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Scattering of Muonic Hydrogen Isotopes

E742

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Françoise Mulhauser

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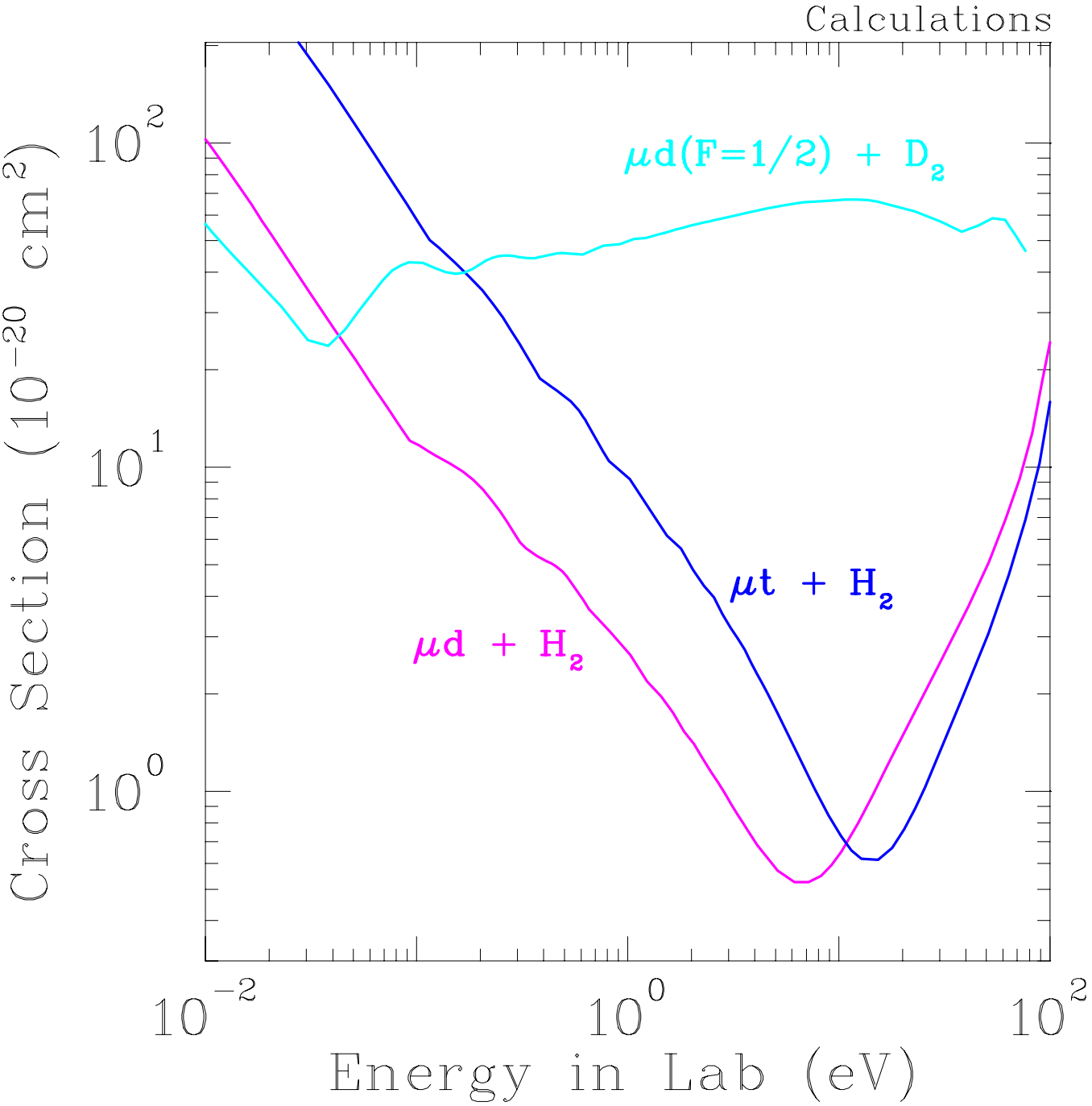
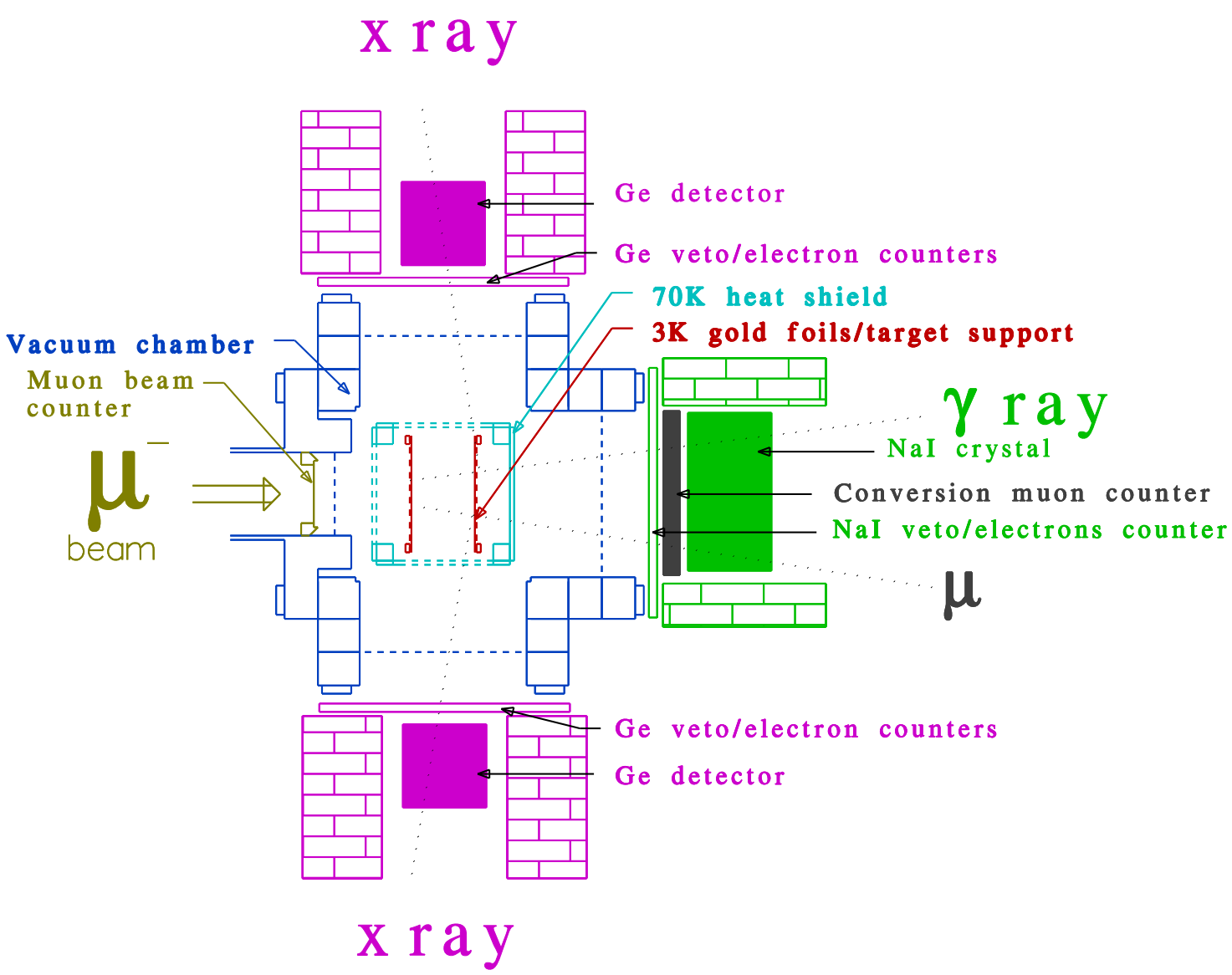
EEC TRIUMF 1996

