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An additional gold ion energy in RHIC for the FY2021 run

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Parameters for an additional gold ion energy in RHIC between 7.3 and 9.8 GeV per nucleon are considered here. The critical factor driving the choice of an energy in this range is the need to be sufficiently far from transition at AGS extraction. The ion energy favored by STAR, 8.65 GeV per nucleon, is found to be a suitable choice. The parameters for this energy are given in Section 7 of the following.

Details on how the following parameters are calculated can be found in references [1] and [2].

1 Ion mass

The mass-energy equivalent of the Au79+ ion is

$$mc^2 = 183.433343902 \ \text{GeV}. \tag{1}$$

Here, as discussed in Sections 1 and 18 of [3], the binding energy of the electrons removed from the gold atom is included in the mass calculation. For lighter atoms this energy is negligible and is generally not included.

2 Revolution frequencies and radii

We use f to denote the revolution frequency in AGS or RHIC. The revolution frequency in AGS at extraction is held at 19/4 times the set revolution frequency in RHIC at injection. If the gamma of the ion at RHIC injection is the same as the gamma at AGS extraction, the closed orbit radius in AGS then will be 4/19 times the radius in RHIC. The nominal circumference of the closed orbit in RHIC is

$$C_r = 3833.845181 \text{ m.} \tag{2}$$

3 AGS phase slip factor eta

For the energies considered here, the phase slip factor

$$\eta = \frac{1}{\gamma_t^2} - \frac{1}{\gamma^2} \tag{3}$$

is close to zero in AGS at extraction. We take the AGS γ_t to be

$$\gamma_t = 8.5. \tag{4}$$

For computation of η in AGS we assume that the gold ion has the same gamma at AGS extraction that it has at RHIC injection. This neglects any change in gamma upon traversal of the ATR stripping foil (where the two electrons attached to the ion are stripped away).

4 Parameters at 7.3 GeV per nucleon

$$E/A = 7.30950517185 \;\text{ GeV per nucleon} \tag{5}$$

$$B\rho = 60.3050632557 \;\text{ Tm} \tag{6}$$

$$\gamma = 7.85011322489, \quad \underline{\text{AGS } \eta = -0.002387} \tag{7}$$

$$hf = 9.30710782858 \;\text{ MHz}, \quad h = 120 \tag{8}$$

$$\text{AGS } hf = 4.42087621857 \;\text{ MHz}, \quad h = 12 \tag{9}$$

5 Parameters at 8.55 GeV per nucleon

$$E/A = 8.55 \;\text{ GeV per nucleon} \tag{10}$$

$$B\rho = 70.6958211777 \;\text{ Tm} \tag{11}$$

$$\gamma = 9.18235454998, \quad \underline{\text{AGS } \eta = +0.001981} \tag{12}$$

$$hf = 9.32774306046 \;\text{ MHz}, \quad h = 120 \tag{13}$$

$$3hf = 27.98322918138 \;\text{ MHz} \tag{14}$$

$$\text{AGS } hf = 4.43067795372 \;\text{ MHz}, \quad h = 12 \tag{15}$$

6 Parameters at 8.60 GeV per nucleon

$$E/A = 8.60 \text{ GeV per nucleon} \tag{16}$$

$$B\rho = 71.1141945996 \text{ Tm} \tag{17}$$

$$\gamma = 9.23605252981, \quad \underline{\text{AGS } \eta = +0.002118} \tag{18}$$

$$hf = 9.32839205671 \text{ MHz}, \quad h = 120 \tag{19}$$

$$3hf = 27.98517617014 \text{ MHz} \tag{20}$$

$$\text{AGS } hf = 4.43098622694 \text{ MHz}, \quad h = 12 \tag{21}$$

7 Parameters at 8.65 GeV per nucleon

$$E/A = 8.65 \text{ GeV per nucleon} \tag{22}$$

$$B\rho = 71.5325391690 \text{ Tm} \tag{23}$$

$$\gamma = 9.28975050963, \quad \underline{\text{AGS } \eta = +0.002253} \tag{24}$$

