8 GeV H^- and Carbon Foil Calculations

What we are calculating:

(1) H^- field stripping (Bryant, Chou)
(2) H^- gas stripping (Chou)
(3) H^- foil stripping efficiency (Chou, Burgdoerfer)
(4) Energy deposition (Chou, Drozhdin)
(5) Temperature rise and stress analysis (Tang)
(6) Multiple Coulomb scattering and emittance dilution (Chou)
(7) Radiation dose (Mokhov)
(8) Lifetime of H^0 excited states in a field (Drozhdin, Chou)

What remains to be done:

(9) H^0 excited states population (? difficult)

(1) H^- Field Stripping – Theories on Lifetime

- T. Khoe – unpublished
- J.R. Hiskes – unpublished (1962)
- L.R. Scherk – Canadian Journal of Physics, vol. 57, p. 558 (1979):

$$\tau = 4mz_T / [S_0 N^2 \eta (1+p)^2 (1 - 1/2k_0 z_T)] \times \exp(4k_0 z_T / 3)$$

Several ways to parameterize this formula. The simplest and most commonly used one is:

$$\tau = A_1/E \times \exp(A_2/E)$$

where the electric field E is the Lorentz-transform of the magnetic field B:

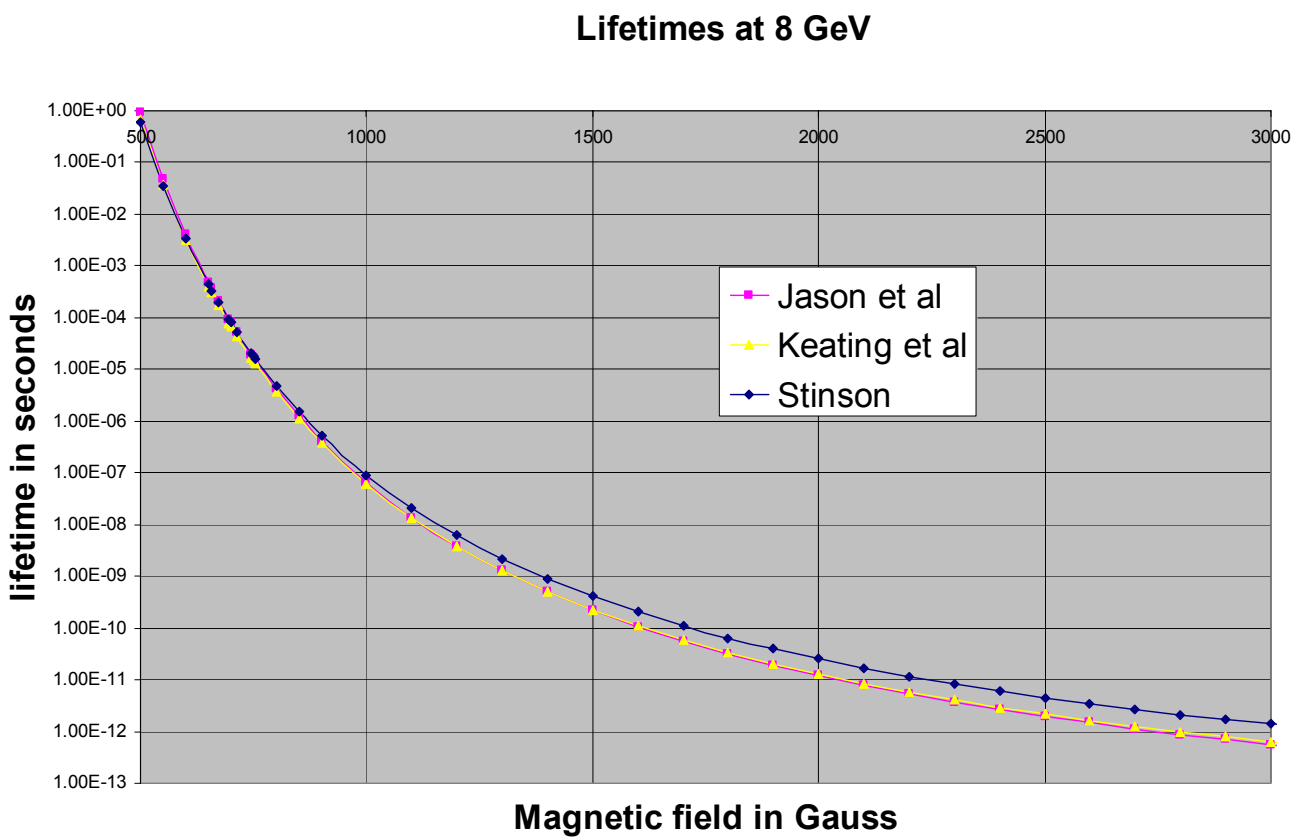
$$E\ (\mathrm{MV/cm}) = 3.197\ p\ (\mathrm{GeV/c})\ B\ (\mathrm{Tesla})$$