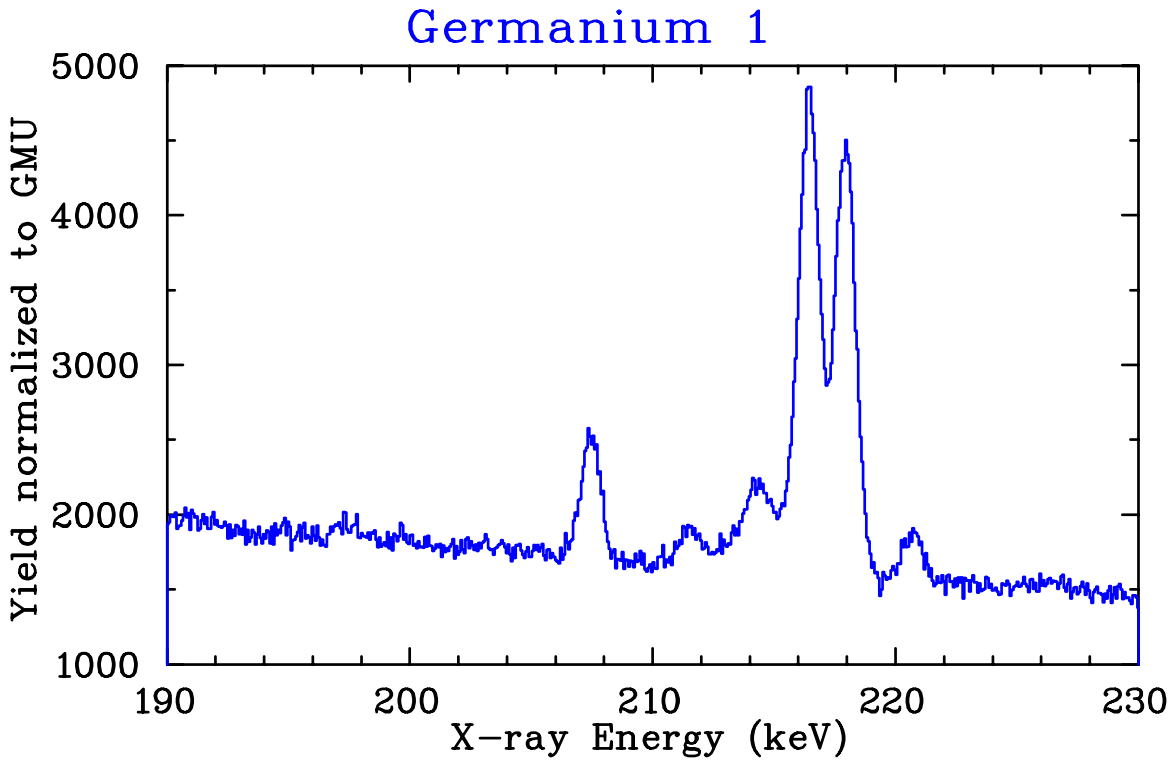
Scattering Cross Sections

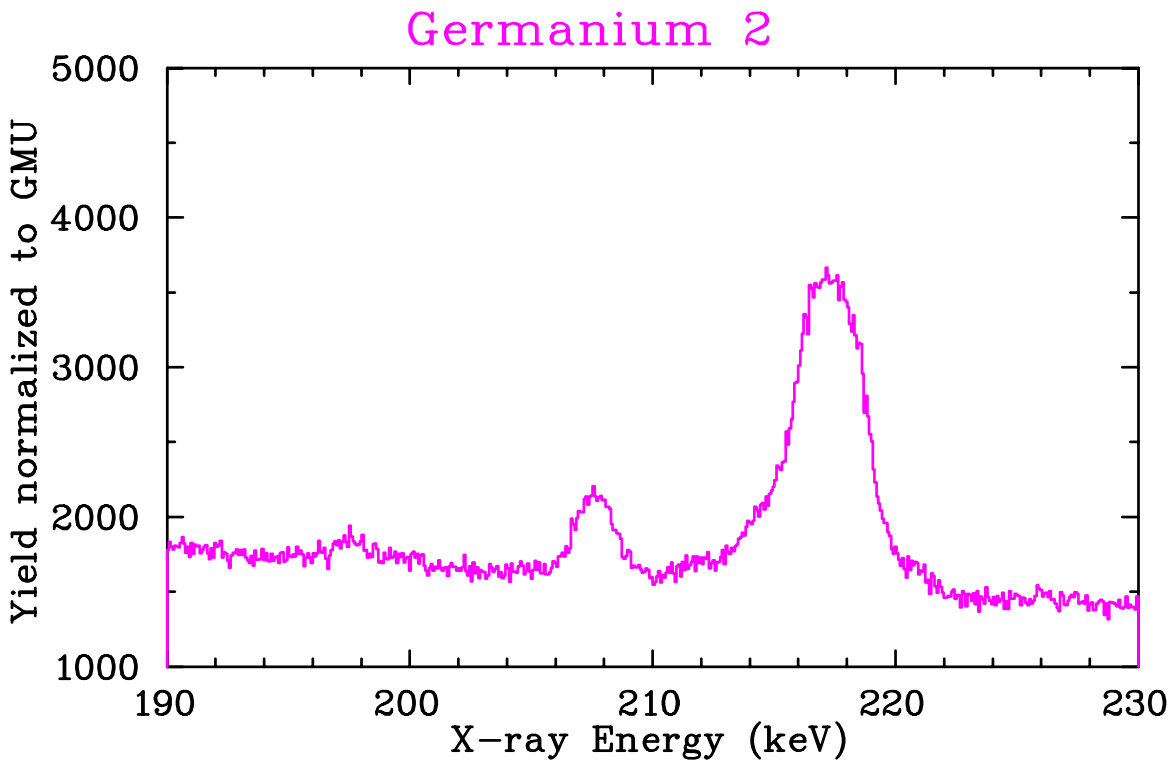


Experimental Setup

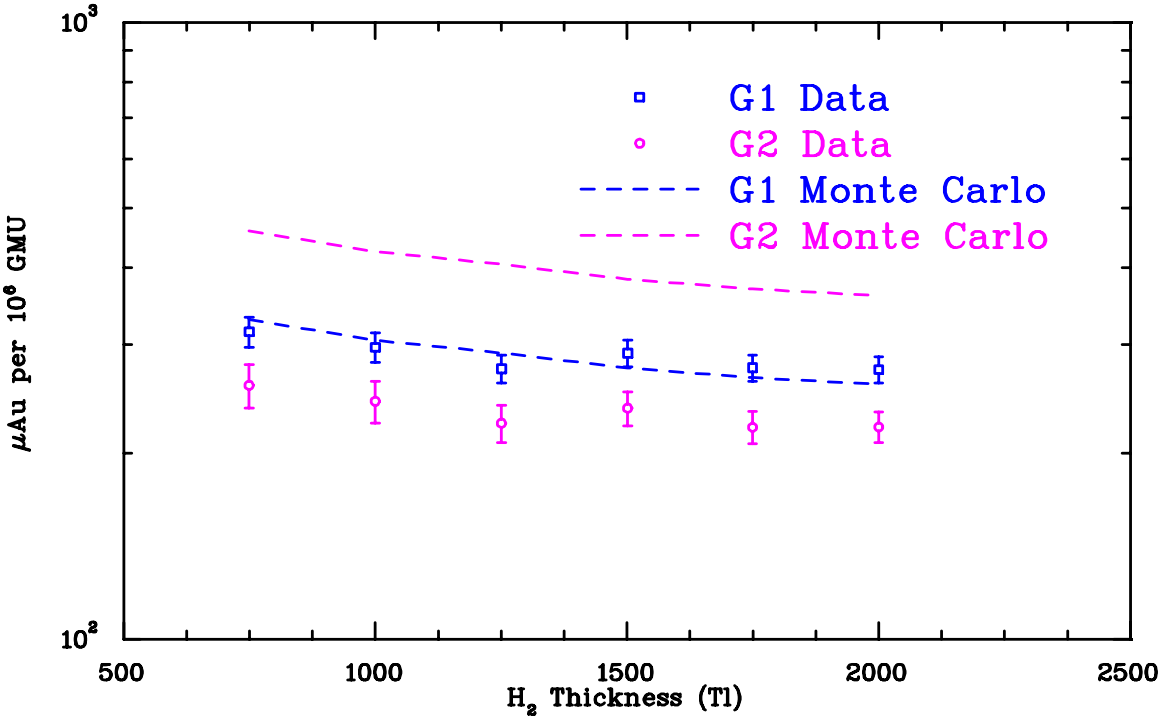


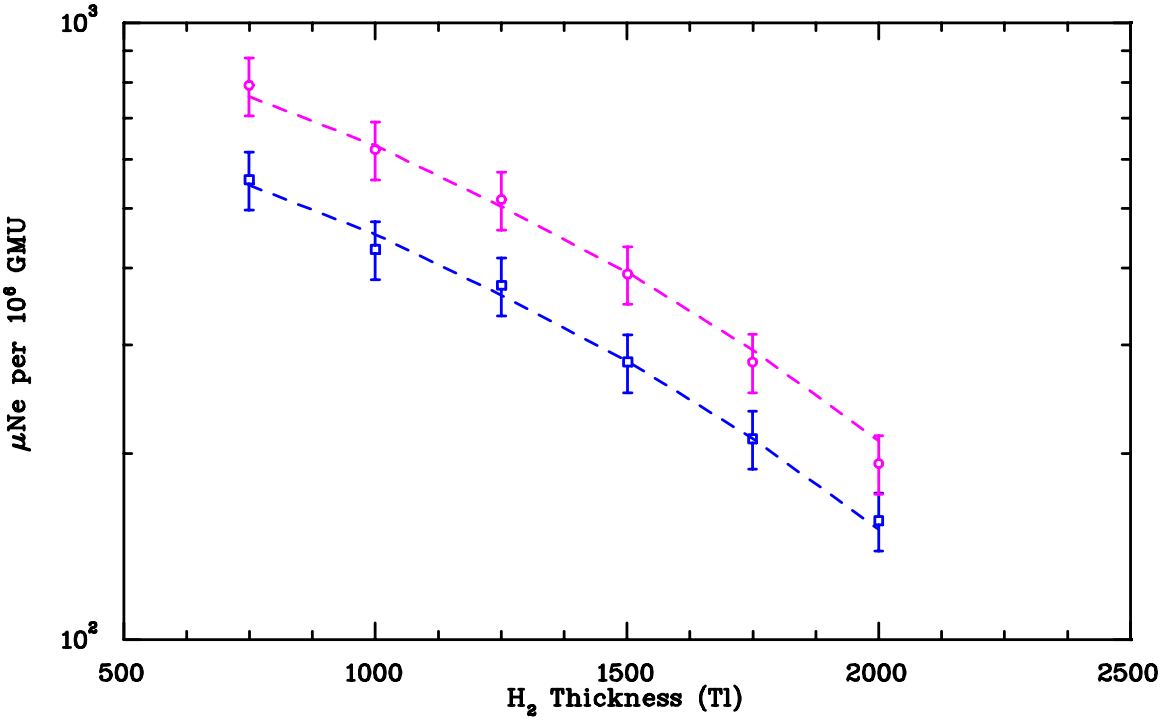
Comparison


Germanium 1
Yield normalized to GMU
5000
4000
3000
2000
1000
190
200
210
220
230
X-ray Energy (keV)

