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

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TRANSPARENCIES FOR SUMMARY

Booster, AGS & Collider Backgrounds

(mostly Vacuum)

G. R. Young

(BNL, December 16, 1983)

Collider Vacuum (RHIC - PG-11)

Fractional beam loss

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

σ_T = total charge changing cross section

$$l = \beta c t$$

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

P = pressure in torr

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

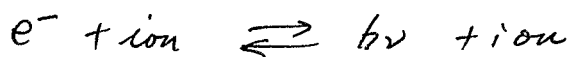
σ_{capture} : a) few measurements above 10 MeV/A

H Gould et al LBL -16467 16eV/A U

J Alonso + H Gould Phys Rev A 26, 1134 (1982)

8.5 MeV/A Kr, Xe

b) estimate radiative capture of e^-



from detailed balance & photo ionization

outer shell capture
multiple capture
etc.

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

σ_{capture} 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

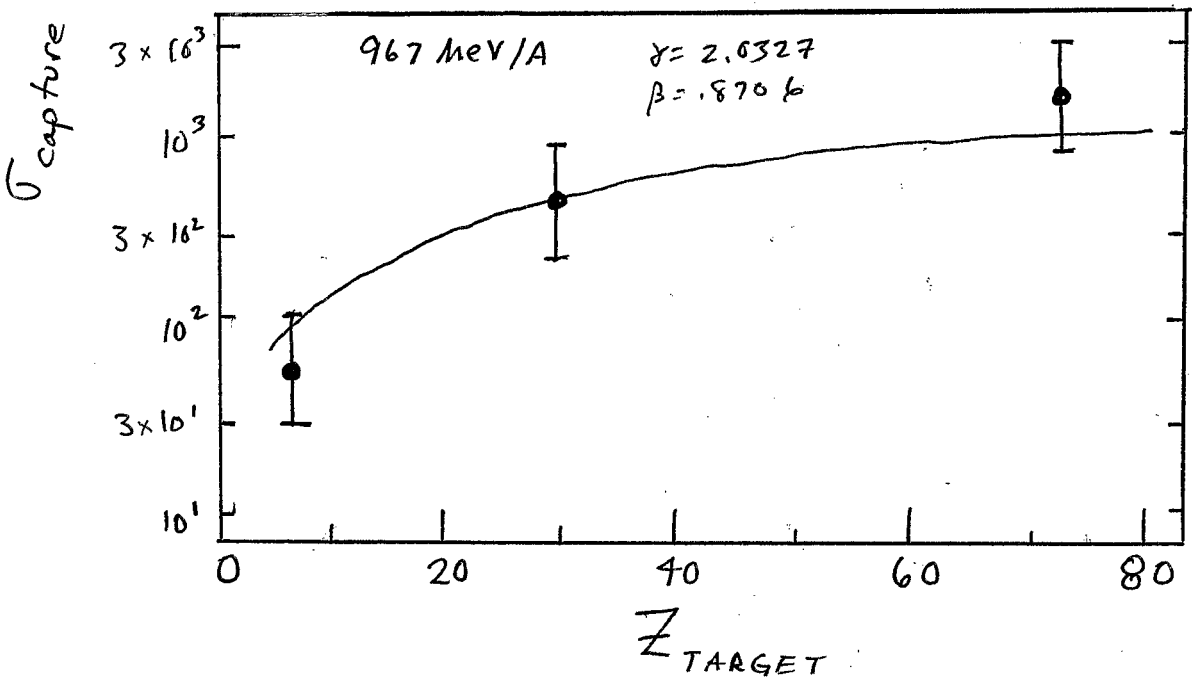
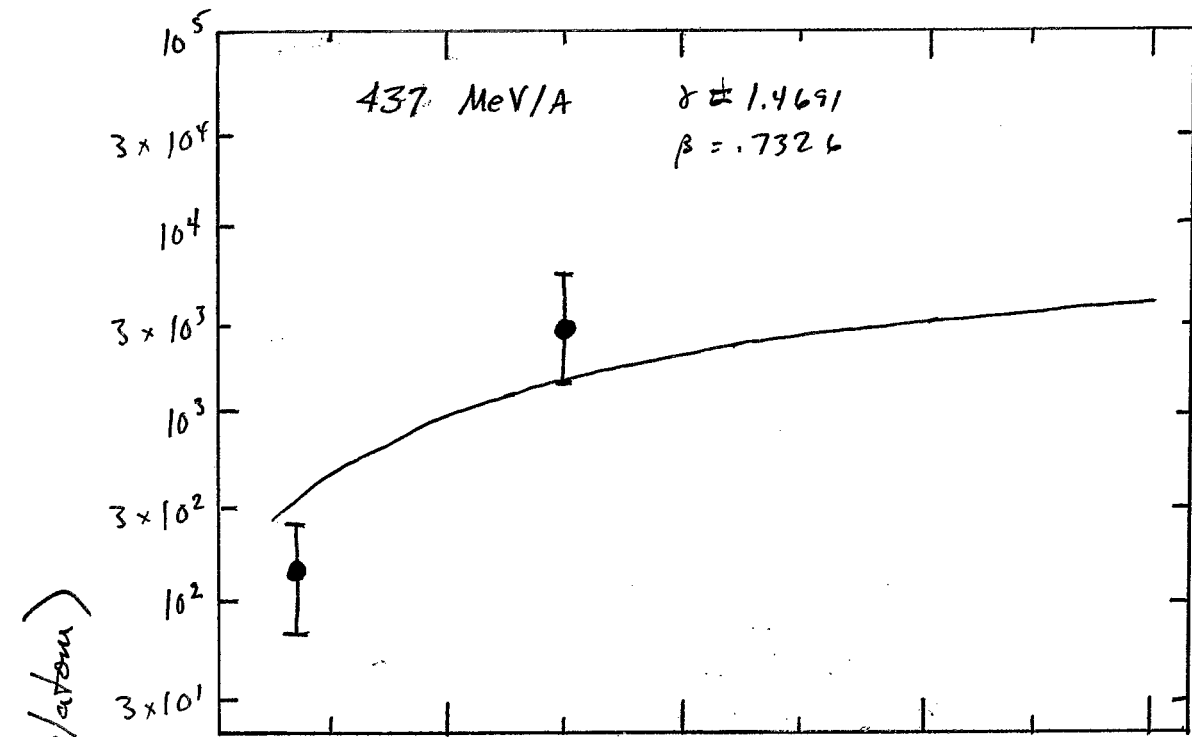
As expected, Gold is our main headache

