2 \text{ cm}^2$$

Ionization Rate for the  $i$ th specie per proton

$$\frac{dn_i}{dt} = c \sigma_i n_i \quad (\beta = 1)$$

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ions

ionization rate

$H_2^+$	0.243 $s^{-1}$ / proton
$He^+$	0.186
$CO^+$	0.397

electrons

0.826  $s^{-1}$  / proton

The ions (positively charged) are rejected by the potential barrier of the proton beam -

The electrons could be trapped

Average energy of the electrons at production

$$\frac{1}{40} \text{ eV}$$

which corresponds to a velocity

$$v_e \approx 10^7 \text{ cm/sec}$$

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To "clear" the electrons one can create one or several gaps in the beam - these gaps though are to be no less than ~~300 nsec~~ nsec if the electrons have to reach a wall 3 cm away with the velocity given above -

Assume the probe beam has a uniform density distribution with elliptical cross-section of semi-axis  $\sigma_x, \sigma_z$  -

$$I, \text{ beam current} = Ne f_{\text{rev}} = 57 \times 10^{12} \times 1.6 \times 10^{-19} \times 78.2 \times 10^3 \\ = 0.71 \text{ Amperes}$$

Electric Field produced by the beam

$$E_{x,z} = \frac{(120 \pi \text{hm}) I_{\text{avg}}}{\sigma_x + \sigma_z} \frac{(x,z)}{\sigma_{x,z}} \quad \text{Volt/cm}$$

The voltage distribution is

$$V = \frac{43 \text{ Volt}}{\sigma_x + \sigma_z} \left( \frac{x^2}{\sigma_x} + \frac{z^2}{\sigma_z} \right)$$

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The potential barrier depth is calculated by setting  $x = \sigma_x$  and  $z = \sigma_z$ , and that is

$$\Delta V = 43 \text{ Volts}$$

Oscillation Frequency of the Trapped Electrons

$$\omega_{x,z}^2 = \frac{(120 \text{ ohm}) I e c^2}{m_e c^2 \sigma_{x,z} (\sigma_x + \sigma_z)}$$

where  $m_e c^2 = 0.5 \text{ MeV}$  and  $\sigma_{x,z}$  is in meter.

$$\langle \sigma_{x,z} (\sigma_x + \sigma_z) \rangle \approx 20^2, \quad \sigma \approx 4 \text{ mm}$$

As a result

$$\omega_{x,z} \approx 700 \text{ MHz}$$

### Betatron Tune Depression

$$\Delta \nu_{x,z} = \frac{e}{4\pi m \beta^2 \gamma c^2} \oint ds \beta_{x,z}(s) \frac{\partial E_{x,z}^{electron}(s)}{\partial x,z}$$

$E^{electron}$  is the electric field generated by the electrons in the background

$$\frac{\partial E_{x,z}^{electron}}{\partial x,z} = \eta \frac{(120 \text{ statV}) I}{\sigma_{x,z} (\sigma_x + \sigma_z)} = \frac{86 \eta}{\sigma_{x,z} (\sigma_x + \sigma_z)}$$

$\eta$ , charge neutralization coefficient caused by the electrons

We have

$$\Delta \nu_{x,z} = \frac{120 e I}{4\pi m \beta^2 \gamma c^2} \oint \frac{\eta(s) \beta_{x,z}(s)}{\sigma_{x,z} (\sigma_x + \sigma_z)} ds$$

$$= \frac{120 I e}{8\pi m c^2 \beta^2 \gamma} \bar{\eta} \int \frac{\beta(s)}{\sigma^2(s)} ds$$

or



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$$\Delta v = \frac{120 I_e}{4\pi mc^2 \beta^2 \gamma} \frac{\bar{\eta}}{\varepsilon} 2\pi R$$

with

$$\varepsilon = \frac{20^2}{\beta} = 0.05 \text{ @ mm-mrad}$$

$$R = 610.2 \text{ m}$$

$$\gamma = 100$$

$$mc^2 = 0.9383 \text{ GeV}$$

We get

$$\Delta v = 4.64 \bar{\eta}$$

It is safe to keep  
therefore we requires

$$\Delta v \leq 0.0025$$

$$\bar{\eta} \leq 0.0005$$

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## Removal of the Electrons

Electrons have a longitudinal drift  
After a time  $t$  they have travelled a  
distance

$$l = v_e t$$

where  $v_e \approx 1 \times 10^7$  cm/sec

We assume that after this distance they are  
removed. We take

$$t = \eta \tau_e$$

$\tau_e = 1.21$  sec is the production time per  
proton

With  $\eta = 0.0005$

$$l = \underline{\underline{6,050 \text{ m}}}$$

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## Drift in a Dipole ( $B_z$ )