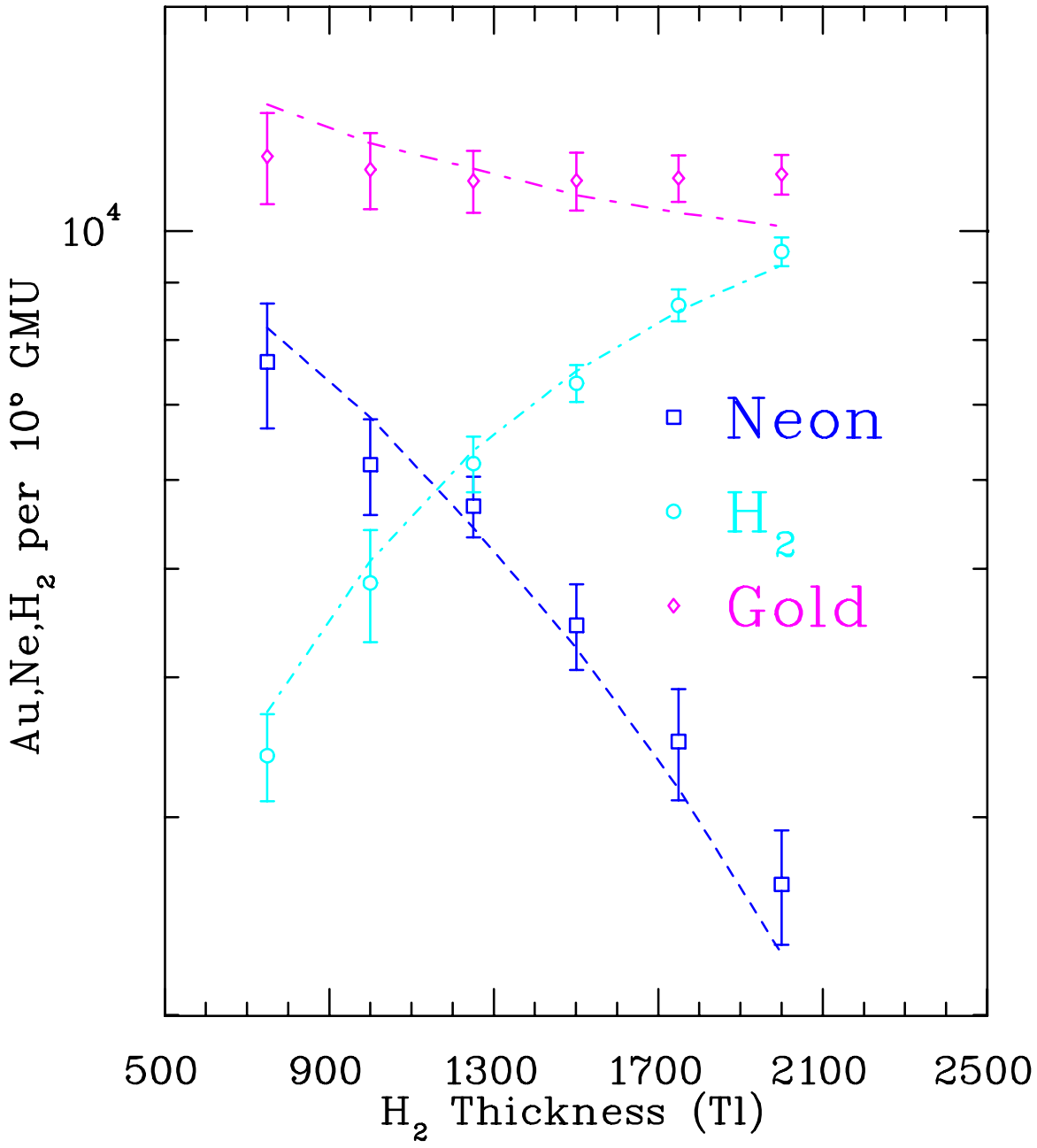

Germanium 2
Yield normalized to GMU
5000
4000
3000
2000
1000
190
200
210
220
230
X-ray Energy (keV)

