BROOKHAVEN NATIONAL LABORATORY
Associated Universities, Inc.
Upton, New York

ACCELERATOR DEPARTMENT
Informal Report

UPDATED LIST OF PARAMETERS FOR ISABELLE

R.W. Chasman, E.D. Courant,

M. Month, A. vanSteenbergen

February 8, 1972

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Accelerator Department
BROOKHAVEN NATIONAL LABORATORY
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CRISP 72-5
ISABELLE PROJECT

INTERSECTING STORAGE ACCELERATOR NOTES

UPDATED LIST OF PARAMETERS FOR ISABELLE

R.W. Chasman, E.D. Courant, M. Month, A. van Steenberg
February 8, 1972

General

Ring arrangement	Two interlaced racetracks, each consisting of two half circles with a regular lattice structure and two long experimental straight sections. Orbits in the regular lattice separated by 0.4 m in the vertical plane.
Magnet system	Superconducting magnets
Average radius, curved section	220.06 m
Experimental insertion length	300.0 m
Total circumference	2017.77 m ($2.5 \times C_{\text{AGS}}$)
Proton energy, each ring	200 BeV
Injector	AGS
Injection energy	30 BeV
Acceleration time	120 sec
Stacked protons, each ring	6×10^{14} protons
Optimum luminosity, L' (high luminosity insertion I, $\beta_v = 0.83$ m, $\beta_h = 0.63$ m, un- bunched beam)	$0.9 \times 10^{34} \text{ (cm}^{-2} \text{ sec}^{-1})/\text{m}$
$L_{\text{tot}} = \int L' ds$	$2 \times 10^{34} \text{ (cm}^{-2} \text{ sec}^{-1})$
Luminosity improvement factor, for bunched beam	2.3

General Ring Arrangement

Fig. 1

ISABELLE

Regular Lattice Structure

Cell structure

Separated function, FoDo

Regular lattice, number of cells

52

Cell length

22.6 m

Normal cell structure

$(QHF/2)L(B)s(B)s(B)s(QHD)L(B)s(B)s(B)s(QHF/2)$

Cell components

LB = 2.9 m

LQHF = LQHD = 1.0 m

Straight sections

$L = 1.0$ m, $s = 0.2$ m

Orbit Parameters ("18.25 lattice")

Maximum dipole field, $\hat{B}$

40.32 kG

Regular lattice quadrupole gradient, QHF

901.9 kG/m

QHD

862.3 kG/m

Betatron oscillation wave number, ν_x

18.26

ν_y

18.25

Phase advance per cell, $\Delta\psi_x$

0.267 (2π)

$\Delta\psi_y$

0.247 (2π)

Phase advance per long "insertion" $\Delta\psi_{x,ins.}$

1.446 (2π)

$\Delta\psi_{y,ins.}$

0.919 (2π)

Phase advance per short "insertion" $\Delta\psi_{x,ins.}$

0.391 (2π)

$\Delta\psi_{y,ins.}$

0.915 (2π)

Fig. 2, Betatron oscillation functions β_x , β_y ; momentum function X_p , in a regular cell.

Transition energy, γ_{tr}	18.03
Betatron function and momentum compaction function, regular cell	See Fig. 1
Maximum values, regular cell, β_H	38.29 m
β_V	38.84 m
X_p (per $\Delta p/p$)	1.45 m
Bend angle, per cell	0.1047 rad.
Bend angle, per magnet	0.0174 rad.
Dipole magnet, magnetic radius, ρ_B	166.2 m
$(B\rho)_{max}$	6.7025 10^3 kG-m

Beam Transfer Parameters

Transfer energy	30 BeV
AGS beam intensity	2×10^{13} protons per pulse
AGS* transverse phase space, 30 GeV	$A_{2V} \times A_{2H} = 0.4\pi \times 3.0\pi (\mu\text{rad-m})^2$
* longitudinal phase space, 30 GeV	0.345 eV-sec (per bunch)
* momentum spread, $(\Delta p/p)(95\%)$	$\pm 0.58 \cdot 10^{-3}$
* final rf frequency	4.45 MHz
AGS harmonic number, h	12
orbital frequency	371 KHz
revolution period	2.70 μsec
bunching factor, $\bar{B}$	0.043
phase width, $\delta\phi$	$\pm 0.17 (\pm 9.8^\circ)$
bunch length	12.3 nsec or 3.65 m

* Parameters prior to beam manipulation for transfer.

