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

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USDOE Office of Science (SC)

# DISCLAIMER

# 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

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

$\sigma_T$ = 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 & photo ionization

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

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

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

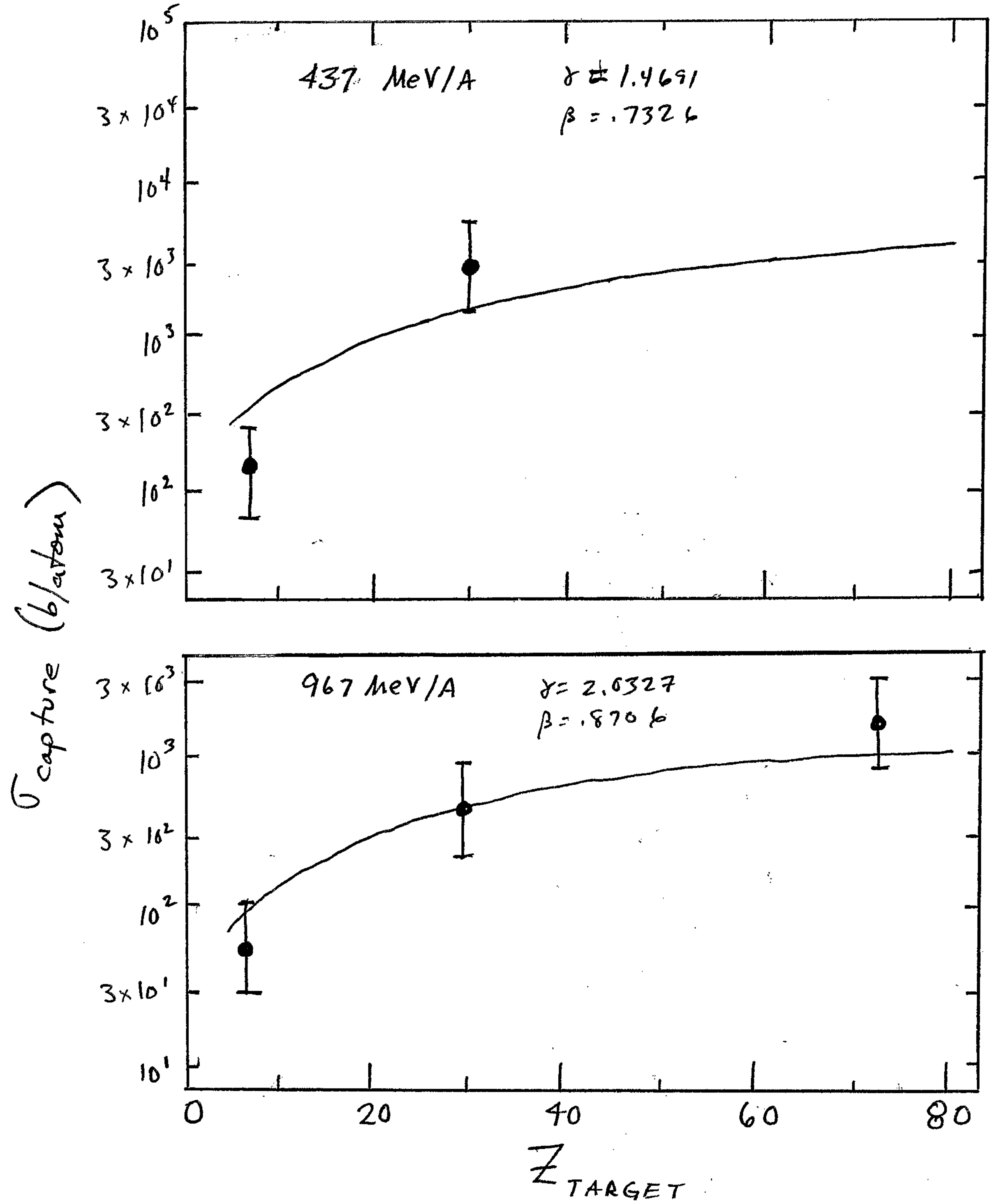
As expected, Gold is our main headache

| T/A (GeV/A) | $\gamma$ | $\sigma_{capture}$ (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

