RELATIVISTIC HEAVY IONS

FROM

BNL--44606

THE BNL BOOSTER

DE90 011122

FOR

MEDICAL RESEARCH

AND

TECHNOLOGICAL APPLICATIONS

BY

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Compatibility of Primary and Time-Sharing Booster Beams for Medical Research and Technological Applications

Introduction

The BNL Booster, now nearing completion, was designed to inject protons and heavy ions into the Alternating Gradient Synchrotron (AGS) for further acceleration. In the future, ion beams from the AGS will in turn be further accelerated in the Relativistic Heavy Ion Collider (RHIC). Given the wide range of ion masses, energies and beam intensities the Booster will generate, other important applications should be considered. Dedicated use of the Booster for such applications may be possible during limited periods. However shared use would be preferable from the points of view of availability, affordability and efficiency.

While heavy ions of a given isotope are injected into the AGS, the same or other ion species from the Booster could be simultaneously delivered to a new irradiation area for treatment of patients, testing of electronic devices or other applications and research. To generate two different beam species, ion sources on both Tandem accelerators would be used; one for AGS injection and the other one for a time-sharing application. Since the beam transport from the Tandems to the Booster can not be rapidly adjusted, it will be necessary to select beams of identical magnetic rigidity. The present study was performed to determine to what extent this compatibility requirement imposes limitations on the available ion species, energies and/or intensities.

Description of the Tables.

The tables on the following pages summarize the results of this study for a selection of the available beam species. In the first two tables, heavy ion beam parameters are listed for dedicated use. For these cases the accelerating voltages and the selected charge-states can be optimized without the restriction of a given magnetic rigidity.

In the remaining tables, all the typical primary beams listed in the Booster Design Manual are considered, except protons which will not originate at the Tandem and will not be transported through the heavy ion transfer line. The deuteron injection energy has been changed from 30 MeV to 15 MeV which will be required due to radiation safety considerations. For each of these primary beams, possible time-sharing beams are listed having identical magnetic rigidity in the transfer line. The terms used in the tables are explained below:

Q_{TANDEM} : The selected charge-state accelerated in the Tandem.
 V_{TANDEM} : The accelerating voltage of the Tandem in mega volts.
 E_{HITL} : The energy (in mega electron volts) of the beam in the Heavy Ion Transfer Line.
 Q_{HITL} : The charge-state of the ions in the transfer line.
 Q_{BOOSTER} : The charge-state of the ions accelerated in the Booster.
 E_{max}
 "11 Tm" : The maximum Booster accelerated beam energy (in mega electron volts per atomic mass unit) if the present extraction line were used.
 E_{max}
 "17.51 Tm": The maximum Booster accelerated beam energy (in mega electron volts per atomic mass unit) if a new extraction line is installed with a magnetic rigidity matching the Booster ring.

For each beam species in each table, the first or only entry corresponds to choosing charge-states as close as possible to the most abundant ones resulting in the highest possible intensities. For those species listed more than once, subsequent entries show examples of how intensity can be traded off for higher energies. Twenty turn injection was assumed for all beams.

The intensities were estimated adopting a nominal ion-source output of 100 μA for all beams except for iron for which an ion-source output of 8 μA was assumed. In several of these cases there is no experience for pulsed ion-source operation and those estimates are based on DC performance. For some of the beams intensities as high as 200 μA have been produced and it is probable that even higher intensities will result from recent ion-source developments. In addition to the intensity reductions due to stripper efficiencies an overall transmission of 25% was assumed, which includes the Tandem, the transfer line, capture, acceleration, extraction and beam transport to the target.

In all cases, whether solid or gas stripping is used, it was assumed that the stripper thickness is optimized. This can be accomplished for gas strippers by changing the pressure in the stripper canal and for foil strippers by providing a sufficient selection of thicknesses in the foil changer. In those cases for which $Q_{\text{BOOSTER}} > Q_{\text{HITL}}$ a stripper is required close to the Booster injection point. If this stripper is not adequate for the primary beam it will have to be moved in and out of the beam for each cycle. This will be easy to accomplish in time available between pulses.

Conclusions

Comparing ion beam energies and intensities in the "dedicated use" and the "time sharing" tables one finds surprisingly few, and surprisingly minor differences. All pairs of beams are compatible and it is always possible to find charge-state and voltage combinations, in the shared mode, which yield energies and intensities which are not very different from the best possible values. For proton operation of the Booster it should be possible to deliver time-sharing heavy ion beams identical to the ones characterized in the "dedicated use" tables.

