Comparison of Plastics used in Tissue Equivalent Proportional Counters (TEPCs)

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Introduction: A-150 Tissue Equivalent Plastic

- A-150 tissue equivalent plastic was first described by Shonka in 1958
- Developed to be tissue equivalent for photons and neutrons
- Based off the International Commission of Radiological Units (ICRU) definition of muscle tissue
- Has been commonly used as tissue equivalent material for energetic protons and heavy ions.

TISSUE-EQUIVALENT MUSCLE

For Photons and Neutrons

Since there is little agreement in the literature on the composition of wet muscle, the decision was made to adopt the composition recommended by the International Commission of Radiological Units (ICRU).[6] The percentage compositions by weight given therein yield the formula

$$C_{1.024}H_{10.2}O_{4.556}N_{0.25}Na_{0.0035}Mg_{0.0008}P_{0.0065}S_{0.0156}K_{0.0077}Ca_{0.00017}$$

containing a total of 55.087 electrons, a value used in Eq. 4. The proper choice of materials from Table 1 results in a simulating blend that may be written as

$$(C)_a(CH_2)_b(C_6H_{11}NO)_d(SiO_2)_e(CaF_2)_g$$

Materials	*Manufacturer*	*Chemical composition*	*Compression molding temperature* (°C)	*Mean particle size* (mμ)
Polystyrene P1X5	Monsanto	(CH)	130–205	—
Polyethylene Alathon HD	Du Pont	(CH_2)	150–205	—
Nylon–Zytel 61	Du Pont	$(C_6H_{11}NO)$	235	—
Teflon-T30	Du Pont		380[a]	—
Oil Furnace Black Vulcan XC72	Cabot	(C)	—	29
Silica-Cabosil	Cabot	(SiO_2)	—	18
Calcium fluoride	Sturtevant Mill	(CaF_2)	—	380

[a] Sintered in air.

Problems with A-150

- Difficult to produce due to the different melting temperatures of nylon and polyethylene
- Not commercially common and more expensive due to its specialized use
- Lacks the structural integrity of other more common plastics

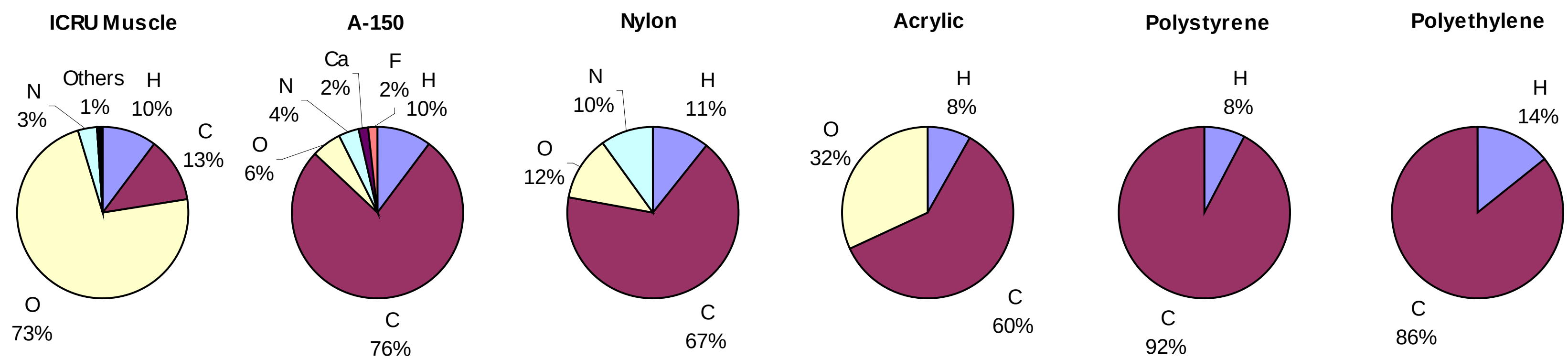
Goals of this Study

- To experimentally compare A-150 with four other alternative plastics to determine their differences in response to energetic proton and heavy ion beams
  - Nylon
  - Acrylic
  - Polystyrene
  - Polyethylene
- To compare all five plastics as well as the ICRU definition of muscle through Monte Carlo simulations in radiation fields using FLUKA
- Based on these comparisons, to determine if any of the alternative materials may be an acceptable substitute for tissue for use in gas filled detectors

