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Transparencies For Summary Boosters, AGS and Collider Backgrounds (mostly Vacuum)

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DISCLAIMER

RHIC-PG-24

TRANSPARENCIES FOR SUMMARY

Booster, AGS & Collider Backgrounds

(mostly Vacuum)

G. R. Young

(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 crosssection

$\ell = \beta c t$

$n_0 = 3.27 \times 10^{16}$ $\frac{\text{molecules}}{\text{cm}^3 \text{ torr}}$ (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 & photoionization

(outer shell capture, multiple capture etc. ↓)

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

on Hydrogen

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

$\sigma_{capture}$ on Z_T = Z_T $\sigma_{\substack{capture \\ on\ hydrogen}}$

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

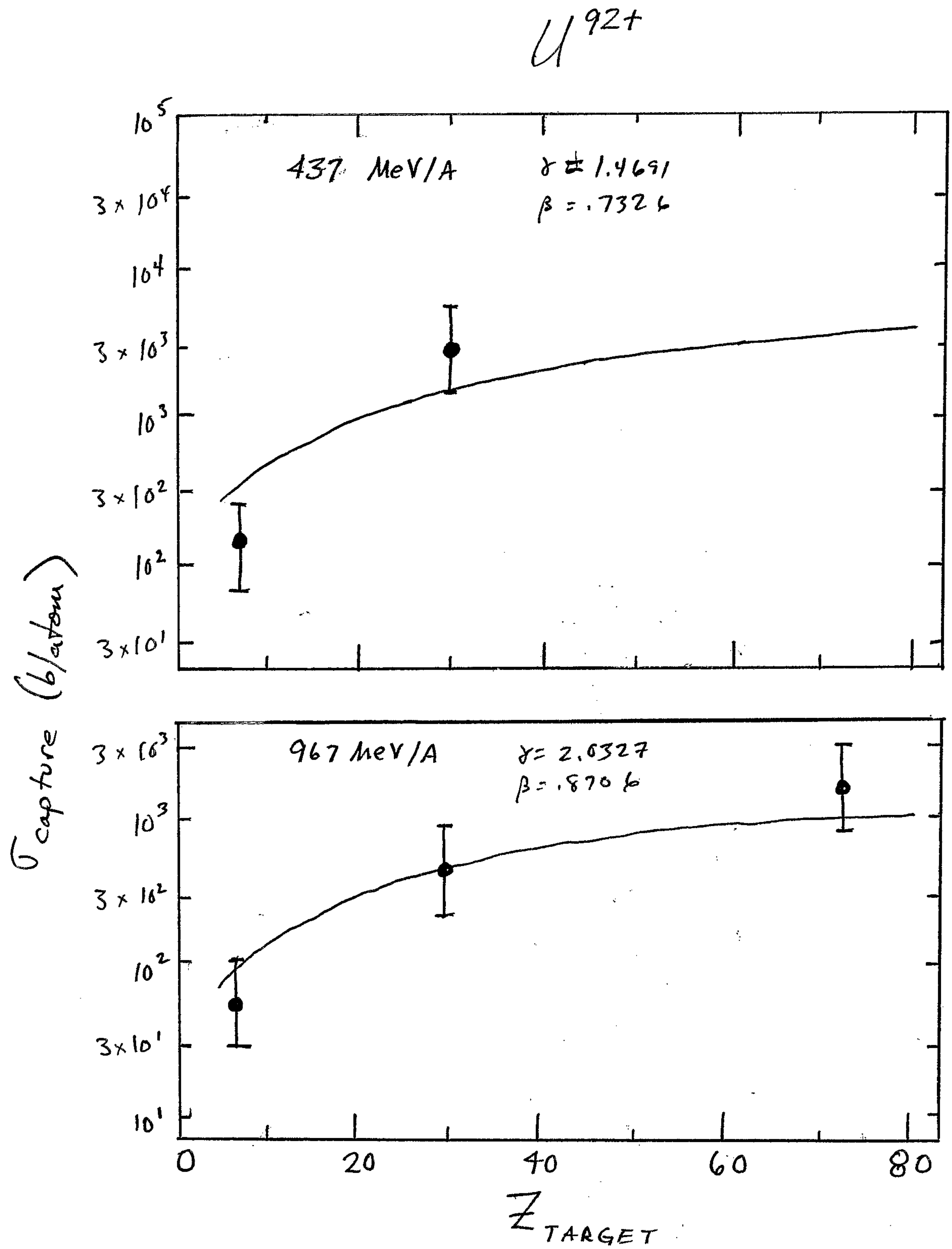
For light ions (C, S, Cu) this cross section is less than the geometrical nuclear cross section

