TRANSPARENCIES FOR SUMMARY

Booster, AGS & Collider Backgrounds

(mostly Vacuum)

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(BNL, December 16, 1983)

Collider Vacuum (RHIC-PG-11)

Fractional beam loss

$$\eta = \frac{I}{I_0} = e^{-\sigma_T \ell n_0 P}$$

σ_T = total charge changing cross section

$\ell = \beta c t$

$n_0 = 3.27 \times 10^{16} \frac{\text{molecules}}{\text{cm}^3 \text{ torr}}$ (22°C) "warm"

P = pressure in torr

In collider, bare nuclei $\therefore \sigma_{loss} \equiv 0$

$\sigma_{capture}$: a) few measurements above 10 MeV/A

H Gould et al LBL-16467 1 GeV/A U

J Alonso + H Gould Phys Rev A 26, 1134 (1982)
8.5 MeV/A Kr, Xe

b) estimate radiative capture of e^-

$e^- + \text{ion} \rightleftarrows h\nu + \text{ion}$

from detailed balance & photo ionization

$$\sigma_{capture} \sim 1.2 \times 10^{-32} (Xf) Z^{4.4} \frac{(\gamma + 1 + B_K/mc^2)^2}{(\gamma^2-1)(\gamma-1+B_K/mc^2)} \text{ cm}^2$$

(outer shell capture, multiple capture, etc.)

on Hydrogen

B_K = K shell binding energy $(Xf) = 1$ empty K shell

$\sigma_{\text{capture on } Z_T} = Z_T \, \sigma_{\text{capture on hydrogen}}$

Compare to LBL results for 437,962 MeV/A U^{92+} (figure)

For light ions (C, S, Cu) this cross section is less than the geometrical nuclear cross section

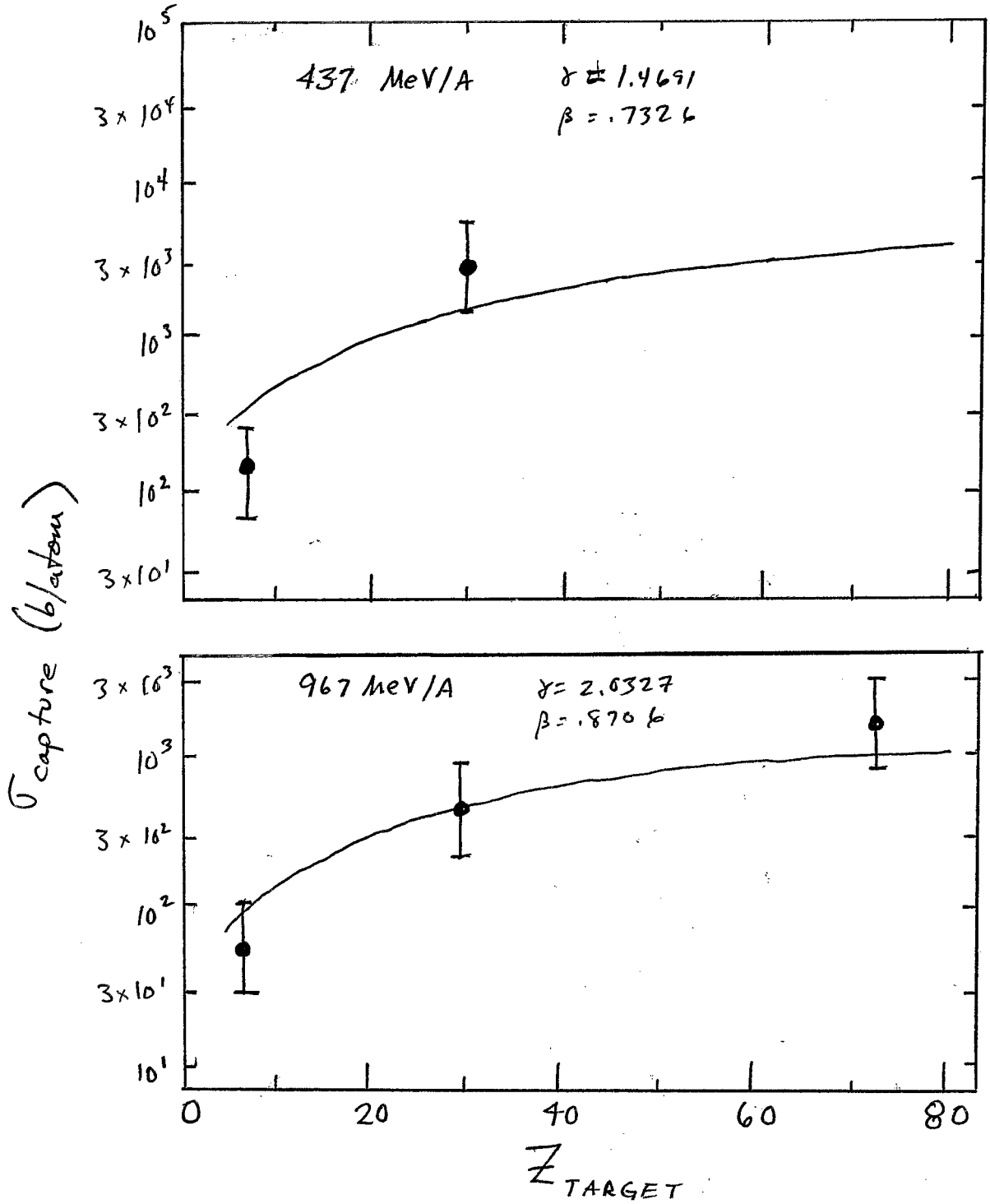
As expected, Gold is our main headache

T/A (GeV/A)	γ	σ_{capture} (barns) H	He	C	O
1	2.074	6.9	13.8	41.4	55.1
5	6.37	.7	1.4	4.2	5.6
10	11.74	.3	.6	1.8	2.4

