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Particle Distribution at Injection Dump for Off Normal Linac Emittances

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DISCLAIMER

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March 29, 2004

Introduction

Target group calculation shows that the present design of the injection dump will not satisfy the requirement in the SNS parameter list for the injection dump (see Table I). Specially, the requirement that beam center can be off center by ± 5.0 cm for 200kW of beam power. Simulations were carried out to ensure beam size and centroid off set for off normal emittance from the linac

Table I: Injection Beam Dump Specification from the Parameters List.

Parameter	
Power	150 kWatts
Beam radius	100 mm (99% of beam energy)
Centroid displacement	±50mm
Mac particle/current density	$5.0\text{x}10^{15}$ PPP/m^2 =0.048A/m^2
Operation hours per year	5000

Injection Dump Optics

Injection beam dump is designed to absorb 200 kW of beam power and requires that 99% of the beam should lie in 200 mm diameter circle. It will collect un-stripped H^- and partially stripped H^0 ions. Figure 1 shows the layout of the injection region.

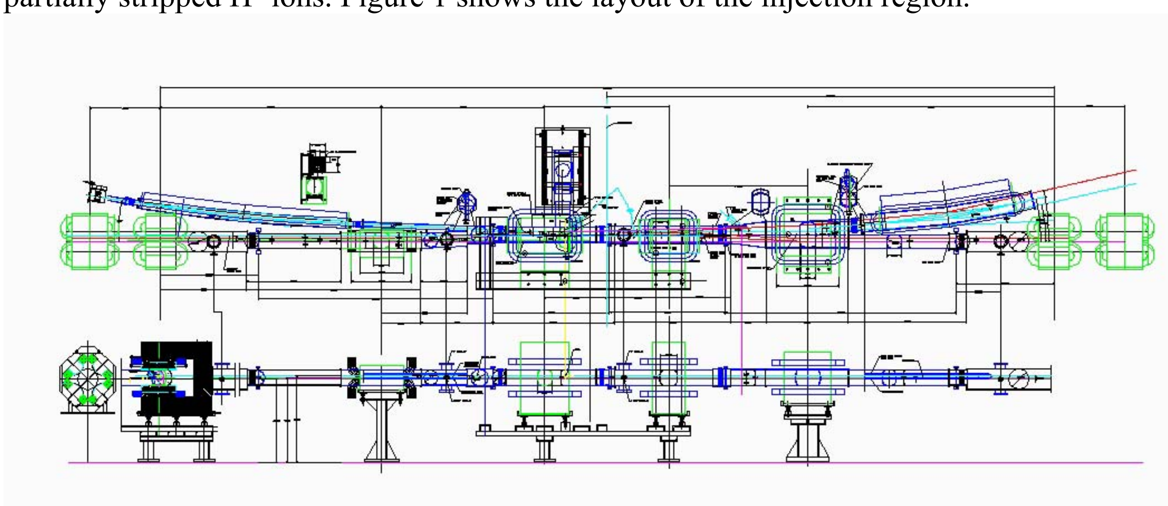

Figure 1: Layout of the injection region.

H^- ions are injected into the ring via charge exchange through carbon foil of thickness ranging 200 –400 μg/cm^2. Final foil thickness will depend on the R&D on the diamond foil carried out at ORNL. The striping efficiency at 1 GeV is shown in fig 2.

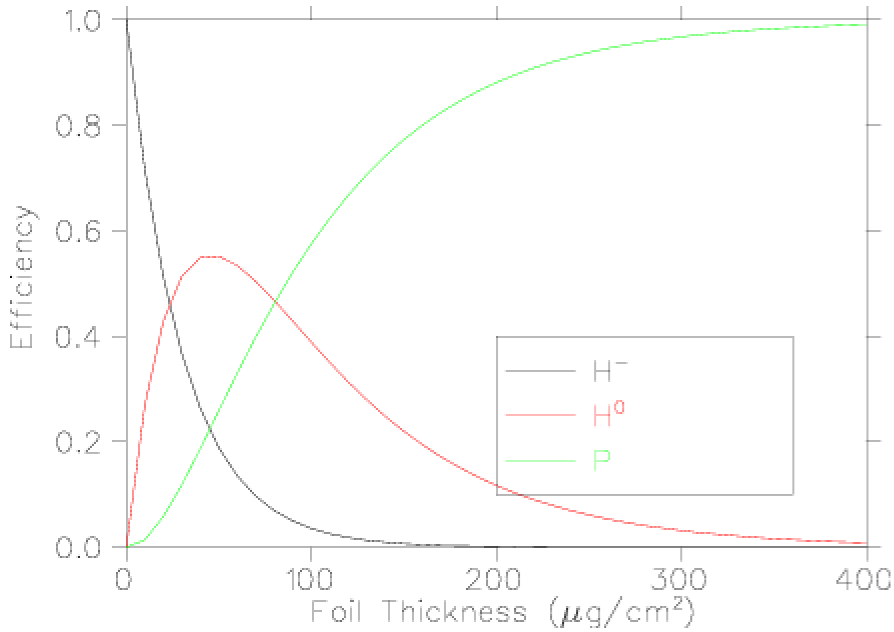

Fig 2. Stripping efficiency for 1GeV H^- ions.