The main difference between both operating modes has to do with the available pulse repetition rates. In the dedicated mode, periods as short as 0.8 sec. are possible for some beams, while AGS requirements will lead to periods between 1.6 and 3.5 sec. in the shared mode.

Some of the lighter ions, require Tandem terminal voltages which are below 10 MV. Those beams could be produced in the shared mode before upgrading the first Tandem (MP6). However, the majority of beams requires higher voltages and their shared acceleration must await the upgrading of MP6.

The most significant technical development which will be required to achieve shared mode operation is the implementation of pulse to pulse parameter switching for the Booster. While this is by no means a trivial task it should be pointed out that such systems have been successfully operated for decades at other accelerators. Our modern control system based on much more powerful computers should make the development of such a system relatively straightforward.

This study has shown that shared operation will not only be feasible but that it can be accomplished with great flexibility and without significant compatibility restrictions.

ACKNOWLEDGEMENT

I am grateful to Horst Foelsche for suggesting this study and for helpful discussions.

Booster Beams - Dedicated Use

BEAM	Q _{TANDEM}	V _{TANDEM} (MV)	E _{HITL} (MEV)	Q _{HITL}	Q _{BOOSTER}	E _{max} "11 Tm" (MeV/AMU)	E _{max} "17.5 Tm" (MeV/AMU)	IONS PER PULSE (×10 ⁸)
⁶ C ¹²	5	8	48	6	6	968	1500	99
⁸ O ¹⁶	5	8	48	8	8	968	1500	71
⁹ F ¹⁹	6	8.6	60	9	9	892	1500	70
¹⁴ Si ²⁸	7	8.7	70	12	12	968	1500	44
¹⁵ P ³¹	9	14	140	14	14	921	1500	29
¹⁶ S ³²	9	15	150	15	15	968	1500	29
¹⁷ Cl ³⁵	9	15	150	15	15	927	1500	28
²⁶ Fe ⁵⁶	10	15	165	21	21	866	1248	1.5
²⁹ Cu ⁶³	11	15	180	22	22	854	1127	19
²⁹ Cu ⁶³	11	15	180	24	24	854	1277	6

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Booster Beams - Dedicated Use

BEAM	Q _{TANDEM}	V _{TANDEM} (MV)	E _{HITL} (MEV)	Q _{HITL}	Q _{BOOSTER}	E _{max} "11 Tm" (MeV/AMU)	E _{max} "17.5 Tm" (MeV/AMU)	IONS PER PULSE (×10 ⁸)
³² Ge ⁷⁰	11	15	180	24	24	845	1097	15
³² Ge ⁷⁰	11	15	180	26	26	845	1231	2.8
³⁵ Br ⁷⁹	11	15	180	24	24	806	917	19
³⁵ Br ⁷⁹	12	15	195	27	27	806	1092	2.5
⁵³ I ¹²⁷	12	15	195	30	30	620	620	12
⁵³ I ¹²⁷	12	15	195	33	33	722	722	2.1
⁷⁹ Au ¹⁹⁷	12	15	195	33	33	153	350	12
⁷⁹ Au ¹⁹⁷	13	15	210	38	38	198	445	1.1
⁷⁹ Au ¹⁹⁷	12	15	195	33	33	350		5.8
⁷⁹ Au ¹⁹⁷	13	15	210	38	38	445		0.7

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Compatibility of Primary and Time-Sharing Booster Beams

Primary Tandem Beams: 90 MeV ${}^6\text{C}^{12}$ $Q_{\text{HITL}} = 6$ $B\rho_{\text{HITL}} = 0.7896$
 15 MeV ${}^1\text{H}^2$ $Q_{\text{HITL}} = 1$ $B\rho_{\text{HITL}} = 0.7896$