Stopping with Germanium

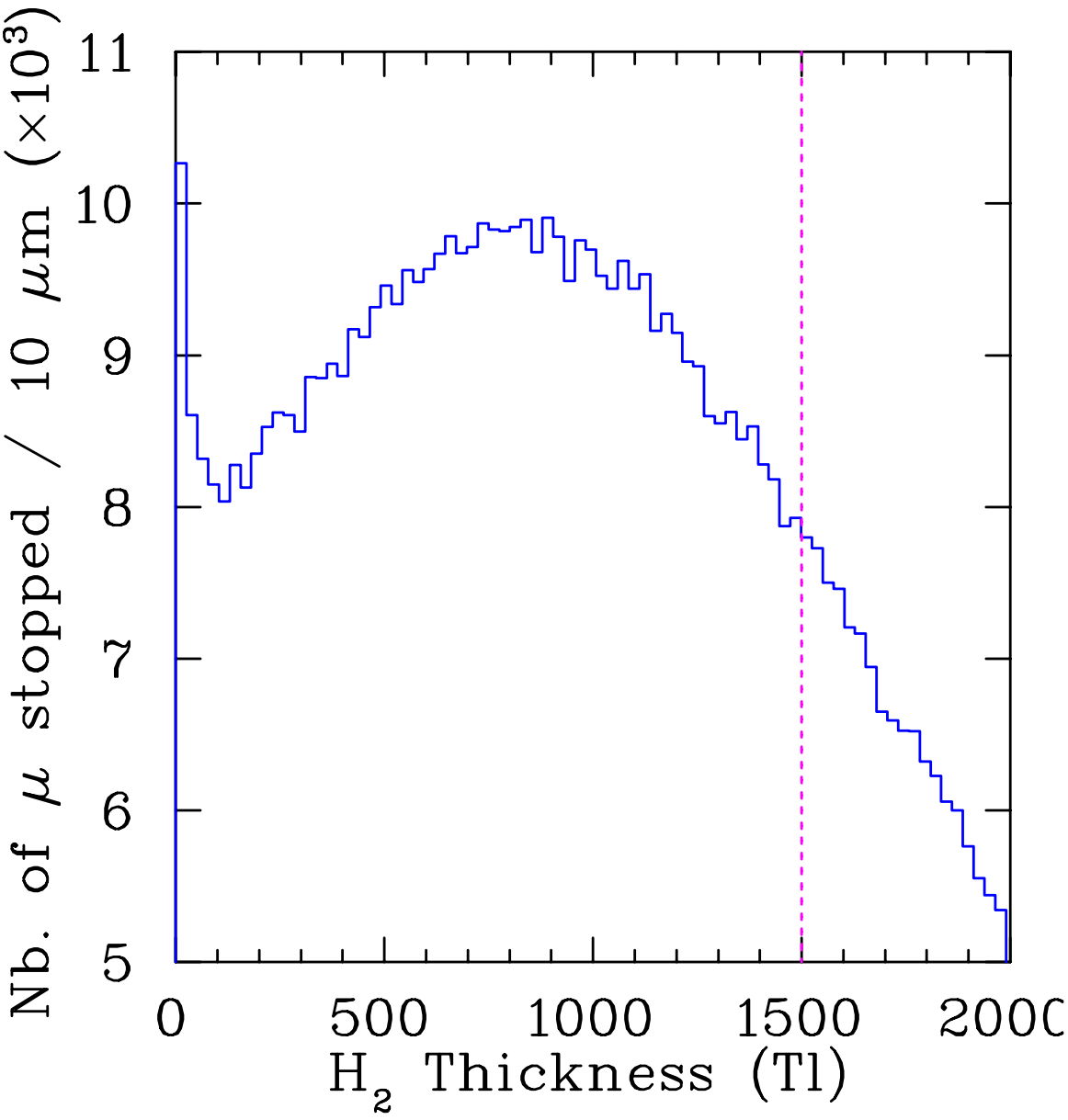




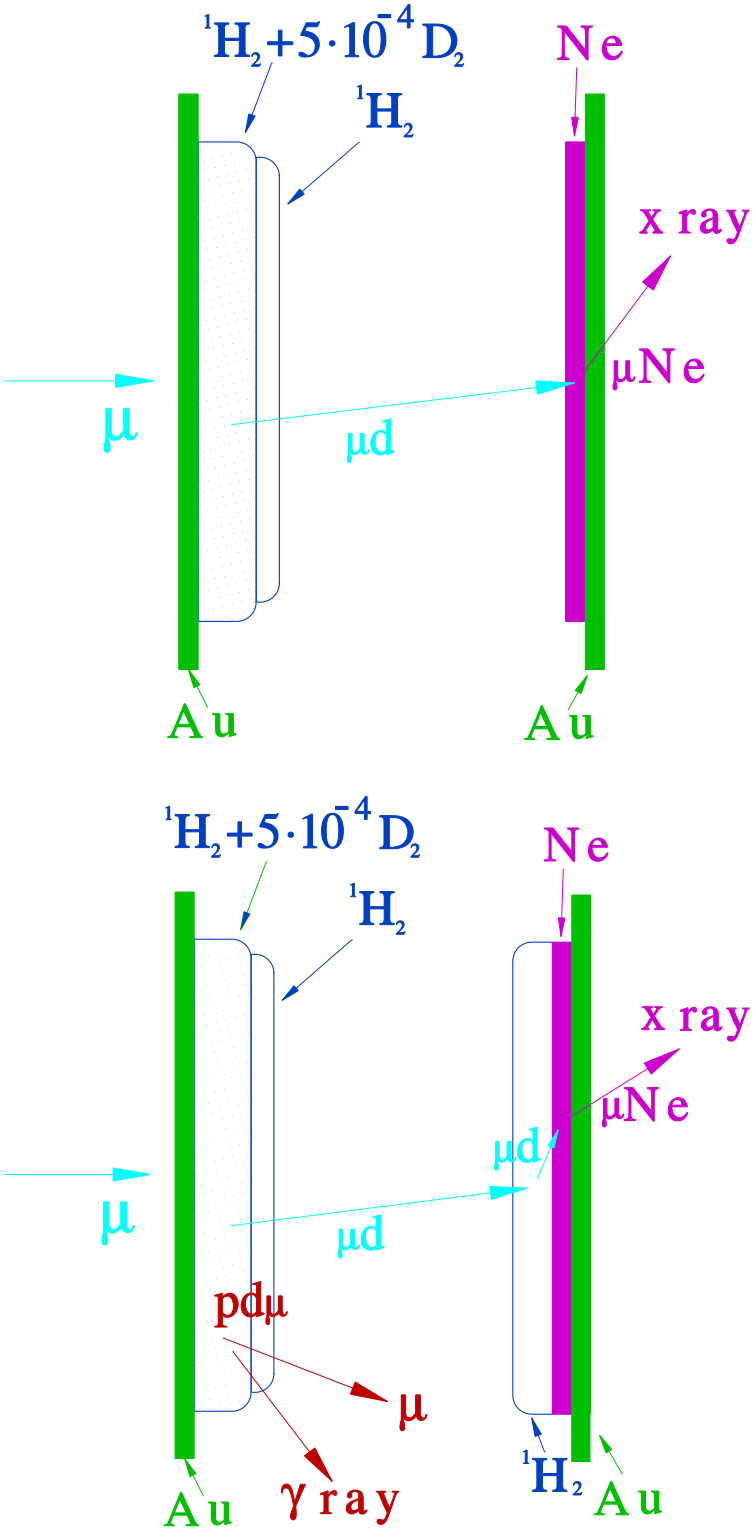
Stopping with Electrons



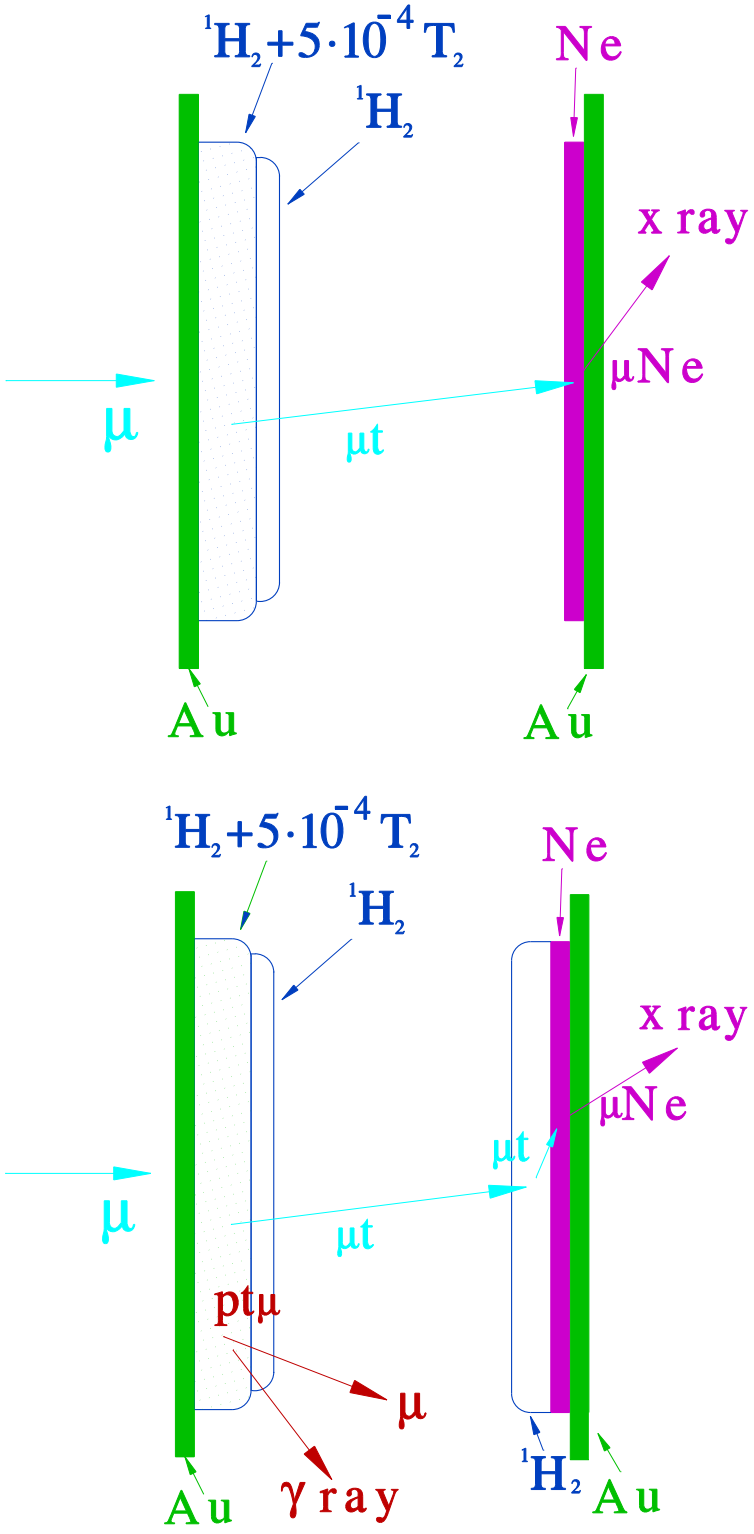
μ^- Stopping Distribution



Deuterium Experiment

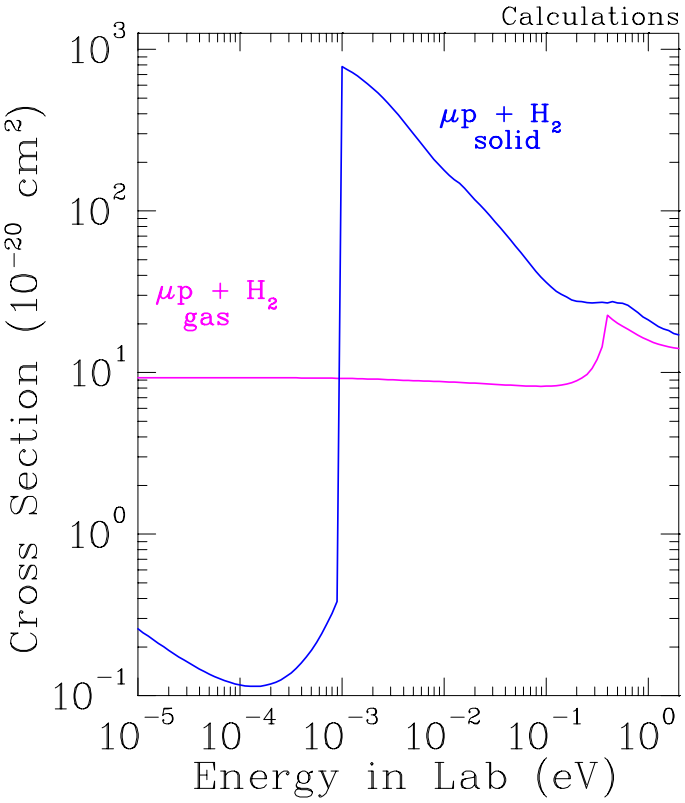


Tritium Experiment

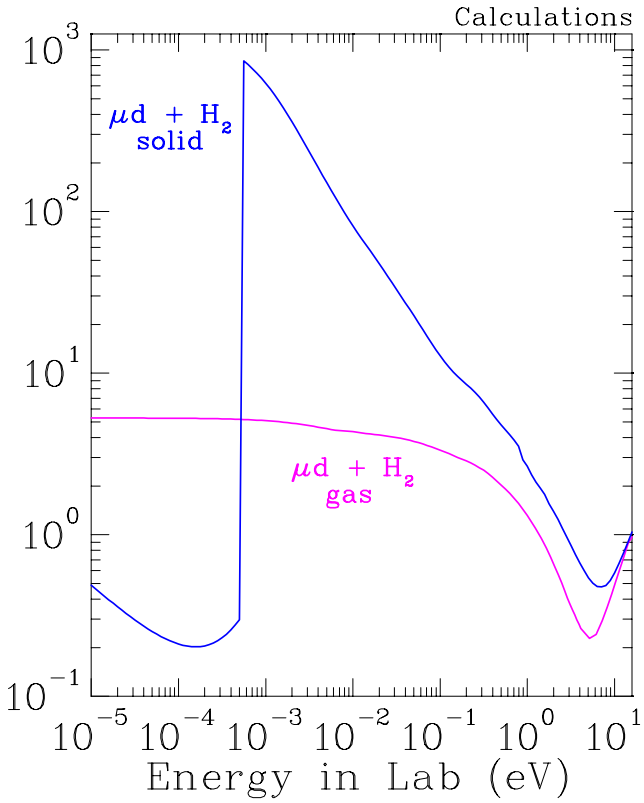


Gas and Solid
Scattering Cross Sections

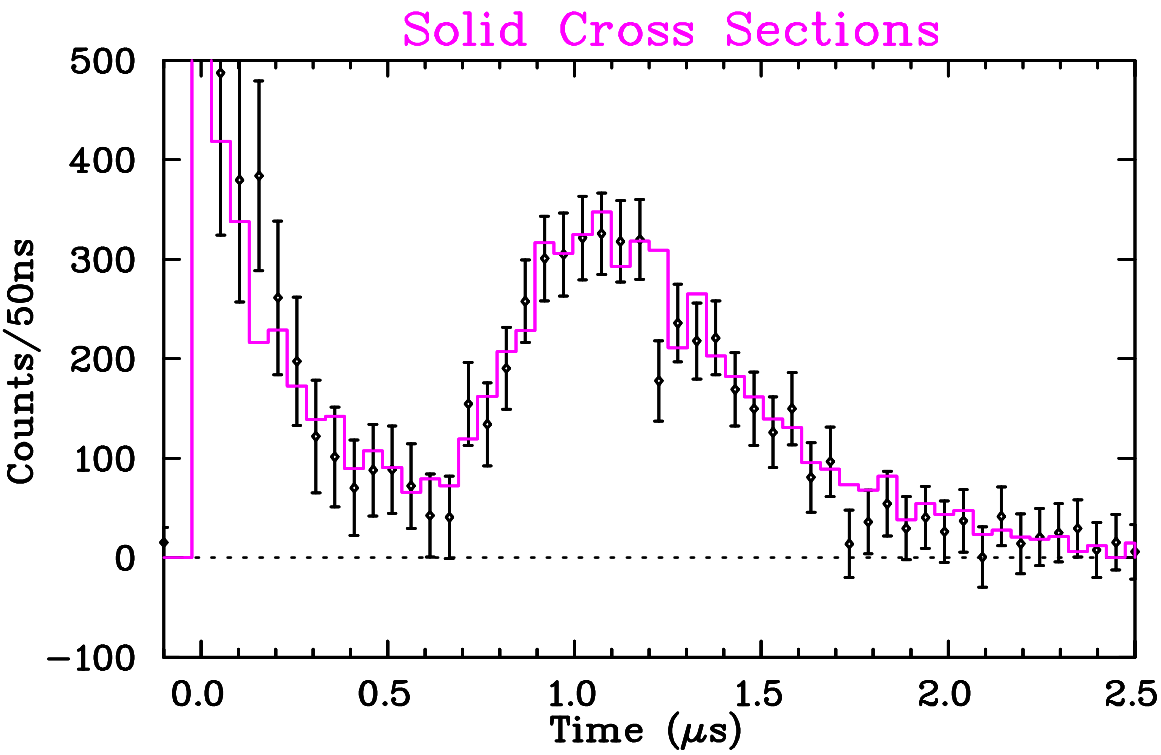
$\mu p + \mathrm{H}_2$

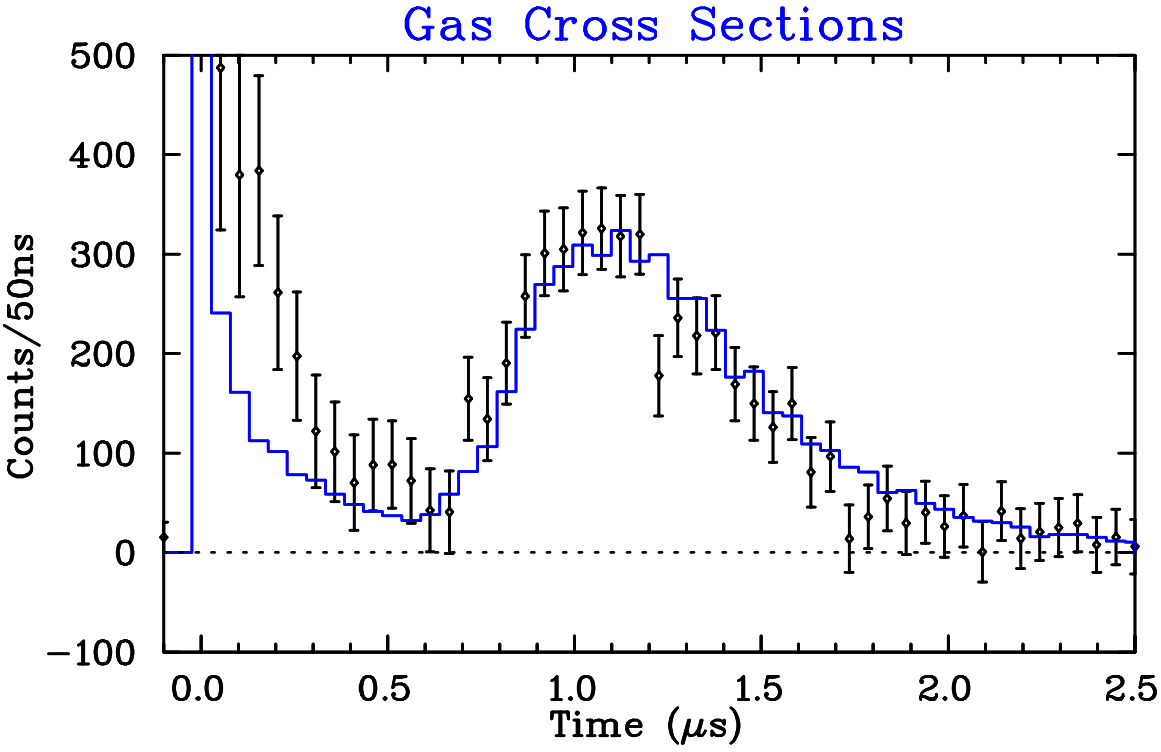


$\mu d + \mathrm{H}_2$

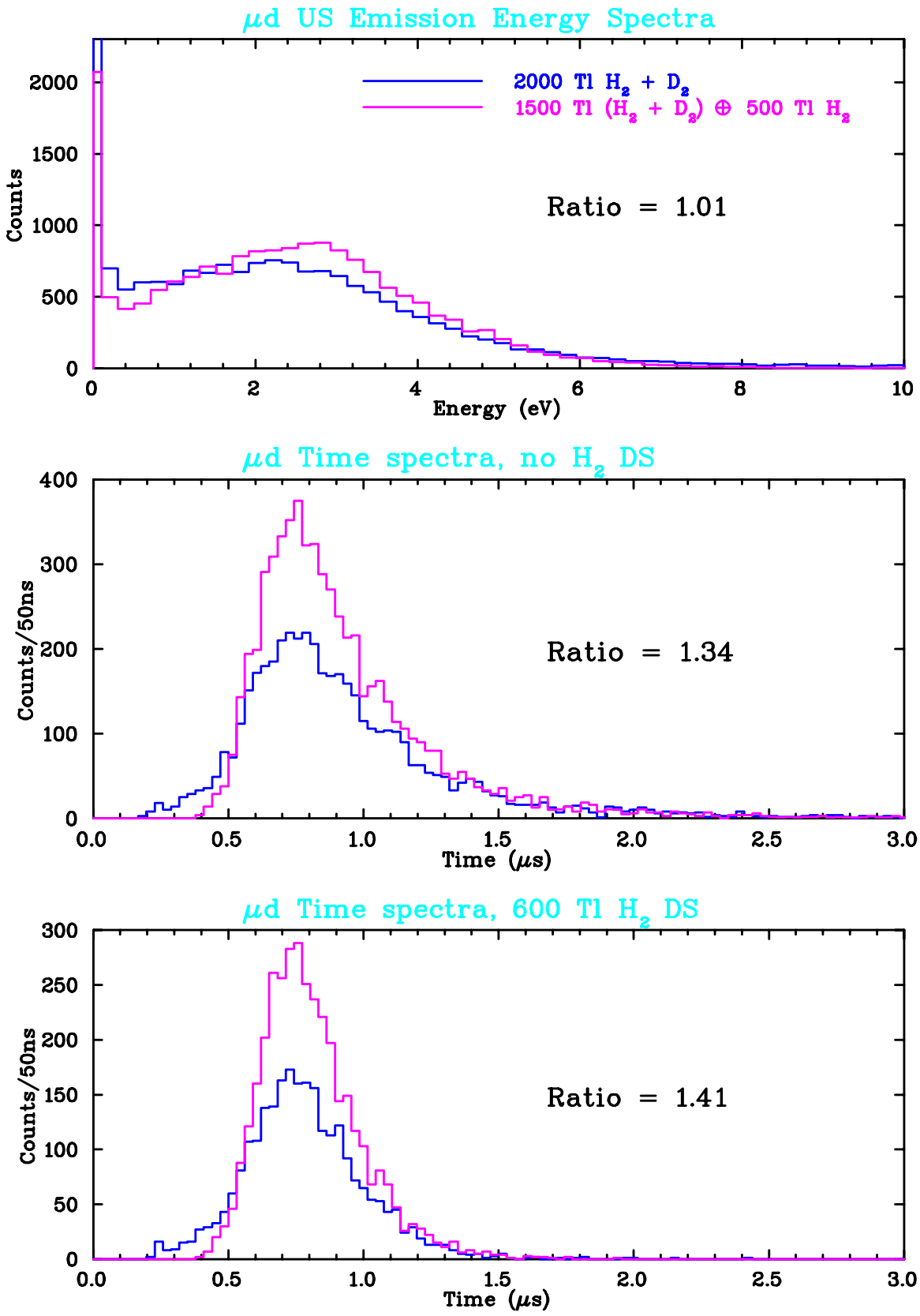


Comparison Data and Monte Carlo

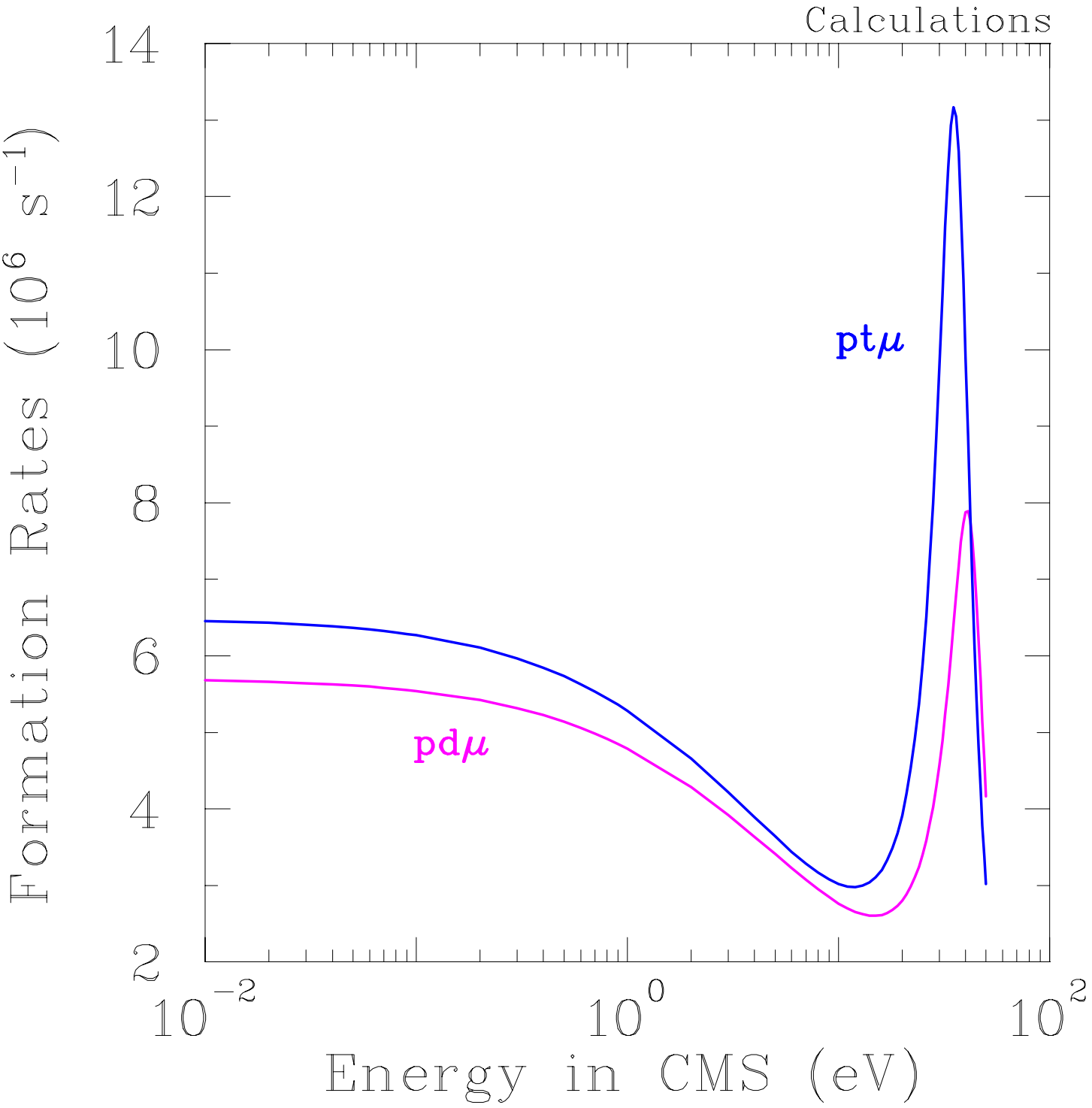




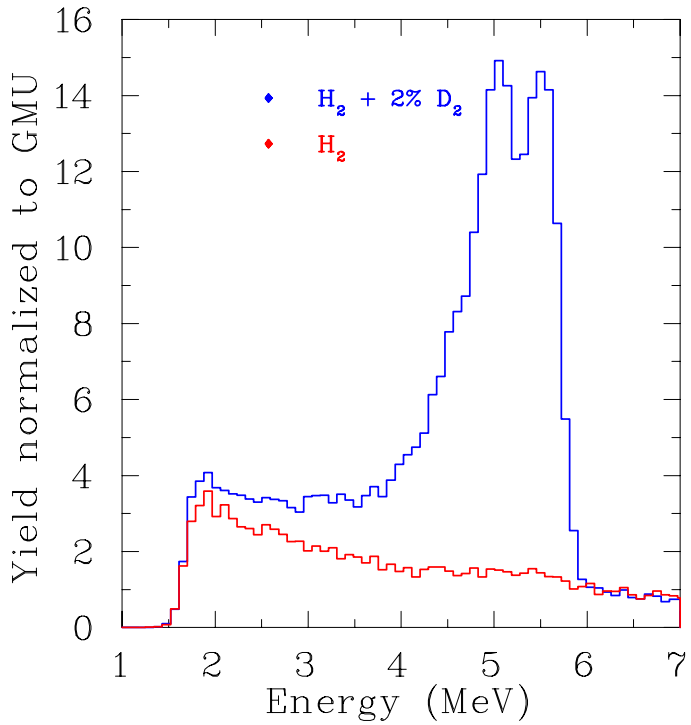
Different Targets

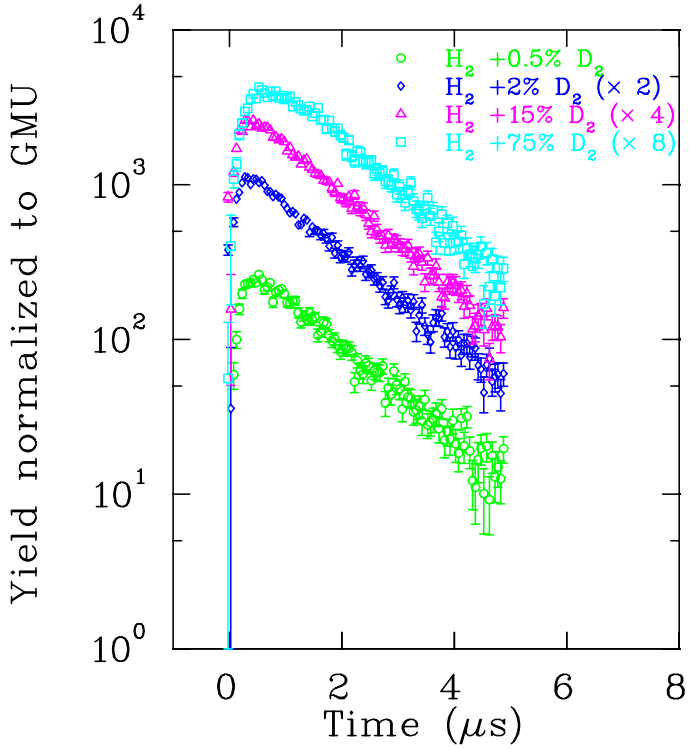


Molecular Formation Rates

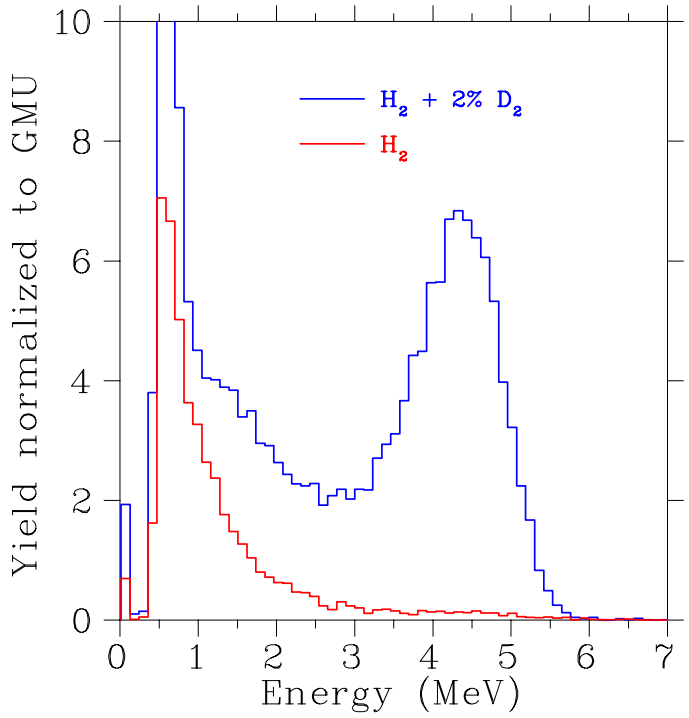


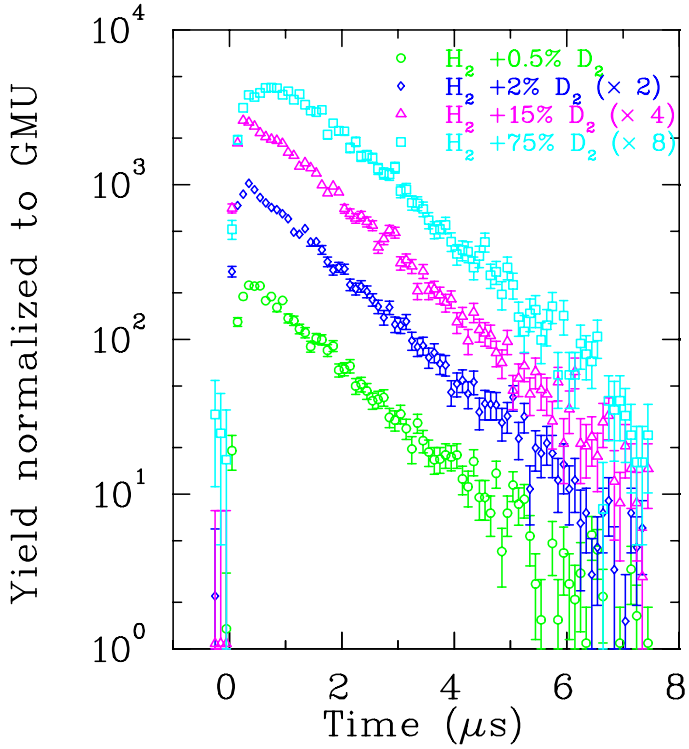
γ-ray Spectra



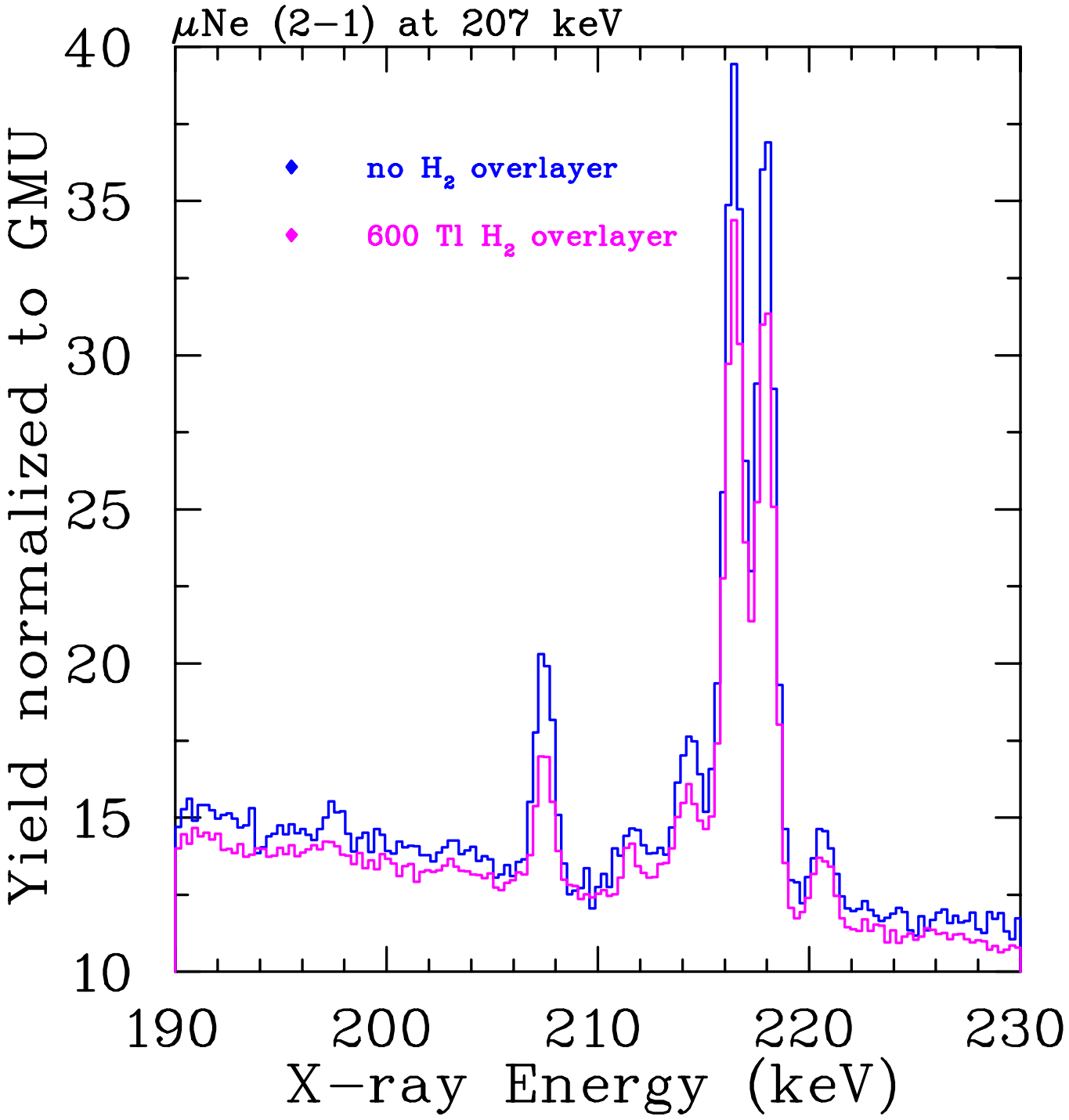


μ^- Conversion Spectra

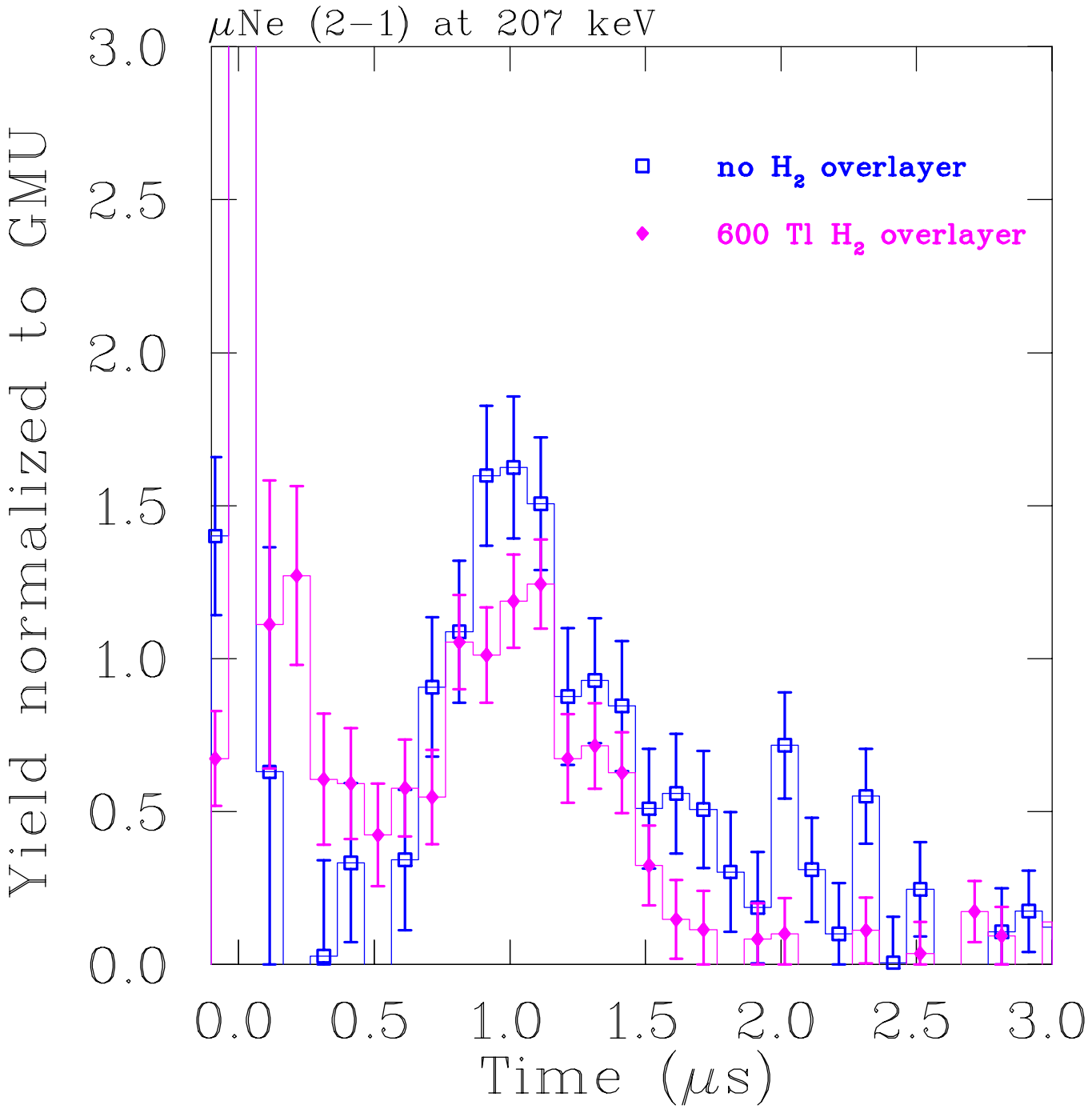