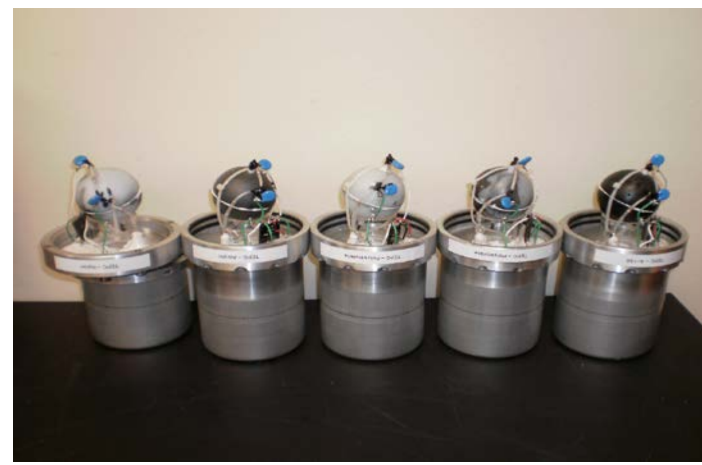
Outline

- Differences in materials
  - Composition
  - Attenuation coefficients, stopping powers, and cross sections
- Detector Design
- Proton beam results
  - Experimental
  - Simulation
- Heavy ion results – experimental
- Conclusions and future work

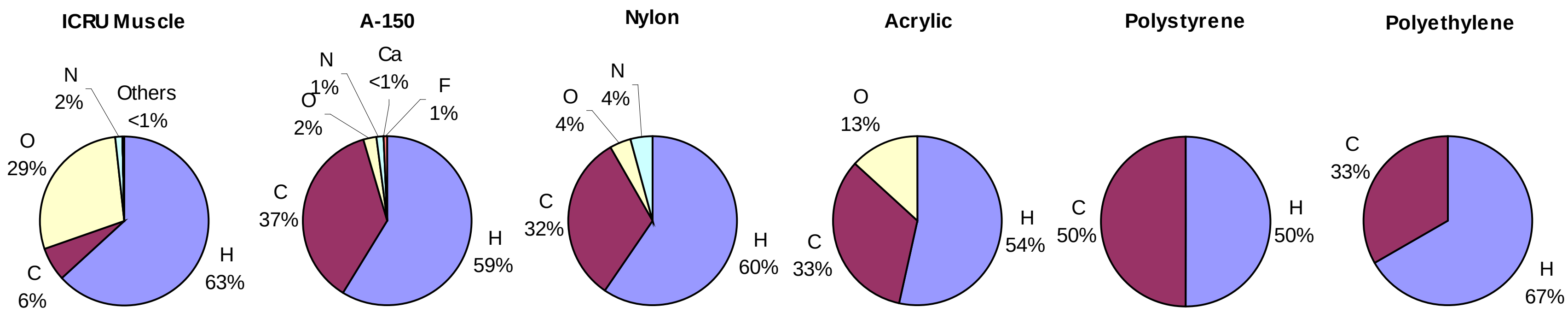
Mass Percentages



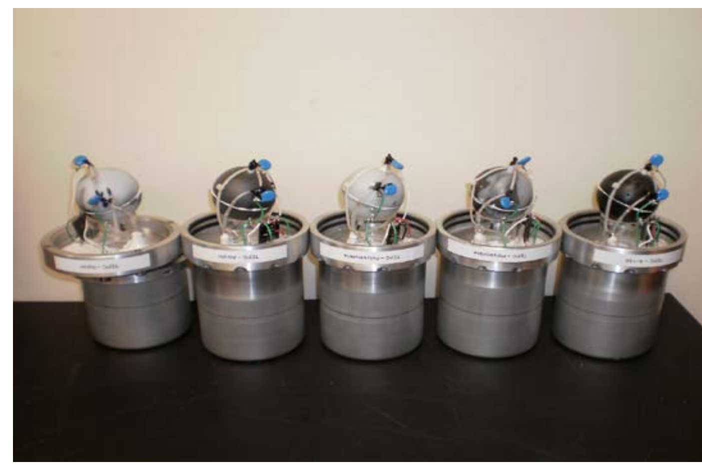
	ICRU Muscle	A-150	Nylon	Acrylic	Polystyrene	Polyethylene
H	10.2	10.2	10.6	8.1	7.8	14.4
C	12.3	76.8	67.2	60.0	92.2	85.6
O	72.9	5.9	12.3	32.0		
N	3.5	3.6	10.0			
Ca	0.007	1.8				
F		1.7				
Na	0.08					
Mg	0.02					
P	0.2					
S	0.5					
K	0.3					