Transfer mode	Debunch adiabatically 12 AGS bunches, rebunch in AGS to single bunch with 1 ⁰ & 3 ⁰ harm., fast single turn ejection, "fast", bunched, storage ring injection.
Stacking mode	Fill each storage ring azimuthally, in box car fashion, with 30 AGS "single" bunches.
AGS, longitudinal phase space, single bunch, after beam manipulation [†]	7.6 eV-sec (dilution factor 1.8)
momentum spread, $(\Delta p/p)'$ (95%)	$\pm 2.46 \cdot 10^{-3}$
final rf frequency, "sawtooth" fundamental	371 KHz
harmonic number, h'	1
phase width, $(\delta\varphi)'$	$\pm 0.123 (\pm 7.06^0)$
bunch length	102 nsec or 30.3 m
Storage ring	4.45 MHz
orbital length	2017.77 m
orbital frequency	148.3 KHz ($\tau_{orb} = 6.75 \mu\text{sec}$)
harmonic number, h''	30
bunch width, $(\delta\varphi)''$	$\pm 1.476 (\pm 84.72^0)$
acceleration time	120 sec ($\dot{B} = 0.03 \text{ T/sec}$)
rf voltage	$V_{rf} = 50 \text{ kV}$, $\sin \varphi_s = 0.20$, $\varphi_s = 12^0$
Beam emittance, after injection, Phase I [‡]	$A_{2V} \times A_{2H} = 3.75\pi \times 0.5\pi (\mu\text{rad-m})^2$
, Phase II	$A_{2V} \times A_{2H} = 0.5\pi \times 3.75\pi (\mu\text{rad-m})^2$
Injection dipole field, B_{inj}	6.20 kG

[†]Longitudinal phase space, elliptical boundary, $\cong 12.1 \text{ eV-sec}$ (effective dilution factor 2.8).

[‡]Dilution factor, related to transfer component errors, assumed. Phase I involves transverse phase space interchange in 30 GeV transfer line.

Magnet Aperture Subdivision For the Regular Lattice Structure

The parameters below are based on transverse phase space interchange in the 30 GeV beam transfer line. This may be subsequently eliminated, in a Phase II mode of operation, in order to further increase the luminosity of the intersecting beams for specific crossing modes.

$$\text{Beam emittance, after injection } A_{2V} \times A_{2H} = 3.75\pi \times 0.5\pi (\mu\text{rad-m})^2$$

$$\text{Beam momentum spread, } (\Delta p/p) (95\%) = \pm 2.5 \cdot 10^{-3}$$

Aperture Subdivision (half aperture values in mm)	Vertical	Horizontal
Beam betatron amplitude	12.1	4.4
Phase oscillation amplitude, X_p ($\Delta p/p$)	-	3.6
Sagitta	-	3.1
Closed orbit error*	7.3	8.2
Dipole alignment tolerance	1.0	1.0
Reserve	4.6	4.7
<hr/>		
Half aperture, total (mm)	25.0	25.0
<hr/>		
Full vacuum chamber aperture (cm)	5	5
<hr/>		
Cos θ dipole winding, ID (cm)	8	
"Good field" aperture [†] , 60% (cm)	4.8	

* As a start-up mode lower intensity injection will be assumed using a fraction of the transverse phase space and longitudinal phase space populations only, allowing thereby initially larger closed orbit error values by a factor of 2.

[†] Presently defined, as stated by G. Parzen: The field satisfies, within the vacuum chamber aperture, $B = B_0 (1 + a_2 x^2 + a_4 x^4)$, with $a_2 \leq 0.5 \times 10^{-3}/\text{inch}^2$ and $a_4 \leq 0.3 \times 10^{-3}/\text{inch}^4$.