As expected, Gold is our main headache

T/A (GeV/A)	γ	$\sigma_{capture}$ (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

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



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

$$\sigma_{geom} = \frac{\pi \ (1{,}25)^2}{100} (A_1^{1/3} + A_2^{1/3})^2 \text{ barns})$$

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

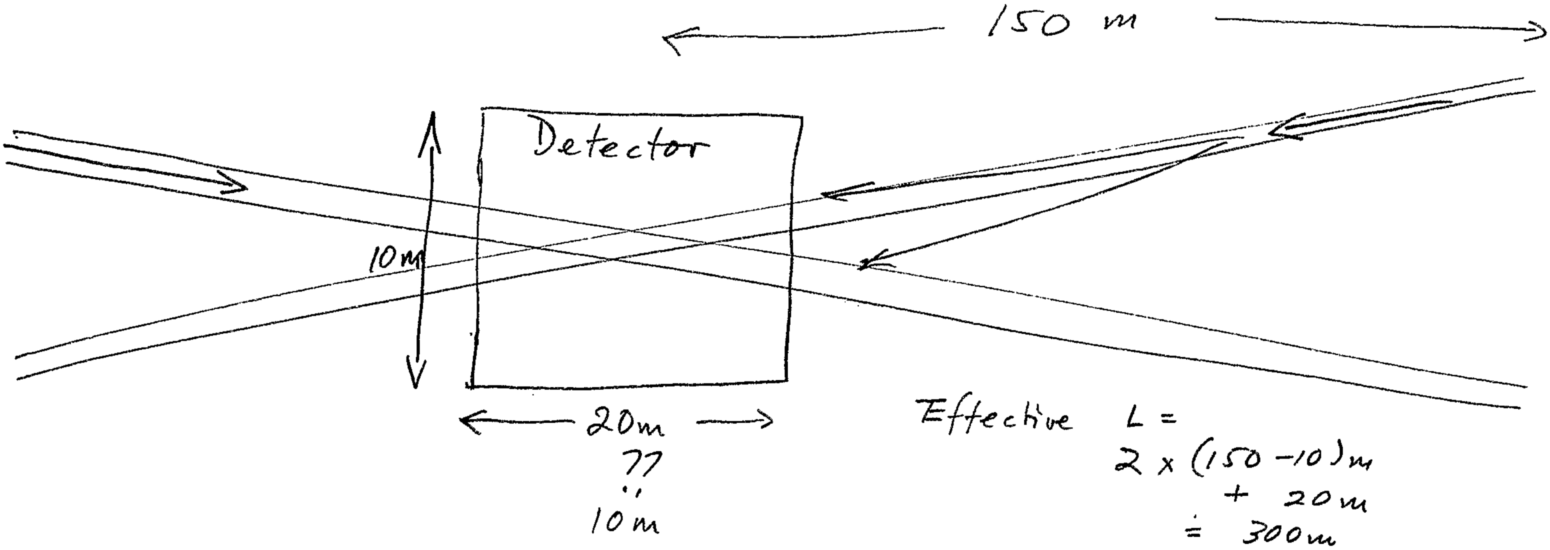
For $\eta = .95$ ($\eta^2 = .9 \Rightarrow$ Luminosity)

we need τ_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 (τ_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, $L = 4 \times 10^{27}\ cm^{-2}s^{-1}$

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

$R_{beamgas} = (NB f_{rev})(n_0 P L)\ \sigma$

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

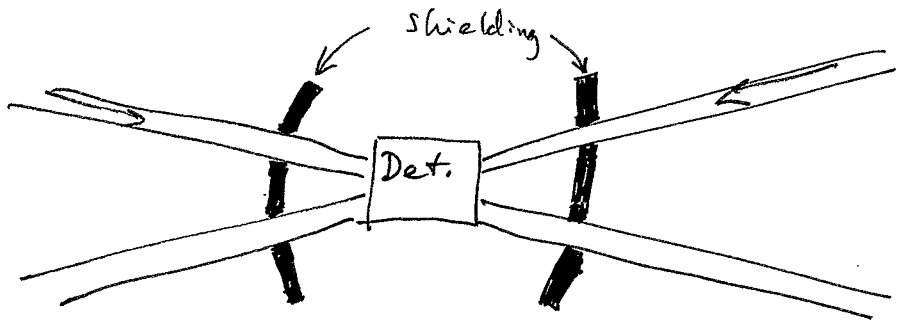
warm 10^{-11} torr $\rightarrow$ $\frac{R_{BG}}{R_{TRUE}} = 1.6\%$

↑ CBA design

cold 10^{-13} torr $\rightarrow$ $\frac{R_{BG}}{R_{TRUE}} = 0.8\%$

↑ ouch!
how to pump small bore?

