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Vertex distribution with 9 MHz cavities and comparison of 9 MHz versus 28 MHz cavities for 7.3 GeV operation

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Introduction

This note is to calculate the vertex distribution with 9 MHz cavities at low energies (3.85, 4.55 and 5.75 GeV/n) in RHIC, and explore the pros and cons of using 9 MHz cavities, instead of the original planned 28 MHz cavities, for operation at 7.3 GeV.

With assumption of Gaussian longitudinal profile, the bunch density distribution can be expressed as,

$$f(z) = {}^{N}\!/_{\sqrt{2\pi}\sigma} \exp(-z^2/2\sigma^2) \quad (1)$$

Here N is the number of particles in a bunch, σ is rms bunch length. The collision rate is a function of longitudinal coordinate and time,

$$R(z,t) = f(z-vt) * f(z+vt) = {}^{N^2}\!/_{2\pi\sigma^2} \exp(-(vt)^2/\sigma^2)\exp(-z^2/\sigma^2) \quad (2)$$

The integration over time is,

$$\mathcal{R}(z) = {}^{N^2}\!/_{2\sqrt{2\pi}\sigma_n v} \exp(-z^2/2\sigma_n^2) \quad (3)$$

Here $\sigma_n = \sigma/\sqrt{2}$.

The integration over longitudinal coordinate is,

$$\mathcal{R}(t) = {}^{N^2}\!/_{2\sqrt{2\pi}\sigma_n} \exp(-(vt)^2/2\sigma_n^2) \quad (4)$$

Note in (3) and (4), z and vt are interchangeable.

Profile and vertex distributions with 9 MHz cavity

Since bunch (full) length is similar (between 50 to 55 ns) [1] for beam energies 3.85, 4.55 and 5.75 GeV/n with 9 MHz cavity, the following calculations assume 50 ns full bunch length with 9 MHz cavities for all these energies. The normalized bunch profile with respect to time is shown in Fig. 1.

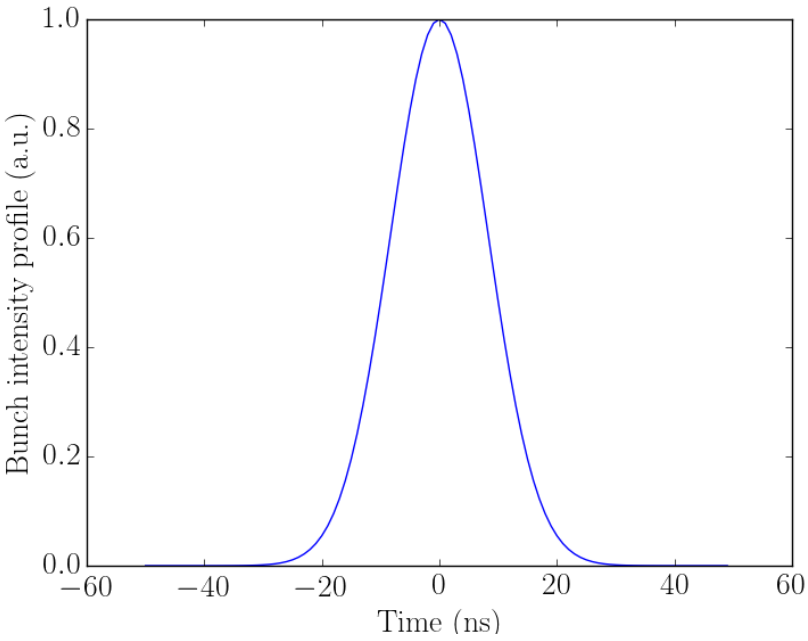

Figure 1: Bunch intensity profile with 9 MHz cavities at low energies in RHIC.

The vertex distribution at 3.85, 4.55 and 5.75 GeV/n with 9 MHz cavities are shown below with respect to longitudinal coordinate in Fig. 2 and time in Fig. 3.