INJECTION STRAIGHT SECTION PARAMETERS*

General arrangement, β functions and local momentum function, See Fig. 3.

Component Parameters

<u>Q Unit</u>	<u>B Unit</u>	<u>L(m)</u>	<u>B' (kG/m)</u>	<u>B(kG)</u>	<u>Aperture(cm)</u>
QHD, insertion part		0.8 ²	- 920		5
	BK	1		2	2 x 4
Q1 = Q8		0.2	- 775		3
	B1,2=B5,6	2.9		40.32	5
	B3=B4	2.9			6
Q2 = Q7		2.9	+ 988		5
Q3 = Q6		2.9	-1076		6
Q4 = Q5		1.4	+ 850		6

* This intermediate length insertion is presently being used only for injection, rf cavities, etc. It is intended to modify the ISABELLE structure by increasing the length of these (4) insertions (possibly at the cost of some length in the long interaction insertions) in order to provide for additional interaction regions and an adequate straight section for the protective fast extraction system, which is now combined in the West Area, (high luminosity) insertion.

Fig. 3 Injection Straight Section

LONG STRAIGHT SECTION PARAMETERS

Straight Section I (High Luminosity Section)

General arrangement, β functions and local momentum function, see Fig. 4.

Long straight section option Ib (high luminosity mode).

Interaction region parameters: Collinear region

$$\check{\beta}_h = 0.63 \text{ m} ; \check{\beta}_v = 0.83 \text{ m}$$

$$\alpha_h = \alpha_v = X_p = X'_p = 0$$

Emittance at 200 BeV: $A_{2v} \times A_{2h} = 0.56\pi \times 0.076\pi (\mu\text{rad-m})^2$

beam size half values $v \times h = 0.70 \times 0.22 (\text{mm})^2$

half divergences $\Delta v' \times \Delta h' = 838 \times 352 (\mu\text{rad})^2$.

Luminosity ($6 \cdot 10^{14}$ pr/ring; 200 BeV; debunched beam):

$$L' = 9.6 \cdot 10^{33} (\text{cm}^{-2} \text{sec}^{-1} / \text{m})$$

$$^{\dagger} L_{\text{tot}} = \int L' ds = 2.2 \cdot 10^{34} (\text{cm}^{-2} \text{sec}^{-1})$$

$$^{\dagger} L_{\text{interaction}} (80\% \text{ domain}) = 4.5 (\text{m}) [\cong 6 \beta_0]$$

† Luminosity improvement factor for bunched beam: 2.3

Component Parameters*

Q	L	B'	Apert.	$\hat{B}$	B	L	$\hat{B}$	Apert.	$\cong \alpha$
Unit	(m)	kG/m	cm	(10^4 kG)	Unit	(m)	kG	cm	mrads
1=14**	1.06	+902	5	22.5	1=24(hb)***	2.9	40.3	5	17.2
2=13	1	-732	8	30	2=23 -	-	-	-	-
3=12	2	+733	-	-	3=22 -	-	-	-	-
4=11	1	-732	-	-	4=21 -	-	-	-	-
5=10	2	+501	20	50	5=20 -	-	-	-	-
6=9	4	-474	-	-	6=19 -	-	-	-	-
7=8	2	+501	-	-	7=18(vb)*	3.0	40.3	12.5	18
					8=17(vs)	-	-	20	-
					9=16(hs)	3.3	40.3	20	20
					10=15(hb)	-	-	-	-
					11=14(hb)	-	-	-	-
					12=13(hs)	-	-	-	-

* Note, only splitter magnets (designated hs, vs, resp.) are common to both beam lines.

** Includes "half" quadrupole length of a regular cell.

*** hb, vb: horizontal, vertical bend, resp.; hs, vs: horizontal, vertical switching magnet, resp.; vb*: vertical (2 channel) splitter magnet.