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 γ and $\therefore$ lower L?

Booster Vacuum, Electron Capture & Loss

warm vacuum 90% H_2, 10% CO_2

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

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

$\sigma_{capture}(\beta) \propto \beta^{-6}$ or β^{-7}

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

↑ 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 $B\rho = \frac{Am}{300 q} \beta\gamma$ 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 $\frac{\sigma(H_2)}{\sigma(He)} = 4$, 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

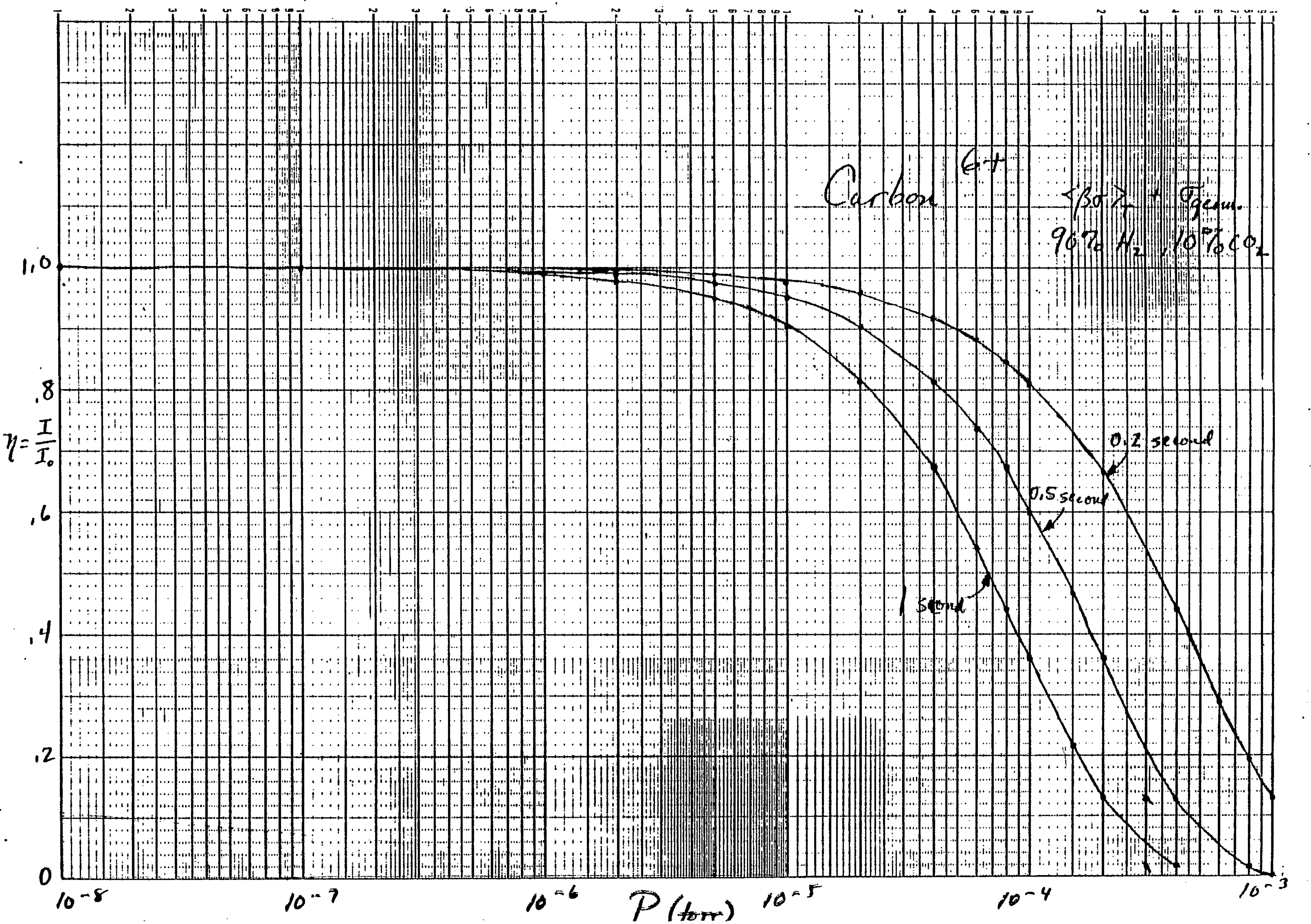
For 90% survival, 2 stage tandem, no linac

