BNL-101551-2014-TECH

RHIC/PG/8;BNL-101551-2013-IR

Accelerator Physics Project Review On The November 23, 1983 Meeting

A. G. Ruggiero

November 1983

Collider Accelerator Department

Brookhaven National Laboratory

U.S. Department of Energy

USDOE Office of Science (SC)

DISCLAIMER

RHIC-PG-8

ACCELERATOR PHYSICS PROJECT REVIEW ON THE NOVEMBER 23, 1983 MEETING

A. G. RUGGIERO

(BNL, November 23, 1983)

ACCELERATOR PHYSICS MILESTONES

1.	WORK OUT LINEAR LATTICE CURVED SECTORS + INSERTIONS TWO CASES: (I) LARGE ANGLE CROSSING, LONG BUNCHES (II) HEAD-ON COLLISION, SHORT BUNCHES	DEC. 1
2.	SEXTUPOLES AND CHROMATIC EFFECT ANALYSIS, PATRICIA TRACKING FOR BOTH CASES	JAN. 1
3.	INTRA-BEAM SCATTERING CALCULATION	DEC. 1
4.	COLLIDER PERFORMANCE RESOLVE PHYSICS IMPLICATIONS OF 2-IN-1 REFERENCE CASE (GOLD ON GOLD) SCALING WITH DIFFERENT A (SOME SPECIES) DIFFERENT SPECIES (A_1 ON A_2)	 NOV. 23 DEC. 1 DEC. 20 JAN. 15
5.	AGREE ON INJECTOR PERFORMANCE	JAN. 5
6.	COMPLETE ANALYSIS OF BEAM SIZE AND APERTURE REQUIREMENTS	JAN. 30

ACCELERATOR PHYSICS SCHEDULE

	NOVEMBER	DECEMBER	JANUARY
Collider Performance			
Lattice Design			
Instabilities			
Vacuum Related Problems			
Intra Beam Scattering			
Injector Performance			
RF-Beam Manipulation			
Magnet Beam Manipulation			

The Sequence

The Heavy Ion Source

The Tandem Van de Graaff

A Pre-Booster

The Booster

The AGS

The Collider (RHIC)