H^- ions which have missed the foil will emerge from the injection bump magnet # 2 as 4.2 mrad toward left, H^0 will go straight and proton will bend 4.2 mrad right. The injection bump magnet # 3 will bend further H^- ions by 42 mrad while H^0 ions will go straight. There will be a thick foil (~ 10 mg/cm^2) before the injection bump magnet #4, which will convert H^- and H^0 ions to proton by stripping two and one electrons respectively. After injection bump magnet #4 both trajectory goes through an injection dump gradient magnet and finally though an x-defocusing quadrupole magnet. The optics is such that that the both trajectories coincide at the injection dump [1]. Figure 3 shows the H^0 centroid displacement with respect to the central ray (average of H^0 and H^- trajectories). H^- trajectory will be just mirror of the H^0 trajectories in Figure 3. Figure 4 show β and η functions for the injection beam dump beam line.

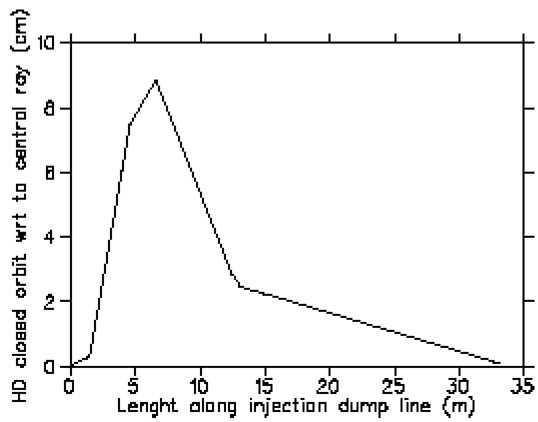

Figure 3: H^0 trajectory displacement with respect to the central ray.

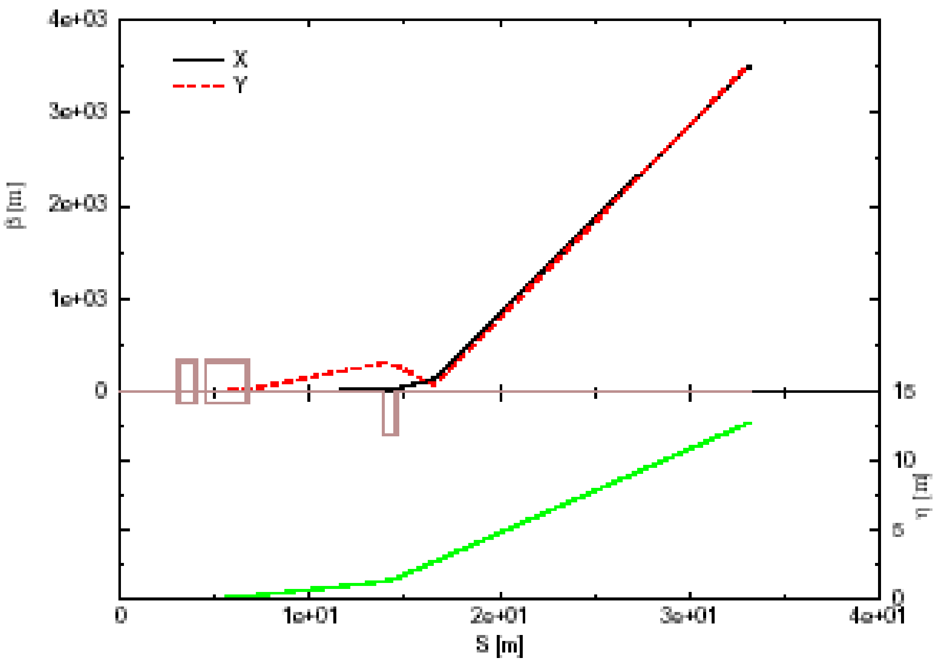

Figure 4: β and η function in the injection dump line.

The design linac emittance is 0.5 π mm mrad (rms, nor). If the linac emittance is bigger than the design, the beam size at the target will grow as the square root of the emittance, Table II shows TRANSPORT calculations for the beam size at the injection dump for different injection-dump quadrupole settings (S) and three different emittances. For run numbers SN 1-5, matched-injections were assumed, which means that as the emittance grows the foil size also grows accordingly. For run numbers, SN 6-9, mismatched injections into the ring were assumed, so that the foil size remains the same as the emittance grows. Table III shows the required gradient in the last quads in the HEBT to achieve mismatch injection. Mismatch injections into the ring were studied [2] and the mismatched schemes considered here will satisfy the conditions required for the mismatch injection into the ring.