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

# $U^{92+}$




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

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

**Warm, 40% $H_2$, 60% $CO_2$** — $\tau_B$ (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 |

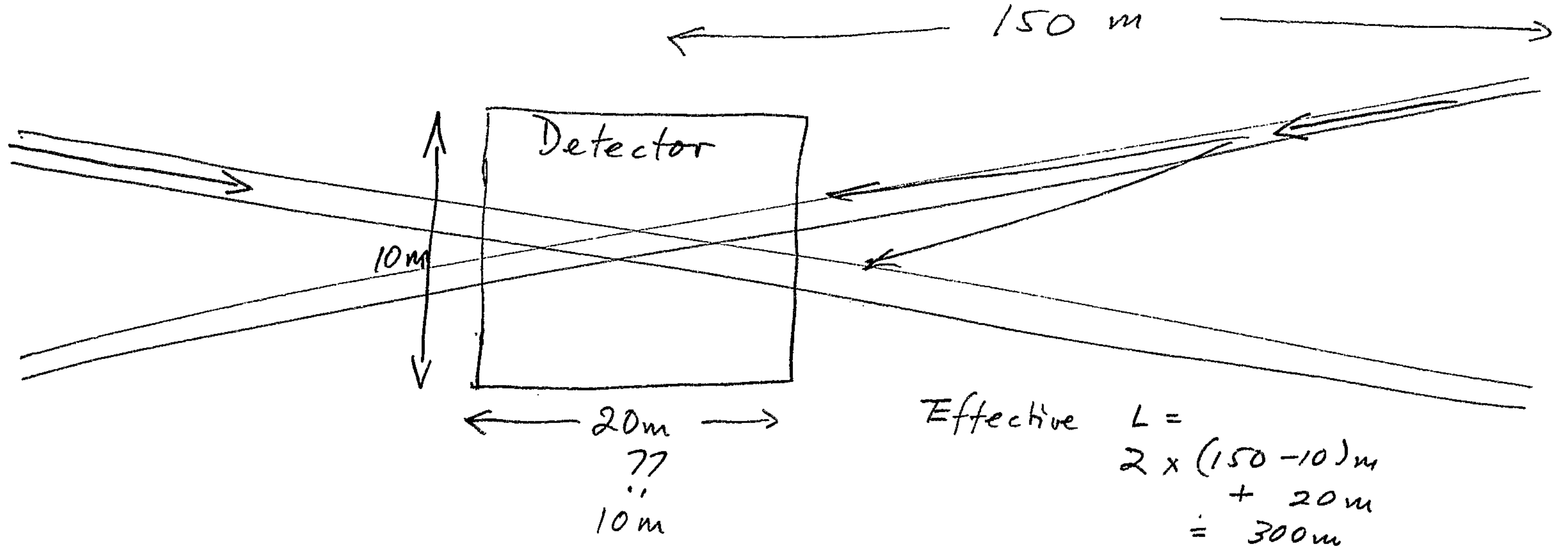
For $\eta = .95$ $\quad (\eta^2 = .9 \Rightarrow \text{Luminosity})$

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




Effective $L =$
$2 \times (150-10)m$
$+ 20m$
$\doteq 300m$

Bunched beam case : Au, $1.87 \times 10^{9}$/bunch, 57 bunches

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

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

$$R_{beamgas} = (NB f_{rev})(n_0 PL)\,\sigma$$

For $\sigma$, use $\sigma_{geom}$ (Au + gas atoms)

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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

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

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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