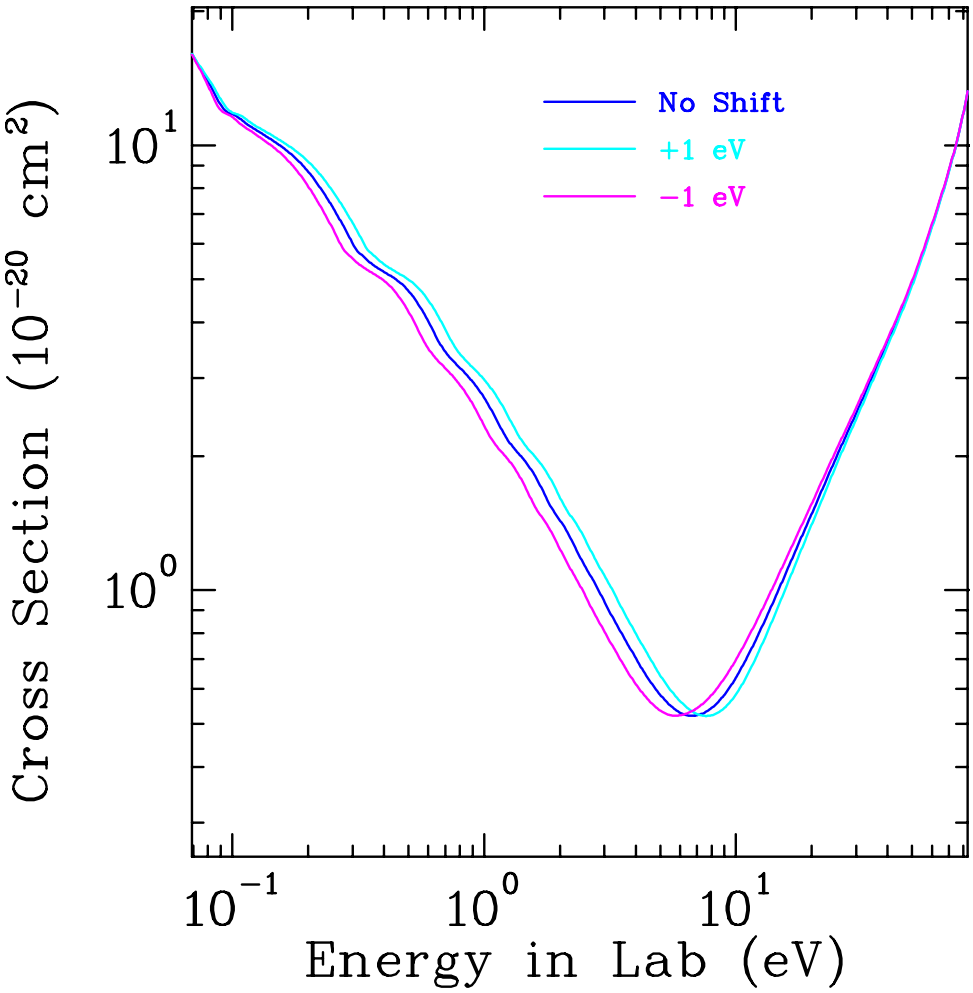
X-ray Energy Spectra



X-ray Time Spectra



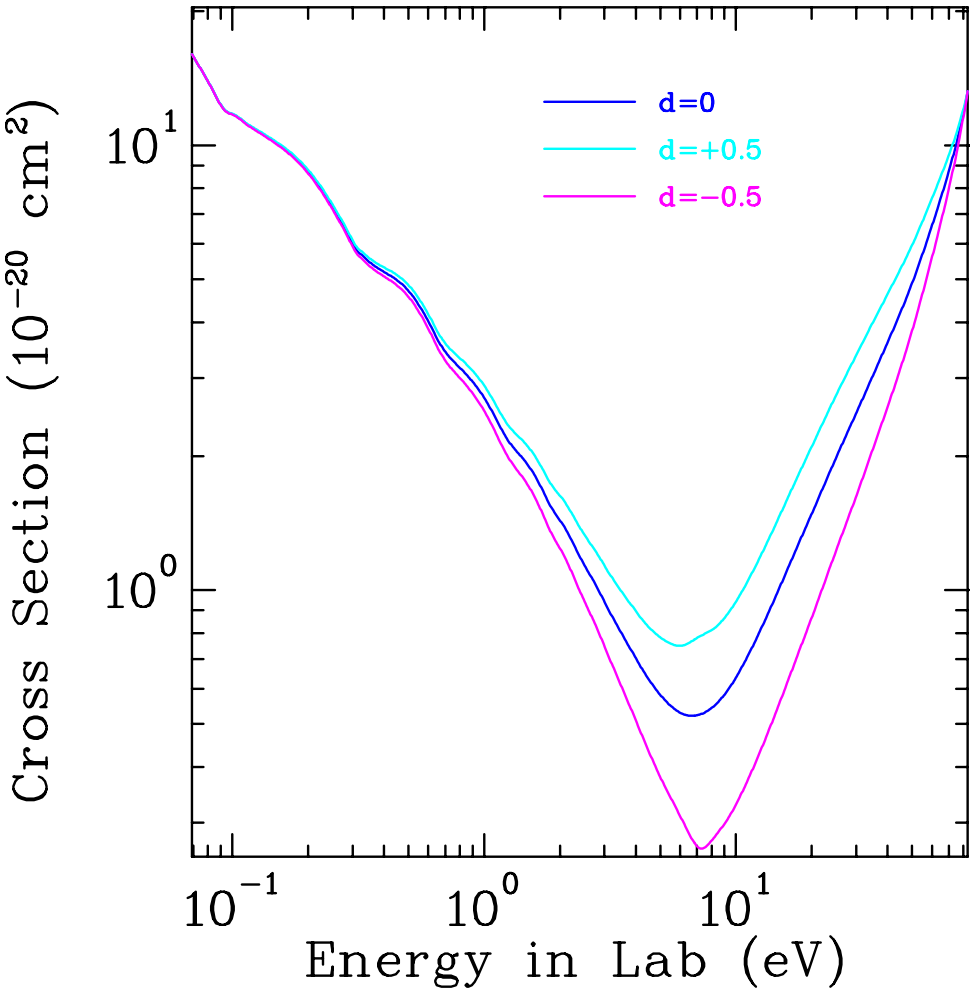
Shift of the Energy Position ΔE_R in $\mu d + H_2$



$$\sigma'(E) = \begin{cases} \sigma(E + \frac{E-E_1}{E_R-E_1} \cdot \Delta E_R) & , E_1 < E \leq E_R \\ \sigma(E + \frac{E_2-E}{E_2-E_R} \cdot \Delta E_R) & , E_2 > E > E_R \\ \sigma(E) & , E \leq E_1 \text{ or } E \geq E_2 \end{cases}$$

where E_R is the energy of the minimum cross section, E_1, E_2 are fixed boundaries around the Ramsauer–Townsend region, and $\sigma(E)$ are the theoretical cross sections.

Change of the Depth Factor d in $\mu d + H_2$



$$\sigma''(E) = \sigma(E) \cdot \begin{cases} (1 + \frac{E-E_1}{E_R-E_1} \cdot d) & , E_1 < E \leq E_R \\ (1 + \frac{E_2-E}{E_2-E_R} \cdot d) & , E_2 > E > E_R \\ 1 & , E \leq E_1 \text{ or } E \geq E_2 \end{cases}$$