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

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

U^{92+}



from LBL - 16467

Calculate $T_B = (\sigma_T \cdot \beta \cdot c \cdot n_0 \cdot P)^{-1} \frac{1}{3600}$ 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			T _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			T _B (hours)	
Ion	T/A	10 ⁻⁸ torr	10 ⁻⁹ torr	10 ⁻¹⁰ torr
	1	.18	1.75	17.5
	5	1.1	11.1	111

warm 90% H ₂ , 10% CO ₂			T _B (hours)	
Ion	T/A	10 ⁻⁸ torr	10 ⁻⁹ torr	10 ⁻¹⁰ torr
	1	.87	8.7	87
	5	3.58	35.8	358

cold 50% H ₂ , 50% He			T _B (hours)	
Ion	T/A	10 ⁻⁸ torr	10 ⁻⁹ torr	10 ⁻¹⁰ torr
	1	.221	2.21	22.1
	5	.765	7.65	76.5

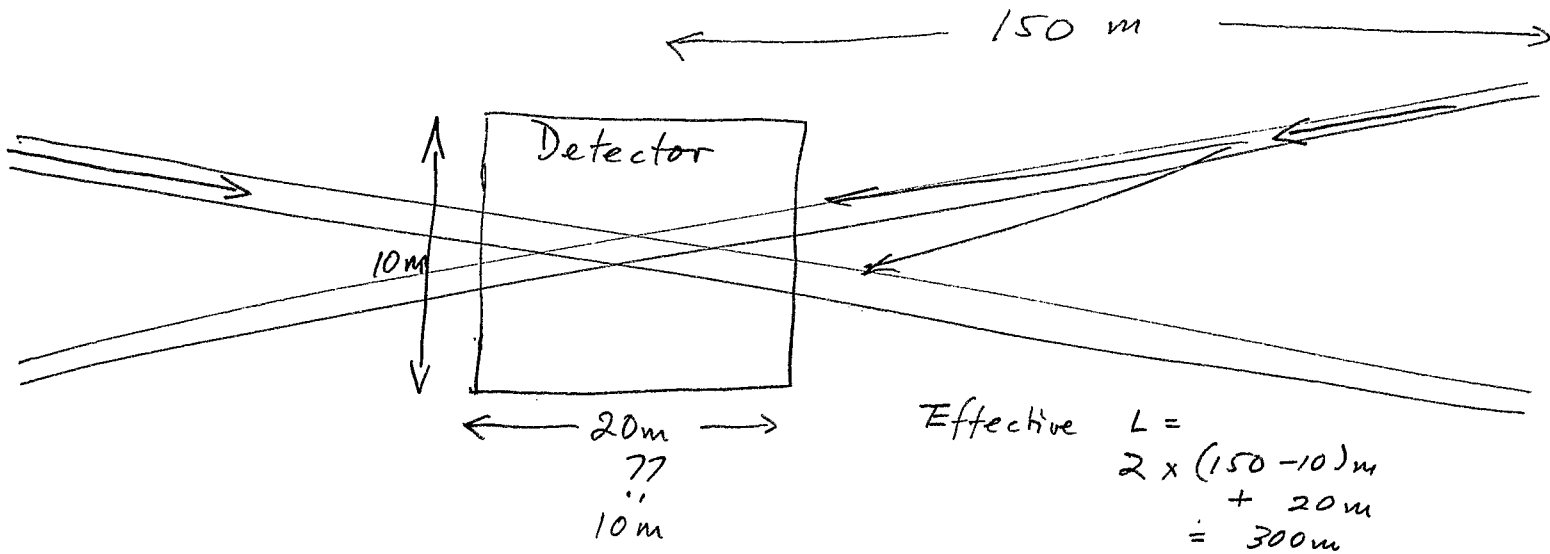
For $\eta = .95$ ($\eta^2 = .9 \Rightarrow$ Luminosity)

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 $\cdot 10^{-10}$ torr
	b) all CO ₂	5.8 $\cdot 10^{-10}$ torr
	c) 90% H ₂ , 10% CO ₂	1.9 $\cdot 10^{-9}$ torr
cold	50% H ₂ , 50% He	4.0 $\cdot 10^{-11}$ torr

Beam Gas Background



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

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

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

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

For σ , use σ_{geom} (Au + gas atoms)

Warm 90% H₂, 10% CO₂ $\langle \sigma_{geom} \rangle = 5.11$ barn

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

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

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

Cold 50% H₂, 50% He $\langle \sigma_{geom} \rangle = 3.63$ barn

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

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