$\boxed{R_{BG}/R_{TRUE} = 3.29\ !}$

# Solutions

a) lower pressure

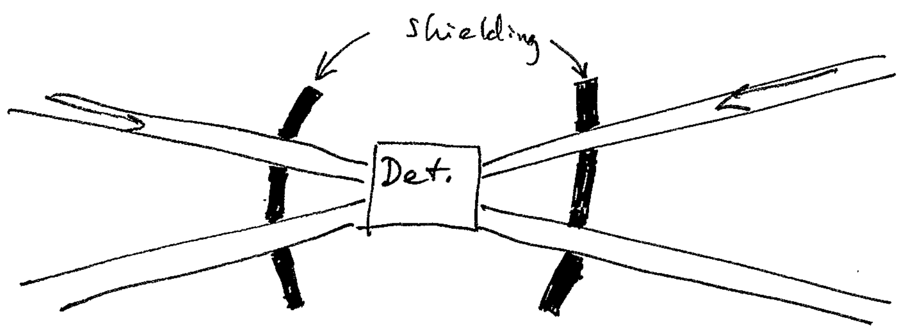
warm $10^{-11}$ torr $\rightarrow$ $\frac{R_{BG}}{R_{TRUE}} = 1.6\%$

↑ 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 $\gamma$ and $\therefore$ lower L?

# Booster Vacuum, Electron Capture & $\boxed{\text{Loss}}$

warm vacuum   90% $H_2$, 10% $CO_2$

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

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

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

$$\sigma_{loss}(\beta) \propto \beta^{-1} \text{ or } \beta^{-2}$$

($\underline{\text{if}}$ $\beta_{ion} > \beta_{\text{outer electrons in atomic orbits}}$)

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