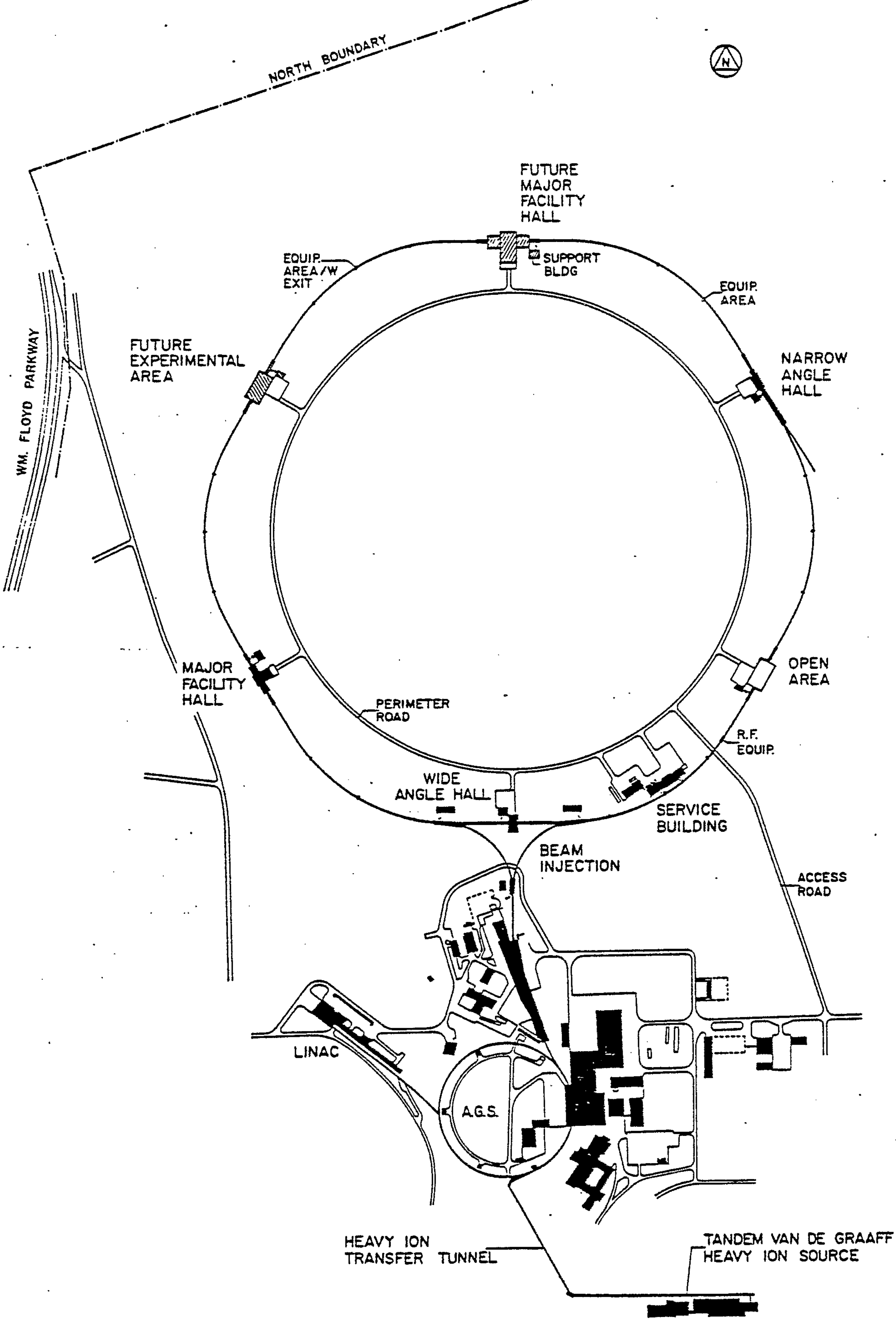
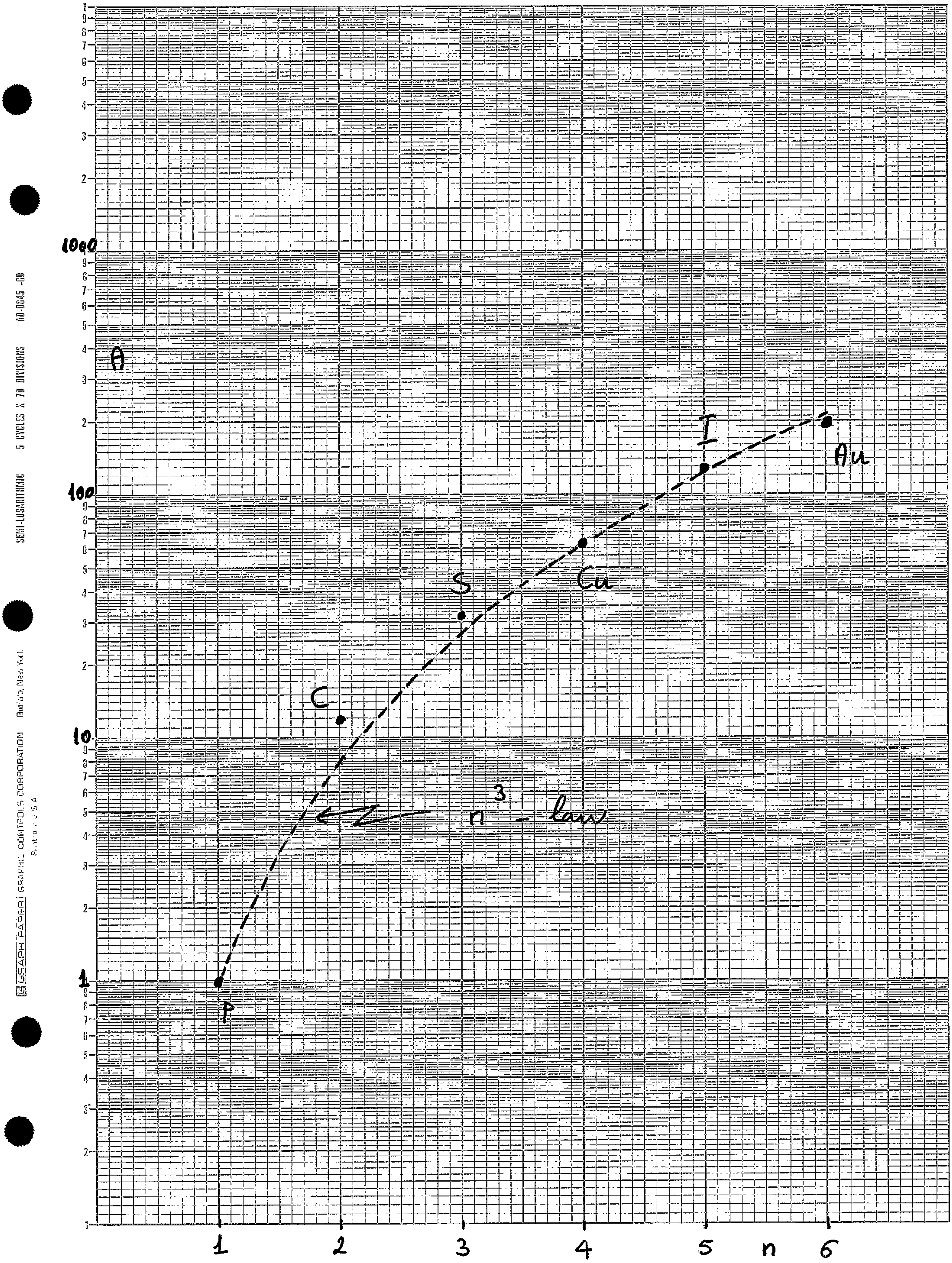