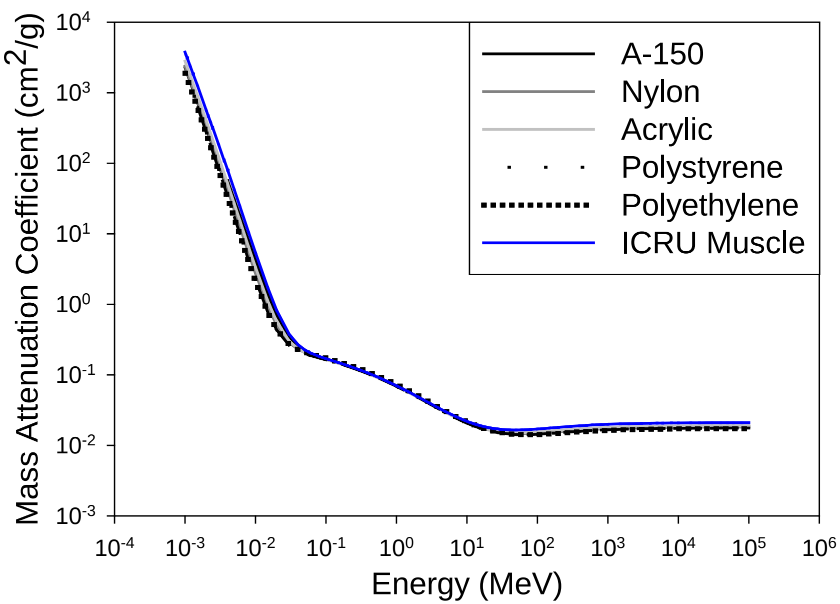
Atomic Percentages

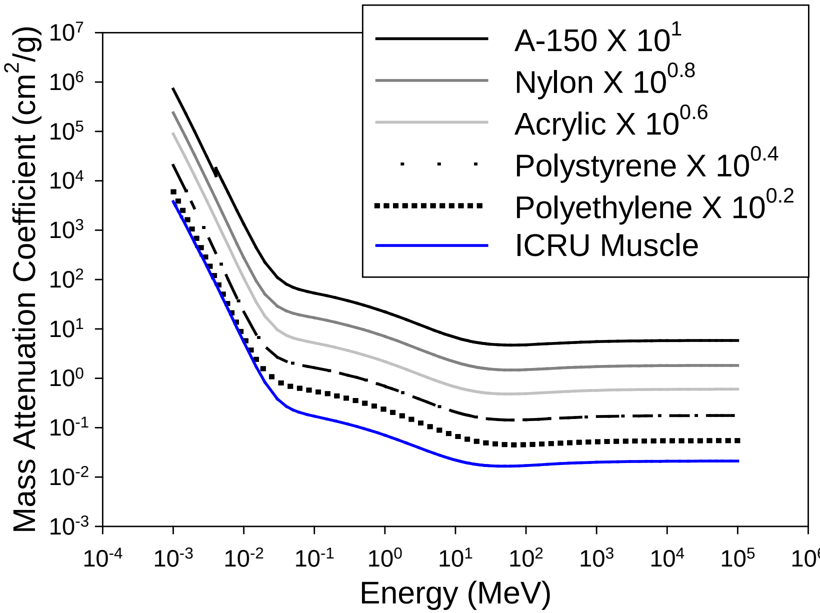


	ICRU Muscle	A-150	Nylon	Acrylic	Polystyrene	Polyethylene
H	63.3	58.5	59.7	53.3	50	66.7
C	6.4	37.1	31.8	33.3	50	33.3
O	28.5	2.1	4.4	13.3		
N	1.56	1.5	4.1			
Ca	0.001	0.3				
F		0.5				
Na	0.02					
Mg	0.01					
P	0.04					
S	0.10					
K	0.05					