At very high energy, theory predicts

$$\sigma_{capt} \propto \frac{(\ln E)^2}{E} \sim 1/\gamma$$

U^{92+}



from LBL - 16467

Calculate $\tau_B = (\sigma_T \cdot \beta \cdot c \cdot n_0 \cdot P)^{-1} \frac{1}{3600}$ hours

Gold at 1, 5 GeV/A various vacuums

(also add the nuclear cross section on the residual gas

$\sigma_{geom} = \frac{\pi (1.25)^2}{100} (A_1^{1/3} + A_2^{1/3})^2$ barns)

Warm, 40% H_2, 60% CO_2		τ_B (hours)		
Ion	T/A	10^{-8} torr	10^{-9} torr	10^{-10} torr
Au	1	.27	2.7	27.2
	5	1.61	16.1	160.5
warm, all CO_2				
	1	.18	1.75	17.5
	5	1.1	11.1	111
warm 90% H_2, 10% CO_2				
	1	.87	8.7	87
	5	3.58	35.8	358
cold 50% H_2, 50% He				
	1	.221	2.21	22.1
	5	.765	7.65	76.5

For $\eta = .95$ ($\eta^2 = .9 \Rightarrow$ Luminosity)

we need $\tau_B = 18.98$ hours to lose only 10% of L

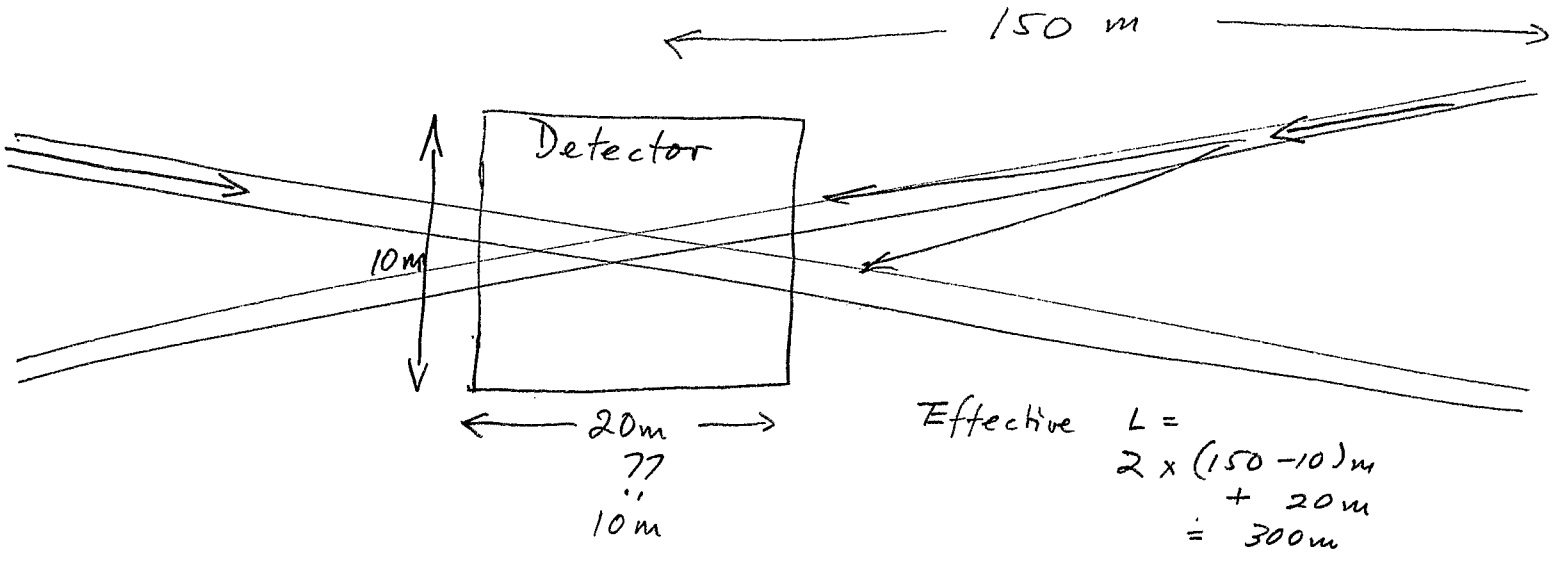
in 1 hour due to charge capture or beam-gas reactions

For Au at 5 GeV/A, this yields

the following pressures

vacuum type		Pressure ($\tau_B = 18.98$ hr)
warm	a) 40% H_2, 60% CO_2	$8.5 \; 10^{-10}$ torr
	b) all CO_2	$5.8 \; 10^{-10}$ torr
	c) 90% H_2, 10% CO_2	$1.9 \; 10^{-9}$ torr
cold	50% H_2, 50% He	$4.0 \; 10^{-11}$ torr

Beam Gas Background



Bunched beam case : Au , 1.87×10^9/bunch , 57 bunches

f_{rev} = 78.194 kHz , $L = 4 \times 10^{27}\ cm^{-2} s^{-1}$

$R_{True} = L \sigma_{geom} = 26{,}600$/sec

$R_{beamgas} = (N B f_{rev})(n_0 P L)\,\sigma$

For σ, use σ_{geom} (Au + gas atoms)

Warm 90% H_2, 10% CO_2 $\langle \sigma_{geom} \rangle$ = 5.11 barn

$P = 1.9\ 10^{-9}$ torr

R_{BG} = 264/meter $\Rightarrow$ 79200 / 300 meters

$R_{BG}/R_{True} = 2.98$!