Fig. II.1 Existing CBA tunnel, experimental halls and proposed Tandem/AGS transfer tunnel.

The Chosen Species

Specie	Z	A	A/Z
proton	1	1	1.0
Carbon (C)	6	12	2.0
Sulphur (S)	16	32	2.0
Copper (Cu)	29	63	2.2
Iodine (I)	53	127	2.4
Gold (Au)	79	197	2.5



SEMI-LOGARITHMIC 5 CYCLES X 70 DIVISIONS AO-0845-60
GRAPH PAPER GRAPHIC CONTROLS CORPORATION Buffalo, New York
Printed in U.S.A.
1000
100
10
1
A
I
Au
S
Cu
C
P
n^3 - law
1
2
3
4
5
n
6

(5)

$$\frac{N_B}{\mathcal{E}_N} = (\beta\gamma^2)\,\frac{\pi B_f\,\Delta\nu}{2r_0\,F}\,\frac{A}{Q^2} \qquad \mathcal{E}_N = (\beta\gamma)\,40\pi \text{ mm}\cdot\text{mrad}$$

T	β	γ		$N_B/\mathcal{E}_N$		$\mathcal{E}_N$		N_B	
MeV				$\pi^{-1}\,m^{-1}$		π mm·mrad			
1.	.04613	1.001066		4×10^{14}		1.85		7.4×10^{8}	
1.5	.05648	1.001599		5×10^{14}		2.26		1.13×10^{9}	
2.	.06519	1.002132		5.7×10^{14}		2.61		1.5×10^{9}	
3.	.07978	1.003197		7×10^{14}		3.20		2.24×10^{9}	
4.	.09204	1.004263		8.1×10^{14}		3.70		3×10^{9}	
5.	.10283	1.005329		9.1×10^{14}		4.115		3.74×10^{9}	

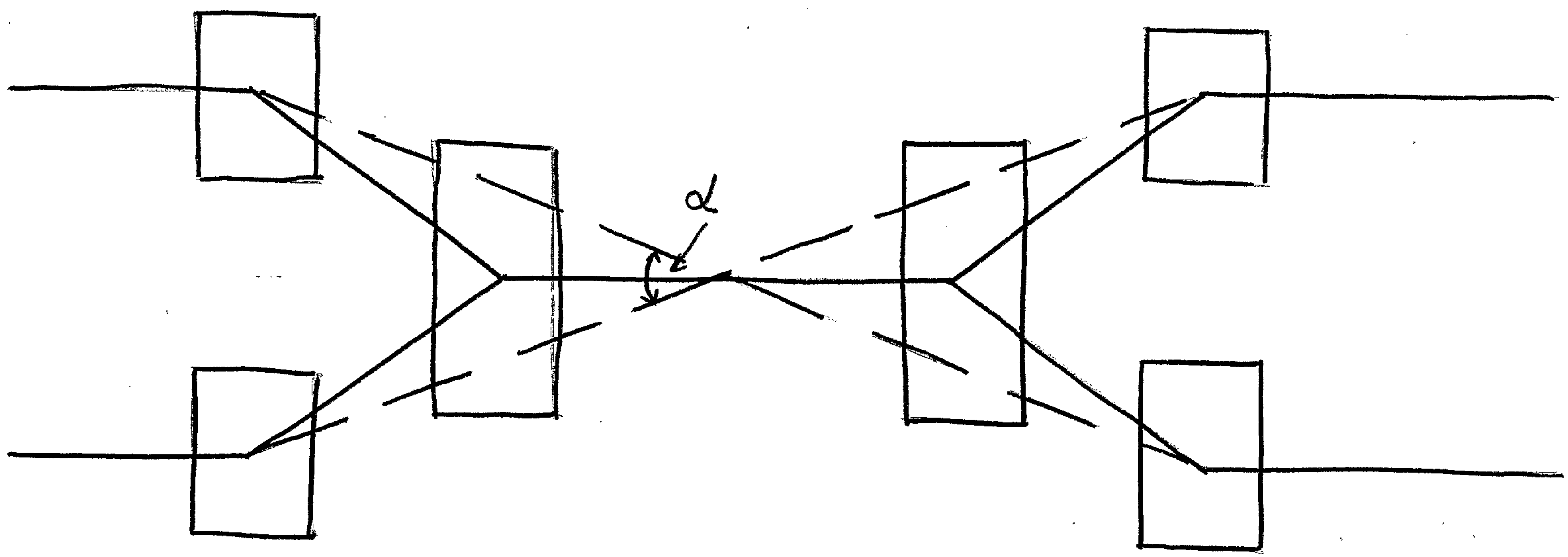
$N = N_B/(3\times2)$ Tandem Current ~ 4.4 pμA

