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Comment On Reactions Occuring Internal To A Bunch In RHIC

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RHIC-PG-54

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Comment on Reactions Occuring internal To a Bunch

Given the RF bucket size needed to operate near transition, which corresponds to a $\Delta p/p$ of $4.96 = 2.5\delta\,(10^{-3})$ at 30 GeV, according to G. Parzen, it is useful to consider losses due to nuclear reactions occuring inside a bunch.

The energy spread inside a bunch at kinetic energy $E_0 \cdot \gamma$ where $E_0 = 0.9315$ GeV/A, is $\Delta E_L = \delta\, E_0\, \gamma$ in the lab frame, or

$$\Delta E_B = \frac{\Delta E_L}{\gamma} = \delta E_0 \quad \text{in the } \underline{\text{bunch}} \text{ frame of reference.}$$

Then with $\delta = 2 \cdot 10^{-3}$ at 30 GeV, this corresponds to

$\Delta E_B = 1.86$ MeV/A in a bunch; this is an rms number so there are particles with relative energies twice this (or more). This is in excess of the Coulomb barrier to the reaction even for the heaviest nuclei; if these nuclei react they are lost from the beam. Above the barrier the cross section rapidly <u>becomes</u> geometric, so we use σ_G to be ~~[illegible]~~ conservative.

Note this problem does not occur for a p-p collider, as even though such protons are above the reaction barrier, no reaction channels are open with any significant cross section (though $p + p \rightarrow p + n + e^+ + \nu_e$ can go, but with modest cross section). In the nuclear case, lots of channels open, especially those leading to n or p emission, causing an A/z shift and consequent beam loss.

We need the particle density in a bunch in the rest frame of a bunch and the relative velocity of a particle in the bunch to the bunch center of mass.

For gold, we have 10^9 ions in a bunch of $\sigma_{length} = 50$ cm, $\sigma_x = \sigma_y = 1$ mm. Taking the peak density for gaussian distributions gives

$$n_{Lab} = \frac{10^9}{10\text{cm} \cdot (0.1\text{ cm})^2 \; (2\pi)^{3/2}} = \frac{6.35 \times 10^8}{\text{cm}^3}$$

In the bunch frame, transverse dimensions are the same but the length is greater by γ, so at 30 GeV/A ($\gamma = 33.206$) we have

$$n_{bunch} = 1.91 \times 10^7 \text{ cm}^{-3}$$

The velocity of an ion relative to the bunch does not exceed $\beta = 0.1$ ($\Rightarrow$ 4.69 MeV/A), so we get a reaction rate in the bunch frame of reference

$$\frac{dN}{dt} = N \cdot n \cdot \sigma \cdot \beta c$$

N = # particles in bunch, σ = cross section = 6.65 barns (σ_{geom} Au+Au)

This gives a loss rate in the bunch frame

$$\tau^{-1}_{Bunch} = n \sigma \beta c = 3.81 \times 10^{-7} \text{ sec}^{-1}$$

In the lab frame, time dilates so rates decrease, so $\tau^{-1}_{lab} = 1.15 \; 10^{-8} \text{ sec}^{-1}$ or ~ 3 years to lose the bunch.

Thus, we can safely neglect nuclear reaction processes occuring within the bunch.

Our caution comes from the concern that atomic processes could occur internal to a bunch could occur with $\sigma \sim 10^4$ barns, leading to loss times of the order of 16 hours for a bunch, or 8 hours for luminosity.

J. Weneser tells us there are no known processes that do this. The loss process suggested by L. Schroeder of LBL in the technical review (Willis panel) of 4/30 - 5/1/84, apparently only causes trouble at very large relative energies, several GeV/A, which makes it a beam-beam loss process.

Weneser says this process, of e^+e^- pair creation, in a collision, in the K shell of one Au ion, with ejection of the e^+ and atomic capture of the e^- (which causes loss of the ion from the beam) has a cross section of ~ 150 barns for U + U at 100 x 100 GeV/A. This is of the order of the Coulomb dissociation process noted earlier by Kahana and Barton. Weneser further says the cross section scales as $\sim Z^7$, meaning for Au + Au it should be 66 % smaller and for I + I it should be less than the geometric nuclear cross section.

Note added: The above estimate was very conservative as we used the central bunch density, maximum relative energy for all ions in the bunch, etc. A "hard" calculation would give a smaller loss rate, but it can already be neglected.