This occurs at velocity  $v_D$

$$v_D = \frac{E_x}{B_z} \frac{\omega_L^2}{\omega_L^2 + \omega_x^2} = \alpha \frac{\omega_L \omega_x^2}{\omega_L^2 + \omega_x^2}$$

$$\omega_L = \frac{e B_z}{m_e} \quad , \quad 2\pi \times \text{Larmor frequency}$$

$$= 5.6 \times 10^{11} \text{ Hz}$$

Therefore  $\omega_L \gg \omega_x$ , and

$$v_D = \alpha \frac{\omega_x^2}{\omega_L} = 3.5 \times 10^5 \text{ cm/sec}$$

## Drift in a Quadrupole with gradient $B'$

$$v_Q = x \frac{\omega_Q \omega_x^2}{\omega_Q^2 + \omega_x^2}$$

where

$$\omega_Q^2 = \frac{1}{2} \left( \frac{eB'}{mc} \right)^2 \sigma^2$$

with  $B' = 550 \text{ kG/m}$  and  $\sigma = 4 \text{ mm}$

$$\omega_Q = 2.9 \times 10^{10} \text{ Hz}$$

Therefore  $\omega_Q \gg \omega_x$  and

$$v_Q = \sigma \frac{\omega_x^2}{\omega_Q} = 6.8 \times 10^6 \text{ cm/sec}$$

In ~~the~~ conclusion the drift velocity is quite smaller in the dipoles - The calculations of page 7 to clear the electrons have to be repeated by taking

$$v_e = v_D \approx 3.5 \times 10^5 \text{ cm/sec}$$

We obtain then

$$l = 212 \text{ m}$$

This corresponds to the length traversed in the dipoles: it is about 10 dipoles, that is 5 cells.

Solution: install pairs of clearing electrodes in the warm sections at the beginning and at the end of each long straight section -

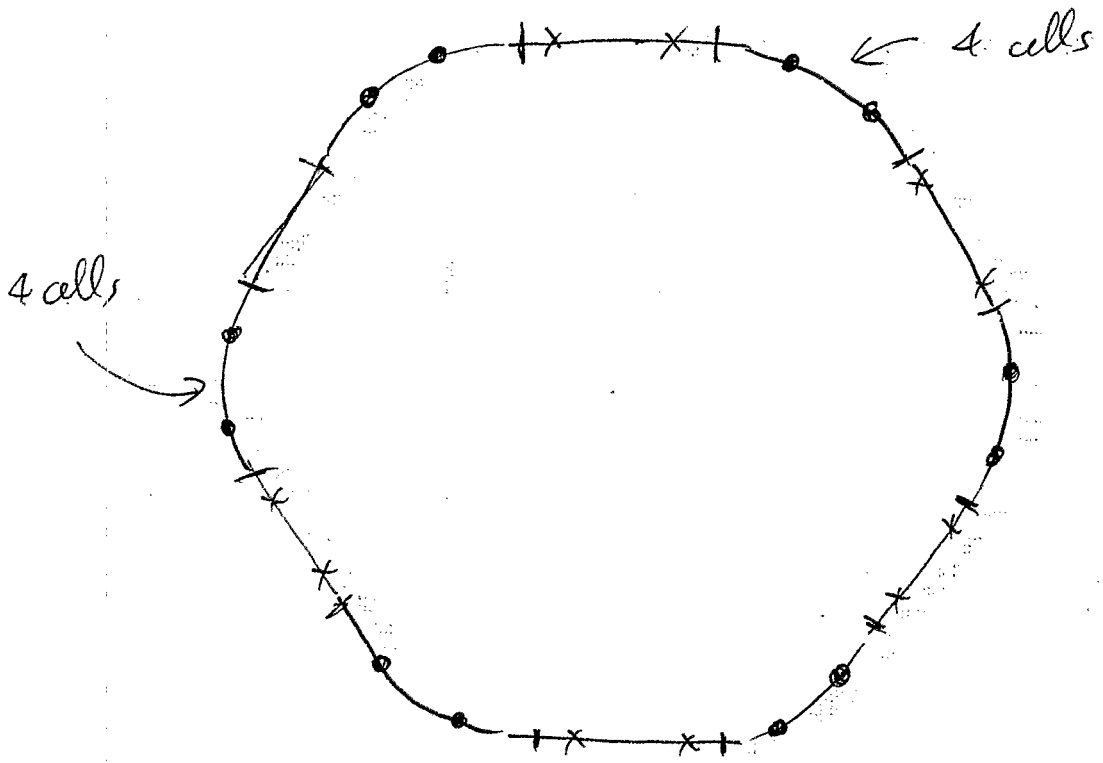
Install also pairs of clearing electrodes in the arcs, equally spaced, 4 full cells apart - So there are in total 24 pairs, 12 in cold sections and 12 in warm sections (see figure next page) -

Take a gap separation  $d$  flush with the vacuum chamber and ~~to~~ a length  $L = d$  -

To sweep the electrons away the following voltage is required

$$V_c = m_e c^2 \left( \frac{dV_e}{cL} \right)^2$$

which is quite negligible compared to  $\Delta V = 43 \text{ Volt}$   
It is quite safe to take  $V_c \approx 100 \text{ Volt}$



- Cleaning Electrods in cold section
- x " " in warm section