warm, 90% H_2, 10% CO_2

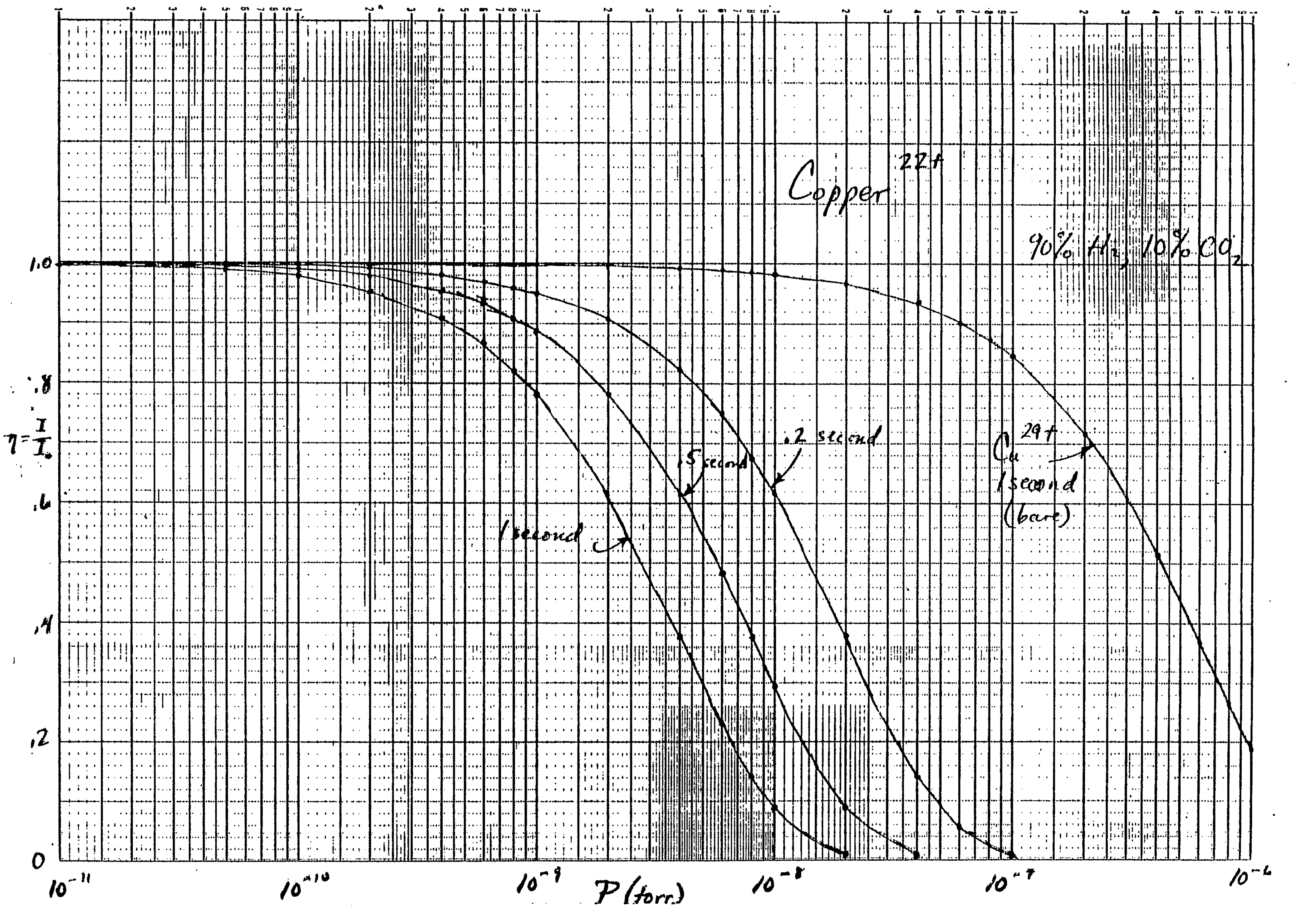
Pressures

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+
<βσ> + σ_geom.
90% H2, 10% CO2
1.0
.8
.6
.4
.2
0
η = I/I0
0.2 second
0.5 second
1 second
10^-8
10^-7
10^-6
10^-5
10^-4
10^-3
P (torr)


