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Space charge effect in the AGS Booster for high intensity proton operation

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U.S. Department of Energy

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SPACE CHARGE EFFECT IN THE AGS BOOSTER FOR HIGH INTENSITY PROTON OPERATION

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This note briefly summarizes the results of a tracking study of the effects of space charge for a high intensity proton beam in the AGS Booster.

This study is being continued. The results so far indicate that the essential space charge limit, which is the space charge limit due to the non linear space charge forces in the absence of resonances due to non-space charge forces, plays an important role. Assuming that the first few resonances due to non-space charge forces, that are crossed by the beam, can be corrected, then the space charge limit is determined by the essential space charge limit, defined above. This is reached at about $.5 \times 10^{13}$ protons/bunch in the booster, corresponding to a space charge ν-shift of about $\Delta\nu \simeq .6$.

The above results are based on looking for self-consistent solutions in which the beam does not grow. It may be that the results are on the pessimistic side. Solutions in which the beam is allowed to grow have so far not been studied. This may be done in the future.

Looking for self-consistent solutions with a tracking program is an improvement in the computation of space charge effects. However, one should keep in mind that the approach shows that certain beam intensities are achievable, and it suggests that higher beam intensities may cause unacceptable beam growth but it does not conclusively demonstrate this.

Model for Space Charge Effects

Two Models for limit on intensity

1) Limit due to resonances driven by non-Space charge forces. Space Charge forces move ν-values on to resonance. This is the traditional model. It indicates that the larger 1/3-booster may have a lower space charge limit than the 1/4-booster. This limit will be called the <u>resonance limit</u>.

2) ~~The~~ A limit arises from the non-linear Space charge forces themselves, even when no resonances are present due ~~to~~ other forces than space charge.

If this limit is reached before the ν-values have reached the damaging resonance, then this limit dominates and provides the basis for comparing two accelerators.

This limit will be called the <u>essential space charge force limit</u>.

Computing the Space Charge Force Limit

This can be done with a tracking program. One difficulty is computing the force on a particle due to the fields of all the other particles. If this is done correctly, this approach is exact.

In the following the fields due to all the other particles is approximated by the field of a beam with a continuous distribution which does not change during the tracking run. One then looks for self-consistent soutions. The results so found suggest values for the space charge limit. The results are not rigorous.

Space Charge Effects in Tracking Studies

At each element, magnet or drift space, the particle is given the kicks, $\Delta x' \sim E_x L/B\rho$, $\Delta y' \sim E_y L/B\rho$.

By varying the initial x, y and $\Delta p/p$, and by fourier analyzing the orbit motion, one can find $\Delta \nu_c$, $\Delta \nu(A)$, $\Delta \nu(p)$. These results include octupole and higer order multipole effects. By including the magnet errors, b_K and a_K, one can observe the instabilities due to imperfection resonances, or systematic resonances.

Running time of the tracking program is considerably increased. Studies are possible for a small accelerator like the booster, where space charge is particalarly important.

Actual Process for Space Charge effects

For a given NBNCH injected, Beam grows in size until it stabilizes at XBM.

Final XBM and NBNCH are related.

XBM = XBM (NBNCH)

XBM ≃ Aperture gives largest NBNCH.

Self-Consistent Solution

For given XBM, increase NBNCH To find largest NBNCH for no beam growth. This gives result for XBM vs. NBNCH relation (Beam dimensions do not change in this search)