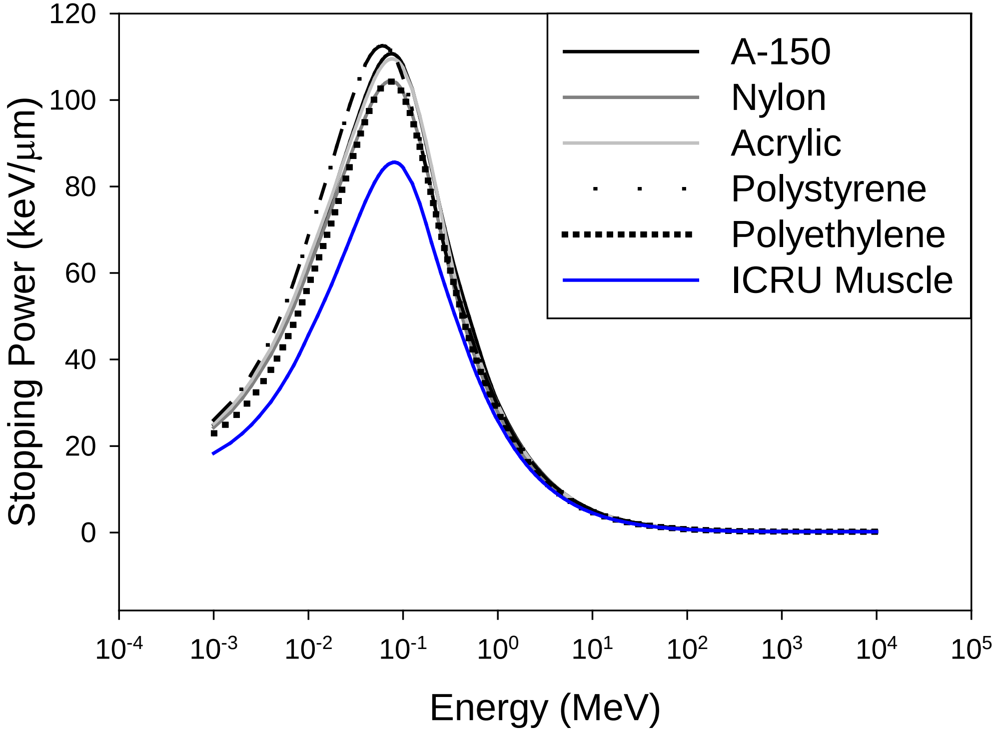
Mass Attenuation Coefficients





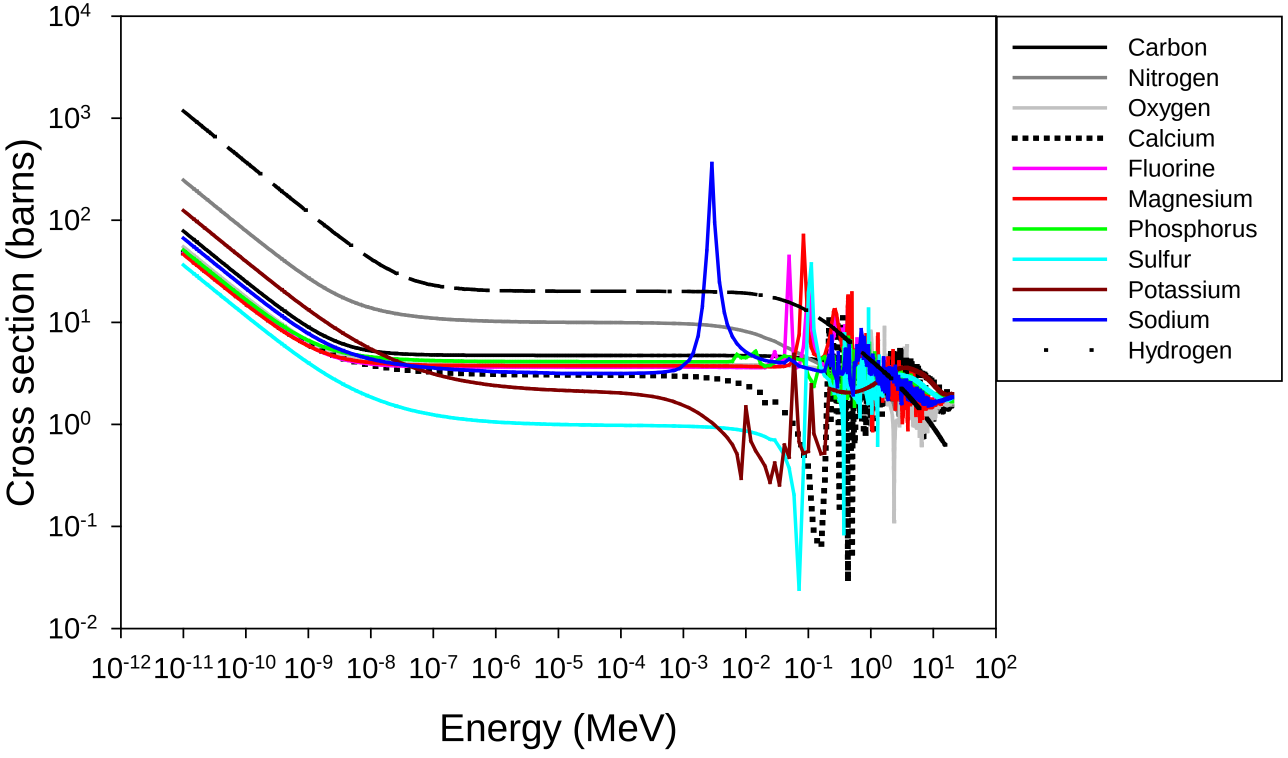
Data taken from the National Institute of Standards and Technology (NIST): XCOM Photon Cross Section Database

Proton Stopping Powers



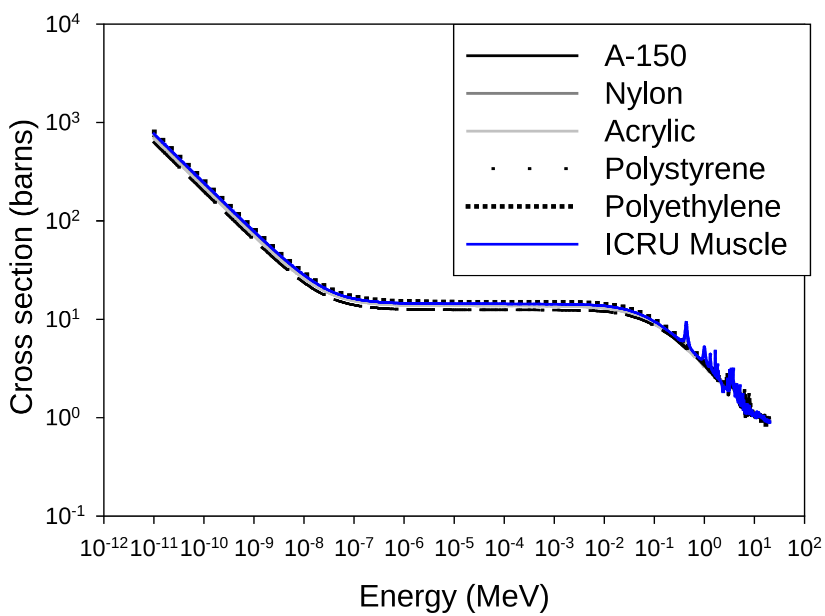
Data taken from the National Institute of Standards and Technology (NIST): pstar - Stopping-Power and Range Tables for Protons