Copper 22f
90% H2, 10% CO2
1.0
.8
.6
.4
.2
0
η = I / I0
.2 second
.5 second
1 second
Cu 29f
1 second
(bare)
10^-11
10^-10
10^-9
10^-8
10^-7
10^-6
P (torr)

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)

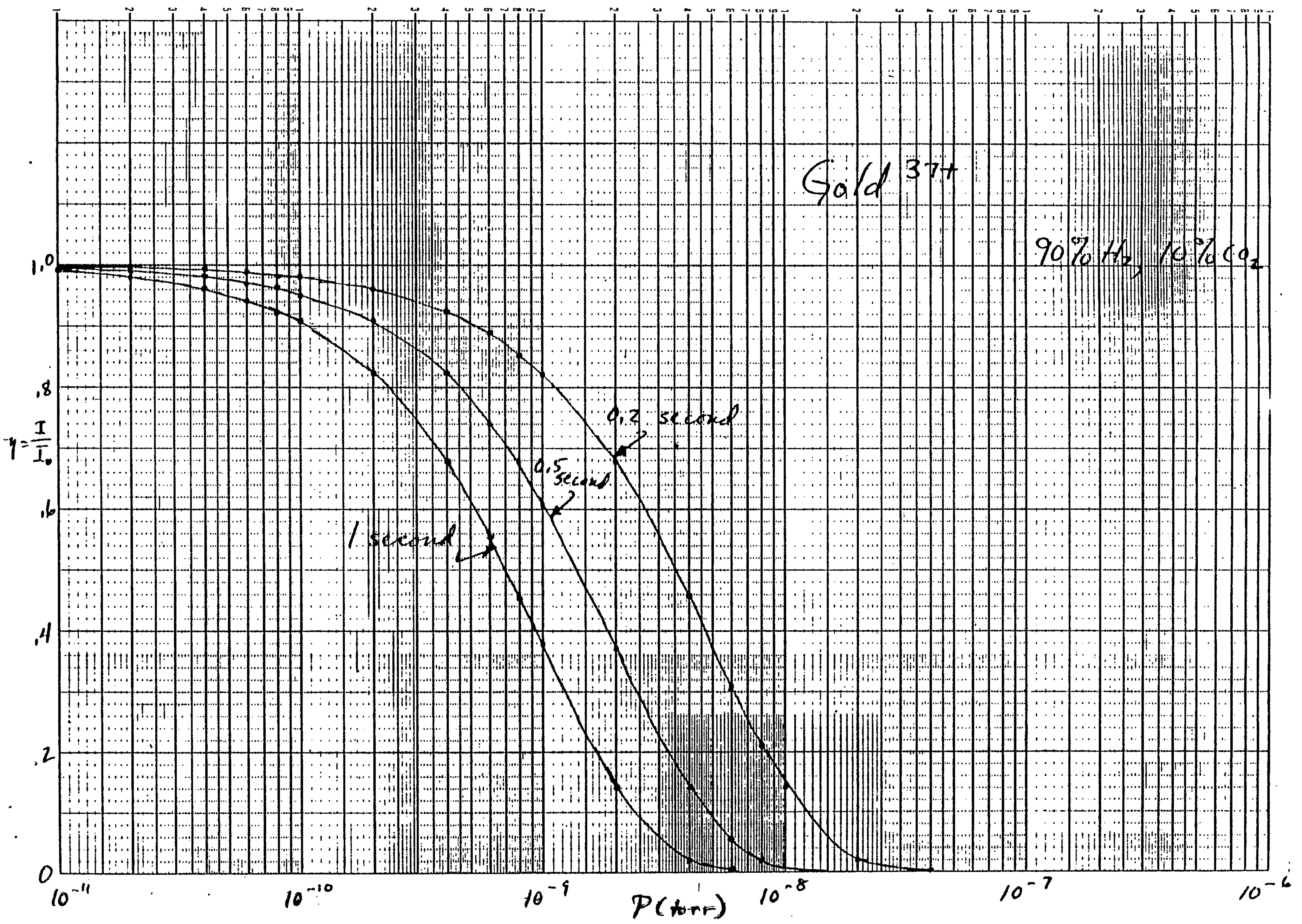
644 barns/mol. N_2 (β^{-7} scaling)