T	τ		N		N_B/turn		no. turns		Pulse length
MeV	μsec		$\times10^{8}$		$\times10^{8}$				μs
1.	14.6		1.23		4.		1.85		27.
1.5	11.9		1.88		3.3		3.4		40.5
2.	10.3		2.48		2.83		5.3		54.6
3.	8.43		3.73		2.32		9.7		81.8
4.	7.3		5.0		2.0		15		109.5
5.	6.54		6.24		1.8		21		137.

$$\text{Luminosity} \sim \frac{N^2}{\sqrt{\mathcal{E}_N}} = \left(\frac{N}{\mathcal{E}_N}\right)^{1/2} N^{3/2} \sim \beta^{1/2}(\beta^2)^{3/2} = \beta^{7/2}$$

Also luminosity $\sim \dfrac{N^2}{\sigma_\ell}$

Head-on Collision vs. Collision at Large Angle



There are 4 cases :

1. Ⓐ colliding with Ⓐ (same species), bunched, head-on
2. A_1 colliding with A_2 (different species), bunched, head-on
   orbit length adjusted
3. Ⓐ colliding with protons, bunched vs. unbunched, angle $\neq 0$
4. Protons colliding with protons, bunched, head-on

With the Same Field and Gradients in both Rings

Au	$\leftrightarrow$	I	100 GeV/A	vs.	104 GeV/A
Au	$\leftrightarrow$	Cu	100		113
Au	$\leftrightarrow$	S	100		125
Au	$\leftrightarrow$	C	100		125
Au	$\leftrightarrow$	p	100		250

Very likely the experimentalist like to have the same energy/nucleon in both beams.

If this is true, then if Au has 100 GeV/A also anything else (I, ..., p) must have 100 GeV/A and no more (and no less). As a consequence

γ and β are the same

the bunched beams can collide matched in velocity.

The argument of different velocities applies only to the case the two beams have different energies so, for instance, the rings magnetic field is the same.