Cold 50% H_2, 50% He $\langle \sigma_{geom} \rangle$ = 3.63 barn

$P = 4\ 10^{-11}$ torr

R_{BG} = 291/meter $\Rightarrow$ 87450 / 300 meter

$R_{BG}/R_{True} = 3.29$!

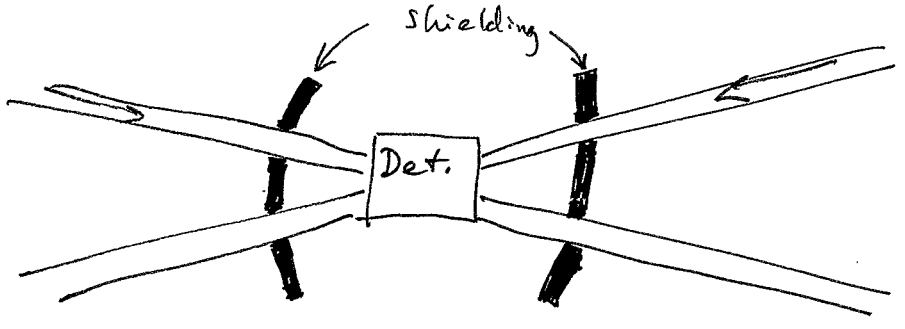
Solutions

a) lower pressure

warm 10^{-11} torr ↑ CBA design $\rightarrow \frac{R_{BG}}{R_{TRUE}} = 1.6\%$

cold 10^{-13} torr ↑ ouch! how to pump small bore? $\rightarrow \frac{R_{BG}}{R_{TRUE}} = 0.8\%$

b) Proper Shielding of most of beam pipe



- easy to reduce L by $\frac{1}{10}$ to 30 meters
- hard to reduce by more than $\frac{1}{30}$ (< 10 meters)
  detectors are "this big" !

Questions for experimenters:

1) How much beam gas background: %, rate
2) Will every detector have a vertex device to isolate beam gas
3) How much worsening can you stand at lower β^* and ∴ lower L?

Booster Vacuum, Electron Capture & Loss

warm vacuum 90% H_2, 10% CO_2

$$\eta = \frac{I}{I_0} = e^{-\sigma_T n_0 P \beta c t}$$

$$\sigma_T = \sigma_{capture} + \sigma_{loss}$$

$\sigma_{capture}(\beta) \propto \beta^{-4}$ or β^{-7}

$\sigma_{loss}(\beta) \propto \beta^{-1}$ or β^{-2} (if $\beta_{ion} > \beta_{outer\ electrons\ in\ atomic\ orbits}$)

↑ if not, $\sigma_{loss}(\beta) \propto \beta^0$ or β^1!

Z, q, β dependences

roughly (conservative)

$$\sigma_{capture} \propto Z^0 q^3 \beta^{-6}$$

$$\sigma_{loss} \propto Z^{2.5} q^{-4} \beta^{-1}$$

need integrals $\dfrac{\int \beta \sigma_T(\beta)\, dt}{\int dt}$ over acceleration cycle

Change time integration dt to $\frac{dt}{dB} dB$

Assume fixed field ramp, so $\left(\frac{dt}{dB}\right)^{-1}$ = constant

Then use $B\rho = \frac{Am}{300q} \beta\gamma$ to change $dB \rightarrow d\beta$

Use $\frac{d(\beta\gamma)}{d\beta} = \gamma^3$

σ capture yields an average $\int \frac{d\beta}{\beta^5 (1-\beta^2)^{3/2}}$

σ_{loss} " " " $\int \frac{d\beta}{(1-\beta^2)^{3/2}}$

} Tables of Integrals

Plow through plenty of atomic physics data

= see RHIC-PG-16 =

Scaling with target

$$\sigma_{capture} \propto Z_T^{2/3} I^{-1}$$

I target atom ionization potential $\propto Z^{-1/3}$

$$\therefore \sigma_{capture} \propto Z$$

Molecular effects $\frac{\sigma(H_2)}{\sigma(H_\bullet)} = 4$, not 2!