Available Time-Sharing Beams

BEAM	Q_{TANDEM}	V_{TANDEM} (MV)	E_{HITL} (MEV)	Q_{HITL}	Q_{BOOSTER}	E_{max} "11 Tm" (MeV/AMU)	E_{max} "17.5 Tm" (MeV/AMU)	IONS PER PULSE ($\times 10^8$)
${}^6\text{C}^{12}$	5	15.0	90.0	6	6	968	1500	57
${}^8\text{O}^{16}$	6	9.7	67.6	6	8	968	1500	71
${}^9\text{F}^{19}$	6	8.1	57.0	6	9	892	1500	66
${}^{14}\text{Si}^{28}$	7	6.6	52.7	7	11	968	1334	42
${}^{14}\text{Si}^{28}$	7	6.6	52.7	7	13	968	1500	8.7
${}^{15}\text{P}^{31}$	7	6.0	47.6	7	12	921	1306	37
${}^{15}\text{P}^{31}$	8	6.9	62.1	8	14	921	1500	3.3
${}^{16}\text{S}^{32}$	7	5.8	46.1	7	12	968	1249	41
${}^{16}\text{S}^{32}$	8	6.7	60.2	8	14	968	1500	7.7
${}^{17}\text{Cl}^{35}$	7	5.3	42.1	7	12	927	1097	39
${}^{17}\text{Cl}^{35}$	9	14.5	145.4	13	16	927	1500	6.5
${}^{26}\text{Fe}^{56}$	10	14.1	155.2	17	17	866	916	1.8

Compatibility of Primary and Time-Sharing Booster Beams

Primary Tandem Beams: 90 MeV $^{12}_6\text{C}$ $Q_{\text{HITL}} = 6$ $B\rho_{\text{HITL}} = 0.7896$
 15 MeV ^1_1H $Q_{\text{HITL}} = 1$ $B\rho_{\text{HITL}} = 0.7896$

Available Time-Sharing Beams

BEAM	Q_{TANDEM}	V_{TANDEM} (MV)	E_{HITL} (MEV)	Q_{HITL}	Q_{BOOSTER}	E_{max} "11 Tm" (MeV/AMU)	E_{max} "17.5 Tm" (MeV/AMU)	IONS PER PULSE ($\times 10^8$)
$^{63}_{29}\text{Cu}$	11	14.4	172.3	19	19	854	907	17
$^{63}_{29}\text{Cu}$	12	14.7	190.9	20	25	854	1353	1.1
$^{70}_{32}\text{Ge}$	11	14.3	171.9	20	20	836	836	18
$^{70}_{32}\text{Ge}$	11	14.3	171.9	20	25	845	1164	1.7
$^{79}_{35}\text{Br}$	12	14.2	184.3	22	22	804	804	12
$^{79}_{35}\text{Br}$	12	14.2	184.3	22	26	806	1033	1.6
$^{127}_{53}\text{I}$	12	14.3	185.8	28	28	555	555	13
$^{127}_{53}\text{I}$	13	14.2	199.3	29	31	654	654	1.2
$^{197}_{79}\text{Au}$	10	13.4	146.9	31	31	136	314	12
$^{197}_{79}\text{Au}$	13	14.9	209.2	37	37	188	426	2.9
$^{197}_{79}\text{Au}$	10	13.4	146.9	31	31	314		4.7
$^{197}_{79}\text{Au}$	13	14.9	209.2	37	37	426		1.8

Compatibility of Primary and Time-Sharing Booster Beams

Primary Tandem Beam: 150 MeV $_{16}\text{S}^{32}$

$Q_{\text{HITL}} = 14$

$B\rho_{\text{HITL}} = 0.7126$

Available Time-Sharing Beams

BEAM	Q_{TANDEN}	V_{TANDEN} (MV)	E_{HITL} (MEV)	Q_{HITL}	Q_{BOOSTER}	E_{MAX} "11 Tm" (MeV/AMU)	E_{MAX} "17.5 Tm" (MeV/AMU)	IONS PER PULSE ($\times 10^8$)
$_{6}\text{C}^{12}$	5	8.5	51.0	5	6	968	1500	82
$_{8}\text{O}^{16}$	6	7.9	55.1	6	8	968	1500	63
$_{9}\text{F}^{19}$	6	6.6	46.4	6	9	892	1500	50
$_{14}\text{Si}^{28}$	9	12.6	125.9	12	12	968	1500	21
$_{15}\text{P}^{31}$	9	13.3	133.4	13	13	921	1462	20
$_{16}\text{S}^{32}$	9	15.0	149.9	14	14	968	1500	24
$_{17}\text{Cl}^{35}$	9	13.7	137.1	14	14	927	1368	28
$_{17}\text{Cl}^{35}$	10	14.3	157.3	15	15	927	1500	17
$_{26}\text{Fe}^{56}$	11	14.6	174.9	20	20	866	1277	1.3