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$Z, q, \beta$ 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 $dB \longrightarrow d\beta$

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

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

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

Tables of Integrals

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Plow through plenty of atomic physics data

= see RHIC-PG-16 =

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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 $\frac{\sigma(H_2)}{\sigma(H)} = 4$, not 2!

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

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

b) Gold as always causes all the trouble

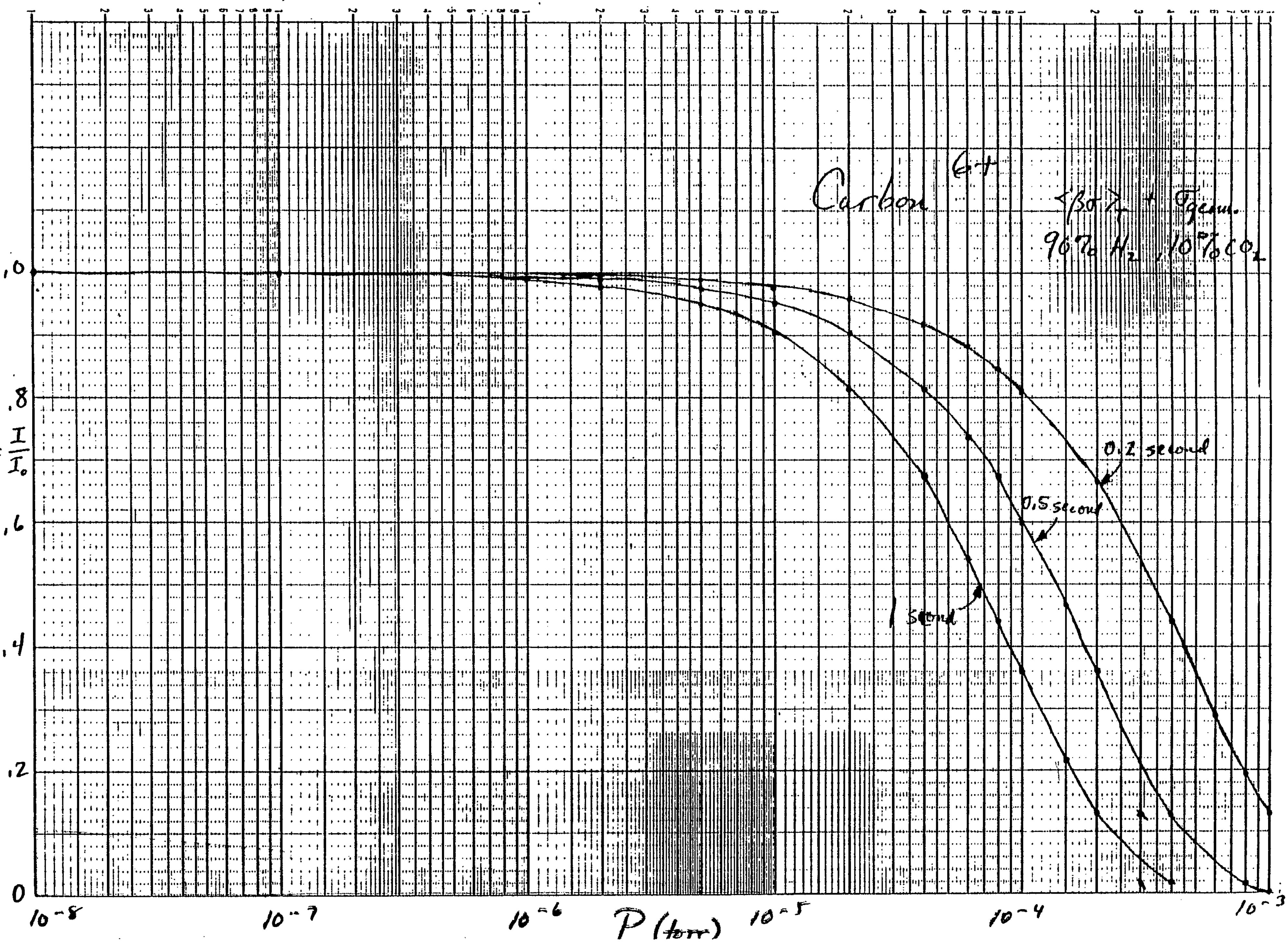
For 90% survival, 2 stage tandem, no linac