For our canonical ions, C, S, Cu, I, Au

a) σ for carbon so small must add $\sigma_{nuclear}$, as for collider

b) Gold as always causes all the trouble

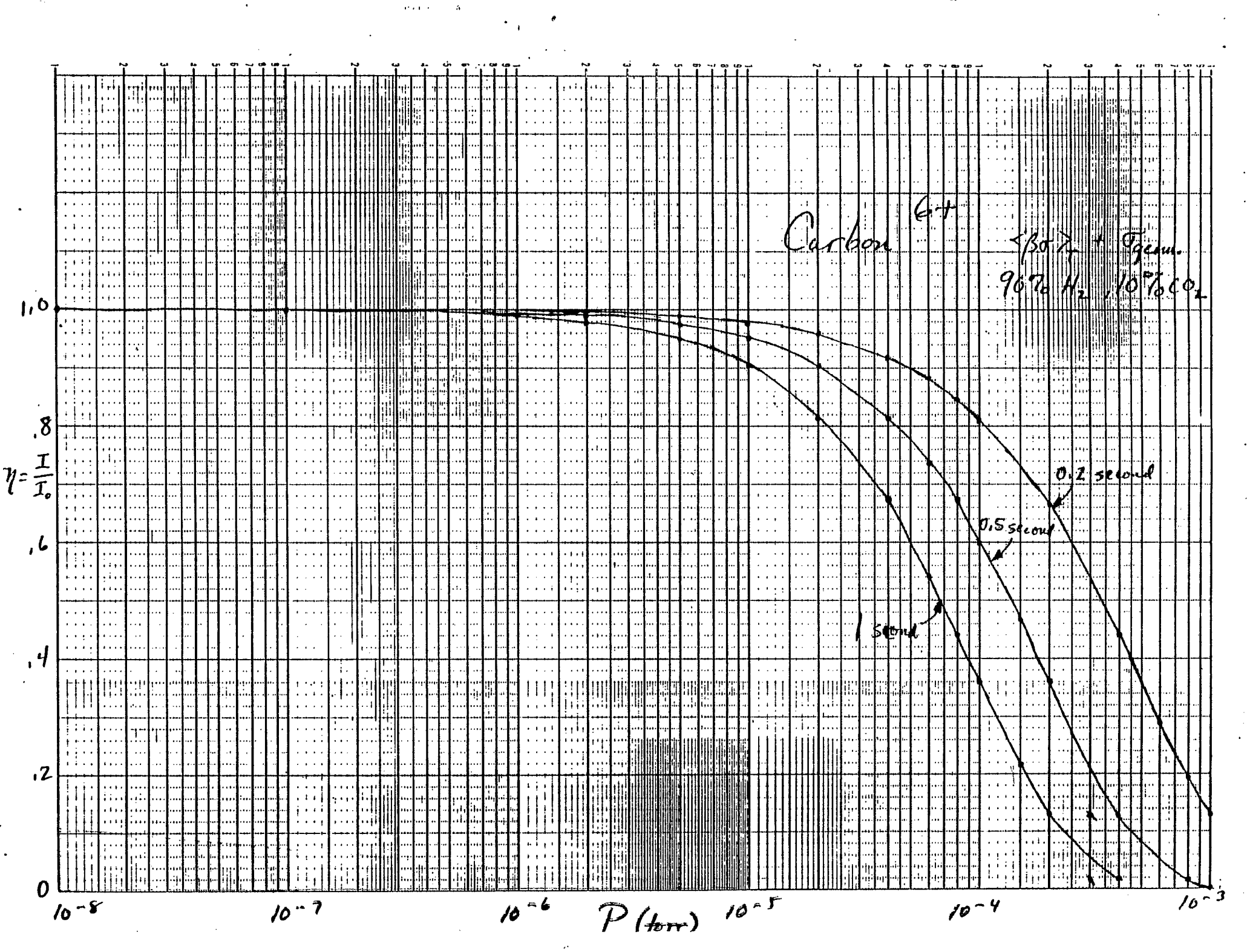
For 90% survival, 2 stage tandem, no linac