where E_R is the energy of the minimum cross section, E_1, E_2 are fixed boundaries around the Ramsauer–Townsend region, and $\sigma(E)$ are the theoretical cross sections.

χ^2 Analysis
One Parameter Fits

Energy shift ΔE_R

$\#$ torr $\cdot$ l H_2 downstream	Time Range [ns]	ΔE_R [eV]	χ^2
0	500-2500	-0.04 $\pm$ 0.03	1.26
300	700-2500	-0.00 $\pm$ 0.01	1.22
600	700-2500	-0.00 $\pm$ 0.10	0.95

Depth factor d at E_R

$\#$ torr $\cdot$ l H_2 downstream	Time Range [ns]	d	χ^2
0	500-2500	-0.03 $\pm$ 0.03	1.29
300	700-2500	-0.05 $\pm$ 0.03	1.21
600	700-2500	0.01 $\pm$ 0.04	0.95

Monte Carlo analysis was performed using the "gas" cross sections.

Rates in $\mu d + H_2$

US: 1500 Tℓ (H_2 + 0.05% D_2) $\oplus$ 500 Tℓ H_2

DS: Ne DS: Ne $\oplus$ 600 Tℓ H_2

Rates per second

Incident μ^-		4.8×10^3
Useful μ^-		3.4×10^3
μ^- stopped US		2.0×10^3 + 470
$pd\mu$		870
γ ray		210
μ conversion		20
μd at US		110
μd at DS		38
μNe (2p-1s) x ray	38	27

Detection efficiency

for 200 keV x ray	2.2×10^{-3}
for 5.5 MeV γ	1.1×10^{-2}