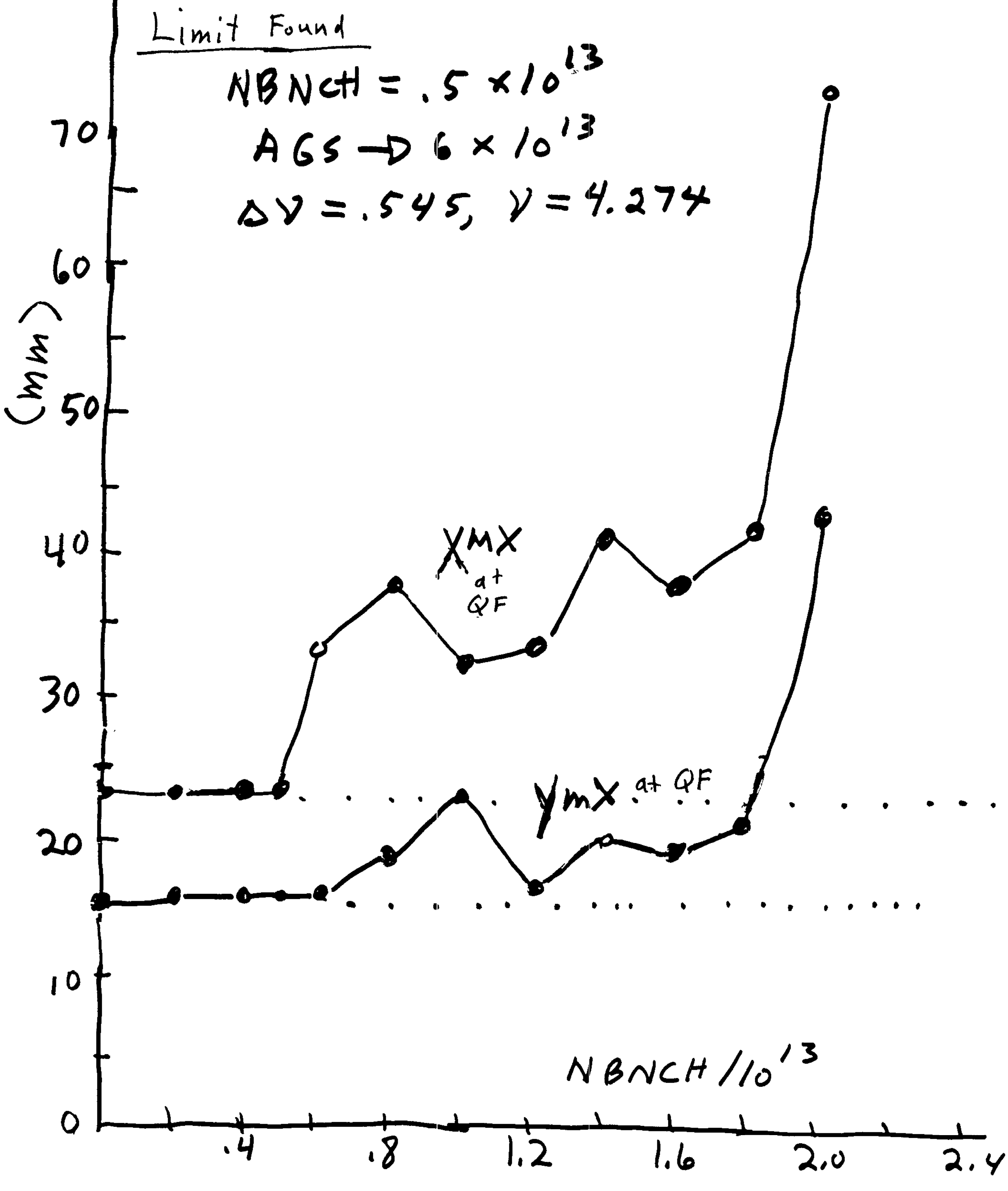
For XBM ≃ Aperture, this gives largest NBNCH.

1/4 - Booster, Tracking Results

$\nu = 4.82, 4.83$

NSP = 6, Round Beam, XBM = 26.5 mm

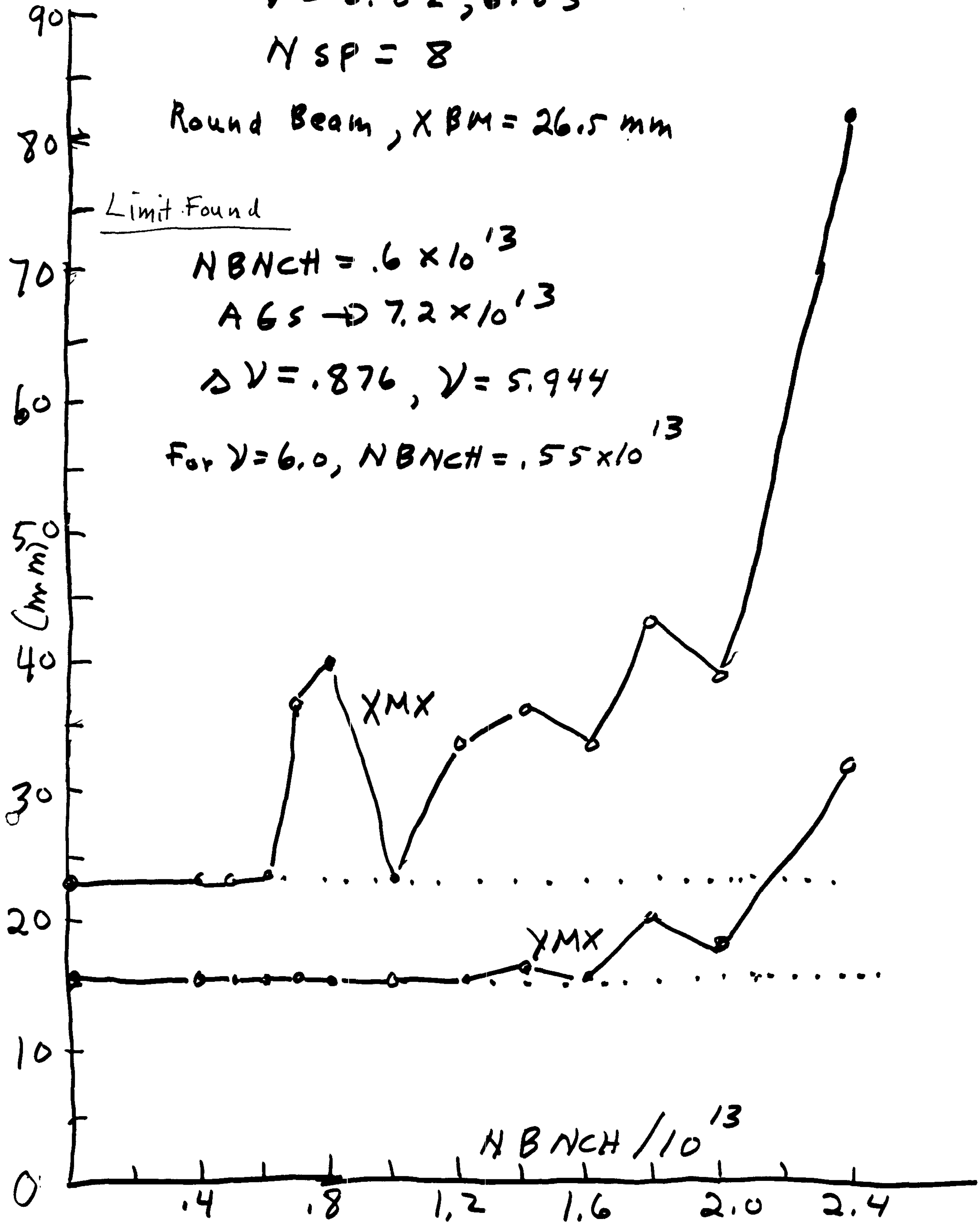
400 revolution runs; X_0 = 23 mm (Beam edge)