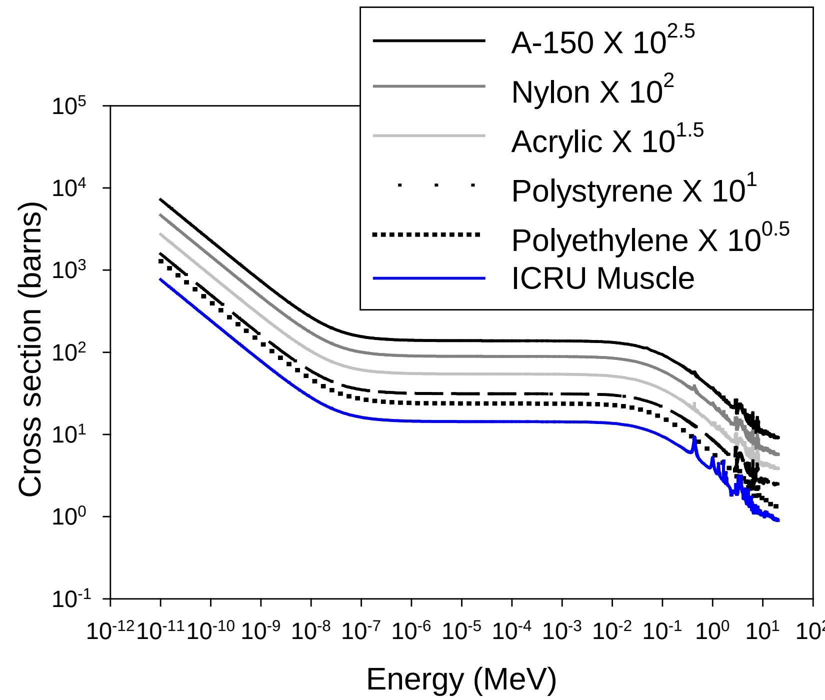
Total Neutron Cross Sections



Data taken from the Brookhaven National Laboratory: National Nuclear Data Center (NNDC)