for 5.5 MeV μ	4.0×10^{-2}
delayed e^- coincidence for γ	2.5×10^{-1}
delayed e^- coincidence for μ	4.2×10^{-1}

Detection rates per minute

μNe (2p-1s) x ray	2	1.4
γ ray		30-40
μ conversion		15-25

Expected Rates in $\mu t + H_2$

US: 1500 Tℓ (H_2 + 0.05% T_2) $\oplus$ 500 Tℓ H_2

DS: Ne DS: Ne $\oplus$ 600 Tℓ H_2

Rates per second

Incident μ^-		4.8×10^3
Useful μ^-		3.4×10^3
μ^- stopped US		2.0×10^3 + 470
$pt\mu$		750
γ ray		37
μ conversion		14 (0.11)
μt at US		110
μt at DS		38
μNe (2p-1s) x ray	38	27

Detection efficiency

for 200 keV x ray	2.2×10^{-3}
for 19.8 MeV γ	8.5×10^{-3}
for 19.2 MeV μ	3.4×10^{-2}
delayed e^- coincidence for γ	2.5×10^{-1}
delayed e^- coincidence for μ	4.2×10^{-1}

Detection rates per minute

μNe (2p-1s) x ray	2	1.4
γ ray		5
μ conversion		12 (0.1)

$pt\mu$

US Target: 300 Tℓ (H_2 + c_t T_2)

$$pt\mu \rightarrow \mu^4He + \gamma$$
$$\rightarrow {}^4He + \mu^-$$

c_t	μ^- Yield	γ Yield	μ^-/γ
0.01	0.00039	0.075	192