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Compatibility of Primary and Time-Sharing Booster Beams

Primary Tandem Beam: 150 MeV $_{16}\text{S}^{32}$

$Q_{\text{HITL}} = 14$

$B\rho_{\text{HITL}} = 0.7126$

Available Time-Sharing Beams

BEAM	Q_{TANDEM}	V_{TANDEM} (MV)	E_{HITL} (MEV)	Q_{HITL}	Q_{BOOSTER}	E_{max} "11 Tm" (MeV/AMU)	E_{max} "17.5 Tm" (MeV/AMU)	IONS PER PULSE ($\times 10^8$)
$_{29}\text{Cu}^{63}$	11	14.3	171.5	21	21	854	1053	16
$_{29}\text{Cu}^{63}$	11	14.3	171.5	21	24	854	1277	1.2
$_{32}\text{Ge}^{70}$	12	14.2	185.1	23	23	845	1031	12
$_{32}\text{Ge}^{70}$	12	14.2	185.1	23	25	845	1164	1.8
$_{35}\text{Br}^{79}$	11	14.9	178.6	24	24	806	917	19
$_{35}\text{Br}^{79}$	11	14.9	178.6	24	26	806	1033	2.2
$_{53}\text{I}^{127}$	11	14.5	173.7	30	30	621	621	11
$_{79}\text{Au}^{197}$	5	10.1	60.3	22	22	71	170	22
$_{79}\text{Au}^{197}$	10	12.3	135.6	33	33	153	350	2.8
$_{79}\text{Au}^{197}$	5	10.1	60.3	22	22	170		3.8
$_{79}\text{Au}^{197}$	10	12.3	135.6	33	33	350		1.4

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Compatibility of Primary and Time-Sharing Booster Beams

Primary Tandem Beam: 180 MeV $_{29}\text{Cu}^{63}$

$Q_{\text{HITL}} = 21$

$B\rho_{\text{HITL}} = 0.7297$

Available Time-Sharing Beams

BEAM	Q_{TANDEM}	V_{TANDEM} (MV)	E_{HITL} (MEV)	Q_{HITL}	Q_{BOOSTER}	E_{MAX} "11 Tm" (MeV/AMU)	E_{MAX} "17.5 Tm" (MeV/AMU)	IONS PER PULSE ($\times 10^8$)
$_{6}\text{C}^{12}$	5	8.9	53.5	5	6	968	1500	97
$_{8}\text{O}^{16}$	6	8.3	57.8	6	8	968	1500	66
$_{9}\text{F}^{19}$	6	7.0	48.7	6	9	892	1500	54
$_{14}\text{Si}^{28}$	8	14.7	132.0	12	12	968	1500	32
$_{15}\text{P}^{31}$	9	14.0	139.9	13	13	921	1461	20
$_{16}\text{S}^{32}$	10	14.3	157.1	14	14	968	1500	12
$_{17}\text{Cl}^{35}$	10	15.0	164.9	15	15	927	1500	18
$_{26}\text{Fe}^{56}$	10	15.0	165.5	19	19	866	1081	1.5
$_{29}\text{Cu}^{63}$	11	15.0	179.8	21	21	854	1053	16
$_{29}\text{Cu}^{63}$	11	15.0	179.8	21	24	854	1500	1.4

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Compatibility of Primary and Time-Sharing Booster Beams

Primary Tandem Beam: 180 MeV $^{63}_{29}\text{Cu}$

$Q_{\text{HITL}} = 21$

$B\rho_{\text{HITL}} = 0.7297$

Available Time-Sharing Beams

BEAM	Q_{TANDEM}	V_{TANDEM} (MV)	E_{HITL} (MEV)	Q_{HITL}	Q_{BOOSTER}	E_{max} "11 Tm" (MeV/AMU)	E_{max} "17.5 Tm" (MeV/AMU)	IONS PER PULSE ($\times 10^8$)
$^{70}_{32}\text{Ge}$	11	14.8	177.6	22	22	845	965	15
$^{70}_{32}\text{Ge}$	11	14.8	177.6	22	25	845	1164	1.6
$^{79}_{35}\text{Br}$	12	14.4	187.3	24	24	806	917	13
$^{79}_{35}\text{Br}$	12	14.4	187.3	24	26	806	1033	1.7
$^{127}_{53}\text{I}$	12	15.0	194.5	31	31	654	654	9.0
$^{127}_{53}\text{I}$	12	15.0	194.5	31	33	722	722	0.3
$^{197}_{79}\text{Au}$	9	8.2	81.6	25	25	90	214	19
$^{197}_{79}\text{Au}$	10	12.9	142.1	33	33	153	350	7.2
$^{197}_{79}\text{Au}$	10	12.9	142.1	33	33	350		3.6