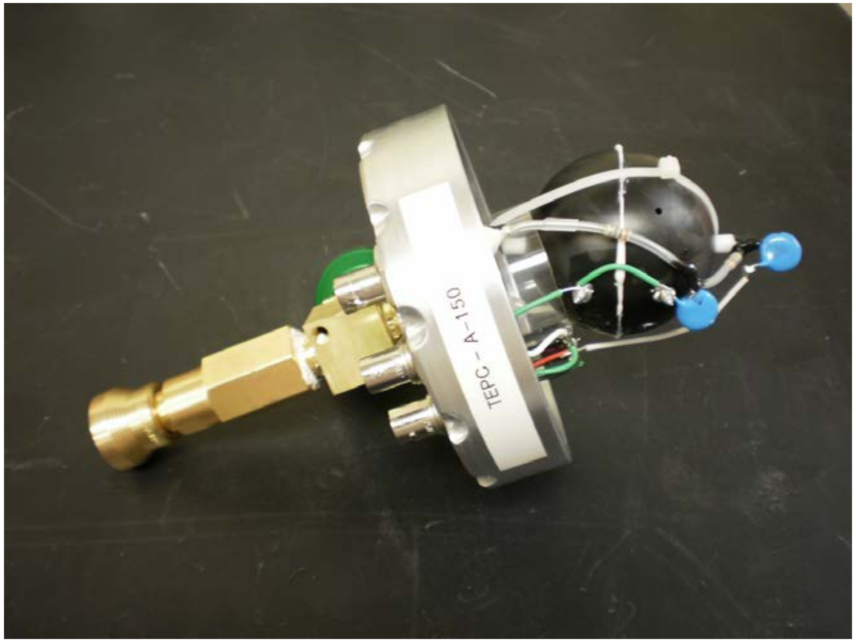
Total Neutron Cross Sections



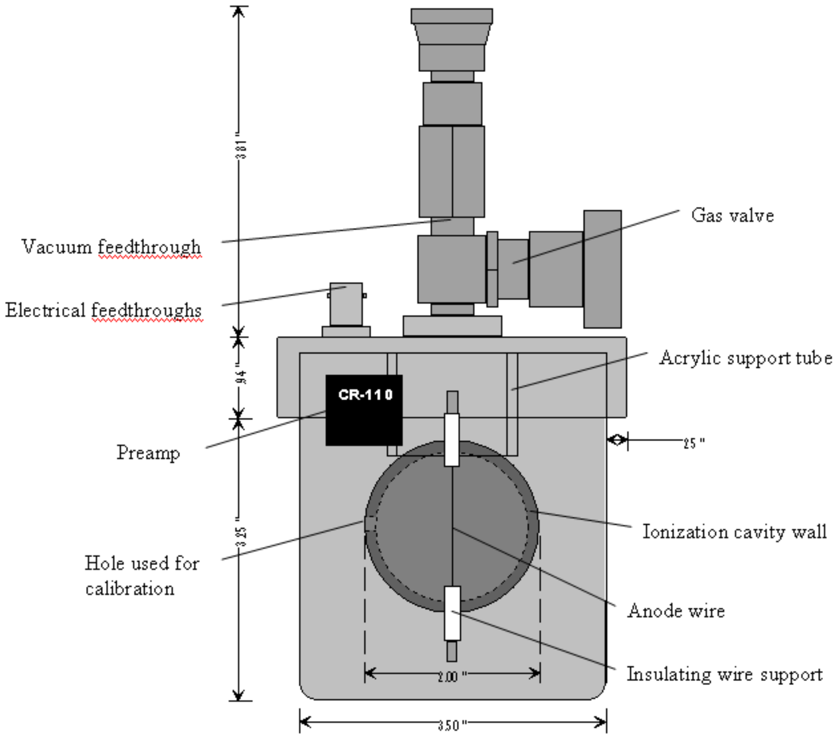


Design

- Fabricated at the OSU Radiation Physics Laboratory
- Follows the Benjamin design (Benjamin 1968)
- Two inch outer diameter
- 3 mm ionization cavity wall thickness
- Single wire anode
- +1400 V
- 173 Torr (10 μm of tissue)
- Inside of ionization chamber sphere is coated with colloidal graphite (Aerodag G) to create a conductive surface
- Built in preamplifier (Cremat CR-110)
- Contained in air tight canister (Zero mfg.)
- Calibrated with an ^{241}Am source

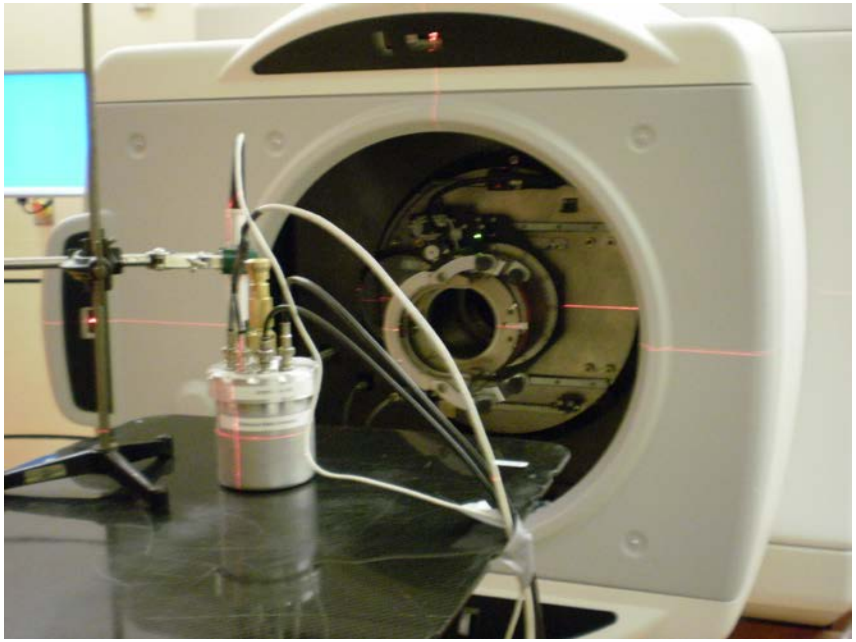


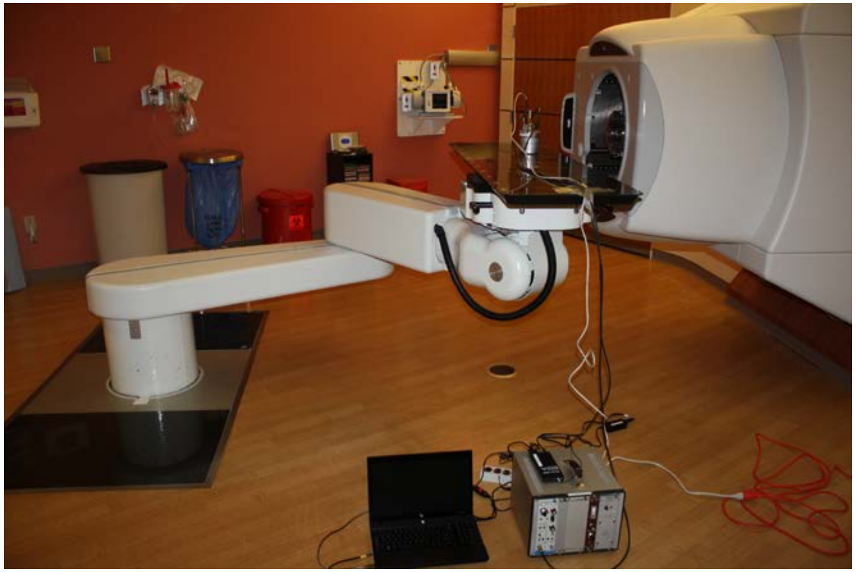
Design (cont.)