Table II: Beam size at the Injection dump for various linac emittances.

delp/p 0.0002

SN	Centroid (cm)	β_X (m)	β_Y (m)	η_X (m)	S(T/m)	(A)ε=0.5 π mm mr (rms, nor)			(B)ε=1.0 π mm mr (rms, nor)			(C)ε=1.5π mm mr(rms,nor)		
						Xdia (mm)	Ydia (mm)	$\frac{CD}{CD_{NORMAL}}$	Xdia (mm)	Ydia (mm)	$\frac{CD}{CD_{NORMAL}}$	Xdia (mm)	Ydia (mm)	$\frac{CD}{CD_{NORMAL}}$
1	0	3423	2425	12	2.6116	185.7521	156.3458	1	262.693	221.11	0.5	321.73	270.79	0.33333
2	±1.41	3137	1759	11.4	2.4116	177.8228	133.1567	1.2265	251.479	188.31	0.61325	308	230.63	0.40883
3	±2.81	2864	1197	10.8	2.2116	169.9092	109.8443	1.55606	240.288	155.34	0.77803	294.29	190.25	0.51869
4	±4.2	2606	740	10.1	2.0116	162.0755	86.36666	2.0747	229.209	122.14	1.03735	280.72	149.59	0.69157
5	±5.59	2361	391	9.5	1.8116	154.2689	62.77961	2.99863	218.169	88.784	1.49931	267.2	108.73	0.99954
2*ε														
6	0	1777	2212	12	2.6116				189.273	211.17	0.7266			
7	±2.81	1494	1073	10.8	2.2116				173.548	147.08	1.13777			
3*ε														
8	0	1268	2608	12	2.6116							195.82	280.83	0.52811
9	±2.81	1074	1255	10.8	2.2116							180.22	194.81	0.82721

Table III: HEBT Quad Strength (QS) at 1 GeV for Mismatch Injection.

Quad #	ε=0.5π mm mr (rms,nor) QS (T/m)	ε=1.0π mm mr (rms,nor) QS (T/m)	ε=1.5π mm mr (rms,nor) QS(T/m)	Opeating I & V (for 1.3 GeV+10%)	PS Rating	comments
25,27,29,31,	3.38761	3.43833	3.65898	351A, 25.5V	390A, 24V	ok
26,28,32	3.39917	3.30015	3.29048	350A, 19.7V	390A, 24V	ok
30	4.25811	4.36870	4.82094	427 A, 10.3V	700A, 18V	ok
33	5.53510	6.09161	5.83802	663 A, 15.5V	700A, 18V	-5%
34	5.00592	5.69822	5.37146	610A, 14.1V	700A, 18V	ok

PARMILA Simulation

PARMILA was modified to track three species (P, H-, H^0) and included multiple and nuclear scattering. Foil will be carbon about 300 $\mu g/cm^2$, about 4 % H^- will be partially stripped and about 1-2% H^- ion will miss the foil. PARMILA simulations were carried out for various emittances at the injection foil. These simulations include multiple and nuclear scattering due the both foils. Particle distribution used in these simulations was obtain from end to end simulation at end of HEBT and has 0.365 and 0.319 π mm rad (rms, nor) emittances in x and y plane respectively for 95610 micro-particles. To obtain larger (2 or 3 times) emittance for matched cases particle co-ordinates (x, x', y y') were multiplied by square root of emittance factor (2 or 3). In case of mismatched injection only angle coordinates (x' and y') were multiplied by the emittance factor (2 or 3).

Reference Distribution: For the reference design Gaussin distribution (truncated at three sigma) was used with emittance ε=0.5 π mm mrad (rms, nor) at the charge exchange foil. Figure 5A and 5B shows the beam size at foil and at the dump for design emittance ε=0.5 π mm mrad (rms, nor) and design optics There were about 0.07 % loss in the flight tube.
SN: 1A- Figure 6A and 6B shows the beam size at foil and at the dump for design emittance ε=0.5 π mm mrad (rms, nor) and design optics There were about 0.3 % loss in the flight tube.
SN: 1B- Figure 7A and 7B shows the particle distribution at the foil and at the dump for ε=1.0 π mm mrad (rms, nor) i.e. twice the design emittance and design optics and foil size was increased by 41% There were about 3.0 % loss in the flight tube.
SN: 1C- Figure: 8A and 8B shows the particle distribution at the foil and at the dump for ε=1.5 π mm mrad (rms, nor) i.e. three times the design emittance and design optics and foil size was increased by 73% There were about 9.0 % loss in the flight tube.
SN: 7B- Figure 9A and 9B shows the particle distribution at the foil and at the dump for ε=1.0 π mm mrad (rms, nor) i.e. twice the design emittance and optimize optics and foil size was same as the design i.e. mismatch injection into the ring. There were about 0.3% loss in the flight tube.
SN: 9C- Figure 10A and 10B shows the particle distribution at the foil and at the dump for ε=1.5 π mm mrad (rms, nor) i.e. three times the design emittance and optimize optics and foil size was same as design. There were about 0.5% loss in the flight tube.

Table IV: Beam loss, particle density and beam size at injection dump.