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Compatibility of Primary and Time-Sharing Booster Beams

Primary Tandem Beam: 210 MeV $_{53}\text{I}^{127}$

$Q_{\text{HITL}} = 29$

$B\rho_{\text{HITL}} = 0.8103$

Available Time-Sharing Beams

BEAM	Q_{TANDEM}	V_{TANDEM} (MV)	E_{HITL} (MEV)	Q_{HITL}	Q_{BOOSTER}	E_{max} "11 Tm" (MeV/AMU)	E_{max} "17.5 Tm" (MeV/AMU)	IONS PER PULSE ($\times 10^8$)
$_{6}\text{C}^{12}$	5	11.0	65.9	5	6	968	1500	84
$_{8}\text{O}^{16}$	6	10.2	71.2	6	8	968	1500	71
$_{9}\text{F}^{19}$	6	8.6	60.0	6	9	892	1500	70
$_{14}\text{Si}^{28}$	8	8.0	72.4	8	12	968	1500	23
$_{15}\text{P}^{31}$	7	6.3	50.1	7	12	921	1306	40
$_{15}\text{P}^{31}$	9	8.3	82.8	9	14	921	1500	4.2
$_{16}\text{S}^{32}$	7	6.1	48.5	7	13	966	1398	28
$_{16}\text{S}^{32}$	8	7.0	63.4	8	14	966	1500	9.0
$_{17}\text{Cl}^{35}$	7	5.6	44.4	7	13	926	1232	23
$_{17}\text{Cl}^{35}$	8	6.4	57.9	8	15	926	1500	3.4
$_{26}\text{Fe}^{56}$	10	14.8	163.4	17	17	866	916	1.6

Compatibility of Primary and Time-Sharing Booster Beams

Primary Tandem Beam: 210 MeV $_{53}\text{I}^{127}$

$Q_{\text{HITL}} = 29$

$B\rho_{\text{HITL}} = .8103$

Available Time-Sharing Beams

BEAM	Q_{TANDEM}	V_{TANDEM} (MV)	E_{HITL} (MEV)	Q_{HITL}	Q_{BOOSTER}	E_{max} "11 Tm" (MeV/AMU)	E_{max} "17.5 Tm" (MeV/AMU)	IONS PER PULSE ($\times 10^8$)
$_{29}\text{Cu}^{63}$	11	15.2	181.8	19	19	854	907	17
$_{29}\text{Cu}^{63}$	11	15.2	181.8	19	23	854	1202	3.5
$_{32}\text{Ge}^{70}$	11	15.1	181.0	20	20	836	836	17
$_{32}\text{Ge}^{70}$	11	15.1	181.0	20	24	845	1097	3.7
$_{35}\text{Br}^{79}$	12	14.9	194.1	22	22	804	804	14
$_{35}\text{Br}^{79}$	12	14.9	194.1	22	25	805	975	3.2
$_{53}\text{I}^{127}$	13	15.0	209.9	29	29	587	587	10
$_{53}\text{I}^{127}$	13	15.0	209.9	29	31	654	654	1.6
$_{79}\text{Au}^{197}$	11	12.9	154.7	31	31	136	314	13
$_{79}\text{Au}^{197}$	13	14.9	208.6	36	36	179	407	4.6
$_{79}\text{Au}^{197}$	11	12.9	154.7	31	31	314		5.2
$_{79}\text{Au}^{197}$	13	14.9	208.6	36	36	407		3.0

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Compatibility of Primary and Time-Sharing Booster Beams