† However, see Appendix for limitations.

Fig. 4 Experimental Insertion WA I (High Luminosity Domain)

Long straight section option Ia ("start-up" parameters).

For β function and local momentum function, see Fig. 4. The luminosity and beam size parameters are approximately equal to that of Case III, below.

Component Parameters

<u>Q</u>	<u>L</u>	<u>B'</u>	<u>B</u>	<u>L</u>	<u>$\hat{B}$</u>	<u>$\cong \alpha$</u>
<u>Unit</u>	<u>(m)</u>	<u>kG/m</u>	<u>Unit</u>	<u>(m)</u>	<u>kG</u>	<u>mrad</u>
1=14	1.06	+902	1=24(hb)	2.9	40.3	17.2
2=13	1	-954	2=23 -	-	-	-
3=12	2	+961	3=22 -	-	-	-
4=11	1	-954	4=21 -	-	-	-
5=10	1	+910	5=20 -	-	-	-
6=9	2	-865	6=19 -	-	-	-
7=8	1	+910	7=18(vb)*	3.0	40.3	18
			8=17(vs)	-	-	-
			9=16(hs)	3.3	40.3	20
			10=15(hb)	-	-	-
			11=14(hb)	-	-	-
			12=13(hs)	-	-	-

Straight Section II (Typical, "Small Angle Scattering")

General arrangement, β functions and local momentum function, see Fig. 5.

Interaction region parameters: Collinear region

$$\beta_h = 1000 \text{ m} ; \beta_v = 1000 \text{ m}$$

$$\alpha_h = \alpha_v = X_p = X'_p = 0$$

$$\text{Emittance at 200 BeV: } A_{2v} \times A_{2h} = 0.56\pi \times 0.076\pi (\mu\text{rad-m})^2$$

$$\text{beam size half values } v \times h = 24.1 \times 8.6 (\text{mm})^2$$

$$\text{half divergences } \Delta v' \times \Delta h' = 24 \times 8.9 (\mu\text{rad})^2$$

Luminosity ($6 \cdot 10^{14}$ pr/ring; 200 BeV; debunched beam):

$$L' = 0.6 \cdot 10^{31} (\text{cm}^{-2} \text{sec}^{-1} / \text{m})$$

$${}^{\dagger} L_{\text{tot}} = \int L' ds = 1.3 \cdot 10^{31} (\text{cm}^{-2} \text{sec}^{-1})$$

$${}^{\dagger} l_{\text{interact}} = \text{free space between triplet} = 2 \text{ m}$$

† Luminosity improvement factor for bunched beam: 2.3

† See Appendix for limitations.

Fig. 5 Experimental Insertion EA II

Beam size at detector location (90 m, 210 m)

$$\beta_h = 3.24 \text{ m} ; \beta_v = 3.16 \text{ m}$$

$$\text{beam size half values } v \times h = 1.35 \times 0.52 \text{ (mm)}^2$$

$$X_p = 0.4 \text{ m}$$

Component Parameters

Q	L	B'	B	L	$\hat{B}$	$\cong \alpha$
Unit	(m)	kG/m	Unit	(m)	kG	mrads
1=20	1.06	+902	1=24(hb)	2.9	40.3	17.2
			2=23 -	-	-	-
2=19	1	-926	3=22 -	-	-	-
3=18	2	+880	4=21 -	-	-	-
4=17	1	-926	5=20 -	-	-	-
			6=19 -	-	-	-
5=16	1	+953				
6=15	2	-907	7=18(vb)	3.3	40.3	18
7=14	1	+953	8=17(vs)	-	-	-
(c) 8=13	1	+594	9=16(hs)	3.3	40.3	20
(c) 9=12	2	-594	10=15(bb)	-	-	-
(c) 10=11	1	+594	11=14(bb)	1.3	-	8
			12=13(hs)	-	-	-

Note, in addition to splitter magnets, the quadrupole units designated by (c) are common elements to both beams.