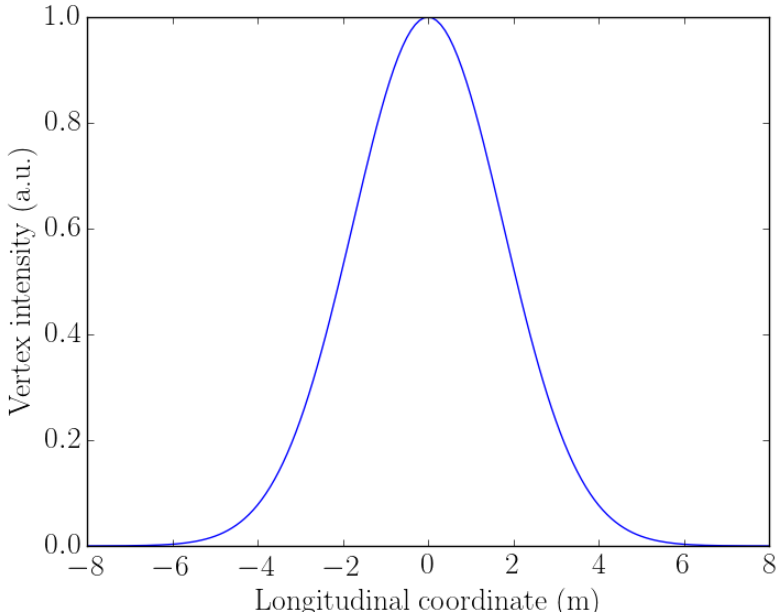

Figure 2: Vertex distribution with respect to longitudinal coordinate with 9 MHz cavities at low energies in RHIC.

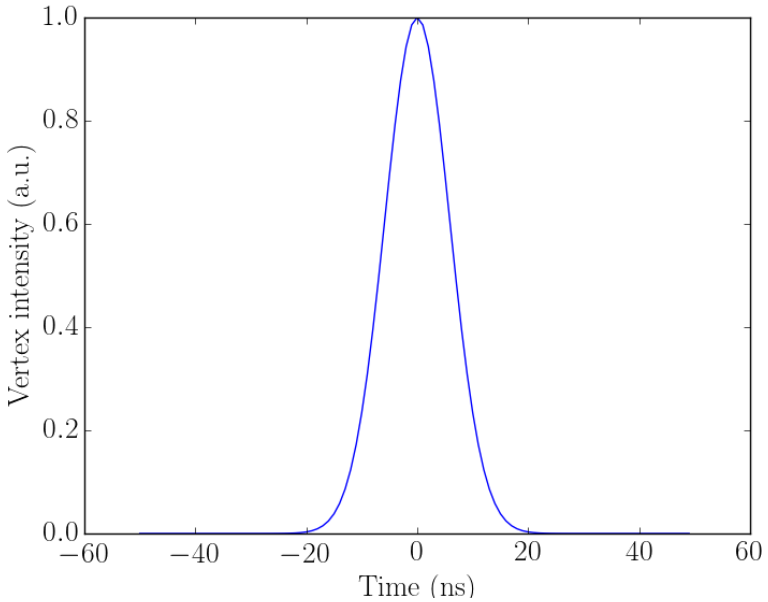

Figure 3: Vertex distribution with respect to time with 9 MHz cavities at low energies in RHIC.

9 vs 28 MHz cavity for 7.3 GeV/n operation

The following table lists the beam parameters used for the calculations below at 7.3 GeV. To take advantage of the larger longitudinal acceptance, one could inject substantial more intensity into RHIC with 9 MHz cavities. However, the bunch length is considerably longer with 9 MHz cavities.

Table 1: Beam parameters at 7.3 GeV for the cases with 9 MHz and 28 MHz cavities

Parameters	9 MHz	28 MHz
Long. Emittance	0.7 ev*s	0.5 ev*s
Bunch intensity	2.3E9	1.8E9
Full width	50 ns	30 ns
Sigma_z	2.5 m	1.5 m

The bunch intensity profiles for both cases are shown in Fig. 4, and the collision rate vertex distribution are shown in Fig. 5. Even with higher bunch intensity, the peak density of the bunch profile with 9 MHz cavities is ~25% lower than that with 28 MHz cavities (Fig. 4). The collision rate vertex peak intensities are comparable due to the factor that the rate is proportional to the square of bunch intensities. With a +/- 70 cm vertex cut (red lines in Fig. 5), the initial luminosities for the cases with 9 MHz cavities is ~3% higher than that with 28 MHz cavities.