Gas valve
Vacuum feedthrough
Electrical feedthroughs
Acrylic support tube
CR-110
Preamp
.25 "
Ionization cavity wall
Hole used for
calibration
Anode wire
Insulating wire support
2.00 "
3.50 "
3.81 "
.94 "
3.25 "

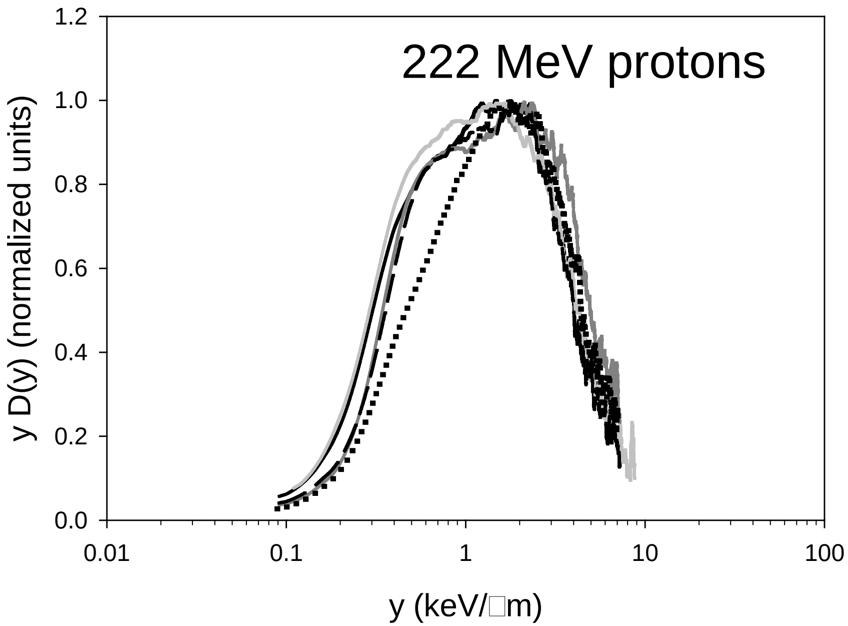
Proton Beam Experiment

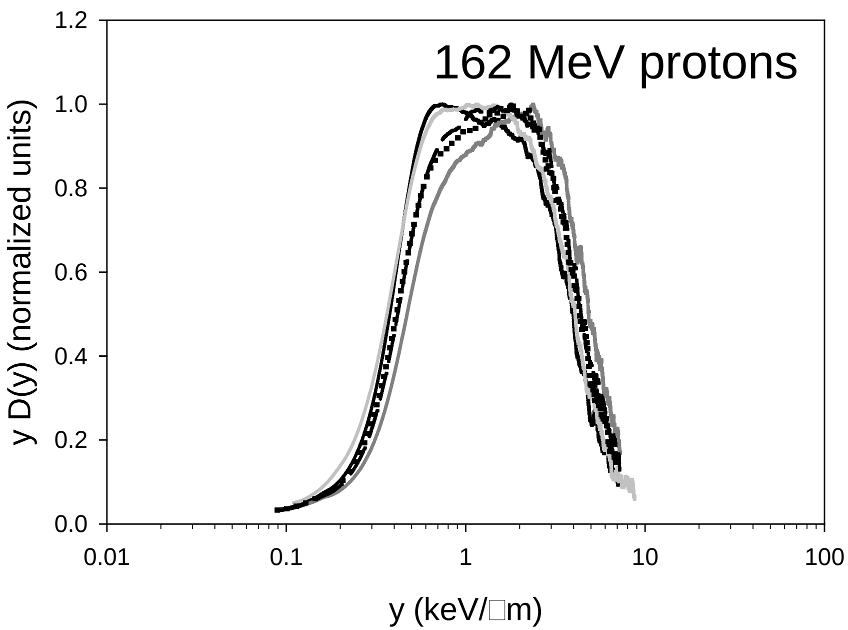
- ProCure Proton Therapy Center in Oklahoma City
- Three beam energies:
  - 87 MeV
  - 162 MeV
  - 222 MeV
- Low flux beam: ~450 particles cm^{-2} s^{-1}