warm, 90% $H_2$, 10% $CO_2$

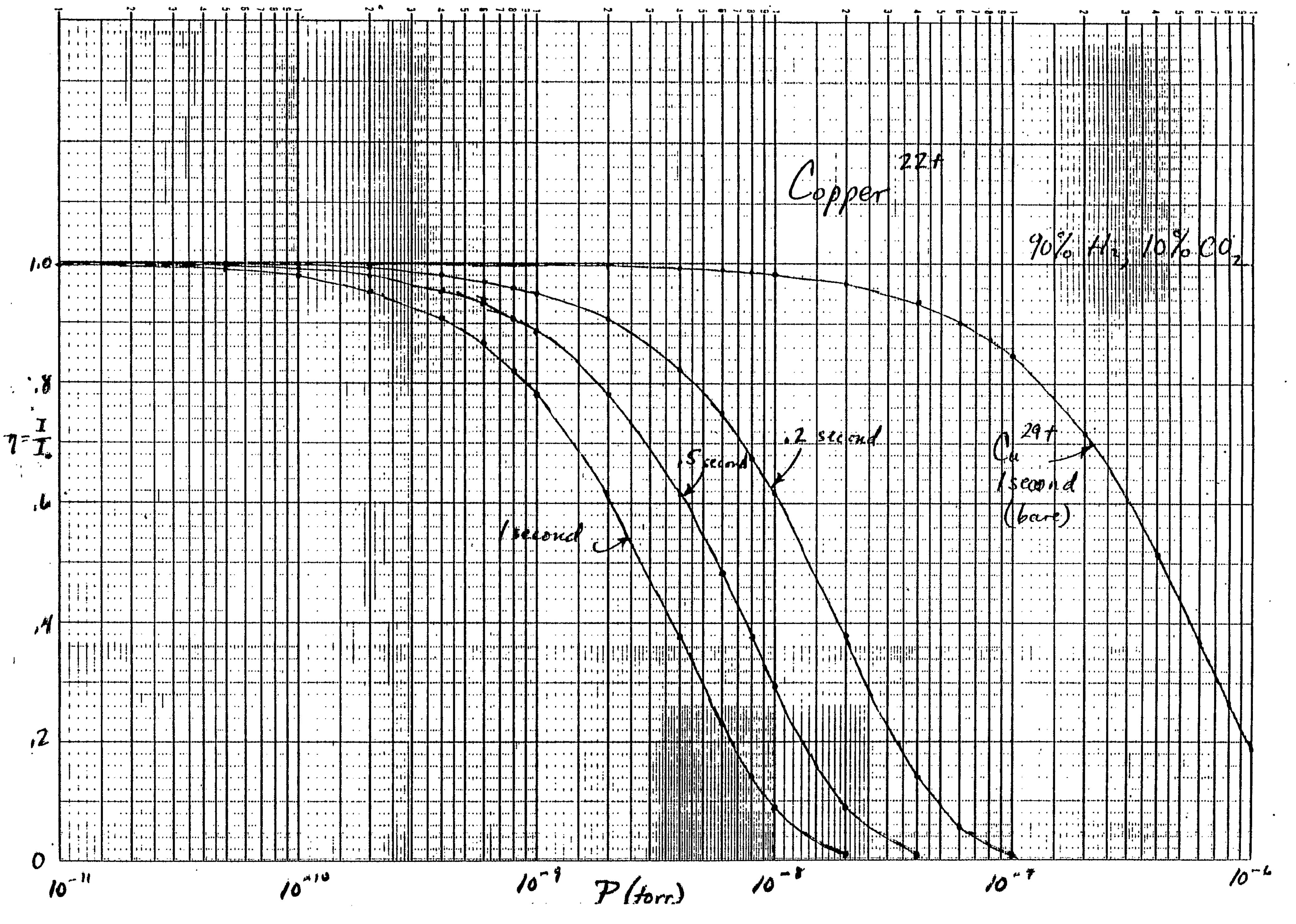
$\boxed{\text{Pressures}}$

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



Copper 22 f
90% $H_2$, 10% $CO_2$
1.0
.8
.6
.4
.2
0
$\eta = \frac{I}{I_0}$
.2 second
.5 second
1 second
Cu 29 f
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. $N_2$ ($\beta^{-6}$ scaling)

644 barns/mol. $N_2$ ($\beta^{-7}$ scaling)

AGS $10^{-7}$ torr, mostly $N_2$, $CO_2$, $H_2O$

(ie leaks)