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
1.0
.8
.6
.4
.2
0
η = I/I0
0.2 second
0.5 second
1 second
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) $\tau = 23.3\,s$

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~~ :

η (worst case 3275 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 ($\gamma = 108.35$)

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

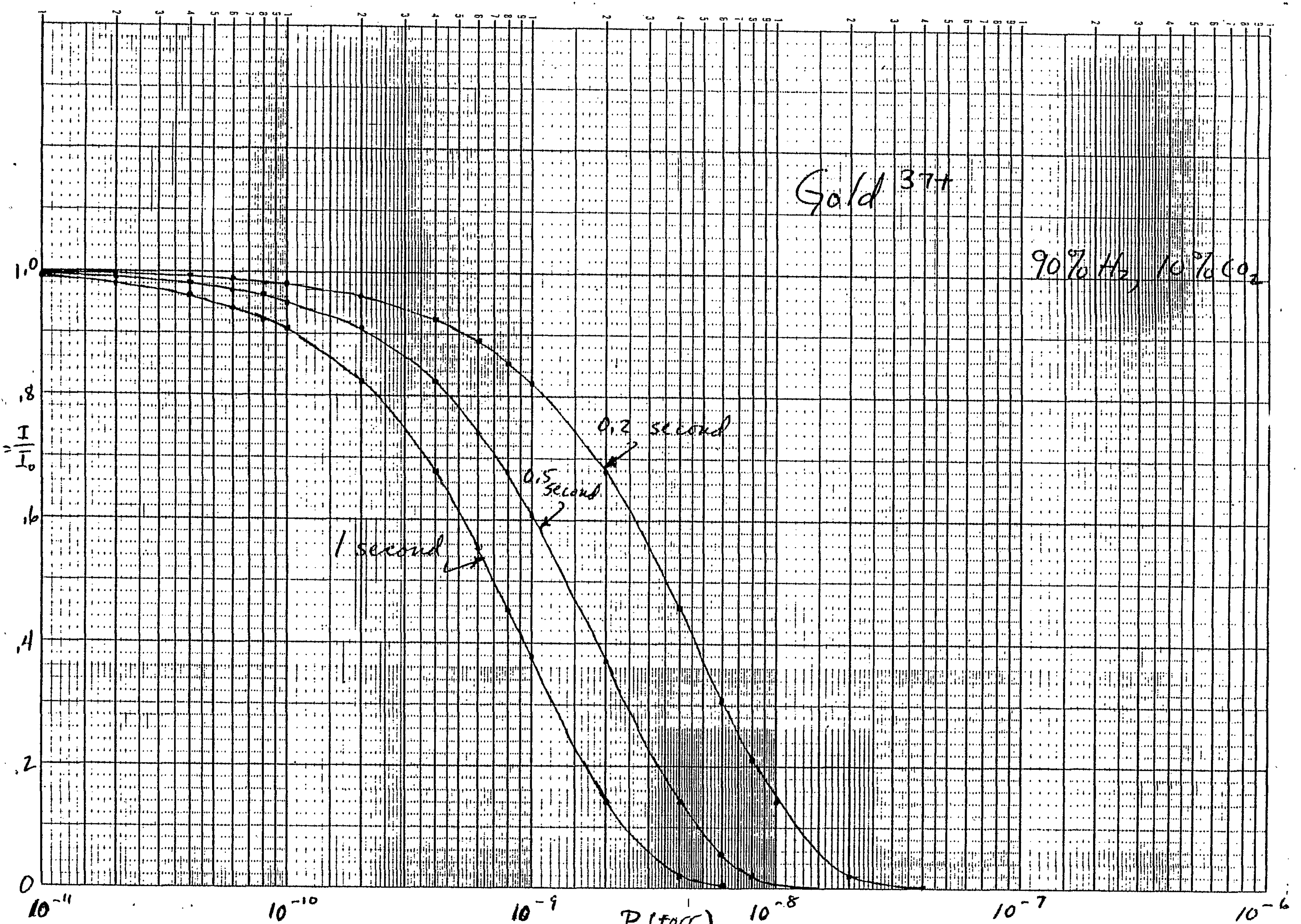
$\rho = \frac{\alpha \sigma_\ell}{2 \sigma_H^*} = 0$ ($\alpha = 0$)