warm, 90% H_2, 10% CO_2

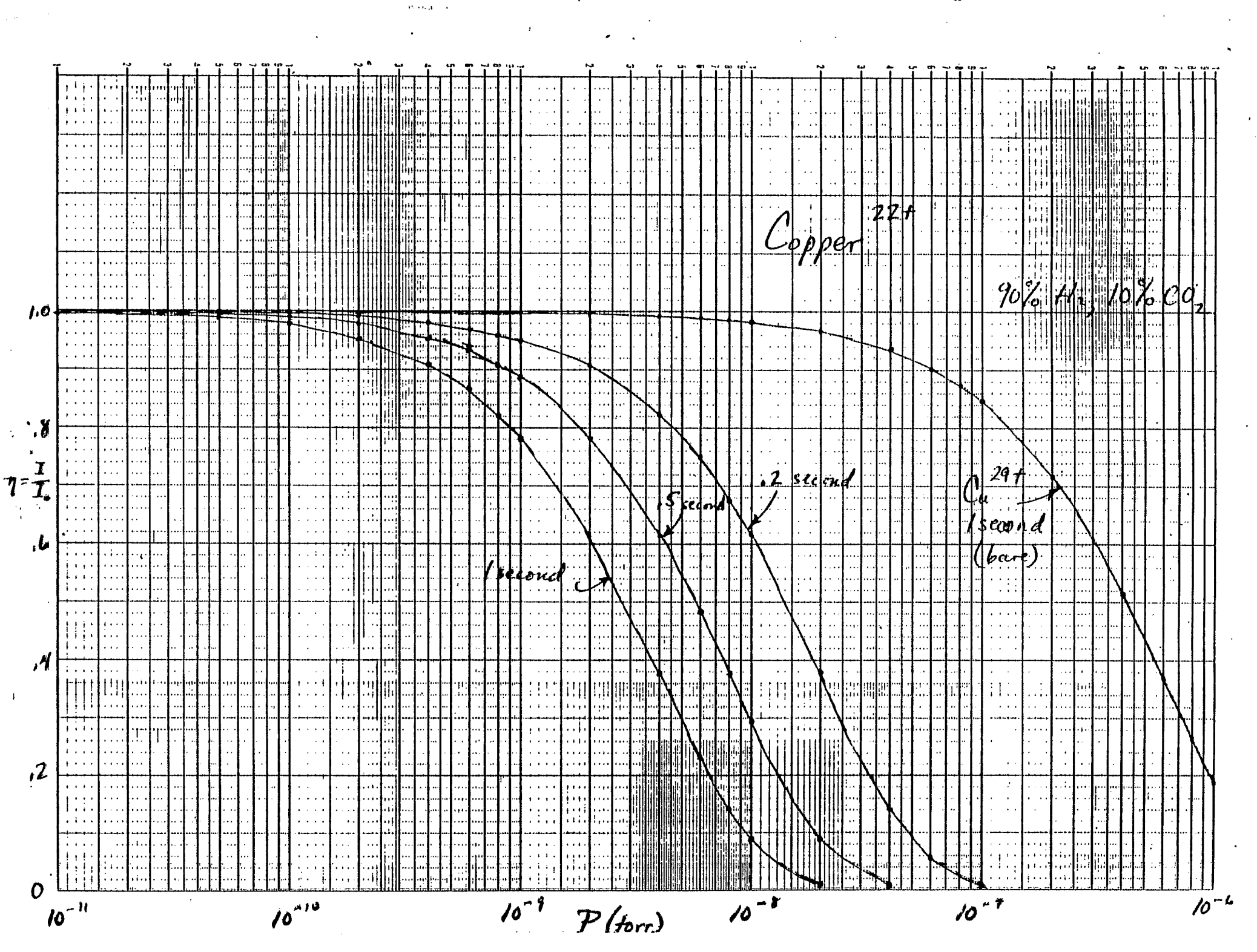
Pressures

Ion	Booster Acceleration Time: 1 second	0.5 second	0.2 second
C^{6+}	$1.1\ 10^{-5}$	$2.2\ 10^{-5}$	$5.5\ 10^{-5}$
S^{15+}	$4.5\ 10^{-10}$	$9.0\ 10^{-10}$	$2.3\ 10^{-9}$
Cu^{22+}	$4.4\ 10^{-10}$	$8.8\ 10^{-10}$	$2.2\ 10^{-9}$
I^{32+}	$2.4\ 10^{-10}$	$4.8\ 10^{-10}$	$1.2\ 10^{-9}$
Au^{37+}	$1.1\ 10^{-10}$	$2.2\ 10^{-10}$	$5.5\ 10^{-10}$
linac + Au^{37+}	$2\ 10^{-10}$	$4\ 10^{-10}$	$1\ 10^{-9}$

To guarantee 99%, 10^{-11} torr.



Carbon 6+
$\langle \beta\sigma \rangle_T + \sigma_{geom.}$
90% H_2, 10% CO_2
0.2 second
0.5 second
1 second
$\eta = \frac{I}{I_0}$
1.0
.8
.6
.4
.2
0
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
P (torr)


Copper 27 f
90% H2, 10% CO2
1.0
.8
η = I/I0
.6
.4
.2
0
.2 second
.5 second
1 second
Cu 29 f
1 second
(bare)
10^-11
10^-10
10^-9
P (torr.)
10^-8
10^-7
10^-6

AGS losses Au^{79+}

$\sigma_{loss} \equiv 0$ (RHIC – PG-17)

$\sigma_{capture}$

(LBL data suggest or)

a) 529 barns on N_2 scaling by our theoretical formula

b) 3275 barns/mol. N_2 (β^{-6} scaling)

644 barns/mol. N_2 (β^{-7} scaling)

AGS 10^{-7} torr, mostly N_2, CO_2, H_2O
(ie leaks)

For 0.6 second ramp up, LAZY estimate (ie $\sigma_{capture}$ fixed)