Run#	Beam Loss					Max Part. PPP/m^2	Beam inside 20 cm Dia. %	Comments
	Chicane # 2 % of 2MW	Chicane #3 %	Chicane #4 %	Dump Sept +Quad %. of 0.2MW	Flight Tube %			
Ref	10^{-3}	-	-	$4x10^{-2}$	0.07	2.4 x10^{15}	99.8	Reference Part. Dis.
1A	10^{-3}	-	-	$4x10^{-2}$	0.40	2.49x10^{15}	91.9	Match Inj. 1x emit
1B	10^{-3}	-	-	$4x10^{-2}$	2.94	1.54x10^{15}	79.8	Match Inj. 2x emit
1C	10^{-3}	-	-	0.17	8.85	1.47x10^{15}	67.32	Match Inj. 3x emit
7B	10^{-3}	-	-	$4x10^{-2}$	0.26	3.32x10^{15}	92.9	Mismatch Inj, 2x emit
9C	10^{-3}	-	-	0.15	0.54	2.45x10^{15}	91.5	Mismatch Inj. 3x emit

Conclusion

Beam size at the injection dump is acceptable for linac emittance up to three times higher than the nominal emittance with mismatch injection. These calculations do not include the partially chopped beams.

References

[1] D. Raparia et al, "Beam Dump Optics for SNS", PAC 2003, pp 3417
[2] J. Bebee Wang et al, "Mismatch injection for SNS accumulator ring", SNS Tech Note # 80, June 1, 2000

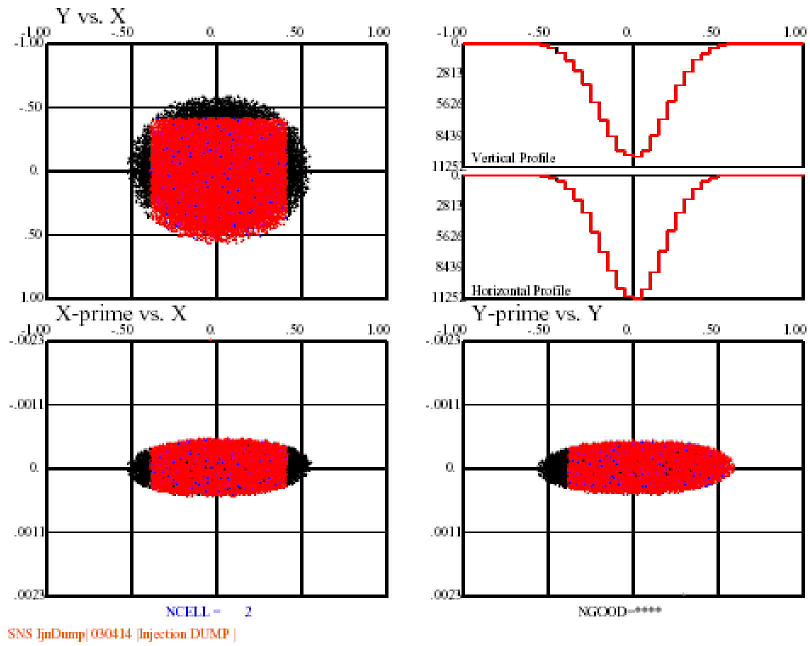

Figure 5A: Reference particle distribution at the foil for the design emittance. **Red** particles representing P, **Black** H^- and **Blue** H^0.

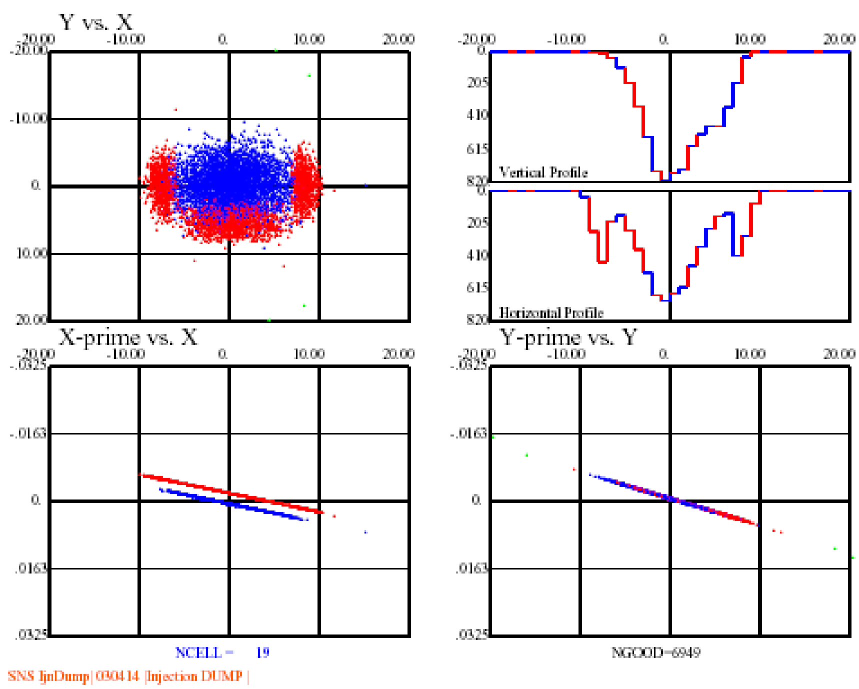

Figure 5B: Reference particle distribution at injection dump for the design emittance (refernce distribution). **Red** particles representing particle started at foil as H^- and **Blue** H^0.