"Rule of thumb:" $p \times B \leq 6\text{-}7\ \mathrm{GeV/c} \times \mathrm{KG}$

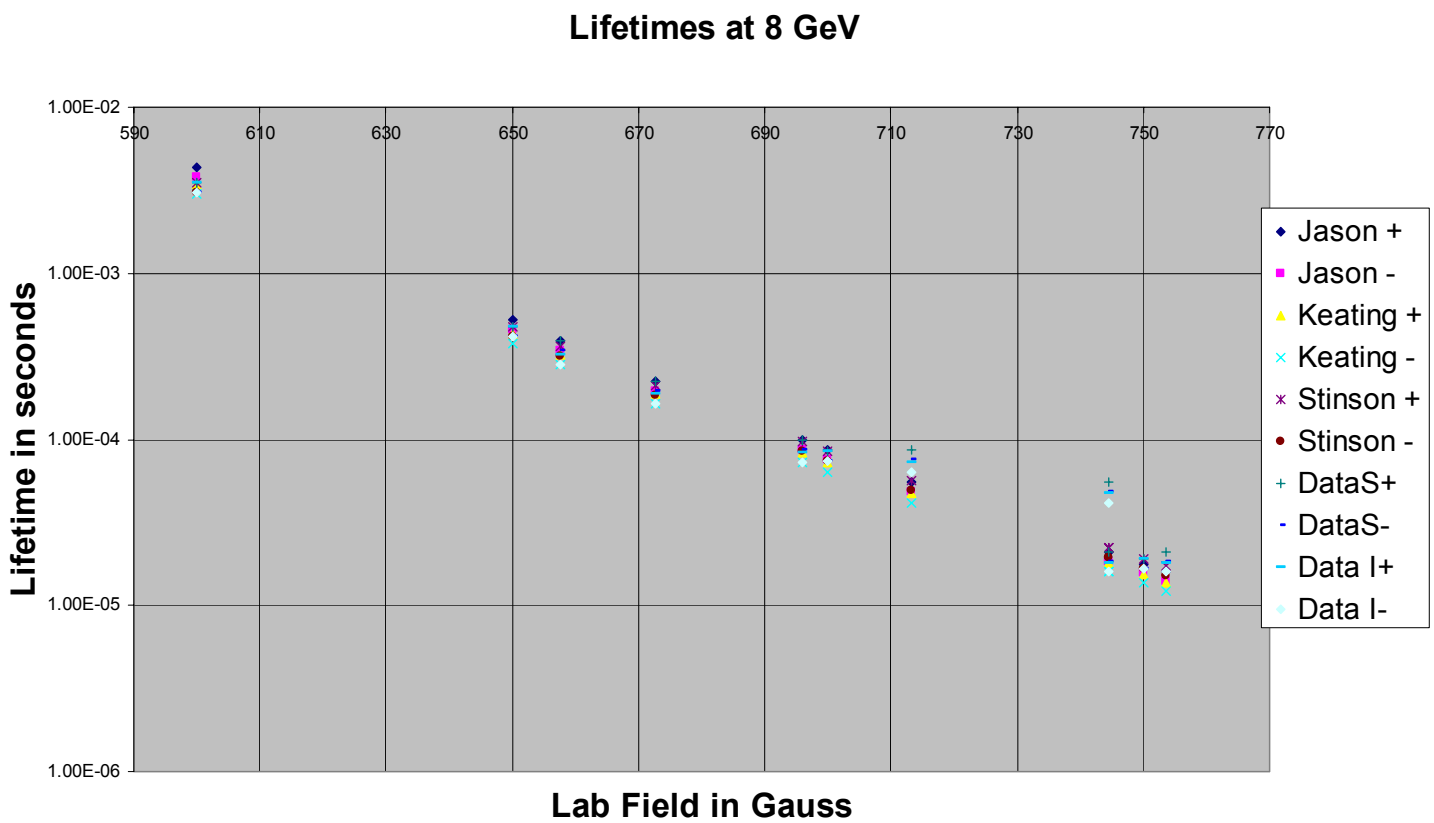
H^- Field Stripping – Measurements

	A_1 (10^{-14} s-MV/cm)	A_2 (MV/cm)
Khuri (1956)		
Darewych (1963)		
Kaplan et al. (1963) D-, 20 MeV, 2.4 MV/cm	1.05 (compared to Hiskes' theory)	49.25
Cahill et al. (1966) H-, 40 Mev	A factor of 3 difference between Hiskes and measurement	
Stinson et al. (1969) H-, 50 MeV, 1.867-2.140 MV/cm	7.96	42.56
Jason et al. (1981) H-, 800 MeV, 1.87-7.02 MV/cm	2.47(±4%)	44.94(±0.25%)
Keating et al. (1998) H-, 800 MeV	3.073	44.14