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

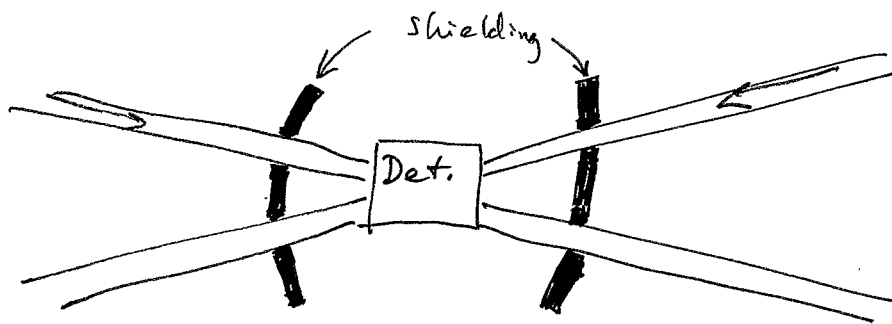
Solutions

a) lower pressure

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

cold 10^{-13} torr $\rightarrow \frac{R_{BG}}{R_{TRUE}} = 0.8\%$
 \uparrow 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 δ and i : lower L ?

Booster Vacuum, Electron Capture: Loss

warm vacuum 90% H₂, 10% CO₂

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

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

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

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

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

Z, q, β dependences

roughly
(conservative) $\sigma_{\text{capture}} \propto Z^0 q^3 \beta^{-6}$

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

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

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

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

Then use $B_p = \frac{A_m}{300} \beta \gamma$ to change $dB \rightarrow d\beta$

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

σ_{capture} yields an average $\int \frac{dB}{\beta^5 (1-\beta^2)^{3/2}}$ } Tables of Integrals
 σ_{loss} " " " $\int \frac{dB}{(1-\beta^2)^{3/2}}$

Plow through plenty of atomic physics data

= see RHIC-PG-16 =

Scaling with target

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

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

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

Molecular effects $\frac{\sigma(\text{H}_2)}{\sigma(\text{H}\bullet)} = 4$, not 2!