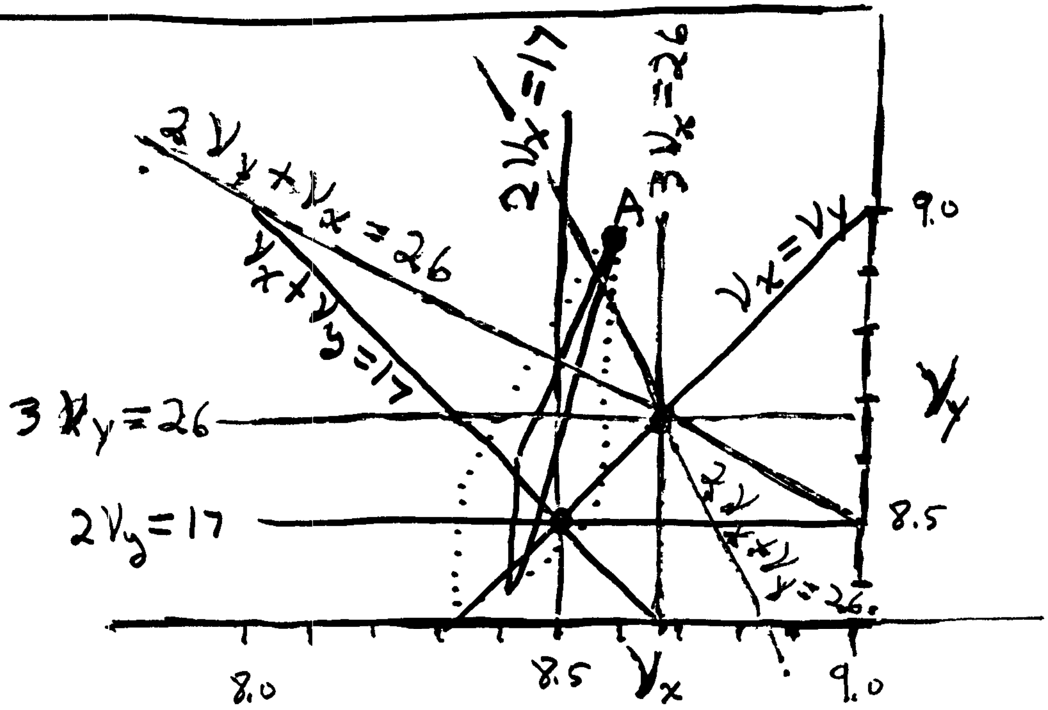
1/3 - Booster, Tracking Results

$\nu = 6.82, 6.83$

NSP = 8



AGS experience and What is the Resonance Limit



Raka, Ahrens, Frey, Gill, Glenn, Sanders, Weng
IEEE Trans. Nucl. Sci. NS-32, No. 5, P. 3110. (1985)

All resonance lines shown can be corrected in AGS.

$\Delta\nu_{y,sc} = -.58$, $\Delta\nu_{x,s,c} = -.16$

No space charge limit has been demonstrated — More current injected gives more current in AGS.

NBNCH achieved, NBNCH $= .16\times10^{13}$ in AGS.

Possible Conclusions

1. The Resonance limit can effectively be removed with correction magnets in the range of interest.

2. The intensity limit is determined primarily by the essential Space charge force limit.

3. Proposed experiment for the AGS - reduce the aperture and measure the limit due to space charge.

4. other factors that may change results
   a. Non-round beams

   b. Image Fields