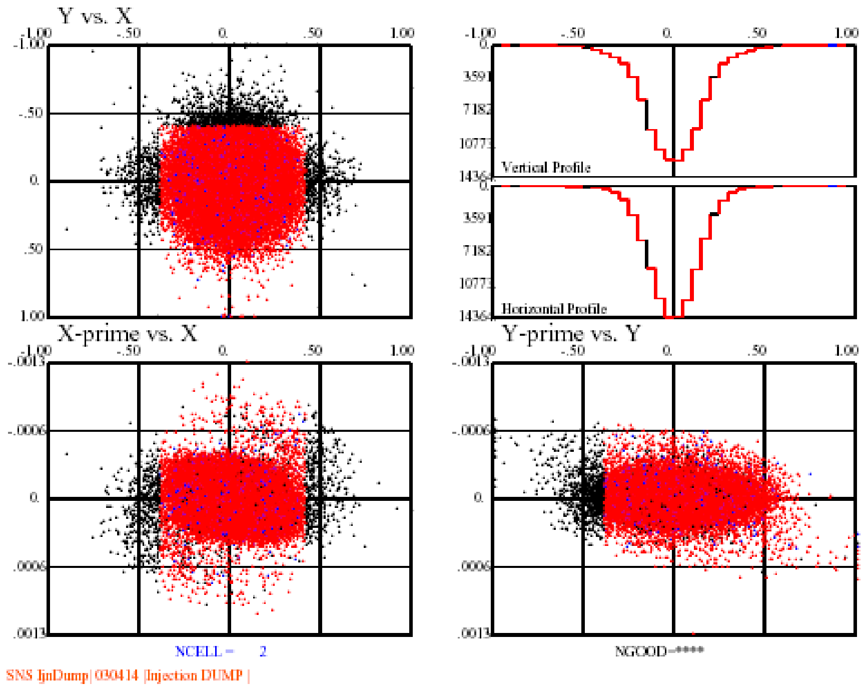

Figure 6A: Particle distribution at the foil for the design emittance. **Red** particles representing P, **Black** H^- and **Blue** H^0.

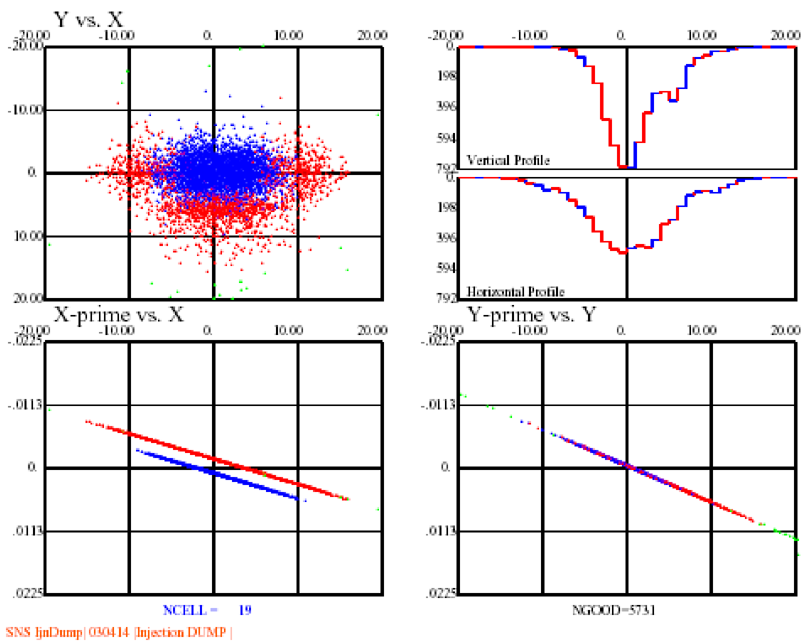

Figure 6B: Particle distribution at Injection Dump for the design emittance. **Red** particles representing particle started at foil as H^- and **Blue** H^0.

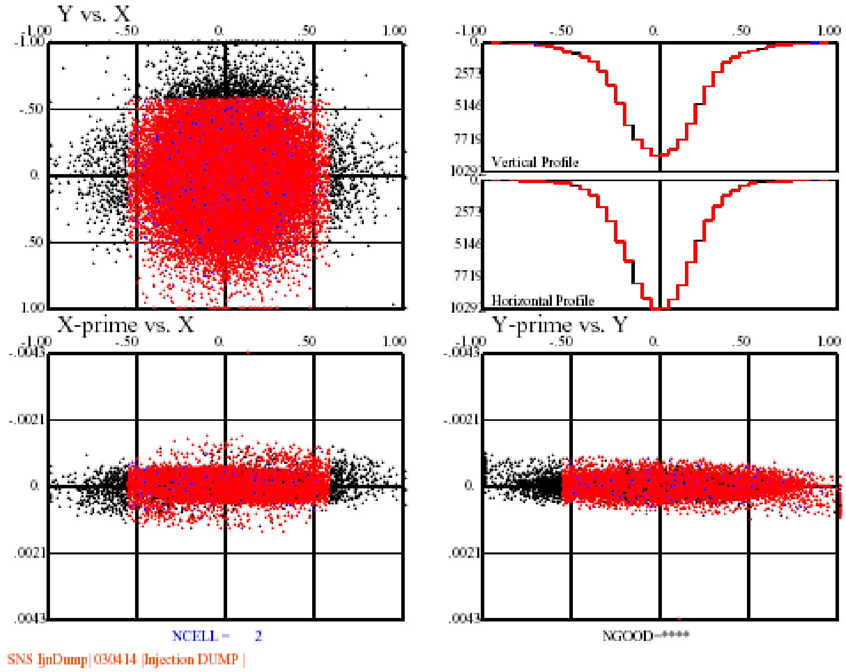

Figure 7A: Particle distribution at the foil for two times the design emittance and matched injection. **Red** particles representing P, **Black** H^- and **Blue** H^0.