Straight Section III (Typical, "Large Angle Scattering")

General arrangement, β function and local momentum function, see Fig. 6.

Interaction region parameters: Collinear region

$$\beta_h = 6.30 \text{ m} ; \beta_v = 8.43 \text{ m}$$

$$\alpha_h = \alpha_v = X_p = X'_p = 0$$

$$\text{Emittance at 200 BeV: } A_{2v} \times A_{2h} = 0.56\pi \times 0.076\pi \text{ (}\mu\text{rad-m)}^2$$

$$\text{beam size half values } v \times h = 2.2 \times 0.7 \text{ (mm)}^2$$

$$\text{half divergences } \Delta v' \times \Delta h' = 265 \times 111 \text{ (}\mu\text{rad)}^2$$

Fig. 6 Experimental Insertion EA III

Luminosity:

$$L' = 0.9 \times 10^{33} \text{ (cm}^{-2} \text{sec}^{-1} \text{/m)}$$

$$^{\dagger} L = 2.0 \times 10^{34} \text{ (cm}^{-2} \text{sec}^{-1} \text{)}$$

$$^{\dagger} l_{\text{interaction}} (80\% \text{ domain}) \cong 4.5 \text{ m}$$

† Luminosity improvement factor for bunched beam: 2.3

Component Parameters

<u>Q</u>	<u>L</u>	<u>B'</u>	<u>B</u>	<u>L</u>	<u>$\frac{\Delta B}{B}$</u>	<u>$\cong \alpha$</u>
<u>Unit</u>	<u>(m)</u>	<u>kG/m</u>	<u>Unit</u>	<u>(m)</u>	<u>kG</u>	<u>mrاد</u>
1=14	1.06	+902	1=24(hb)	2.9	40.3	17.2
2=13	1	-623	2=23 -	-	-	-
3=12	2	+614	3=22 -	-	-	-
4=11	1	-623	4=21 -	-	-	-
5=10	1	+710	5=20 -	-	-	-
6=9	2	-686	6=19 -	-	-	-
7=8	1	-710	7=18(vb)	3.0	40.3	18
			8=17(vs)	-	-	-
			9=16(hs)	3.5	40.3	25
			10=15(hb)	3.0	-	16
			11=14(hb)	3.0	-	16
			12=13(hs)	1.5	-	7

Straight Section IV (Double Crossing Mode)

For β function and local momentum function, see Fig. 7.

Interaction region parameters: 40 mrad horizontal crossing

$$\beta_x = 2 \text{ m}, \beta_y = 4.7 \text{ m}$$

$$\alpha_h = \alpha_v = x_p = x'_p = 0$$

Emittance at 200 BeV: $A_{2v} \times A_{2h} = 0.56\pi \times 0.076\pi \text{ (}\mu\text{rad-m)}^2$

beam size half values $v \times h = 1.6 \times 0.4 \text{ (mm)}^2$

half divergences $\Delta v' \times \Delta h' = 340 \times 200 \text{ (}\mu\text{rad)}^2$

Luminosity - 6×10^{14} pr/ring, 200 BeV, debunched beam

$$L = 0.4 \times 10^{32} \text{ (cm}^{-2} \text{sec}^{-1} \text{)}$$

Luminosity improvement factor for bunched beam: 2.3

† See Appendix for limitations.

Component Parameters

<u>Q</u> <u>Unit</u>	<u>L</u> <u>(m)</u>	<u>B'</u> <u>kG/m</u>
1=20	1.06	+902
2=16	1	-1247
3=15	2	+1013
4=14	1	-1247
5=13	1	+1045
6=12	2	-1052
7=11	1	+1045
8=10	1	+997
9	2	-1036

<u>B</u> <u>Unit</u>	<u>L</u> <u>(m)</u>	<u>B</u> <u>kG</u>	<u>$\cong \alpha$</u> <u>mrads</u>
1=24(hb)	2.9	40.3	17.2
2=23 -	-	-	-
3=22 -	-	-	-
4=21 -	-	-	-
5=20 -	-	-	-
6=19 -	-	-	-
7=18(vb)	3.0	40.3	18
8=17(vs)	-	-	-
9=16(hs)	2.8	40.3	20
10=15(hb)	-	-	20
11=14(hb)	-	-	20
12=13(hb)	-	-	20