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

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	$^{197}_{79}Au$	$^{127}_{53}I$	$^{63}_{29}Cu$	$^{32}_{16}S$	$^{12}_{6}C$
$L_{100 GeV/A}$	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}
$L_{5 GeV/A}$	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}


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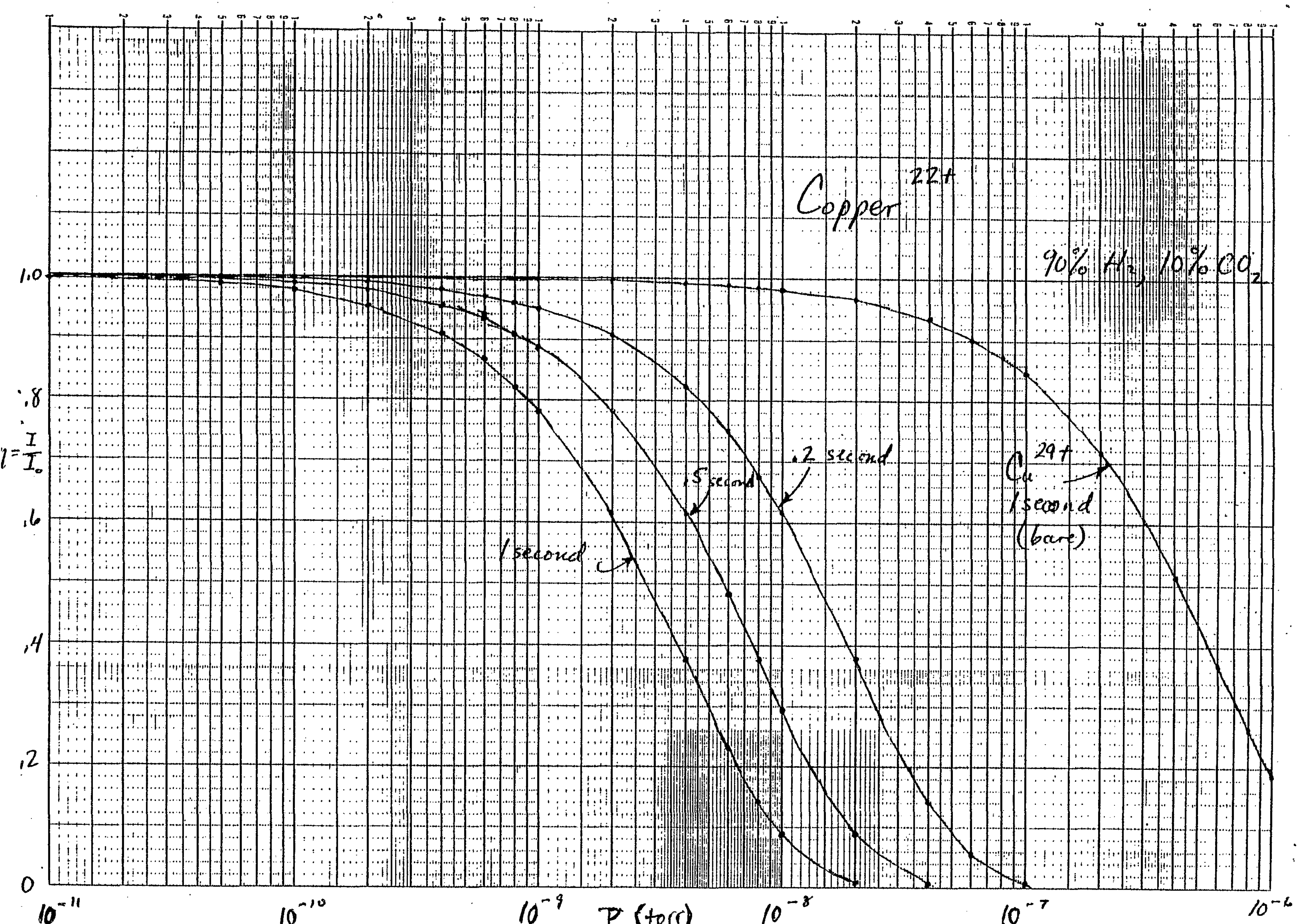
