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The Effects of Antiproton Beam Ionization: First Glance

Krishnaswamy Gounder, John Marriner, Shekhar Mishra, and Chandra Bhatt

Fermi National Accelerator Laboratory
P. O. Box 500, Batavia, IL 60510.
(gounder@fnal.gov)

Abstract

In this report, we briefly describe the effects of anitproton beam ionizing the residual gas atoms in RR vacuum. We compute the effect of the ion distribution on beam lifetime and tunes.

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The following are a typical residual gases in our RR beam pipe measured using RGA.

Gas	**Avg. Pres.** [Torr]	**Gas Density** [M^{-3}]
H_2	1.0E-09	3.54E+13
H_2O	1.8E-10	6.37E+12
CO/N_2	0.7E-10	2.48E+12
Ar	1.0E-10	3.54E+12
CH_4	3.4E-11	1.20E+12
CO_2	2.6E-11	9.20E+11
$Unknwon$	4.5E-11	1.59E+12
Total	1.46E-09	5.15E+13

Now let us assume that about 1×10^{12} antiprotons circulating in RR with a gaussian beam shape of $\sigma = 0.005$m. Now assuming the ionization rate is complete that each antiproton traps an ion. Then there will be 1×10^{12} ions trapped along the beam with a similar gaussian shape. Mostly we expect lighter gases such as H_2 to dominate the ions. But here we assume that these ions also have a similar composition as the above normal vacuum. Also using the convention that all the beam resides in the $\pm 3\sigma$ region, we expect all the ions to be contained in a tube of radius 3σ along the ring (3320 meters in length). Therefore the ion density for each gas can

Ions	**Gas Fraction**	**Ion Density** $[M^{-3}]$	**Par. Pres.** [Torr]
H_2	0.69	2.94E+11	8.29E-12
H_2O	0.12	0.51E+11	1.44E-12
CO/N_2	0.05	0.21E+11	0.58E-12
Ar	0.07	0.30E+11	0.85E-12
CH_4	0.02	0.09E+11	0.25E-12
CO_2	0.02	0.09E+11	0.25E-12
$Unknwon$	0.03	0.04E+11	0.11E-12
Total	1.00	4.26E+11	1.20E-11

be written as in the table below.

Comparing two tables above we see that the partial pressures are roughly two orders of magnitude smaller for ions compared to that of normal gases. At this level we can assume that this additional density the particles see along with normal gas densities. On the otherhand, if we assume that we can stack an order of magnitude higher, then we may not be able to treat the ions densities as independent of the normal gas densities! But in this case, we assume that they are independent, we can compute the lifetimes and compare the relevant parameters.

1. The Direct Effect on Beam Lifetime

- The RR parameters listed above were used - note acceptance is 40π-mm-mr.
- Note the gases listed above were directly used for the life time computations
- The CO and N_2 samples were taken as 50% each.
- Life Time Summary:

Physical Process	Normal Case [hours]	Full Ionization [hours]
Single Coloumb	1.35×10^2	1.34×10^2
Inelastic Scatt.	2.73×10^2	2.71×10^2
Mult. Coloumb	1.68×10^1	1.67×10^1
Nuclear Scatt.	6.63×10^2	6.58×10^2
Total Life Time	1.38×10^1	1.37×10^1

- The emittance growth (95%) predicted are 15.55 π-mm-mr/hour for the normal case and 15.68 π-mm-mr/hour with full ionization.
- It looks like the effect of ionization is a very minor on lifetime for a beam of 1×10^{12} particles, $< 1\%$! For a beam of 1×10^{13} antiprotons, this could become noticeable - around 10%!

- In the computations above, we have assumed uniform ion density given by

  $$n_{ions} = N/(L\pi 9\sigma^2) = \lambda/(\pi(3\sigma)^2)$$

  where N is the total number of ions (1E+12), L is the length of Recycler Ring (3320 m), σ is beam distribution sigma, λ is the longitudinal ion density. We can improve the above treatment by averaging over the gaussian shapes of the beam and the ions. The normalized beam distribution in radial coordinates is given by:

  $$G(r,\phi) = \frac{1}{\pi\sigma^2} e^{-r^2/\sigma^2}$$

  such that,

  $$\int drr \int d\phi G(r,\phi) = 1.$$

  Since the ions have the same distribution, the average ion density can be cast:

  $$< n_{ions} >= \lambda \int drr \int d\phi G(r,\phi)_{beam} G(r,\phi)_{ions} = \lambda/2.$$

  Therefore, above treatment overestimates the effect of ions by a factor of 2!

2. The Effect on Tunes

We noticed sometime ago, when we removed the longitudinal gap in the pbar beam, the lifetime got bad. But the above treatment shows it is not due to the usual beam-ion scattering phenomena. But there is two other effects we should look into: (a) The tune shift induced by the presence of ions is rather large given by:

$$\Delta\nu = \frac{1}{4\pi}\int ds\beta(s)\Delta K$$

with:

$$\Delta K = \frac{r_0\lambda}{\gamma\beta^2\sigma^2}$$

where r_0 is the classical proton radius, ΔK is the quadrupole gradient error contribution from the field of trapped ion density. For simplicity, we assume an average beta of 40 meters around the ring, and for a beam of 1E+12 pbars with full ionization,

$$\Delta\nu = \frac{N\beta_{avg}r_0}{\gamma\beta^2 4\pi\sigma^2} \approx 0.021$$

As we know the beam lifetime is very sensitive to tune changes, this may be important. (b) There could also be coherent instabilities associated with couplings of the ions and the beam when they both experience transverse oscillations during circulation. More work is needed here!

3. Measurements

We carried out measurements on 09/09/2002 with $\approx 2 \times 10^{11}$ antiprotons in the Recycler Ring. The longitudinal gap usually left in the beam was 64 RF buckets. We measured the tunes and beam lifetime using Schottky detectors. After turning off the gap, we remeasured the lifetime and tunes. Then we used the Trambone to reset the tunes to its original values and redid the tune/lifetime measurements. The measurements are summarized in the table below.

Scenario	Lifetime [hours]	Tunes [Fractional]	Beam Intensity
Longitudinal beam gap on - 68 RF bkts	135	(0.4166, 0.4193)	2.00E+11
No longitudinal beam gap	86	(0.4180, 0.4215)	1.91E+11
No longitudinal beam gap but tunes reset using trambone	120	(0.4166, 0.4193)	1.90E+11