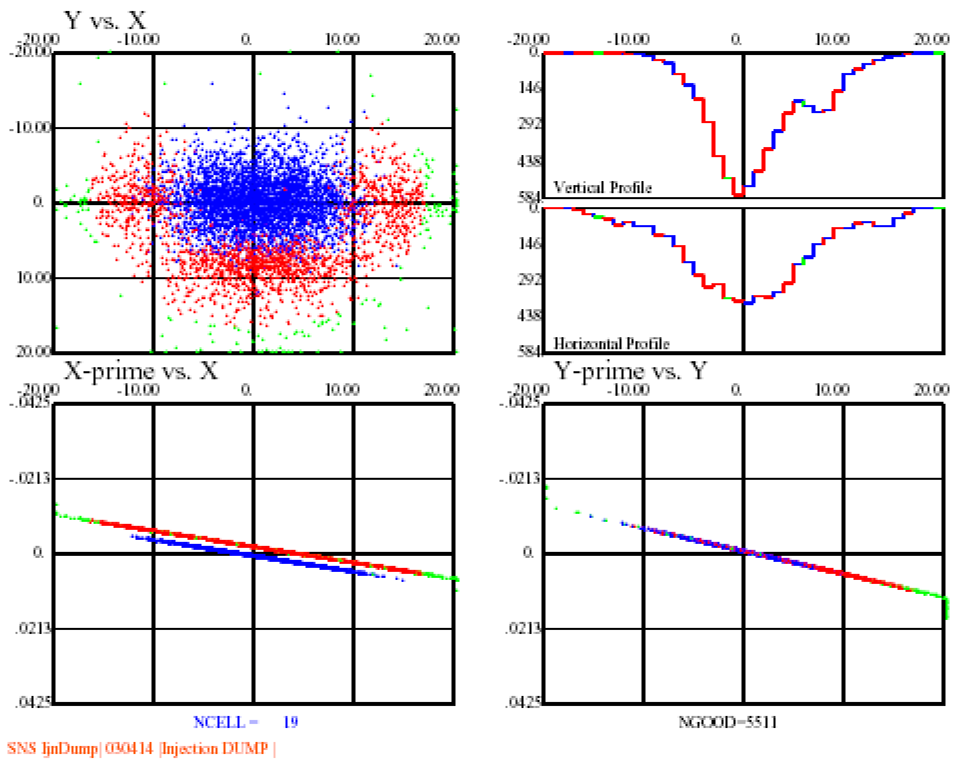

Figure 7B: Particle distribution at Injection Dump for two times the design emittance and matched. **Red** particles representing particle started at foil as H^- , **Blue** H^0 and Green as lost particles in the flight tube.

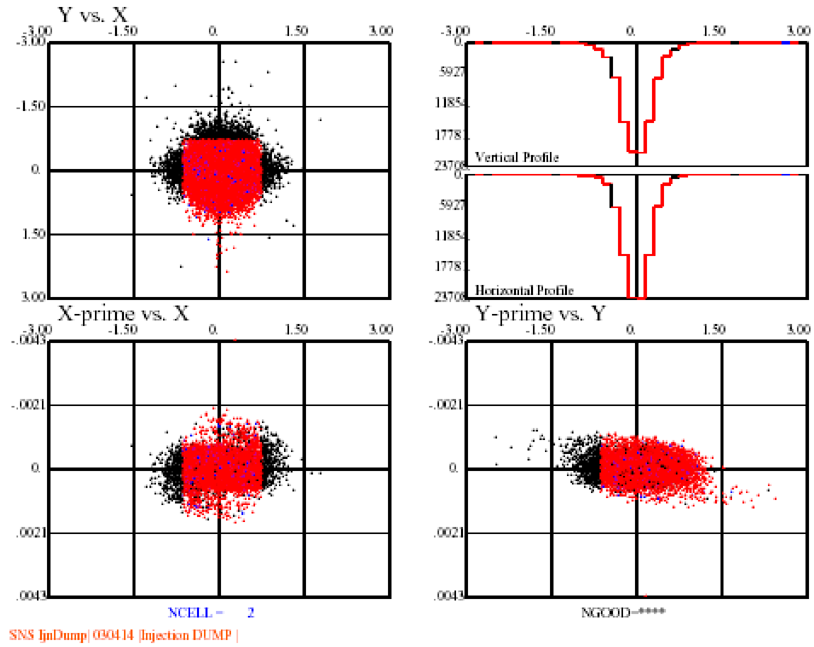

Figure 8A: Particle distribution at the foil for three times the design emittance and matched injection. **Red** particles representing P, **Black** H$^-$ and **Blue** H^0.