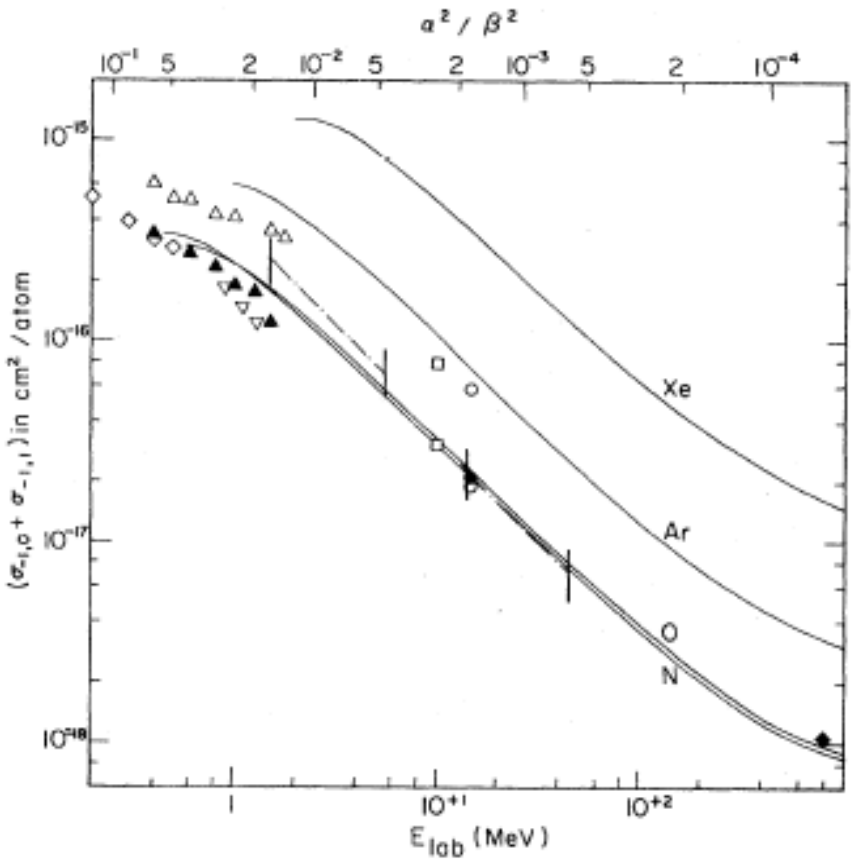
Summary of Three Measurements



Zoomed Region of the Plot



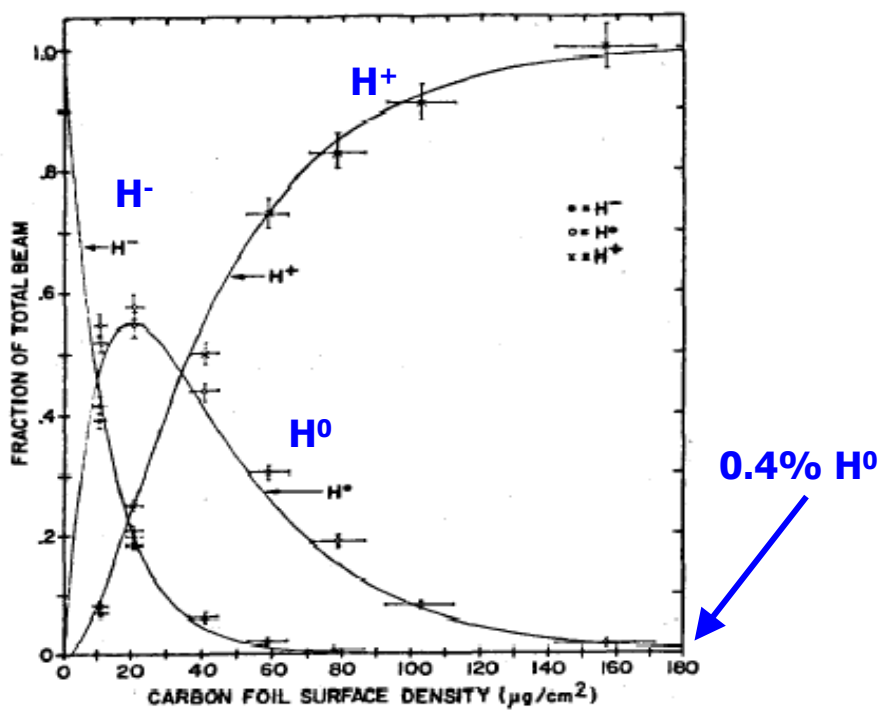
(2) H⁻ Gas Stripping – Theories and Measurements



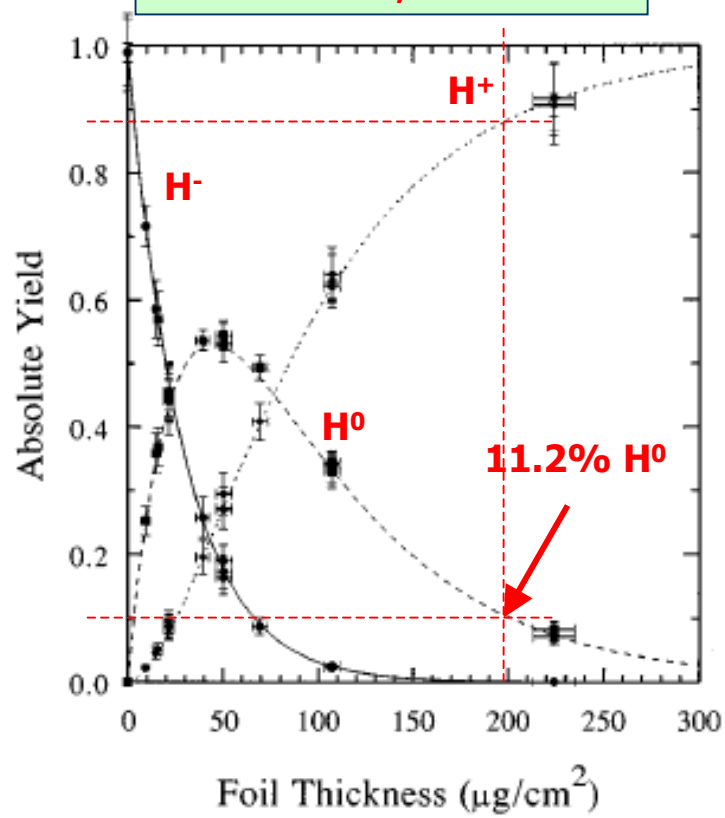
- G.H. Gillespie, Phys. Rev. A, vol.16, p.943 (1977)
- Same theory for foil stripping

(3) H^- Foil Stripping Efficiency – Measurements

Webber & Hojvat, 1979
Fermilab linac, 200 MeV



Gulley et al., 1996
LANL linac, 800 MeV



Measurements of Electron Loss Cross Section

	Webber & Hojvat 200 MeV	Gulley et al. 800 MeV	
$\sigma(-, 0)$	$(1.56 \pm 0.14) \times 10^{-18}$	$(0.676 \pm 0.009) \times 10^{-18}$	cm^2
$\sigma(0, +)$	$(0.60 \pm 0.10) \times 10^{-18}$	$(0.264 \pm 0.005) \times 10^{-18}$	cm^2
$\sigma(-, +)$	$(-0.08 \pm 0.13) \times 10^{-18}$	$(0.012 \pm 0.006) \times 10^{-18}$	cm^2

Scaling of Electron Loss Cross Section – Theories

- Born approximation for single- and double-electron detachment cross section:

$$\sigma(-, 0) + \sigma(-, +) = 8\pi\, a_0^2\, (\alpha^2/\beta^2) \sum_{n\neq 0} \sum_{m} [I_{nm} - J_{nm}(\beta^2) - K_{nm}(\beta^2)]$$

a_0 = Bohr radius

α = fine structure constant

$\beta = v/c$

I_{nm} = collision strength summed over all final states (ion+target atom)