Fig. 7 Experimental Insertion EA IV

Appendix

In the foregoing, luminosity values have been calculated using the following simplified formulae, applicable for two intersecting beams, each of a cross section $2a$ (full horizontal beam width) by $2b$ (full vertical beam height), and homogeneous particle density distribution within the beam cross section:

The luminosity of the intersecting beams is defined by the expression for the interaction rate for a particular nuclear event, with cross section σ_{event} ,

$$N_{\text{IR}} = L \sigma_{\text{event}}.$$

The luminosity^{*} is given by

$$L = \frac{c}{2b \sin \alpha / 2} \left(\frac{N_{\text{st}}}{C} \right)^2 \text{ where } (N_{\text{st}}/C) \text{ is the line current den-}$$

sity in each ring, C = circumference, c the velocity of light and α the crossing angle.

For the collinear crossing regions the expression for the specific luminosity is used:

$$L' = \frac{L}{l_i} = \frac{2c}{(2a)(2b)} \left(\frac{N_{\text{st}}}{C} \right)^2.$$

Using the β function relationship for a free straight section, $\beta = \beta_0 + s^2/\beta_0$ and assuming $\beta_x = \beta_0$, $\beta_y = \beta_0$ at $s = 0$ (center of interacting beams domain) and further, in the domain $|s| < 5 \beta_0$, $\beta_x \cong \beta_y$ then $L'(s) \propto (1 + t^2)^{-1}$ where $t = (s/\beta_0)$, consequently:

$$\text{Total luminosity, unbunched beam, } L_{\text{tot}} = \int_{-\infty}^{+\infty} L' ds = \pi \beta_0 L'(0).$$

However, this must be modified by the following considerations:

Beam-beam interactions will limit the maximum luminosity obtainable. The shift of betatron tune ν in one beam due to the other beam must be less than some maximum allowable limit $\Delta \nu_0$ which probably lies between 0.01 and 0.025.

*For horizontal crossing.

The relation between Δv and luminosity is

$$\frac{\Delta v}{L} = \frac{4\pi R}{c} \frac{r_o}{\gamma N} \langle \beta \rangle_{\text{eff}}$$

where $\langle \beta \rangle$ is the average beta function over the interaction region. Numerically, with present parameters, and taking $\Delta v_o = .025$, this limits L to

$$L \leq \frac{1.6 \times 10^{34}}{\langle \beta \rangle_{\text{eff}}}$$

with $\langle \beta \rangle$ in meters; if $\Delta v_o = .01$ this becomes $0.6 \times 10^{34} / \langle \beta \rangle_{\text{eff}}$. $\langle \beta \rangle$ is obtained by integrating over the whole common beam region and becomes infinite if the beams do not separate. Therefore, this means that strictly collinear geometry is not permissible; in the "collinear" sections a minimum crossing angle is required; further, the "effective" interaction length is limited in all cases to $\ell_{\text{interaction}} = 2.4$ m. (This length depends on the emittance of the beam but not on the particular straight section parameters.)

In the following the maximum attainable luminosities, the effective interaction lengths and the corresponding minimum crossing angles are tabulated for the various straight section configurations.

<u>Geometry</u>	β_o	L_{max}	α_{min}
Ib	0.7 m	2.3×10^{34}	0.09 mrad
Ia	7 m	2.3×10^{33}	0.3 mrad
II	1000 m	1.6×10^{31}	3.2 mrad
III	7 m	2.3×10^{33}	0.3 mrad
IV	3 m	5.4×10^{33}	0.2 mrad

If the beam is bunched, the specific luminosity L' is increased by a factor of 2.3, but the maximum luminosity is unchanged; therefore the interaction region must be shortened and the intersection angle increased by the factor 2.3.