For 0.6 second ramp up, <u>LAZY</u> estimate

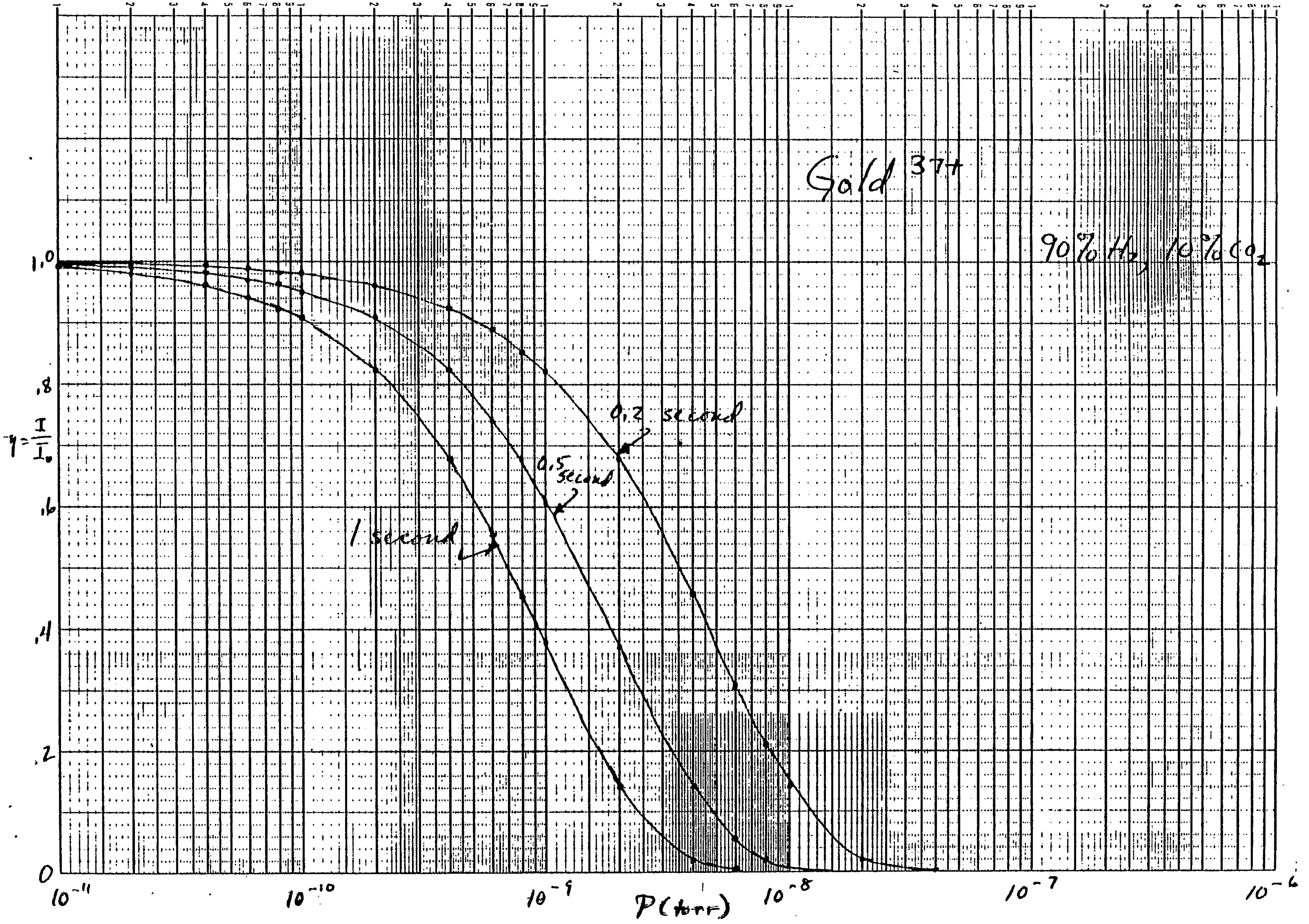
(ie $\sigma_{capture}$ <u>fixed</u>)

$$\eta = \frac{I}{I_0} = .979 \qquad 529 \text{ barns}/N_2$$

$$.877 \qquad 3275 \text{ barns}/N_2$$

$$.975 \qquad 644 \text{ barns}/N_2$$

∴ Not a Problem



Gold 37+
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
$10^{-11}$
$10^{-10}$
$10^{-9}$
$10^{-8}$
$10^{-7}$
$10^{-6}$
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

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

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

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

OK

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

means:

$\eta$ (worst case 3275 barns) $> 0.987$

$\eta' = .998$

# Luminosity vs A

## Equal A collisions

(RHIC – PG – 22
" – " – ?? )