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

a) σ for carbon so small must add σ_{nuclear} , as for colliders

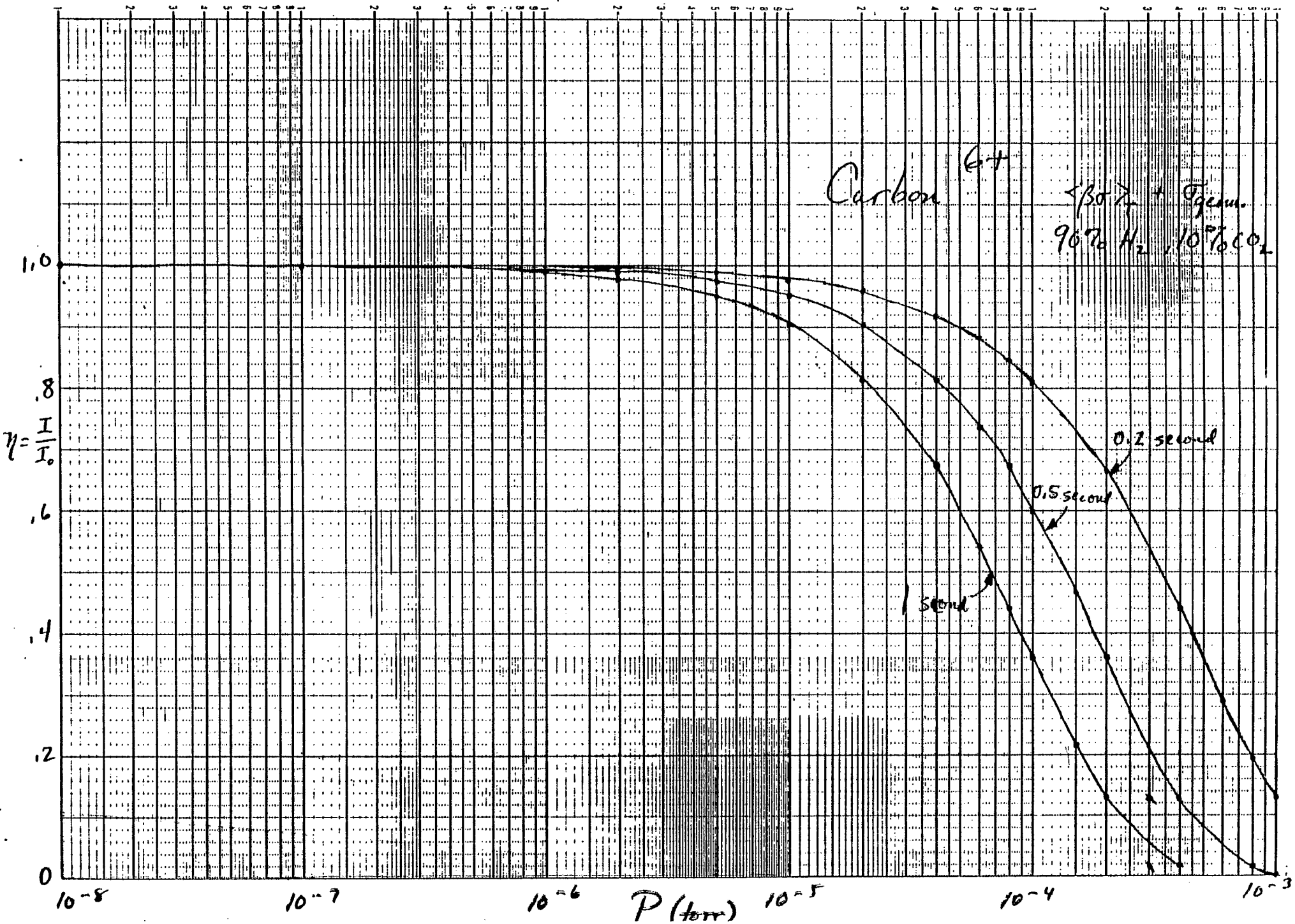
b) Gold as always causes all the trouble