PERFORMANCE COMPARISON BETWEEN SHORT AND LONG BUNCHES

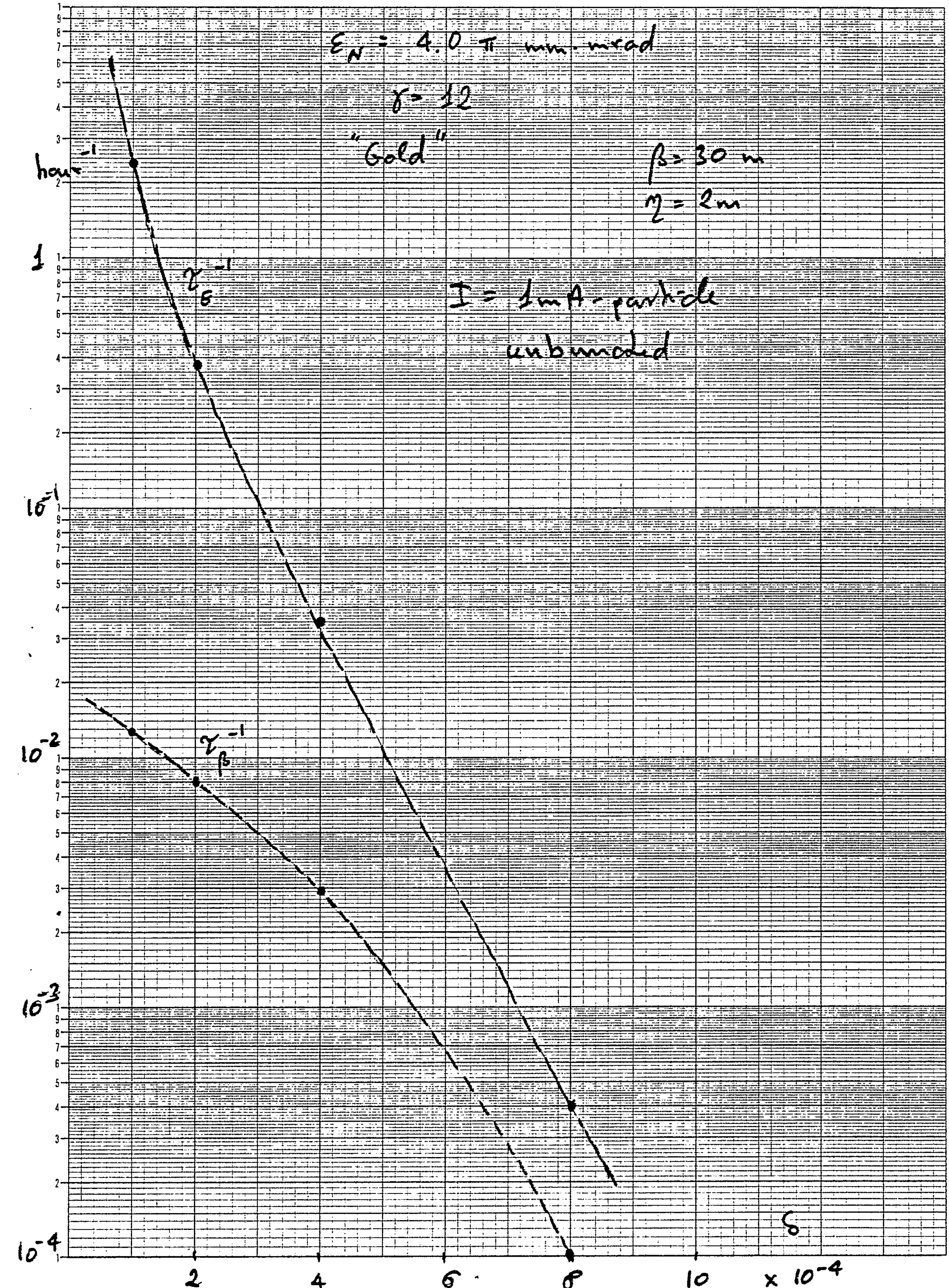
A. Ruggiero

Case Bunches	"S"- Short	"L" Long
Luminosity Formula	$N^2B\ f_{rev}/2\pi\alpha\sigma_e\sigma_v$	same
Cricumference, $2\pi R$	3833.8 m	same
Revolution Frequency, f_{rev}	78.1973 KHz	same
Crossing Angle, α	2 mrad	same
AGS Cycle Time	2 sec	same
rms Bunch Length, σ_e	10 cm	50 m
No. of Bunches, B	57	3
No. of Ions/Bunch, N	6.24×10^8	6×10^{10}
Total No. of Ions/Ring	3.56×10^{10}	1.8×10^{11}
No. of Ions/AGS Pulse	1.87×10^9	same
No. of Bunches/AGS Pulse	3	same
No. of AGS Pulses/Ring	19 box car	(19 box car)×(6RF stacking)
Normalized Emittance	4.0 π mm-mrad	same
Emittance @ 100 GeV/A	0.04 π mm-mrad	same
β^*_v	2m	same
σ^*_v	0.01155 cm	same
Luminosity, L	1.2×10^{27} cm^{-2}s^{-1}	1.2×10^{27} cm^{-2}s^{-1}
Filling Time	2 × 1 minute	2 × 12 minutes