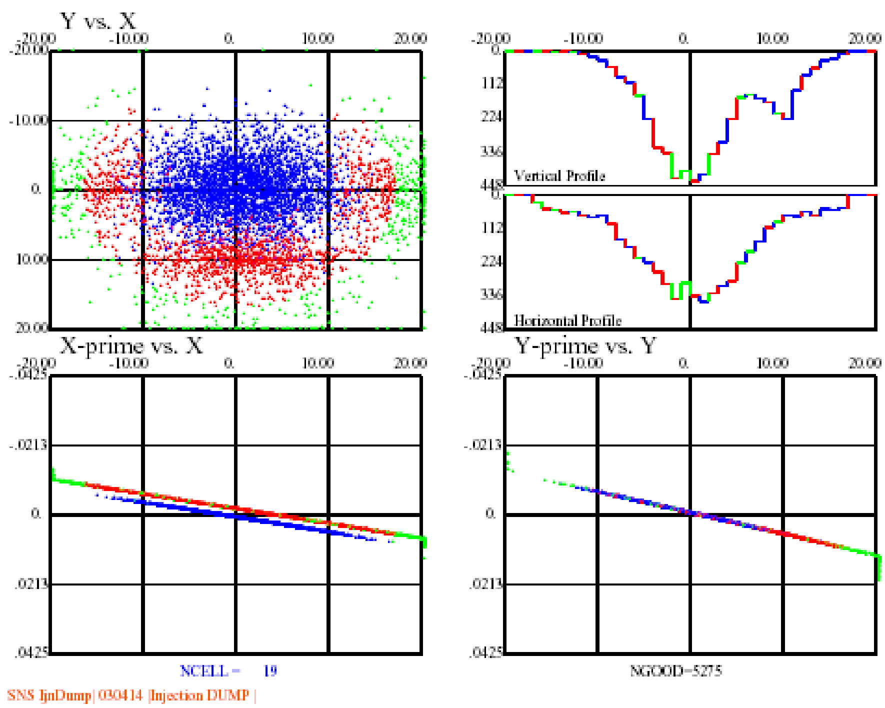

Figure 8B: Particle distribution at Injection Dump for three times the design emittance and matched. **Red** particles representing particle started at foil as H$^-$, **Blue** H^0 and Green as lost particles in the flight tube.

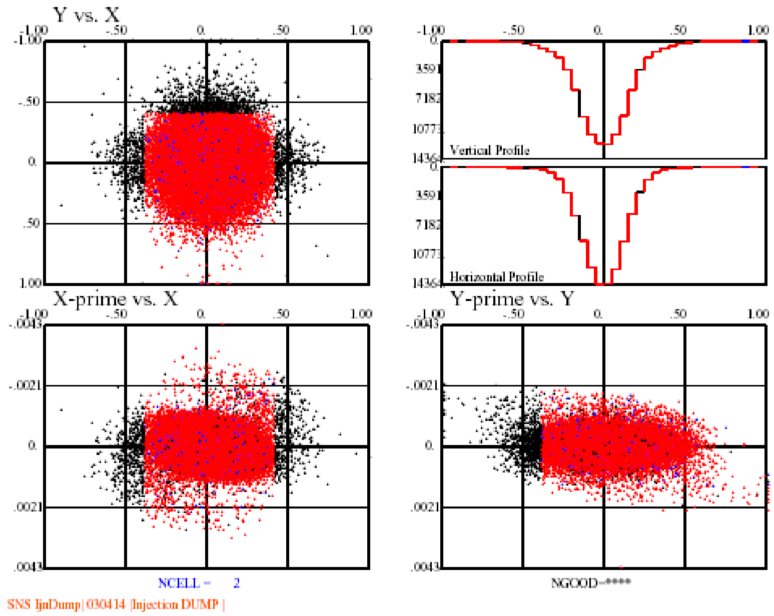

Figure 9A: Particle distribution at the foil for two times the design emittance and mismatched injection. **Red** particles representing P, **Black** H^- and **Blue** H^0.