$J_{nm}(\beta^2)$, $K_{nm}(\beta^2)$ = low energy corrections

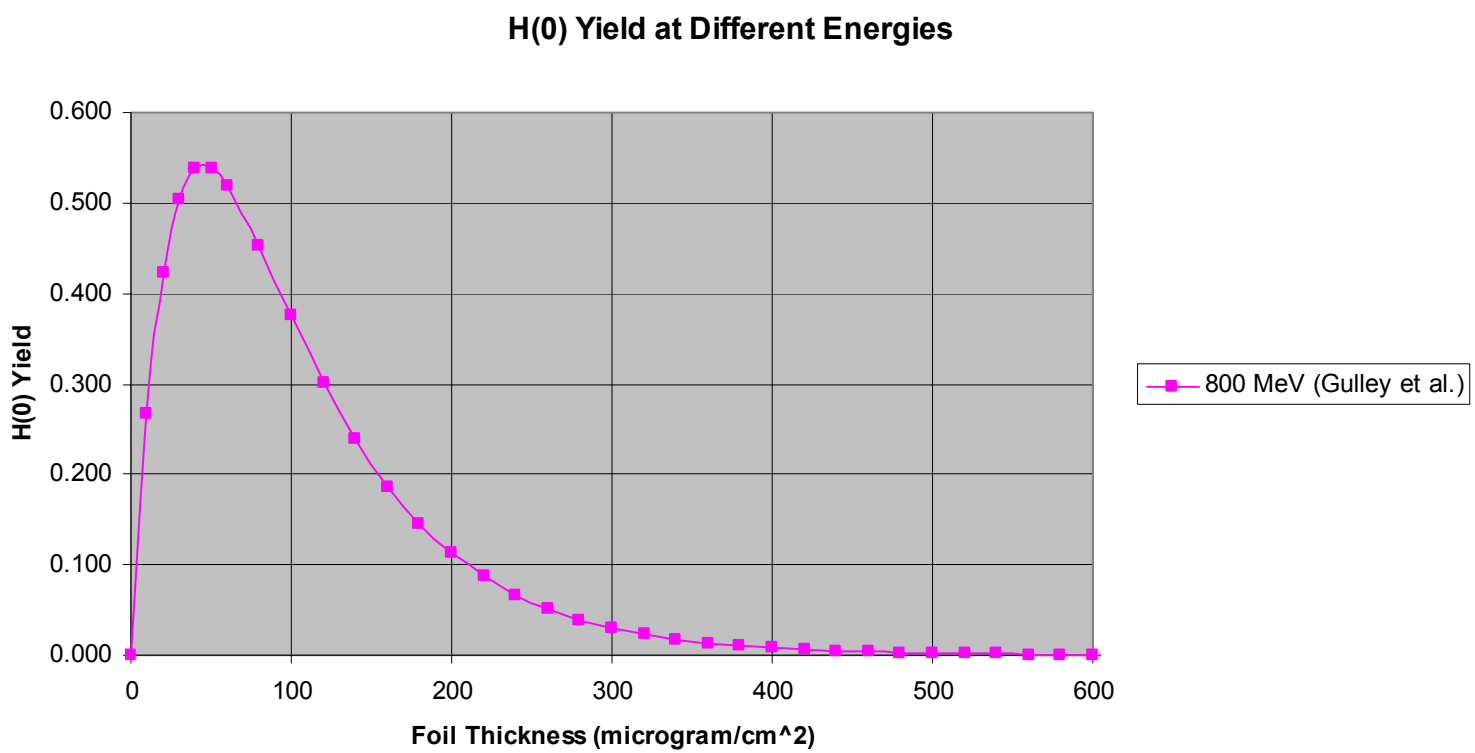
- Theoretical papers:
  - G.H. Gillespie (Feb 1977, Sept 1977, 1984) (use cross section σ)
  - B. Gervais et al. (1996) (use inverse mean free path λ^{-1}, which equals $N\sigma$)
  - P. Kurpick et al. (1998) (ditto)

Scaling of Electron Loss Cross Section – Calculations

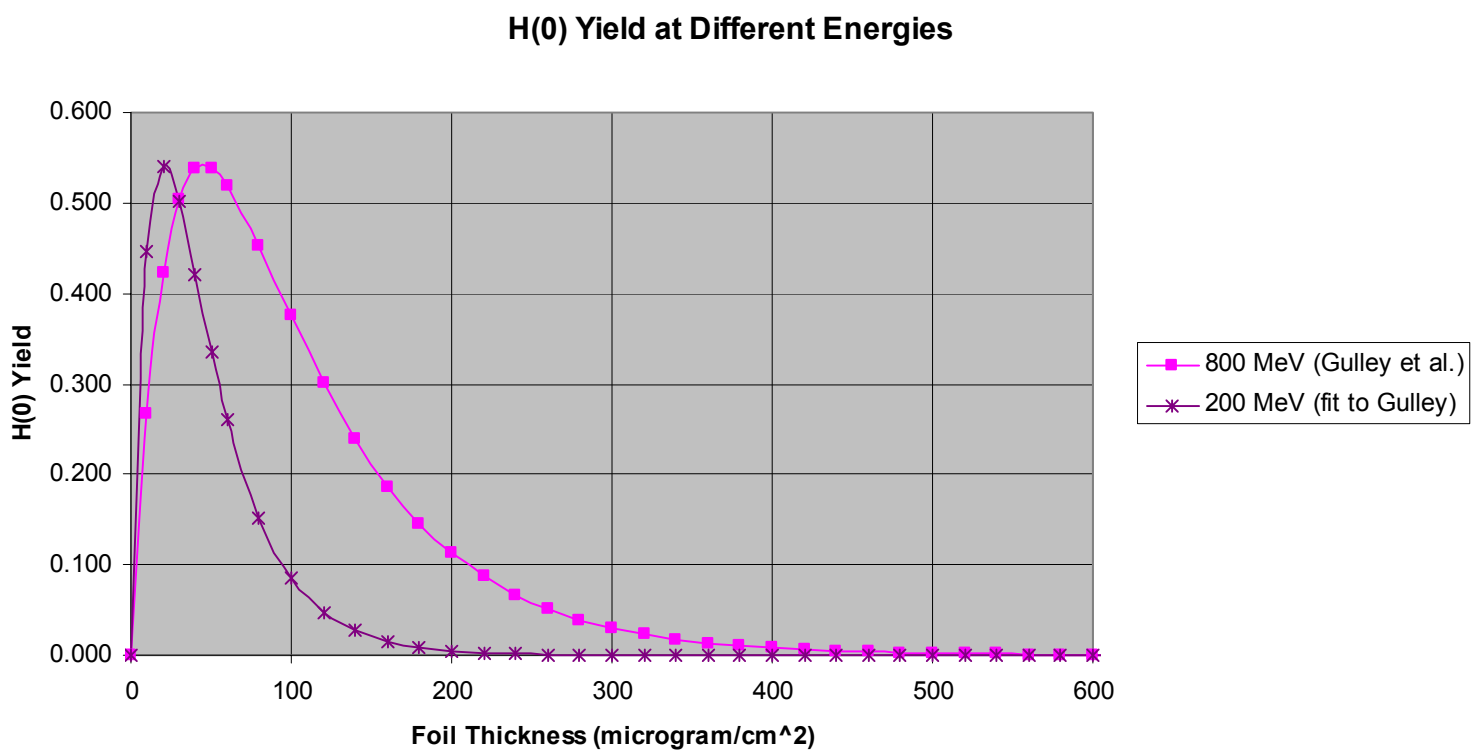
(unit 10^{-18} cm^2)