Primary Tandem Beam: 210 MeV $^{197}_{79}\text{Au}$

$Q_{\text{HITL}} = 33$

$B\rho_{\text{HITL}} = 0.88695$

Available Time-Sharing Beams

BEAM	Q_{TANDEM}	V_{TANDEM} (MV)	E_{HITL} (MEV)	Q_{HITL}	Q_{BOOSTER}	E_{max} "11 Tm" (MeV/AMU)	E_{max} "17.5 Tm" (MeV/AMU)	IONS PER PULSE ($\times 10^8$)
$^6\text{C}^{12}$	5	13.2	78.9	5	6	968	1500	69
$^8\text{O}^{16}$	6	12.2	85.3	6	8	968	1500	70
$^9\text{F}^{19}$	6	10.3	71.9	6	9	892	1500	73
$^{14}\text{Si}^{28}$	8	9.6	86.7	8	12	968	1500	29
$^{15}\text{P}^{31}$	8	8.7	78.4	8	13	921	1459	29
$^{15}\text{P}^{31}$	9	9.9	99.1	9	15	921	1500	3.4
$^{16}\text{S}^{32}$	8	8.4	75.9	8	14	967	1500	20
$^{16}\text{S}^{32}$	9	9.6	96.0	9	15	967	1500	7.1
$^{17}\text{Cl}^{35}$	8	7.7	69.4	8	14	926	1365	24
$^{17}\text{Cl}^{35}$	9	8.8	87.8	9	16	926	1500	2.1
$^{26}\text{Fe}^{56}$	11	14.5	173.4	16	16	836	836	1.3

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Compatibility of Primary and Time-Sharing Booster Beams

Primary Tandem Beam: 210 MeV $^{197}_{79}\text{Au}$ $Q_{\text{HITL}} = 33$ $B\rho_{\text{HITL}} = 0.88695$

Available Time-Sharing Beams

BEAM	Q_{TANDEM}	V_{TANDEM} (MV)	E_{HITL} (MEV)	Q_{HITL}	Q_{BOOSTER}	E_{max} "11 Tm" (MeV/AMU)	E_{max} "17.5 Tm" (MeV/AMU)	IONS PER PULSE ($\times 10^8$)
$^{63}_{29}\text{Cu}$	11	14.5	174.1	17	17	763	763	17
$^{63}_{29}\text{Cu}$	11	14.5	174.1	17	22	854	1125	4.6
$^{70}_{32}\text{Ge}$	12	15.1	195.7	19	19	771	771	12
$^{70}_{32}\text{Ge}$	12	15.1	195.7	19	24	845	1095	2.9
$^{79}_{35}\text{Br}$	12	14.8	192.2	20	20	692	692	13
$^{79}_{35}\text{Br}$	12	14.8	192.2	20	25	806	973	3.0
$^{127}_{53}\text{I}$	12	14.4	186.9	25	25	460	460	13
$^{127}_{53}\text{I}$	12	14.4	186.9	25	30	620	620	2.3
$^{197}_{79}\text{Au}$	13	15.0	210.0	33	33	153	350	9.1
$^{197}_{79}\text{Au}$	16	14.7	250.0	36	36	179	407	1.3
$^{197}_{79}\text{Au}$	13	15.0	210.0	33	33	350		4.6
$^{197}_{79}\text{Au}$	16	14.7	250.0	36	36	407		0.8

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Compatibility of Primary and Time-Sharing Booster Beams

Primary Tandem Beam: 210 MeV $^{197}_{79}\text{Au}$

$Q_{\text{HITL}} = 13$

$B\rho_{\text{HITL}} = 2.2515$

Available Time-Sharing Beams

BEAM	Q_{TANDEM}	V_{TANDEM} (MV)	E_{HITL} (MEV)	Q_{HITL}	Q_{BOOSTER}	E_{max} "11 Tm" (MeV/AMU)	E_{max} "17.5 Tm" (MeV/AMU)	IONS PER PULSE ($\times 10^8$)
$^6\text{C}^{12}$	1	10.2	20.4	1	6	968	1500	56
$^8\text{O}^{16}$	1	7.6	15.3	1	6	968	1248	52
$^8\text{O}^{16}$	1	7.6	15.3	1	7	968	1500	45
$^9\text{F}^{19}$	1	6.4	12.9	1	7	892	1217	54
$^9\text{F}^{19}$	1	6.4	12.9	1	8	892	1469	11
$^{14}\text{Si}^{28}$	2	11.7	35.0	2	10	968	1164	37
$^{14}\text{Si}^{28}$	2	11.7	35.0	2	12	968	1500	10
$^{15}\text{P}^{31}$	2	10.5	31.6	2	11	921	1154	38
$^{15}\text{P}^{31}$	2	10.5	31.6	2	13	921	1462	2.5
$^{16}\text{S}^{32}$	2	10.2	30.6	2	11	968	1101	42
$^{16}\text{S}^{32}$	2	10.2	30.6	2	13	968	1398	4.6
$^{17}\text{Cl}^{35}$	2	9.3	28.0	2	11	927	965	46
$^{17}\text{Cl}^{35}$	2	9.3	28.0	2	13	927	1232	7.6