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  $(\gamma = 108.35)$

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

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

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

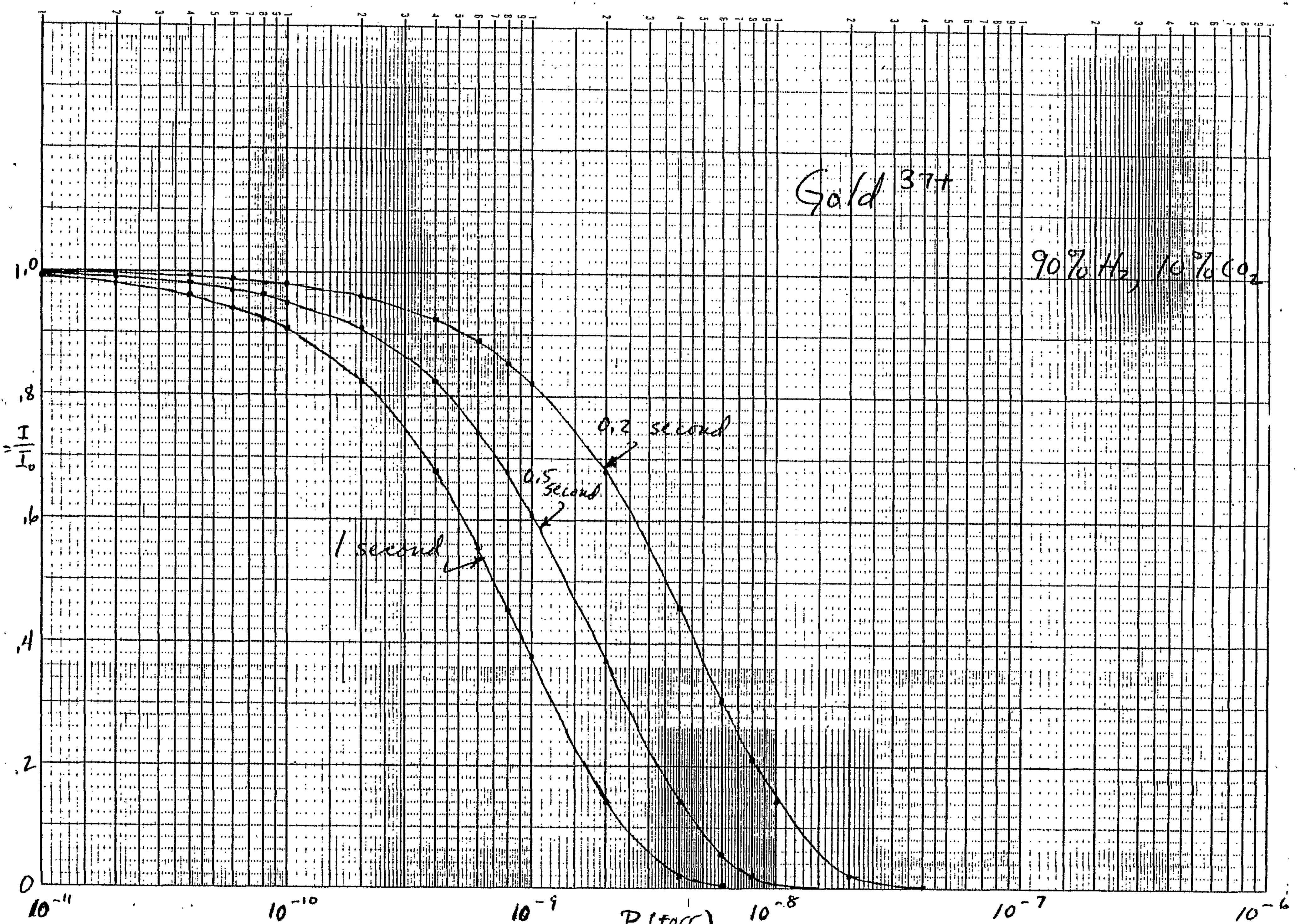
Scale: $L = \frac{N^2 B f_{rev}}{4\pi \sigma_V^* \sigma_H^* f}$ , $\Delta\nu_{BB} = \frac{N r_0 \beta_V^* Z^2}{4\pi \sigma_V^* \sigma_H^* \gamma f A}$