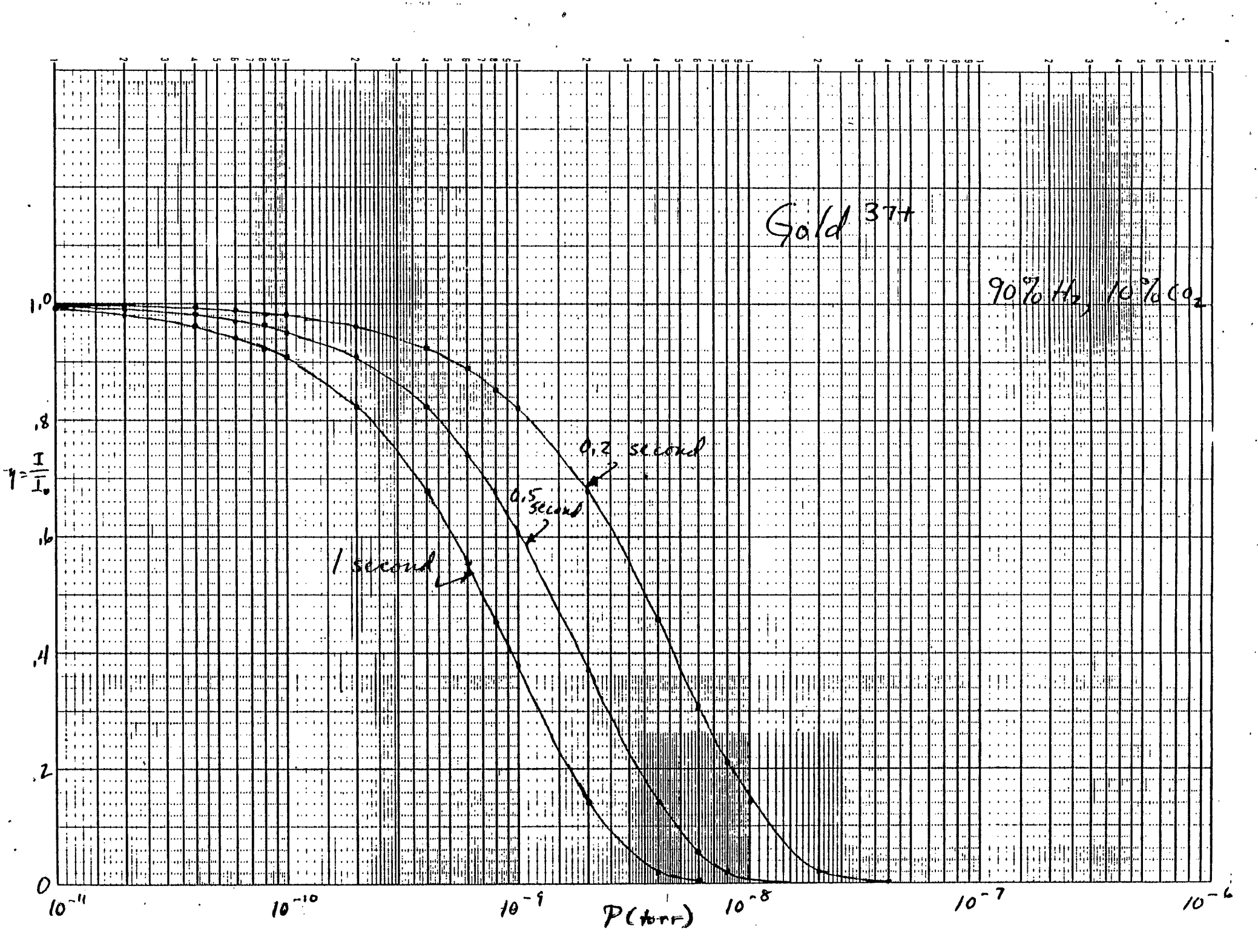
$\eta = \frac{I}{I_0}$ =

.979 529 barns/N_2

.877 3275 barns/N_2

.975 644 barns/N_2

∴ Not a Problem


Gold 37+
90% H2, 10% CO2
0.2 second
0.5 second
1 second
1.0
.8
.6
.4
.2
0
η = I/I0
10^-11
10^-10
10^-9
10^-8
10^-7
10^-6
P(torr)

Fast cycling booster, must store booster bunches in AGS up to 1/second at injection energy

Use $\sigma = 644$ barns at $\beta = .681$ (340 MeV/A) $\quad \tau = 23.3\,s$

a) 10 cycles/second, 100 ms cycle, 50 ms ramp up

$$\eta' = \frac{1}{9} \sum_{i=1}^{9} e^{-(10-i)\,100\,ms/23.3\,s} = .979$$

b) 3 cycles/second, 333 ms cycle, 167 ms ramp up

$$\eta' = \frac{1}{2} \sum_{i=1}^{2} e^{-(3-i)\,333\,ms/23.3\,s} = .979$$

OK

AGS vacuum $\Rightarrow 10^{-8}$ torr

means:

$$\eta\,(\text{worst case } 3275 \text{ barns}) > 0.987$$

$$\eta' = .998$$

Luminosity vs A

(RHIC-PG-22
" - " - ??)

Equal A collisions

Based on AR's latest case for Au^{79+}

$N = 1.87 \times 10^9$ /bunch

$B = 57$ bunches

$\beta^* = 2$ m V & H

$\epsilon_N = 10\pi$ mm mrad

→ head-on collisions ←

$\sigma_H^* = \sigma_V^* = 0.01754$ cm

100 GeV/A $(\gamma = 108.35)$

$f = \sqrt{1+\rho^2} = 1$

$\rho = \frac{\alpha \sigma_l}{2\sigma_H^*} = 0$ $(\alpha = 0)$

$f_{rev} = 78,194\ s^{-1}$

scale: $L = \frac{N^2 B f_{rev}}{4\pi \sigma_V^* \sigma_H^* f}$, $\Delta\nu_{BB} = \frac{N r_0 \beta_V^* Z^2}{4\pi \sigma_V^* \sigma_H^* \gamma f A}$