	800 MeV		200 MeV	400 MeV	8 GeV
		scaling			
σ(–, 0)	0.676±0.009	→	1.49 (1.56±0.14)	0.942	0.484
σ(0, +)	0.264±0.005	→	0.584 (0.60±0.10)	0.368	0.189
σ(–, +)	0.012±0.006	→	0.026 (–0.08 ±0.13)	0.0167	0.0086

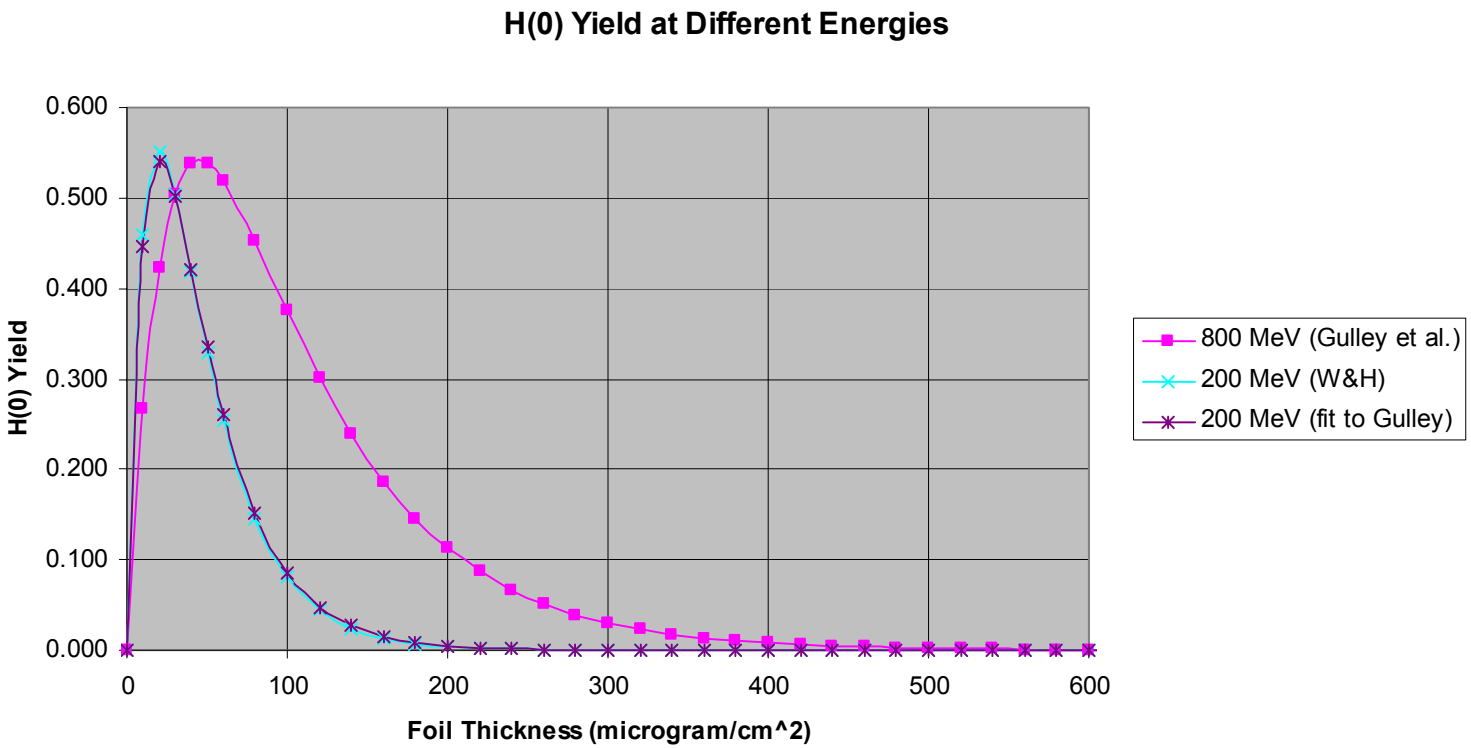
Energy Dependence of H(0) Yield



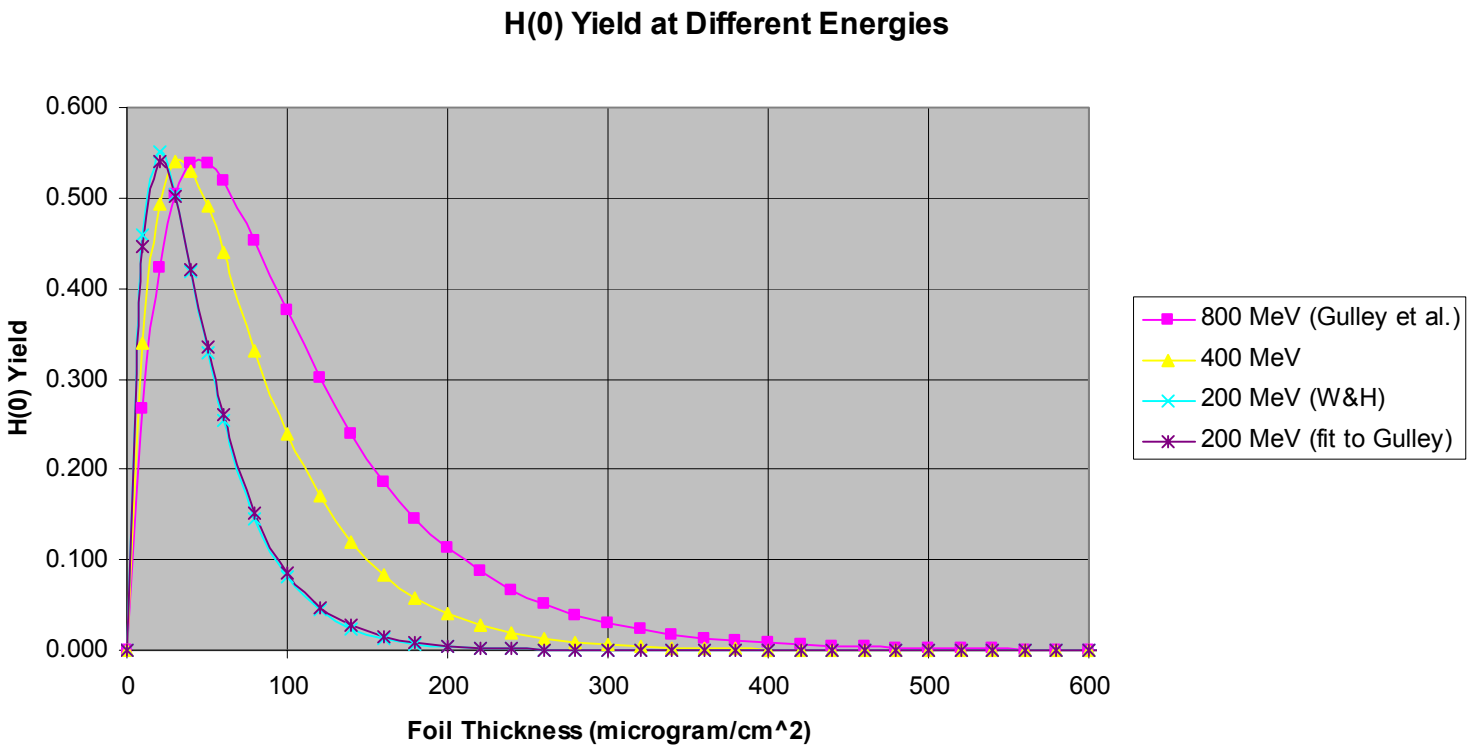
Energy Dependence of H(0) Yield



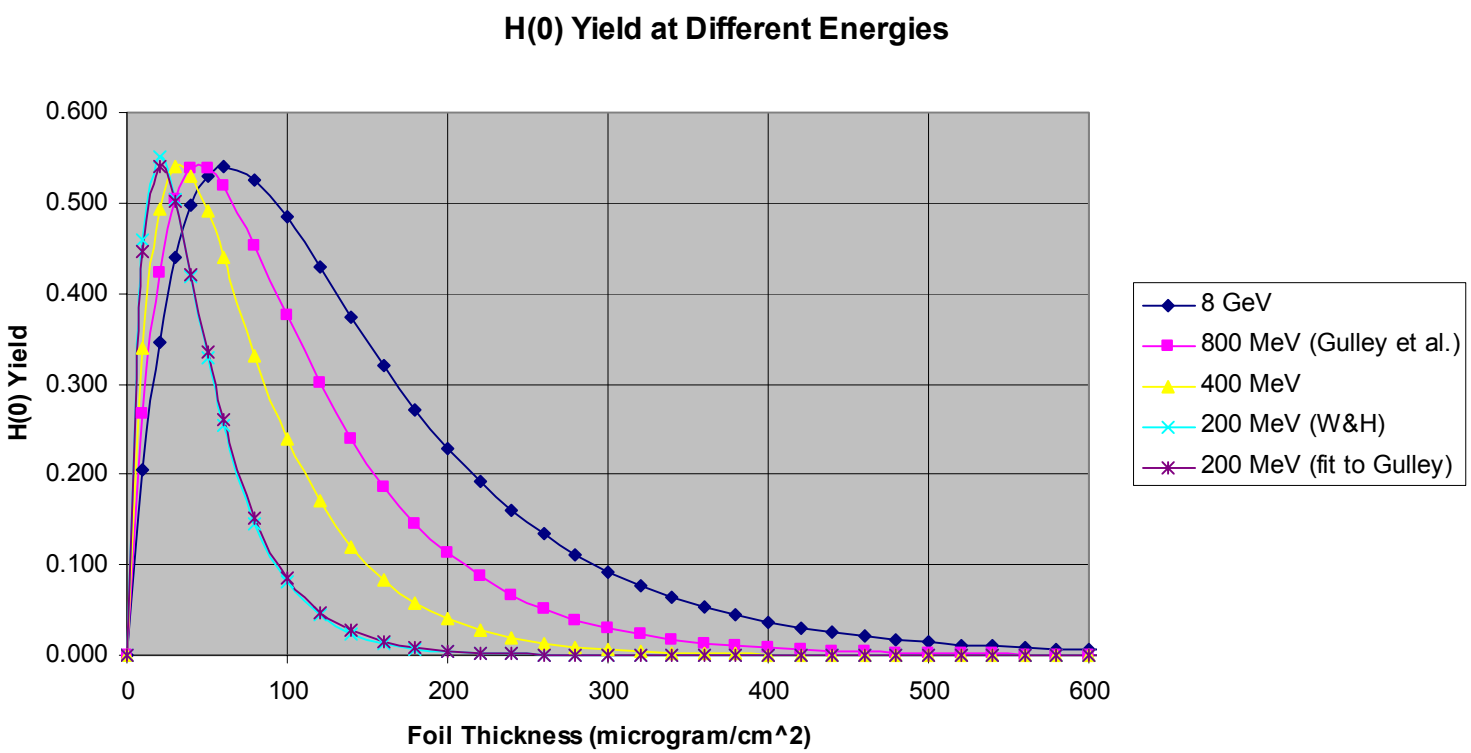
Energy Dependence of H(0) Yield