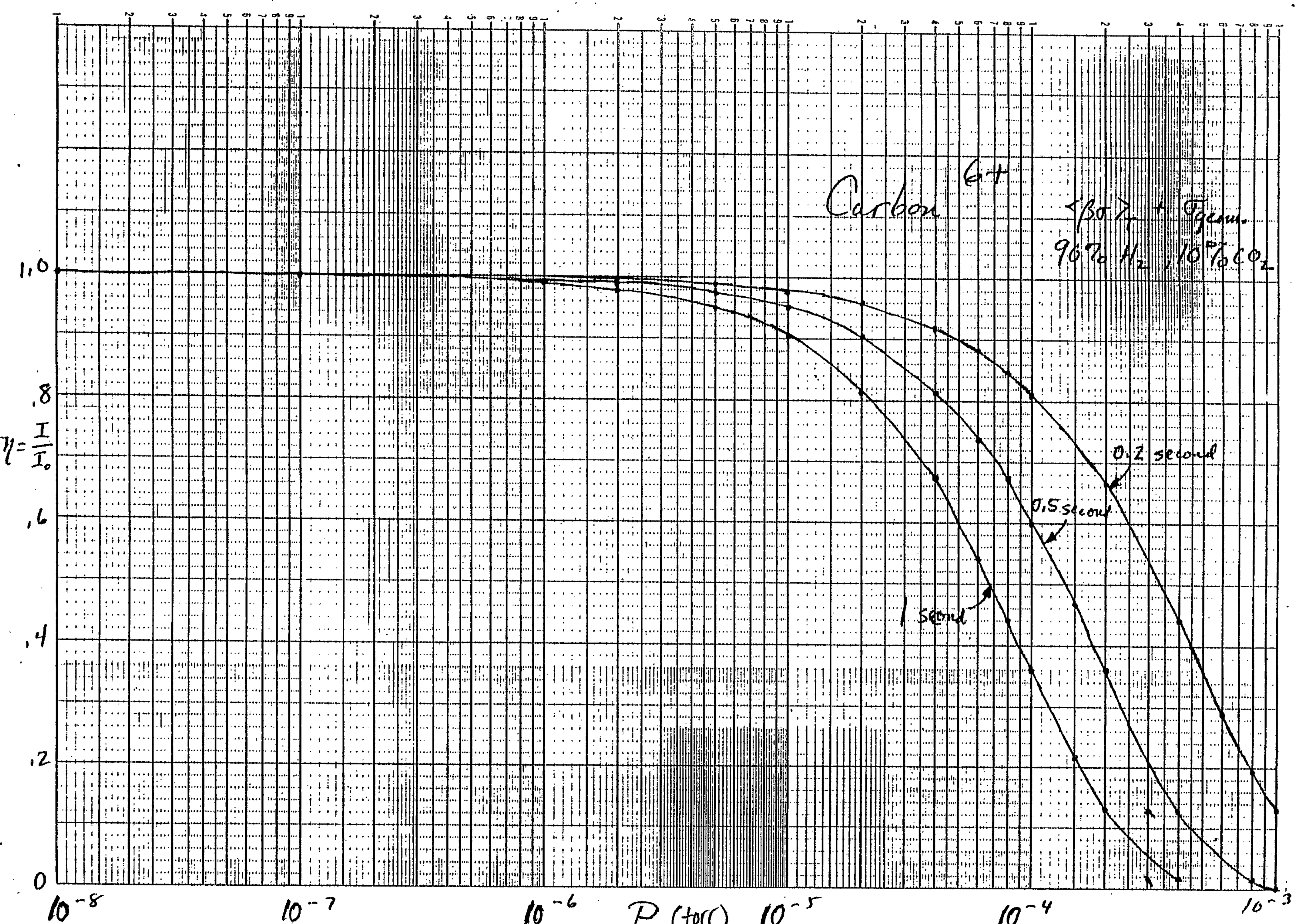
0
10^-11
10^-10
10^-9
10^-8
10^-7
10^-6
P (torr)


Copper 22+
90% H2, 10% CO2
.2 second
.5 second
1 second
Cu 29+
1 second
(bare)
1.0
.8
.6
.4
.2
0
η = I/I0
10^-11
10^-10
10^-9
P (torr)
10^-8
10^-7
10^-6


Carbon 6+
<βσ>₊ + σgeom.
90% H_2 / 10% CO_2
0.2 second
0.5 second
1 second
1.0
.8
.6
.4
.2
0
$\eta = \frac{I}{I_0}$
10^{-8}
10^{-7}
10^{-6}
P (torr)
10^{-5}
10^{-4}
10^{-3}