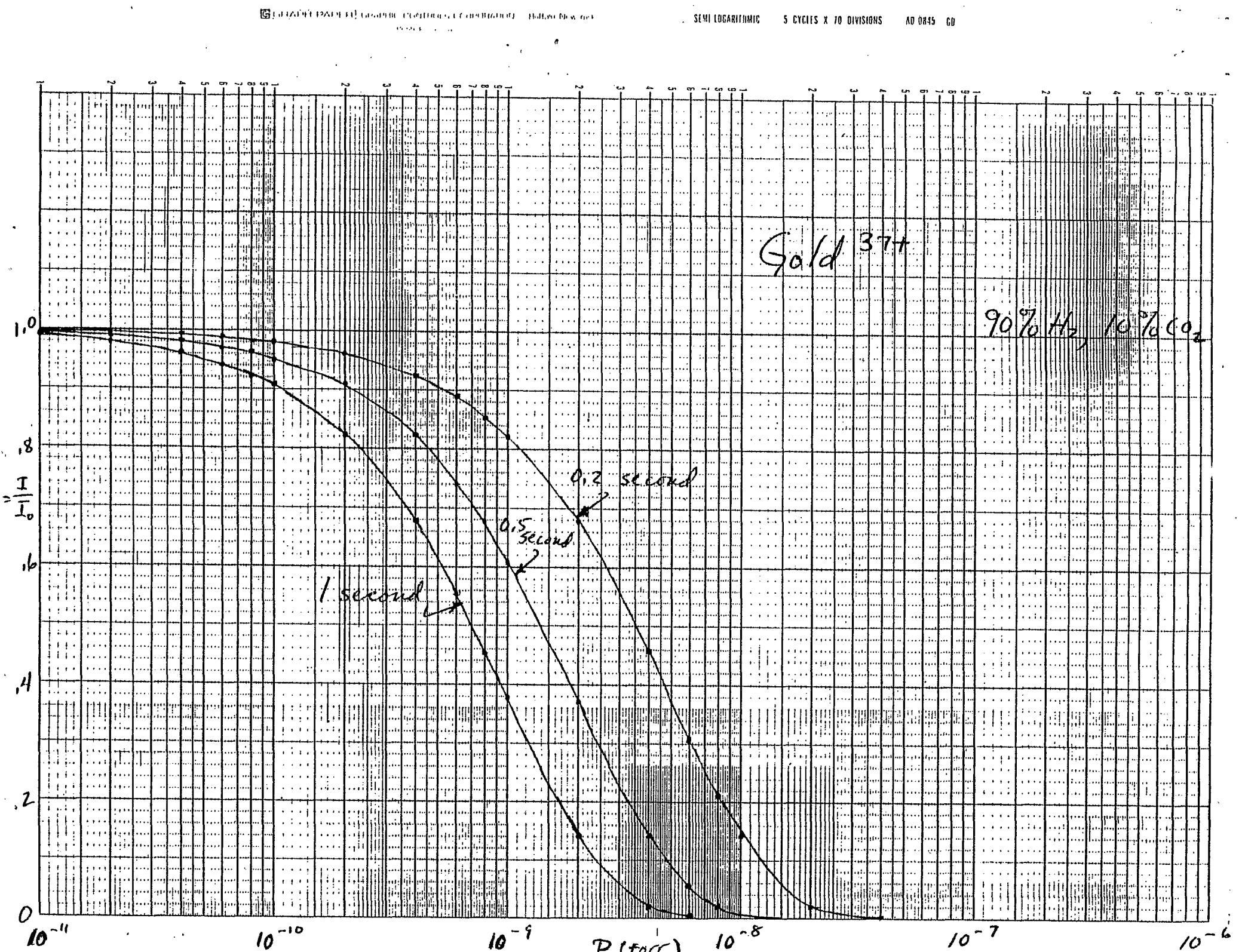
Scale by a) fix $\Delta\nu_{BB}$

b) calculate N (Z^2/A scaling)

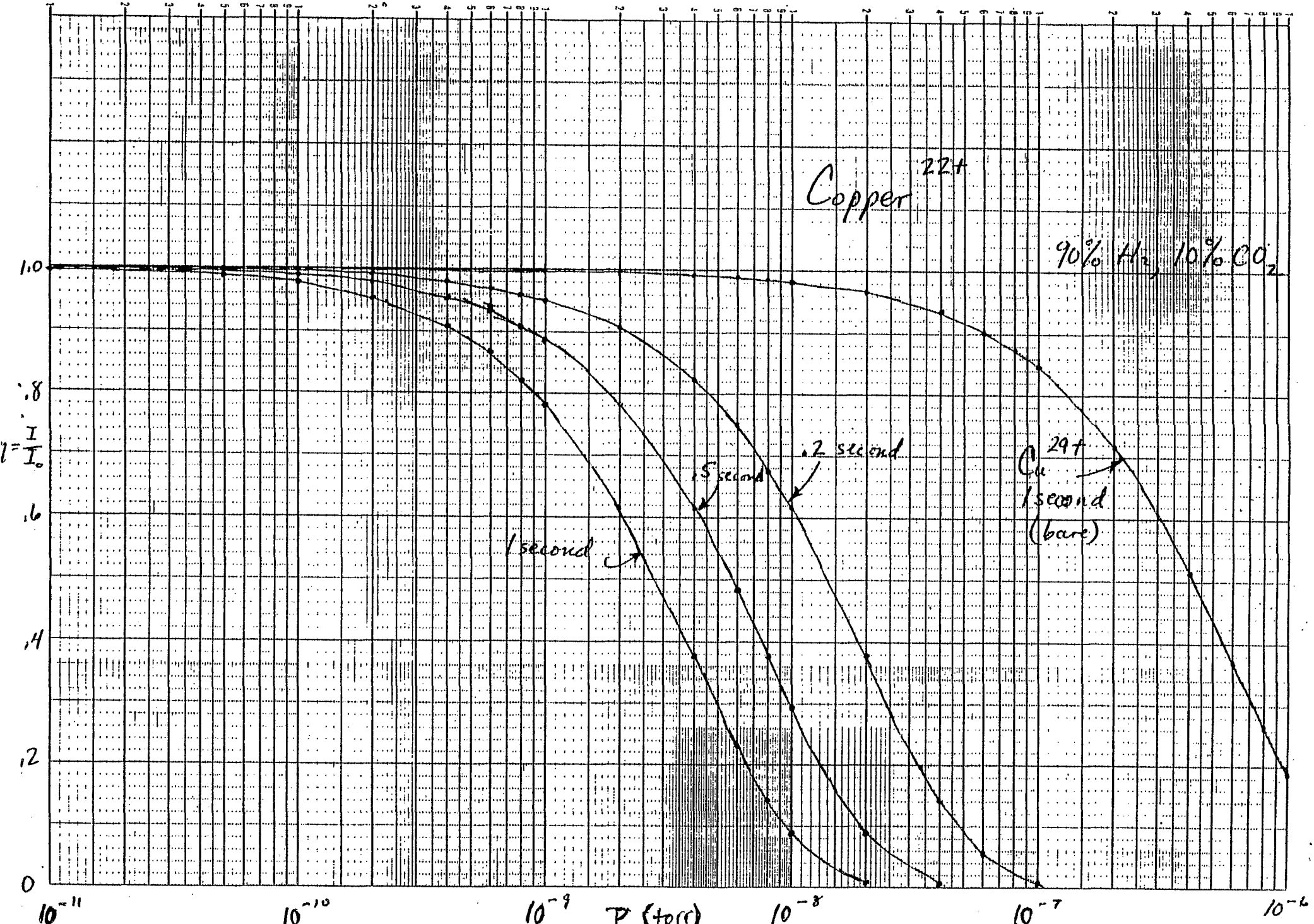
c) " L (B, σ_V^*, σ_H^*, f_{rev} fixed)