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

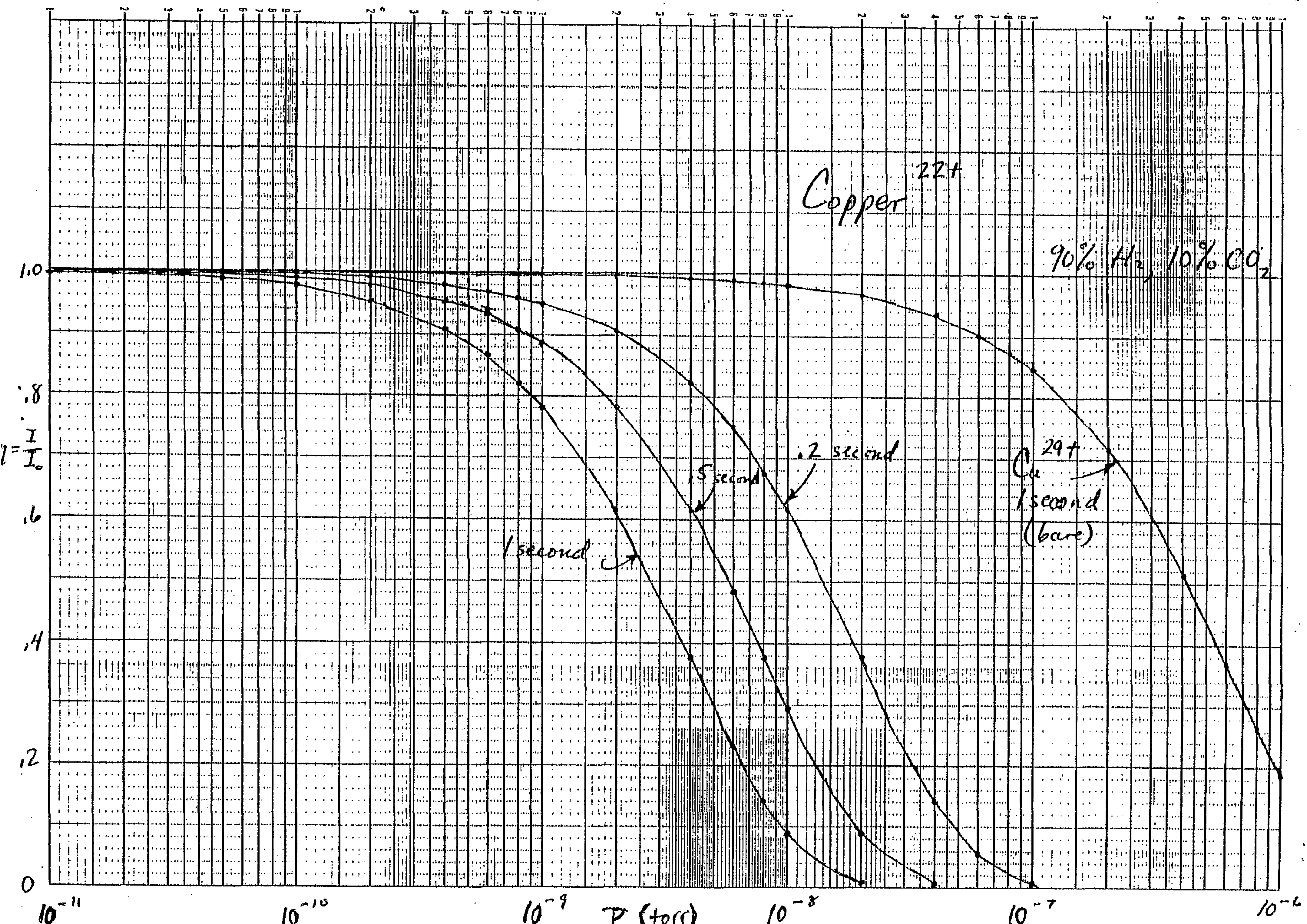
b) calculate N ( $Z^2/A$ scaling)

c) " L ($B, \sigma_V^*, \sigma_H^*, f_{rev}$ fixed)

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



Gold 37+
90% $H_2$, 10% $CO_2$
1.0
.8
.6
.4
.2
0
$\frac{I}{I_0}$
0.2 second
0.5 second
1 second
$10^{-11}$
$10^{-10}$
$10^{-9}$
$10^{-8}$
$10^{-7}$
$10^{-6}$
P (torr)



Copper 22+
90% $H_2$, 10% $CO_2$
1.0
.8
$\eta = \frac{I}{I_o}$
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.4
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0
.2 second
.5 second
1 second
Cu 29+
1 second
(bare)
$10^{-11}$
$10^{-10}$
$10^{-9}$
P (torr)
$10^{-8}$
$10^{-7}$
$10^{-6}$

SEMI LOGARITHMIC 5 CYCLES X 70 DIVISIONS AD 0845 -GO