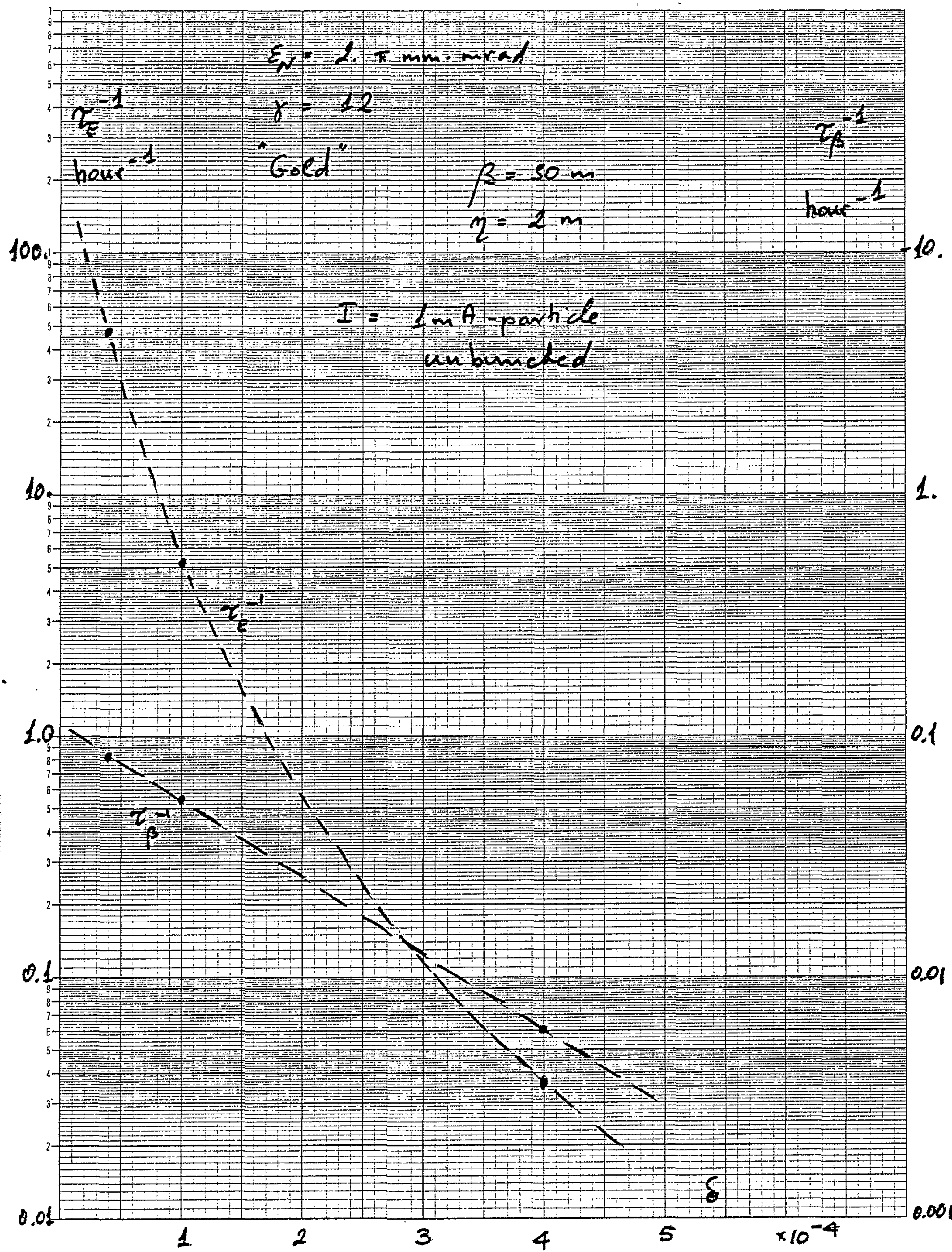
PERFORMANCE COMPARISON BETWEEN SHORT AND LONG BUNCHES

A. Ruggiero

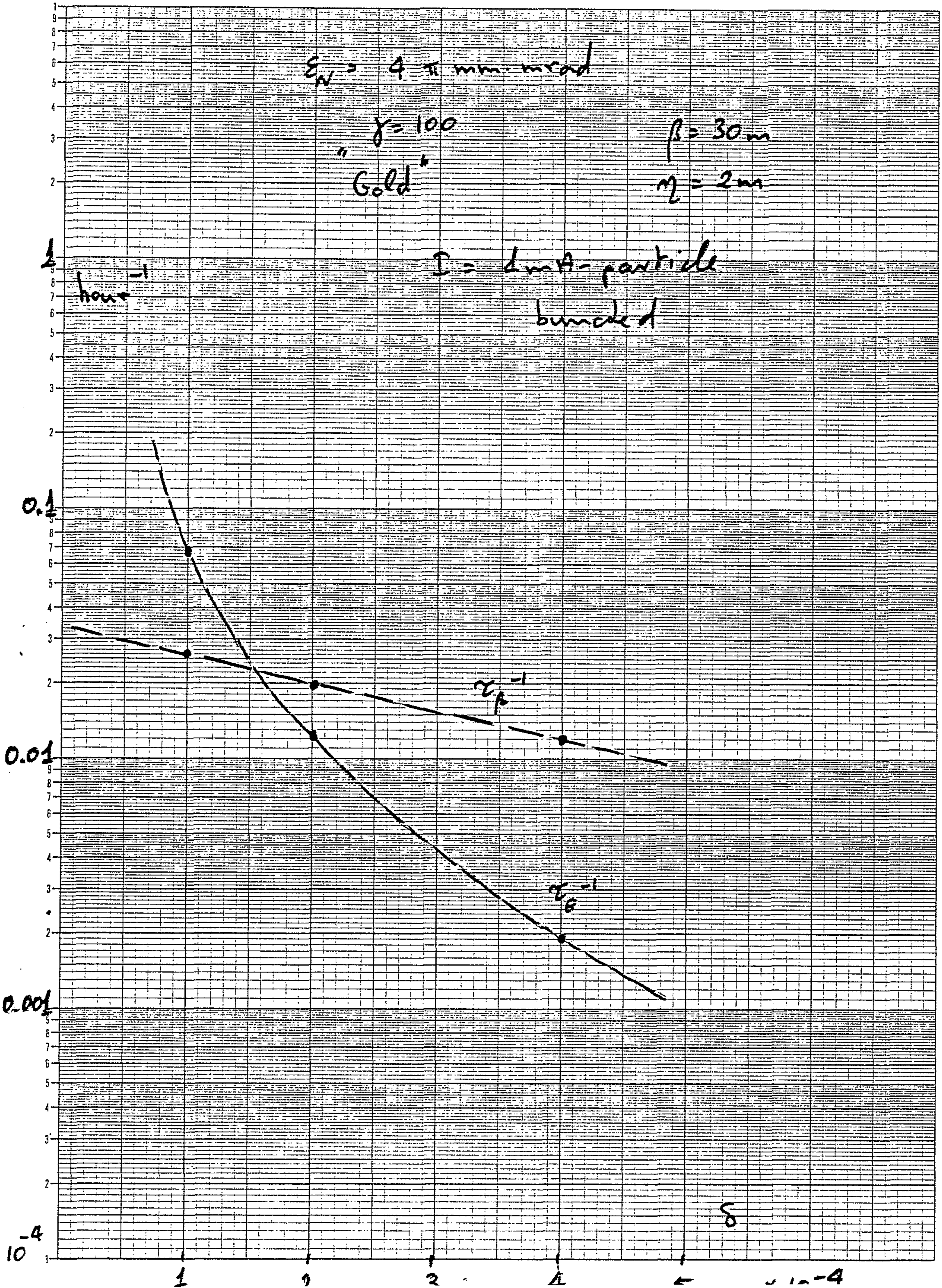
Case Bunches	"S" Short	"L" Long
Initial Luminosity	1.2×10^{27} cm^{-2}s^{-1}	1.2×10^{27} cm^{-2}s^{-1}
Additional Stacking Improved Luminosity New Filling Time	2 × 2 betatron stacking 100% emittance dilution 1.0×10^{28} cm^{-2}s^{-1} 2 × 4 minutes	(A) 24 RF stacking/ring 1.8×10^{28} cm^{-2}s^{-1} 2 × 48 minutes
Additional Stacking Improved Luminosity Filling Time	--- --- ---	(B) 2×2 betatron stacking 100% emittance dilution 1.0×10^{28} cm^{-2}s^{-1} 2 × 30 minutes
Additional Stacking Improved Luminosity Filling Time	--- --- ---	(C) combination of (A) and (B) 1.6×10^{29} cm^{-2}s^{-1} 2 × 2 hours



$\varepsilon_N = 4.0\,\pi$ mm·mrad