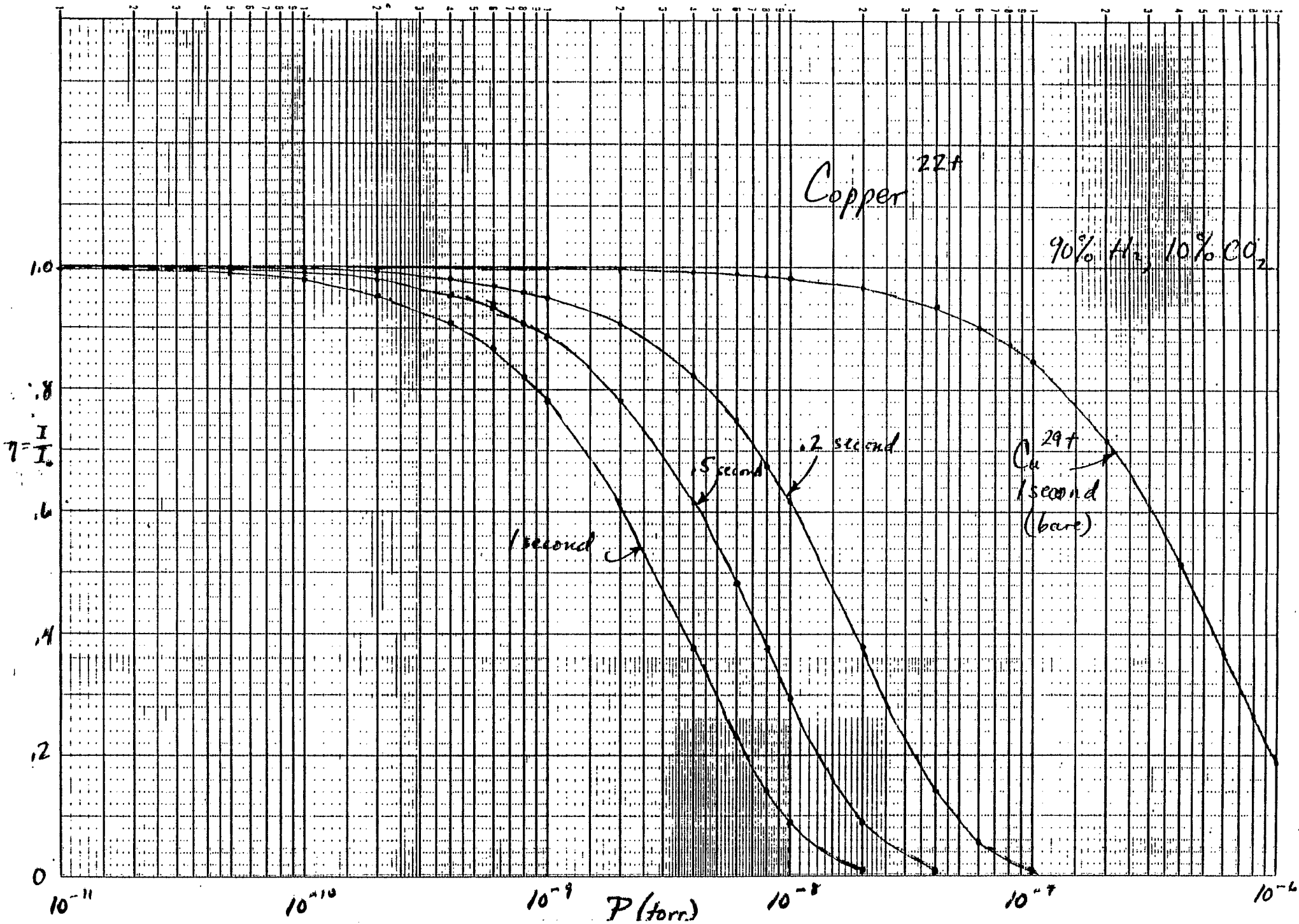
For 90% survival, 2 stage tandem, no linac
warm, 90% H₂, 10% CO₂

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
<u>linac</u> + Au ³⁷⁺	2 10 ⁻¹⁰	4 10 ⁻¹⁰	1 10 ⁻⁹

To guarantee 99%, 10⁻¹¹ Torr





AGS losses Au⁷⁹⁺

$\sigma_{loss} \equiv 0$

(RHIC - PG-17)

$\sigma_{capture}$

a) 529 barns on N₂

scaling by our theoretical formula

(LBL data suggest or)

b) 3275 barns/mol. N₂ (β^{-6} scaling)