Compatibility of Primary and Time-Sharing Booster Beams

Primary Tandem Beam: 210 MeV $^{79}\text{Au}^{197}$

$Q_{\text{HITL}} = 13$

$B\rho_{\text{HITL}} = 2.2515$

Available Time-Sharing Beams

BEAM	Q_{TANDEM}	V_{TANDEM} (MV)	E_{HITL} (MEV)	Q_{HITL}	Q_{BOOSTER}	E_{MAX} "11 Tm" (MeV/AMU)	E_{MAX} "17.5 Tm" (MeV/AMU)	IONS PER PULSE ($\times 10^8$)
$^{26}\text{Fe}^{56}$	4	14.0	69.9	4	17	866	916	2.3
$^{29}\text{Cu}^{63}$	4	12.4	62.2	4	18	835	835	28
$^{29}\text{Cu}^{63}$	4	12.4	62.2	4	20	854	980	5.7
$^{32}\text{Ge}^{70}$	5	14.6	87.4	5	21	845	900	21
$^{32}\text{Ge}^{70}$	5	14.6	87.4	5	23	845	1031	3.6
$^{35}\text{Br}^{79}$	5	12.9	77.5	5	21	748	748	24
$^{35}\text{Br}^{79}$	5	12.9	77.5	5	23	806	860	4.6
$^{53}\text{I}^{127}$	8	13.7	123.3	8	26	491	491	18
$^{53}\text{I}^{127}$	8	13.7	123.3	8	29	588	588	4.2
$^{79}\text{Au}^{197}$	13	15.0	210.0	13	34	161	369	9.1
$^{79}\text{Au}^{197}$	13	15.0	210.0	13	38	198	445	1.1
$^{79}\text{Au}^{197}$	13	15.0	210.0	13	34	369		4.6
$^{79}\text{Au}^{197}$	13	15.0	210.0	13	38	445		0.7

COMPARISON OF DEDICATED USE AND WORST-CASE SHARED USE

B E A M	DEDICATED USE		SHARED WORST-CASE ENERGIES			SHARED WORST-CASE INTENSITIES		
	ENERGY (MeV/AMU)	INTENSITY $\times 10^8$ _{ppp}	ENERGY (MeV/AMU)	INTENSITY $\times 10^8$ _{ppp}	PRIMARY BEAM	ENERGY (MeV/AMU)	INTENSITY $\times 10^8$ _{ppp}	PRIMARY BEAM
${}_6\text{C}^{12}$	1500	99	1500	56	Au ₁₃₊	1500	56	Au ₁₃₊
${}_8\text{O}^{16}$	1500	71	1500	52	Au ₁₃₊	1500	52	Au ₁₃₊
${}_9\text{F}^{19}$	1500	70	1217	54	Au ₁₃₊	1500	50	S
${}_{14}\text{Si}^{28}$	1500	44	1164	37	Au ₁₃₊	1500	21	S
${}_{15}\text{P}^{31}$	1500	29	1154	38	Au ₁₃₊	1500	20	S
${}_{16}\text{S}^{32}$	1500	29	1249	41	C	1500	12	Cu
${}_{17}\text{Cl}^{35}$	1500	28	965	46	Au ₁₃₊	1500	18	Cu
${}_{26}\text{Fe}^{56}$	1248	1.5	836	1.3	Au ₃₃₊	836	1.3	Au ₃₃₊
${}_{29}\text{Cu}^{63}$	1127	19	763	17	Au ₃₃₊	1053	16	S
${}_{32}\text{Ge}^{70}$	1097	15	771	12	Au ₃₃₊	771	12	Au ₃₃₊
${}_{35}\text{Br}^{79}$	917	19	692	13	Au ₃₃₊	804	12	C
${}_{53}\text{I}^{127}$	620	12	460	13	Au ₃₃₊	654	9.0	Cu
${}_{79}\text{Au}^{197}$	350	12	170	22	S	350	12	Au ₃₃₊

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