$\gamma = 12$
"Gold"
$\beta = 30$ m
$\eta = 2$m
$I = 1$mA-particle
unbunched
hour^{-1}
τ_ε^{-1}
τ_β^{-1}
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
2
4
6
8
10
$\times 10^{-4}$
δ
SEMI LOGARITHMIC 5 CYCLES X 70 DIVISIONS AD 0845 GD
GRAPHIC CONTROLS CORPORATION Buffalo, New York



$\varepsilon_N = 1.\ \pi$ mm · mrad
$\gamma = 12$
"Gold"
$\beta = 30$ m
$\eta = 2$ m
$I = 1$ mA-particle
unbunched
τ_E^{-1}
hour^{-1}
τ_β^{-1}
hour^{-1}
τ_E^{-1}
τ_β^{-1}
100.
10.
1.0
0.1
0.01
10.
1.
0.1
0.01
0.001
1
2
3
4
5
$\times 10^{-4}$
δ
SEMI-LOGARITHMIC 5 CYCLES X 70 DIVISIONS AD 0845 .GD
GRAPHIC CONTROLS CORPORATION Buffalo, New York
Printed in U.S.A.



ε_N = 4 π mm·mrad
γ = 100
"Gold"
β = 30 m
η = 2 m
I = 1 mA - particle
bunched
hour^-1
1
0.1
0.01
0.001
10^-4
τ_β^-1
τ_ε^-1
δ
1
2
3
4
5
×10^-4

