Intensity Limits in the V2 Baseline Scenario

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Top-down Intensity Requirements

The Beta-beam is supposed to deliver 2.9×10^{18} antineutrinos (from ^{6}He decays) and 1.1×10^{18} neutrinos (from ^{18}Ne decays) per "Snowmass" year.

Version 2 reaches the former (with no margin!) but, because we are a long way short of the latter, we choose to take the somewhat hypothetical approach of considering what would be the consequences of the intensities implied by these figures if they could both be achieved within the V2 framework.

	Total ^{6}He ions	Total ^{18}Ne ions
RCS ej (1 bunch)	0.90×10^{12}	0.27×10^{12}
PS ej (20 bunches)	9.5×10^{12}	4.3×10^{12}
SPS ej (20 bunches)	9.0×10^{12}	4.3×10^{12}

Intensity Limits due to RF Power

The rf power that can be coupled to the beam is modified by a (frequency dependent) efficiency. The resultant available power translates into an upper limit on beam intensity.

Machine	RF Power [MW]	Efficiency [%]	Eff. Power [MW]	Beam Limit [charges]	Proton Record
PS	10×0.1	~ 20	~ 0.2	$\sim 4\times10^{13}$	3.4×10^{13}
SPS	4×0.7	~ 40	~ 1.1	$\sim 6\times10^{13}$	5.3×10^{13}

Clearly, there is no immediate problem due to a shortage of rf power.

1σ Physical Emittances at Injection

Scaling from normalized rms values of 7.8μm (H) and 4.2μm (V) for 11Tm ^{6}He ions at PS injection, then

$$\varepsilon(ion, machine) = \frac{\varepsilon^*(ref, PSinj)}{\beta\gamma(ion, machine)}$$

H,V [μm]	^{6}He	^{18}Ne
RCS inj	16.4, 8.8	16.4, 8.8
PS inj	6.6, 3.5	4.0, 2.1
SPS inj	0.8, 0.4	0.5, 0.3

Cf., Acceptance
?
60, 20
28, 4.5

We assume the ^{18}Ne has the same normalized emittance as the ^{6}He because it comes from the Linac with identical $\beta\gamma$ and is multi-turn injected into the RCS with the same geometrical set-up.

Intensity Limits due to Tune Shift at Injection

Considering for simplicity a round Gaussian beam of fully stripped ions, the self-field incoherent ("Laslett") tune shift is

$$\Delta Q_V = -\frac{Z^2}{A_p}\frac{3r_p}{4(\beta\gamma)^3 c}\frac{R}{\tau_b}\frac{N_b}{\varepsilon_V}$$

This allows upper limits on the total number of ions per shot to be estimated (taking into account unequal bunches) based on known limits at injection.

	Max ^{6}He ions	Max ^{18}Ne ions
RCS ej (1 bunch)	7×10^{12}	0.8×10^{12}
PS ej (20 bunches)	7×10^{12}	3×10^{12}
SPS ej (20 bunches)	6×10^{12}	3×10^{12}

Max $\lvert\Delta Q_V\rvert$
0.5 (?)
0.3
0.2

We assume τ_b = 80% of the rf bucket duration in all cases.

Tentative Solutions

Two batches from the PS instead of one.

Required	Total ^{6}He ions	Total ^{18}Ne ions
RCS ej (1 bunch)	0.63×10^{12}	0.16×10^{12}
PS ej (20 bunches)	6.7×10^{12}	2.6×10^{12}
SPS ej (40 bunches)	11×10^{12}	4.9×10^{12}

ΔQ_V Limit	Max ^{6}He ions	Max ^{18}Ne ions
RCS ej (1 bunch)	7×10^{12}	0.8×10^{12}
PS ej (20 bunches)	7×10^{12}	3×10^{12}
SPS ej (40 bunches)	10×10^{12}	5×10^{12}

One could also imagine deliberately blowing up the emittance (except for ^{6}He in the RCS) to improve the situation in the downstream machine.

Conclusions

Version 2 pushes us beyond the limits set by space charge in both the PS and SPS machines. There remains some room for manoeuvre, but little scope to provide much of a safety margin. There is also the issue of intra-beam scattering which still needs to be evaluated.

Do we abandon the baseline design and consider green-field accelerators?

Corollary: Switching to ^{19}Ne (for source reasons), which would require an order of magnitude more intensity to be delivered by the SPS, is excluded in the V2 framework.