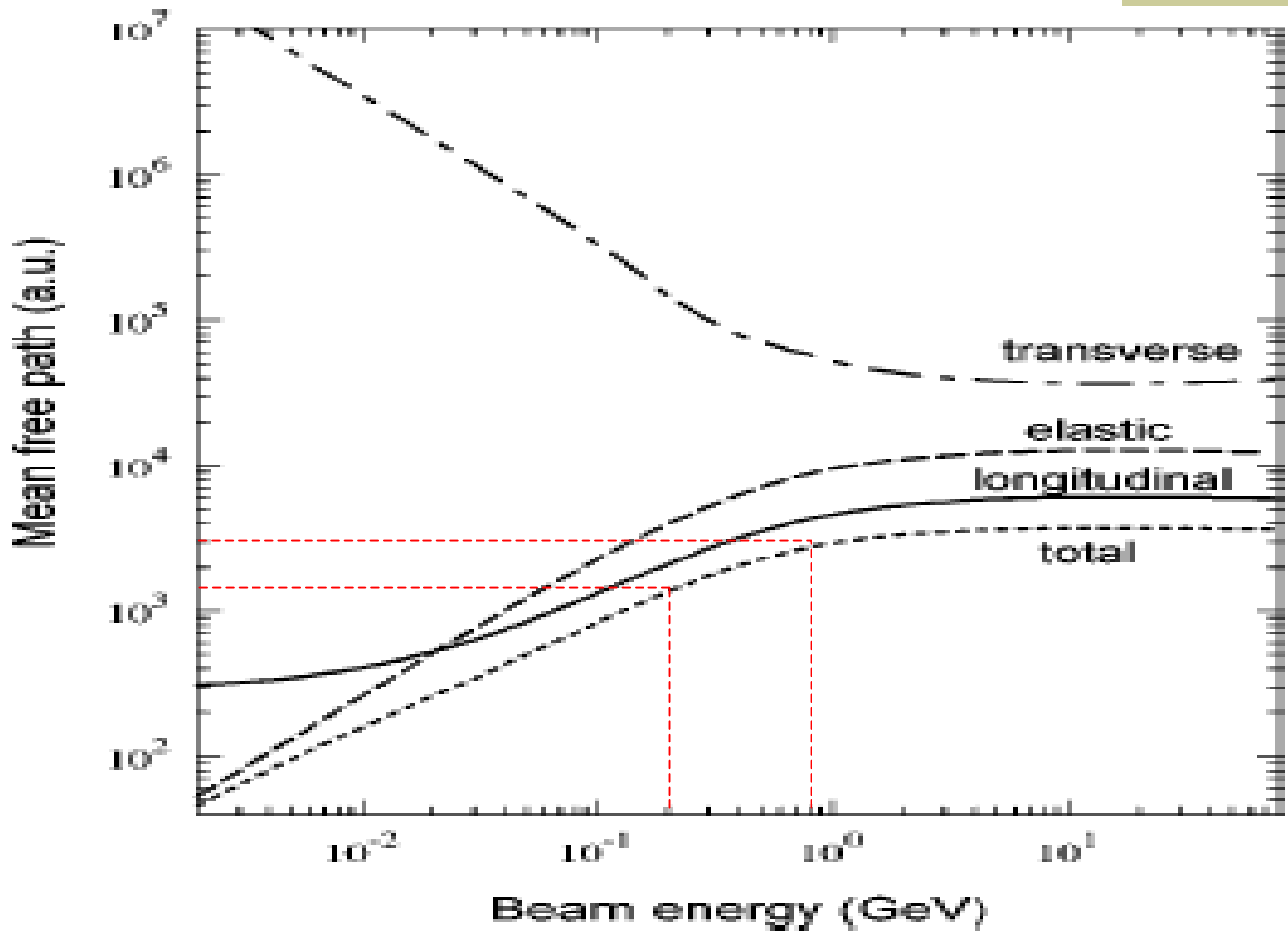
Energy Dependence of H(0) Yield



Energy Dependence of H(0) Yield

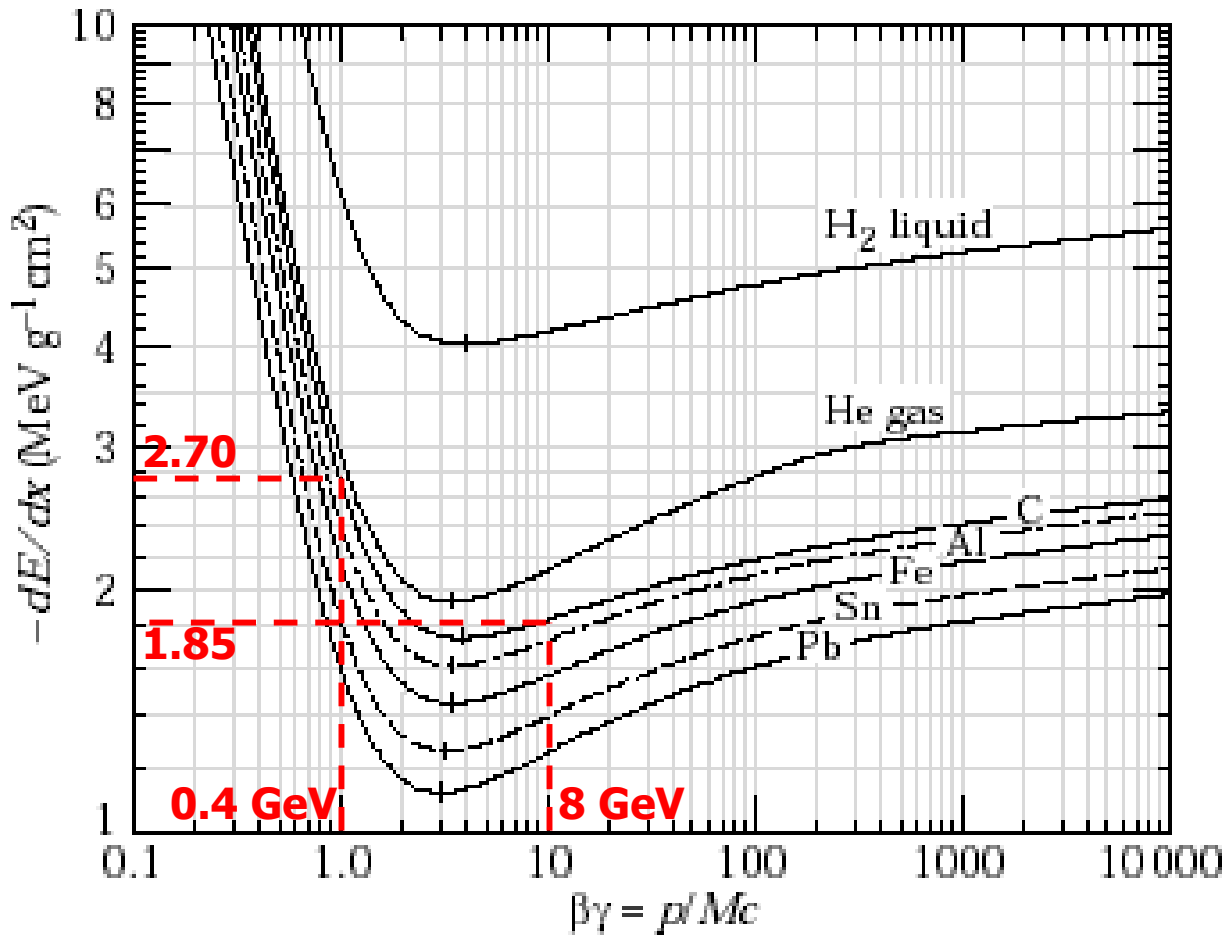


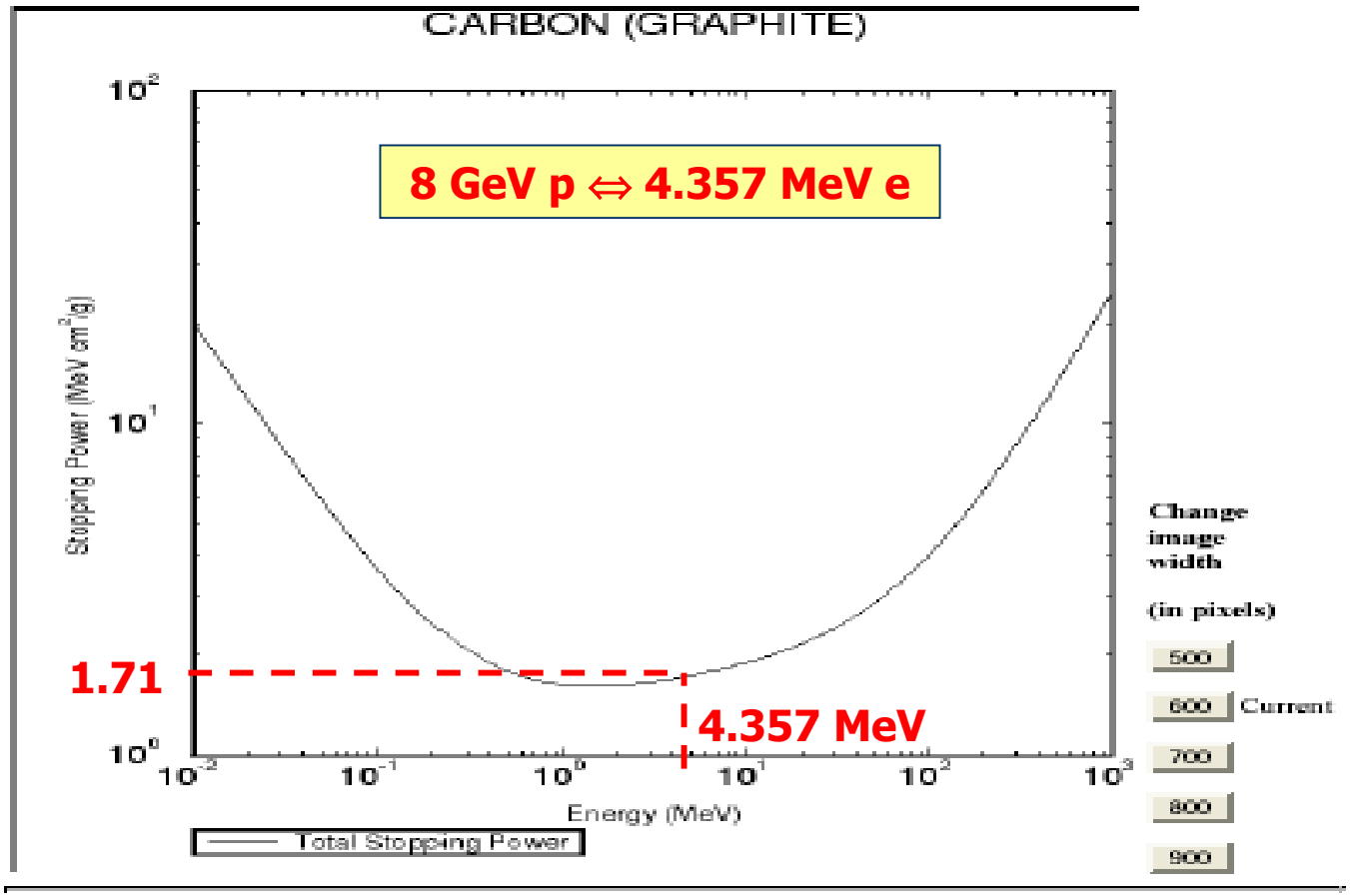
Theory of Energy Dependence of Mean Free Path



(4) Mean Energy Loss Rate by Heavy Particles (**p**, μ, π)

(Data from Particle Data Group)



Mean Energy Loss Rate by Electrons

(Data from NIST ESTAR Database)