	0.052	0.075	1.4
0.005	0.00034	0.078	231
	0.045	0.078	1.7
0.001	0.00022	0.070	318
	0.029	0.070	2.4
0.0001	0.00006	0.023	362
	0.086	0.023	2.7

L.N. Bogdanova and V.E. Markushin, Nucl. Phys. A **508**, 29c (1990)

F.J. Hartmann *et al.*, Hyperfine Interaction **82**, 259 (1993)

Backgrounds

Source of background	Time correlation	x ray	γ	μ	Reduced by del e^-?
μ^- capture:					
in target	prompt	Y	Y	Y	Y
before μ-counter	random	Y	Y	Y	N
μ^- transfer:					
to target support	fast emission	Y	Y	N	Y
decay e^-	μ^- lifetime	N	Y	N	Y
neutrons	random	N	Y	N	Y
cosmic	random	N	Y	Y	Y

Measurement Schedule

Measurement	Targets (US,DS)	Shifts
Setup		4
Tuning and Efficiency Background	2000 Tℓ H_2 50 Tℓ Ne $\oplus$ 300 Tℓ H_2	 1 3
Energy Distribution	1500 Tℓ (H_2 + 0.05% T_2) $\oplus$ 500 Tℓ H_2 50 Tℓ Ne	4
Ramsauer–Townsend Cross Sections	$\oplus$ 300 Tℓ H_2 $\oplus$ 300 Tℓ H_2 (600 Tℓ) $\oplus$ 300 Tℓ H_2 (900 Tℓ)	6 6 6
$pt\mu$ rate	300 Tℓ (H_2 + c_t T_2)	6
Total		36