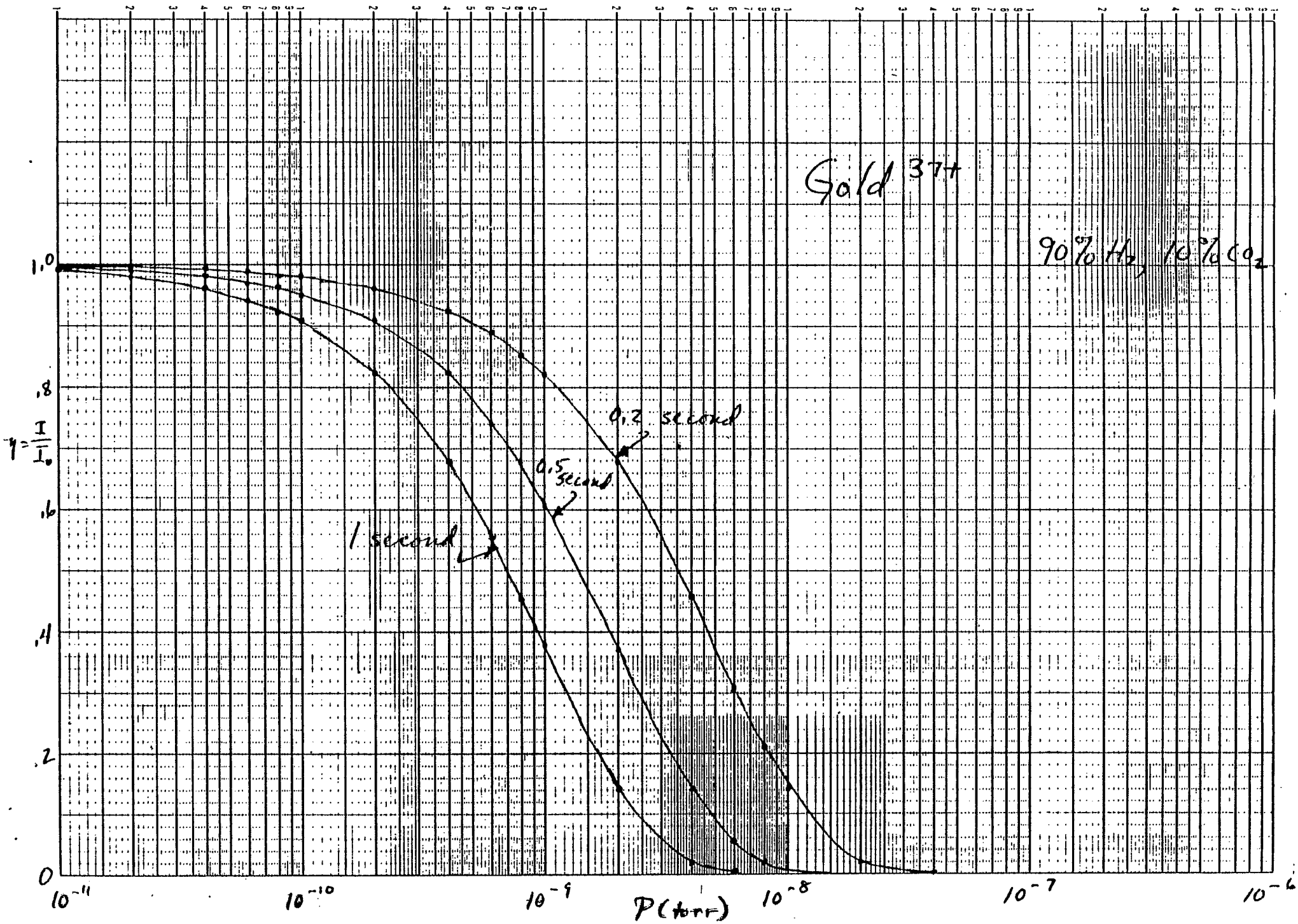
644 barns/mol. N₂ (β^{-7} scaling)

AGS 10⁻⁷ force, mostly N₂, CO₂, H₂O (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



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) $T = 23.3$ 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

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 Au⁷⁹⁺

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

$B = 57$ bunches

$\beta^* = 2$ m $V \frac{1}{c} H$

$\epsilon_N = 10 \pi$ mm mrad

→ head-on collisions ←

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

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

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

$p = \frac{\alpha \sigma_p}{2 \sigma_H^*} = 0$ ($\alpha = 0$)

$f_{rev} = 78,194$ s⁻¹

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

- Scale by
- fix ΔV_{BB}
 - calculate N (Z^2/A scaling)
 - " 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
$L_{100 \text{ GeV/A}}$	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
$L_{5 \text{ GeV/A}}$	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