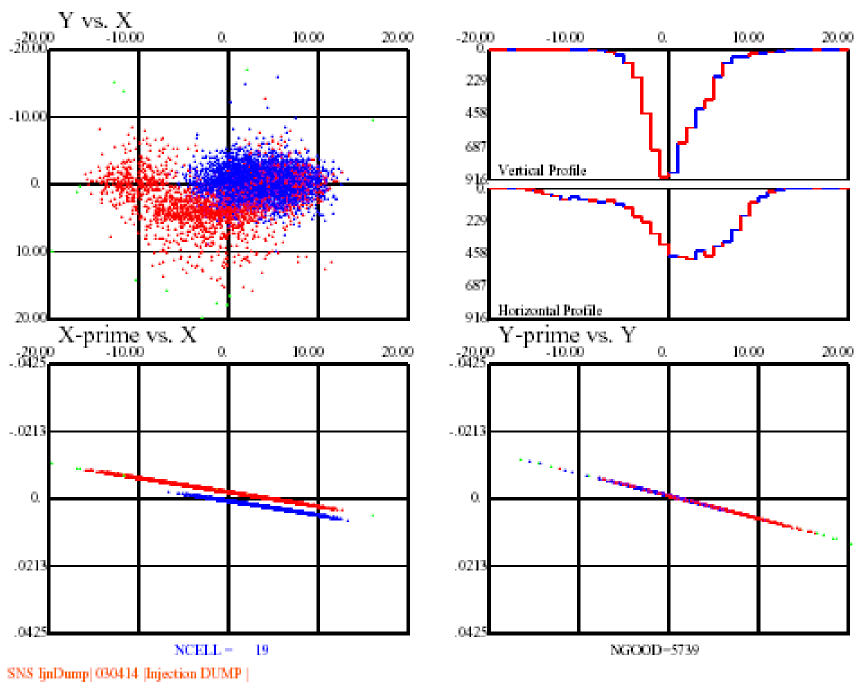

Figure 9B: Particle distribution at Injection Dump for two times the design emittance and mismatched. **Red** particles representing particle started at foil as H^-, **Blue** H^0 and Green as lost particles in the flight tube.

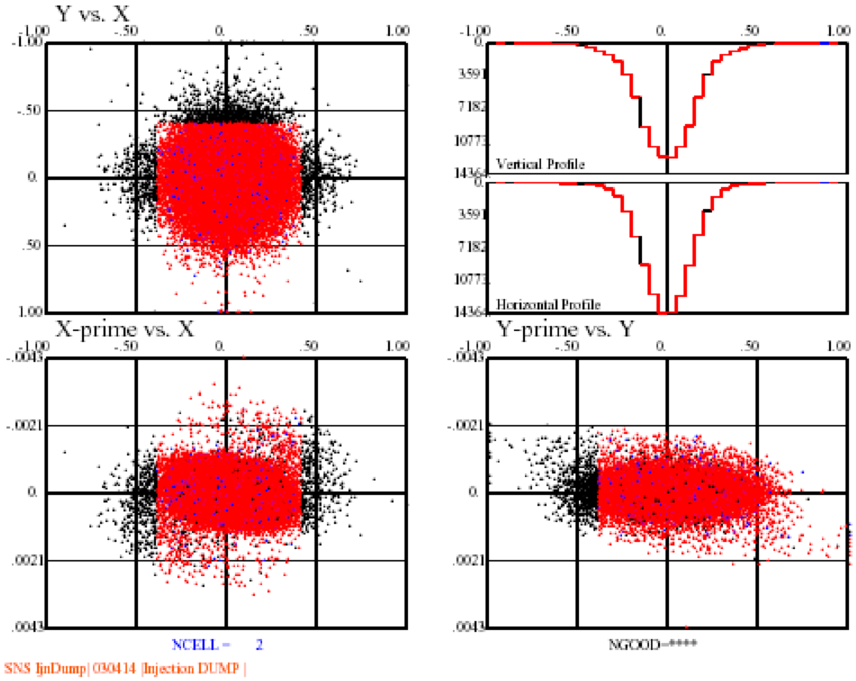

Figure 10A: Particle distribution at the foil for three times the design emittance and mismatched injection. **Red** particles representing P, **Black** H^- and **Blue** H^0.

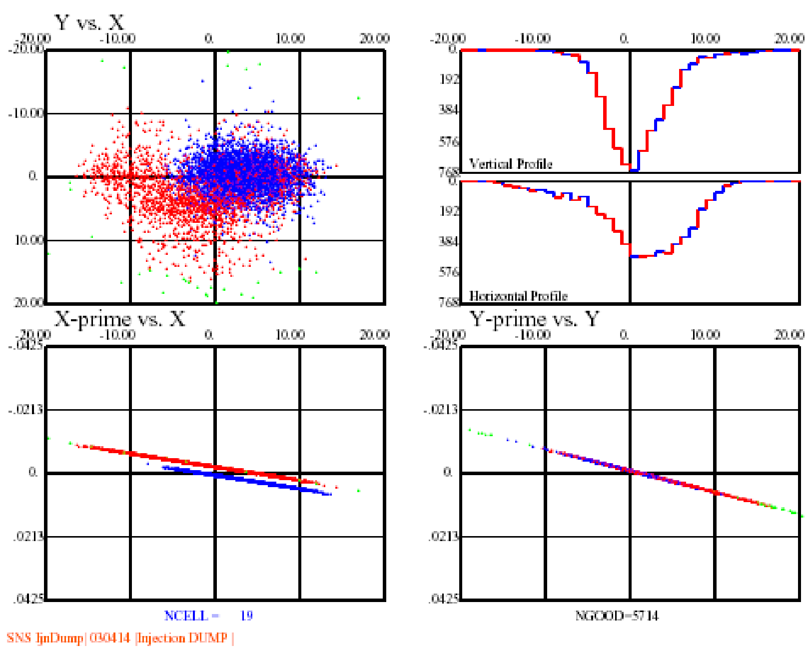

Figure 10B: Particle distribution at Injection Dump for three times the design emittance and mismatched. **Red** particles representing particle started at foil as H^-, **Blue** H^0 and Green as lost particles in the flight tube.