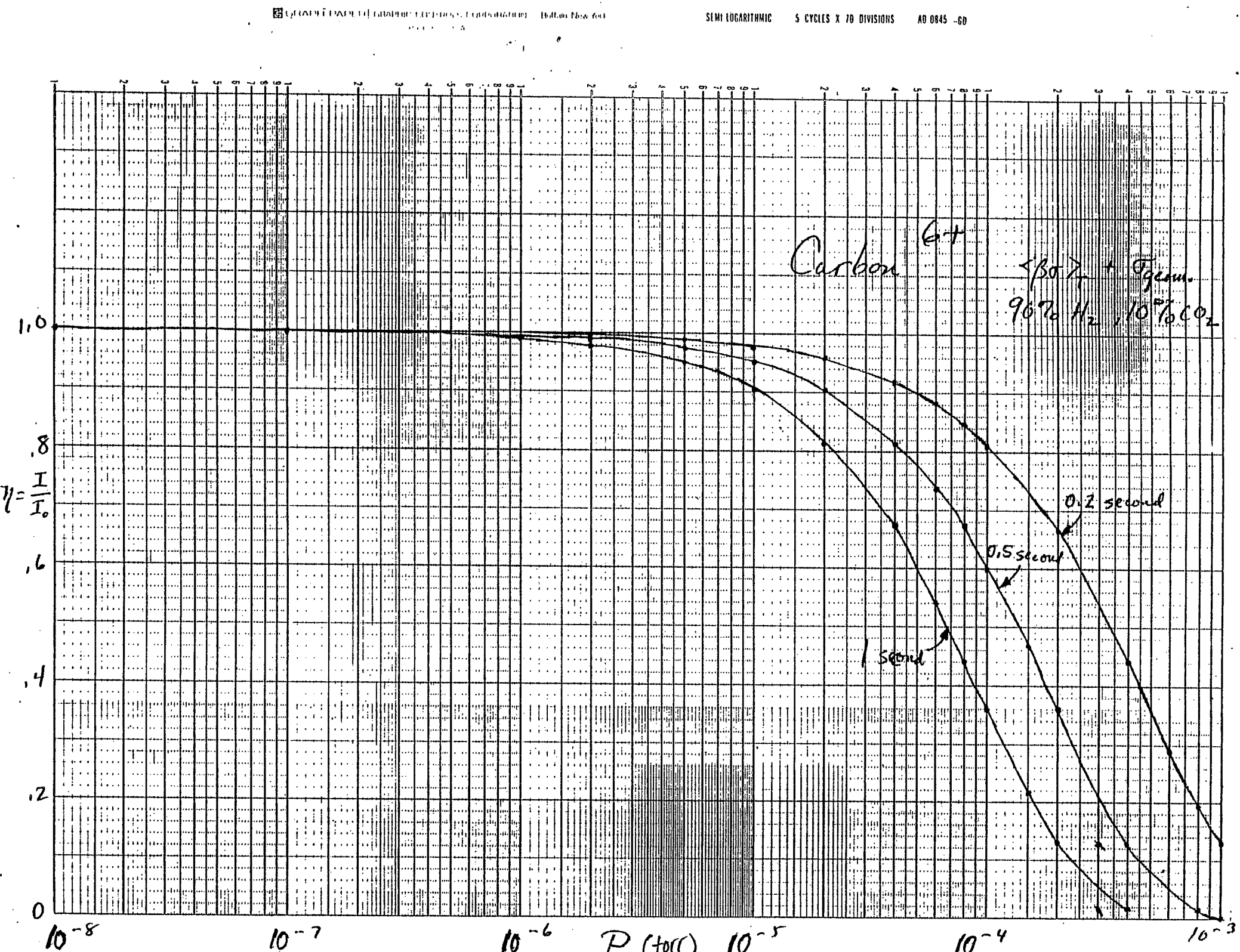
Ion	$^{197}_{79}Au$	$^{127}_{53}I$	$^{63}_{29}Cu$	$^{32}_{16}S$	$^{12}_{6}C$
$L_{100GeV/A}$	4.0×10^{27}	$8.3\ 10^{27}$	2.27×10^{28}	6.3×10^{28}	4.5×10^{29}
$R = L\sigma_{geom}$	$26,600\ s^{-1}$	$41,168\ s^{-1}$	$70,597\ s^{-1}$	$124,740\ s^{-1}$	$463,500\ s^{-1}$
$L_{5GeV/A}$	2.3×10^{26}	4.75×10^{26}	$1.3\ 10^{27}$	$3.62\ 10^{27}$	$2.57\ 10^{28}$
$R = L\sigma_{geom}$	$1529\ s^{-1}$	$2356\ s^{-1}$	$4043\ s^{-1}$	$7168\ s^{-1}$	$26,471\ s^{-1}$

SEMI LOGARITHMIC 5 CYCLES X 70 DIVISIONS AD 0845 GD



SEMI LOGARITHMIC 5 CYCLES X 70 DIVISIONS AD 0845 - GD



GRAPH PAPER by GRAPHIC CONTROLS CORPORATION Buffalo New York

SEMI LOGARITHMIC 5 CYCLES X 70 DIVISIONS AD 0845 -GD