# Performance and Comparison of the Different Coalescing Schemes Used in the Fermilab Main Ring.

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*Abstract*

The two different coalescing schemes used in the Fermilab Main Ring during the last collider run are compared using the ESME [1] simulation program. The simulation results are compared with the operational data. Finally, possible improvements are suggested.

## Introduction

Two types of coalescing are being used in the Main Ring during this collider run. The first is the traditional type of coalescing which was used before [2], and the second is the so called "SNAP" coalescing used for protons. The voltage waveform vs. time for the two types of coalescing is shown in Fig.1. In the regular type of coalescing 11-15 h=1113 (53 Mhz) bunches are accelerated to 150 GeV in the Main Ring and the RF voltage is adiabatically reduced by paraphasing to a low value (depending on the beam emittance) until the beam area fills the rf bucket. Then the bunches are coalesced by a rotation in a 2.5 plus 5.0 MHz bucket and recaptured in a 53 MHz bucket. The whole coalescing process in this case takes about 1 sec.

In SNAP coalescing the paraphasing has been replaced with a rotation. The 53 MHz voltage is suddenly reduced to 30-50 kV (depending on the beam emittance) where the bucket height equals the beam height. Then the beam is left to rotate for a quarter of a period in order to achieve the minimum $\Delta E$. The rest of the coalescing process is the same as in the regular coalescing. The SNAP coalescing process takes about 200 msec.

## ESME Comparison

The program ESME was used to compare the two coalescing schemes. We considered 11 bunches with variable longitudinal emittance rotated in a bucket formed by 20.6 kV of 2.5 MHz and 4.12 kV of 5.0 MHz. These values were chosen because they are the maximum voltages available.

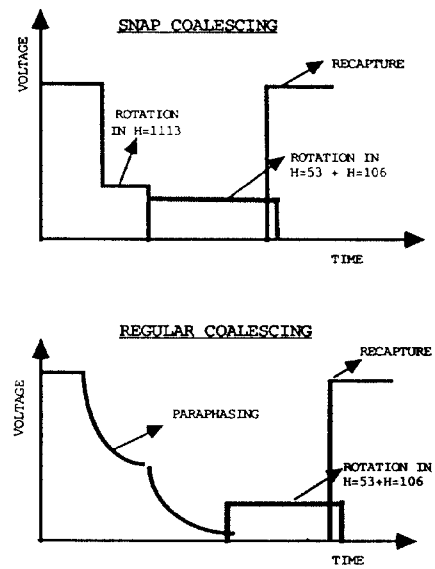


Figure 1: *Voltage vs time for Regular and SNAP Coalescing*

TABLE 1: MINIMUM ΔE vs. EMITTANCE FOR REGULAR AND "SNAP" COALESCING COMPARED WITH THE IDEAL CASE

| EMITTANCE (eV-sec) | REGULAR COALESCING ΔE (MeV) | "SNAP" COALESCING ΔE (MeV) | IDEAL ΔE (MeV) |
|---|---|---|---|
| 0.10 | 4.60 | 6.00 | 2.60 |
| 0.15 | 6.70 | 8.50 | 4.00 |
| 0.20 | 8.60 | 11.10 | 5.30 |
| 0.25 | 10.70 | 13.10 | 6.60 |
| 0.30 | 12.90 | 16.00 | 7.90 |

The capture voltage used was 800 kV, resulting in a final longitudinal emittance of 3.78 eV-sec. It turns out that even in regular coalescing where the 53 MHz rf voltage is reduced till the beam fills the bucket, the maximum bucket height achieved is still larger than the $\Delta E$ of a rectangle with base equal to the 53 MHz bucket width of 18.9 nsec and area equal to the beam emittance. In SNAP coalescing, due to nonlinearities in the rotation, the beam does not extend to the edges of the bucket. As a result, the $\Delta E$ after the rotation is larger than the $\Delta E$ in the regular coalescing. Table 1 contains the 95% $\Delta E$ of the beam as

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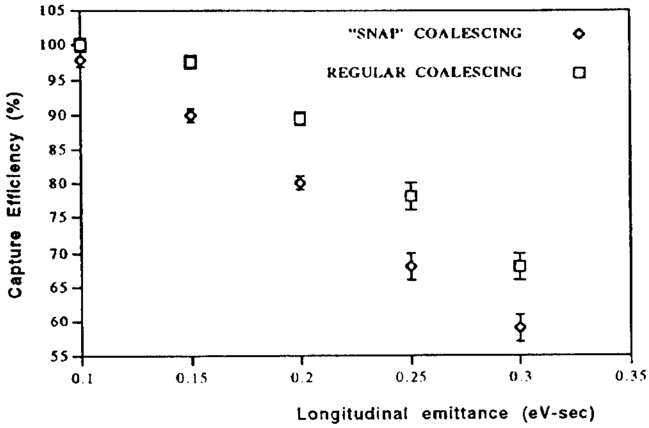


Figure 2: *Capture efficiency vs long. emittance for Regular and "SNAP" Coalescing computed by ESME*