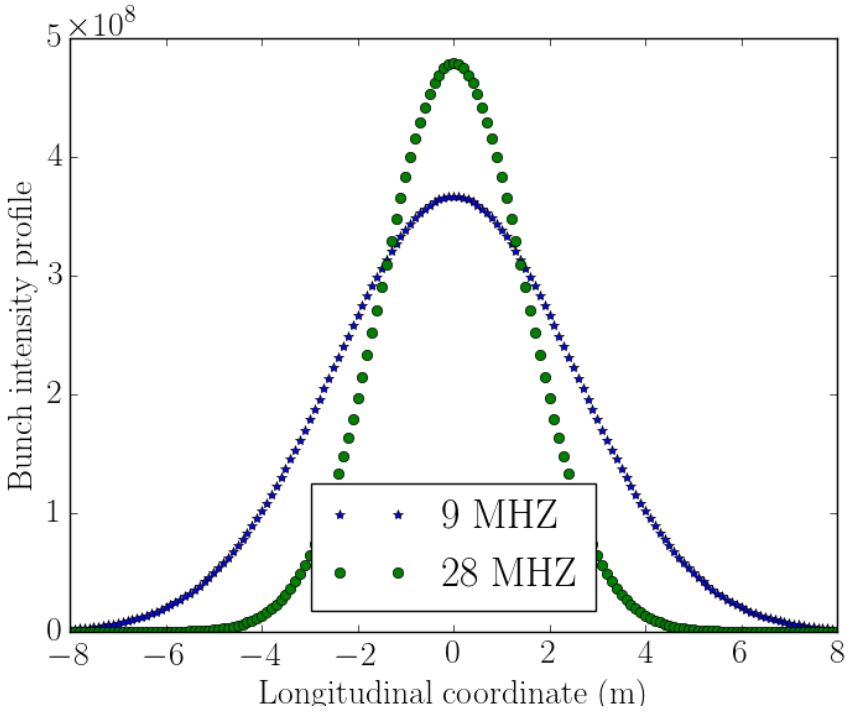

Figure 4: Bunch intensity profiles for cases with 9 MHz and 28 MHz cavities

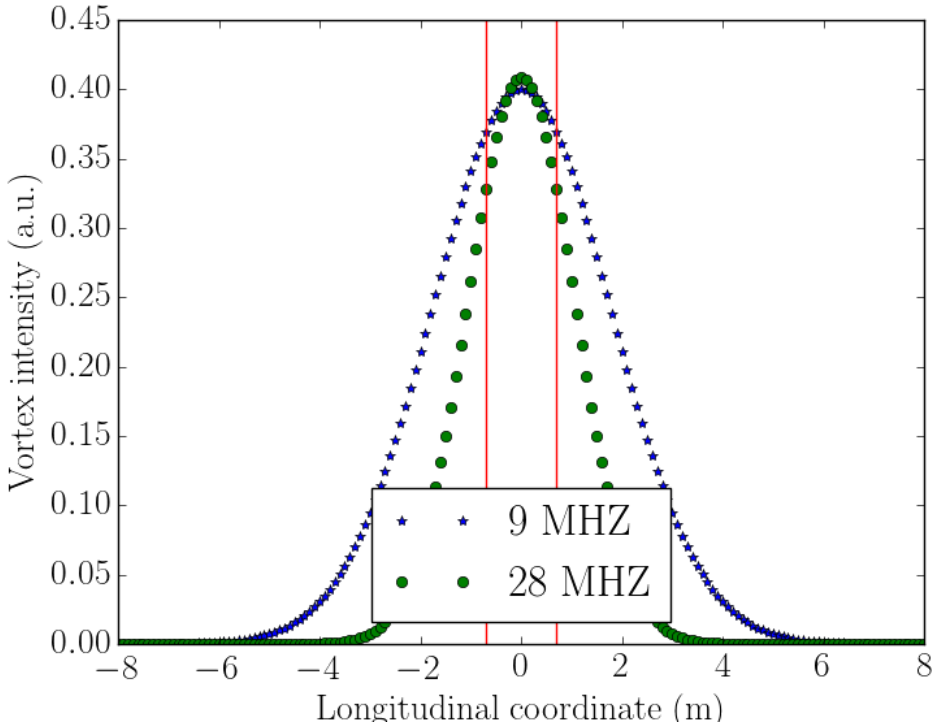

Figure 5: Vertex distributions for the cases with 9 MHz and 28 MHz cavities. The red lines show the +/- 70 cm vertex cut boundary.

The IBS lifetimes for both cases were studied as well, the preference was found with 28 MHz cavities. The lifetimes are 32 and 105 minutes in longitudinal and transverse planes with 9 MHz cavities; 64 and 48 minutes in longitudinal and transverse planes with 28 MHz cavities.

Conclusion

In conclusion, the initial luminosities, within +/- 70 cm spatial vortex cut, are comparable with 9 and 28 MHz cavities. However, the luminosity lifetime is superior with 28 MHz cavities at 7.3 GeV operation. Other considerations, like difficulties with injecting long bunches into RHIC [2] and concern of background from the long tail of the bunches, also lead to the preference of 28 MHz cavity at 7.3 GeV.

References

[1] C.J. Gardner, “Bucket and bunch parameters for clean injection of low energy gold ions into RHIC”, tech-note, C-A/AP/607, 2018
[2] V. Schoefer, et al, “RHIC Injection Kicker Measurement and Emittance Growth Simulation”, tech-note C-A/AP/606, 2018