$$hf = 9.32902978727 \text{ MHz}, \quad h = 120 \tag{25}$$

$$3hf = 27.98708936180 \text{ MHz} \tag{26}$$

$$\text{AGS } hf = 4.43128914895 \text{ MHz}, \quad h = 12 \tag{27}$$

8 Parameters at 8.70 GeV per nucleon

$$E/A = 8.70 \text{ GeV per nucleon} \tag{28}$$

$$B\rho = 71.9508553892 \text{ Tm} \tag{29}$$

$$\gamma = 9.34344848945, \quad \underline{\text{AGS } \eta = +0.002386} \tag{30}$$

$$hf = 9.32965651162 \text{ MHz}, \quad h = 120 \tag{31}$$

$$3hf = 27.98896953485 \text{ MHz} \tag{32}$$

$$\text{AGS } hf = 4.43158684302 \text{ MHz}, \quad h = 12 \tag{33}$$

9 Parameters at 8.75 GeV per nucleon

$$E/A = 8.75 \text{ GeV per nucleon} \tag{34}$$

$$B\rho = 72.3691437517 \text{ Tm} \tag{35}$$

$$\gamma = 9.39714646928, \quad \underline{\text{AGS } \eta = +0.002517} \tag{36}$$

$$hf = 9.33027248183 \text{ MHz}, \quad h = 120 \tag{37}$$

$$3hf = 27.99081744548 \text{ MHz} \tag{38}$$

$$\text{AGS } hf = 4.43187942887 \text{ MHz}, \quad h = 12 \tag{39}$$

10 Heating in the AGS PSF and dump

For calculation of heating in the AGS tungsten plunging stripping foil (PSF), we need the kinetic energy

$$W_p = m_p c^2(\gamma - 1) \tag{40}$$

of a proton with the same γ as the gold ion. For energies $E/A = 8.55$, 8.60, 8.65, 8.70, and 8.75 GeV per nucleon, we have

$$W_p = 7.6773,\ 7.7277,\ 7.7780,\ 7.8284,\ 7.8788 \text{ GeV}. \tag{41}$$

The corresponding rates at which the proton loses energy as it passes through tungsten are

$$-\frac{dE_p}{dx} = 1.256,\ 1.257,\ 1.258,\ 1.259,\ 1.260 \text{ MeV cm}^2/\text{g}. \tag{42}$$

The rate at which the gold ion loses energy as it passes through tungsten is then

$$-\frac{dE}{dx} = -Q^2 \frac{dE_p}{dx} \tag{43}$$

where

$$Q = 79. \tag{44}$$

Taking the maximum rate

$$-\frac{dE_p}{dx} = 1.260 \text{ MeV cm}^2/\text{g} \tag{45}$$

we get

$$-\frac{dE}{dx} = 7.864 \ \text{GeV}\,\text{cm}^2/\text{g}. \tag{46}$$

Carrying out the foil heating and radiative cooling analysis as in [1], with

$$N = 8.0 \times 10^9 \text{ ions}, \quad A = 0.023 \text{ cm}^2, \quad \mathcal{T} = 3.6 \text{ s}, \quad \tau = 1.35 \text{ ms} \tag{47}$$

then gives maximum temperature

$$T_H = 3774 \text{ K}. \tag{48}$$

This is 79 K above the melting point (3695 K) of tungsten. If the supercycle period $\mathcal{T}$ is increased to 5.6 s, then the maximum temperature is reduced to

$$T_H = 3708 \text{ K}. \tag{49}$$

An analysis of the energy deposition and heating in the AGS beam dump is given in Sections 32 and 33 of reference [1].

As per reference [4], the maximum number of gold ions allowed per AGS cycle at any of the energies considered in this note is $\underline{8.0 \times 10^9}$.

References

[1] C.J. Gardner, "FY20-21 parameters for Gold ions in Booster, AGS, and RHIC," C-A/AP/Note 639, February 2021.

[2] C.J. Gardner, "FY2016 Parameters for gold ions in Booster, AGS, and RHIC," C-A/AP/Note 574, October 2016.

[3] C.J. Gardner, "Notes on calculating various parameters of ions circulating in Booster and destined for NSRL," C-A/AP/Note 621, June 2019, Sections 1 and 18.

[4] C.J. Gardner, "A short note on high-intensity gold in AGS," C-A/AP/Note 640, February 2021.