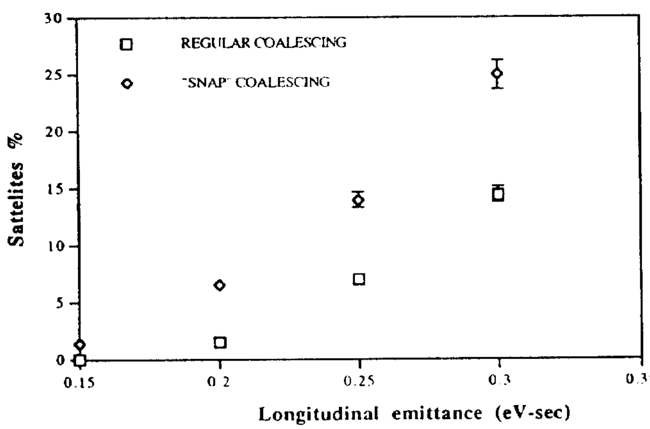


Figure 3: *Fraction of beam captured in sattelites vs longitudinal emittance for Regular and "SNAP" Coalescing computed by ESME*

calculated from ESME at the end of paraphasing for regular coalescing and at the end of the 53 MHz rotation for SNAP coalescing, compared at different beam emittances. Also shown in the same table is the $\Delta E$ for the equivalent rectangle. As shown in Table 1, the paraphasing in regular coalescing leads to a blowup in the beam emittance of a factor of 1.6, while the rotation in SNAP coalescing leads to a blowup of about 2.0. The capture efficiency for both coalescing schemes versus long. emittance as calculated by ESME is plotted in Fig. 2. As expected the efficiency varies linearly with long. emittance. The fraction of the beam captured in the two nearest sattelite buckets as a function of the longitudinal emittance for the two coalescing schemes is plotted in Fig. 3.

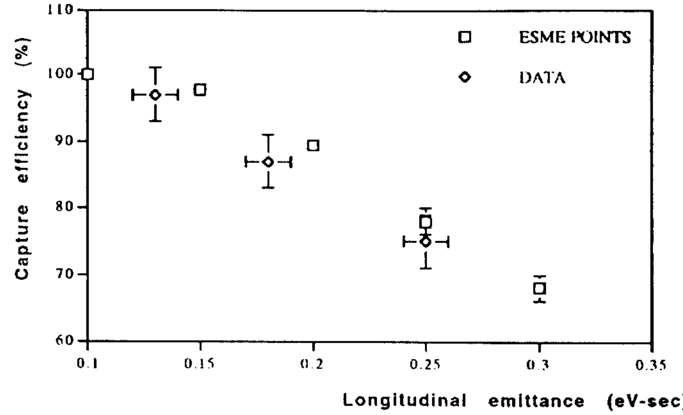


Figure 4: *Capture efficiency vs long. emittance for Regular Coalescing*

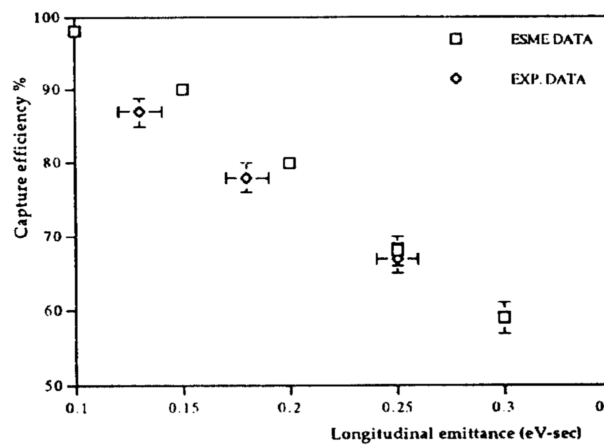


Figure 5: *Capture efficiency vs long. emittance for "SNAP" Coalescing*

## Operational Experience

ESME simulation results were compared with experiment by using a Main Ring cycle with low intensity (to avoid emittance blowup at transition) and using an injection phase mismatch to vary the longitudinal emittance. The results of this comparison are plotted in Fig. 4 and Fig. 5. From these figures we see that the experimental data agree fairly well with the ESME simulation predictions. The data also show that the capture efficiencies achieved with regular coalescing are about 10% higher than SNAP coalescing for the same emittance. The problem with regular coalescing is that at higher intensities the bunches become unstable during the adiabatic debunching, having as result the blowup of the longitudinal emittance and the eventual deterioration of the coalescing efficiency. This is the reason that regular coalescing is used only for the low intensity antiprotons while SNAP coalescing is used for the protons. During collider operations we coalesce 13-15 proton bunches with typical intensities of $2 \times 10^{10}$ ppb and emittances of 0.28-0.30 eV-sec. The capture efficiency varies between 54 % for 15 bunches to 61 % for 13 bunches with about 20 % of the beam captured in the two neighboring sattelites. Typical coalesced proton bunches have intensities of $130 - 150 \times 10^9$ ppb, while a few bunches have been observed with $165 \times 10^9$ ppb. These values agree with ESME predictions which are 58% for 15 bunches and 62% for 13 bunches. Antiprotons have a parabolic bunch intensity and emittance profile, i.e the intensity and emittance is larger for the central bunches. The typical longitudinal emittance of the central antiproton bunches is 0.23-0.25 eV-sec and the coalescing efficiency is about 85-88% in agreement with the ESME values of 89-92%. Typical coalesced antiproton intensities are $65 \times 10^9$.

## CONCLUSION

A new method of coalescing called SNAP has been succesfully tried in the Fermilab Main Ring in order to avoid the instability problems happening during adiabatic debunching at high intensities. In the future we plan to add a second harmonic cavity (106 MHz) in order to linearize the rotation in the 53 MHz bucket. This will make SNAP coalescing as efficient as regular coalescing.

## REFERENCES


[1] S. Stahl and J. MacLachlan, *"Users Guide to ESME v.7.1", Fermilab internal note TM-1650(2/90).*

[2] P. Martin, K. Meisner, H. Miller, G. Nicholls, D. Wildman, *"Performance of the RF Bunch Coalescing in the Fermilab Main Ring" IEEE Trans. Nucl. Sci. NS-32, No. 5, 1684 (1985).*