60° phase advance cell

$\sigma_E/E = 4\times10^{-4}$

$\gamma = 100$

$\varepsilon_N = 4\pi$ mm·mrad

L	$\bar{\beta}$	$\bar{\eta}$	τ_E^{-1}	τ_β^{-1}	t_L	γ_T	Z/n	
m	m	m	h^{-1}	h^{-1}	hours		ohm	
2.16	5	0.05	–	–	–	110	0.3	
4.33	10	0.2	–	–	–	55	3.9	
6.49	15	0.44	.0044	.0034	1.1	37	10.6	
8.66	20	0.786	.0033	.002 / .0073	1.6/0.8	28	19.8	
10.82	25	1.23	.0025	.0051 / .01	1.1/0.7	22	33	*
12.99	30	1.77	.002	.0076 / .0119	0.9/0.6	18.6	47	
15.15	35	2.41	.0016	.0133	0.56	16	64	
17.32	40	3.146	.0013	.0143	0.53	14	84	
19.48	45	3.98	.0011	.0181	0.43	12.4	108	
21.64	50	4.92	.0009	.0211	0.38	11	137	

I_p = 120 mA - particle (σ_ℓ = 10 cm)

S = 0.25 eV/A - sec

90° phase advance $\sigma_E/E = 4 \times 10^{-4}$ $S = 0.25$ eV/A-sec (5)

$\gamma = 100$ $\varepsilon_N = 4\pi$ mm.mrad

L	$\bar{\beta}$	$\bar{\eta}$	τ_E^{-1}	τ_β^{-1}	t_L	γ_T	Z/n	
m	m	m	h^{-1}	h^{-1}	hours		ohm	
2.5	5	0.033	–	–	–	136	0.77	
5.	10	0.131	–	–	–	68	2.	
7.5	15	0.295	–	–	–	45	6.6	
10.	20	0.525	.0036	.0020	1.5	34	13	
12.5	25	0.82	.0028	.0013 / .0051	2. / 1.0	27.3	21	
15.	30	1.18	.0024	.0037	1.37	22.7	31	*
17.5	35	1.61	.0020	.0060	1.0	19.5	42	
20.	40	2.10	.0017	.0078	0.9	17.	56	
22.5	45	2.66	.0014	.0092	0.8	15.	73	
25.	50	3.28	.0011	.0120	0.64	13.6	89	

I_p = 120 mA -particle

90° phase advance

$\gamma > 100$

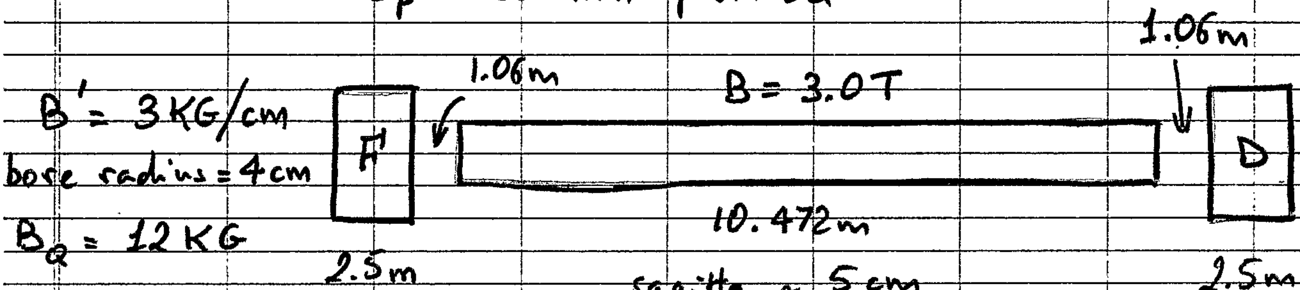
$\sigma_E / E = 2 \times 10^{-4}$

$\varepsilon_N = 4\pi$ mm·mrad

$S = 0.125$ eV/A-sec

L	$\bar{\beta}$	$\bar{\eta}$	τ_E^{-1}	τ_β^{-1}	t_L	γ_T	Z/n	
m	m	m	h^{-1}	h^{-1}	hours		ohm	
2.5	5	.033	–	–	–	136	0.19	
5	10	0.131	–	–	–	68	0.5	
7.5	15	0.295	–	–	–	45	1.7	
10	20	0.525	0.0195	0.0027	0.4	34	3.2	
12.5	25	0.82	0.0162	0.0018 / .0074	0.5/0.35	27.3	5.2	
15	30	1.18	0.0144	0.0055	0.4	22.7	7.7	*
17.5	35	1.61	0.0123	0.0092	0.4	19.5	10.5	
20	40	2.10	0.0107	0.0126	0.36	17	14	
22.5	45	2.66	0.0094	0.0154	0.34	15	18.2	
25	50	3.28	0.0081	0.0178/0.0229	0.32/0.27	13.6	22.2	

$I_p = 120$ mA-particle



$\beta_{max} = 51$ m $\qquad \eta_{max} = 1.6$ m

At 5GeV/A <u>max</u> <u>full</u> beam height = 12 mm

<u>max</u> <u>full</u> beam width = 13-15 mm

($\sim 5\,\sigma$)