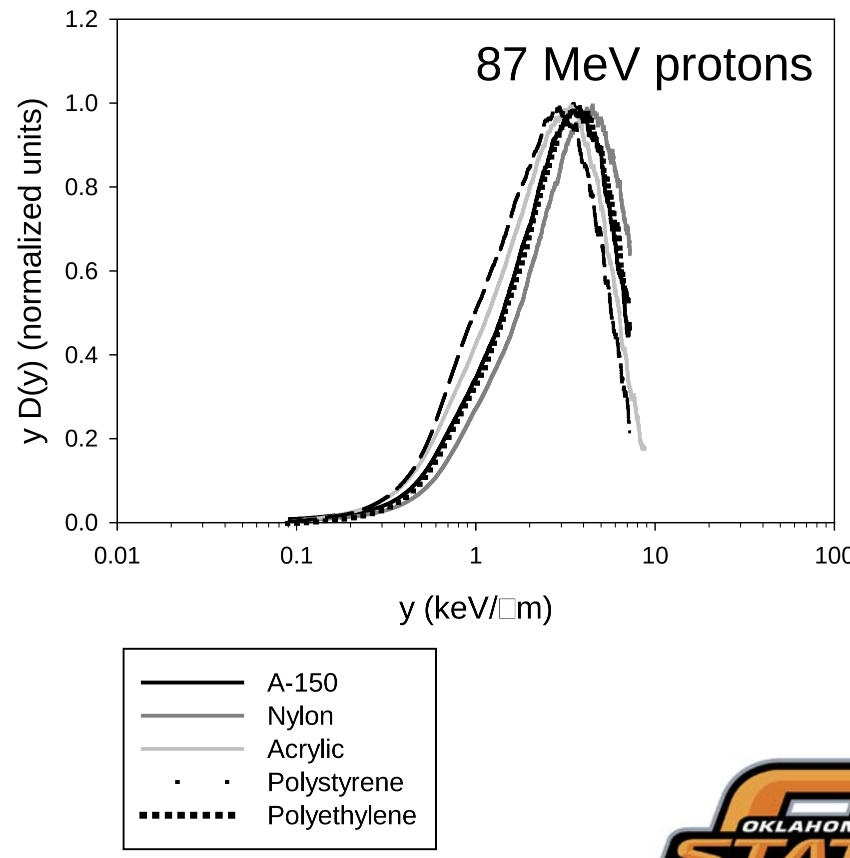




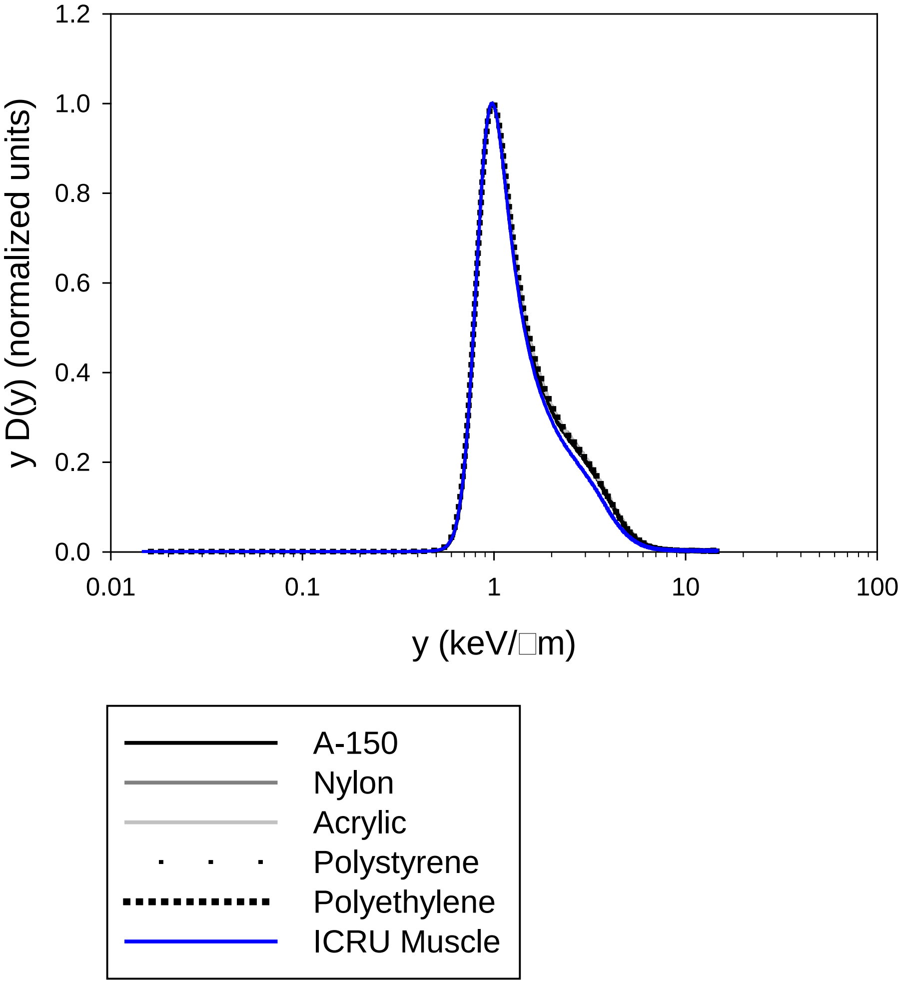
Experimental Results

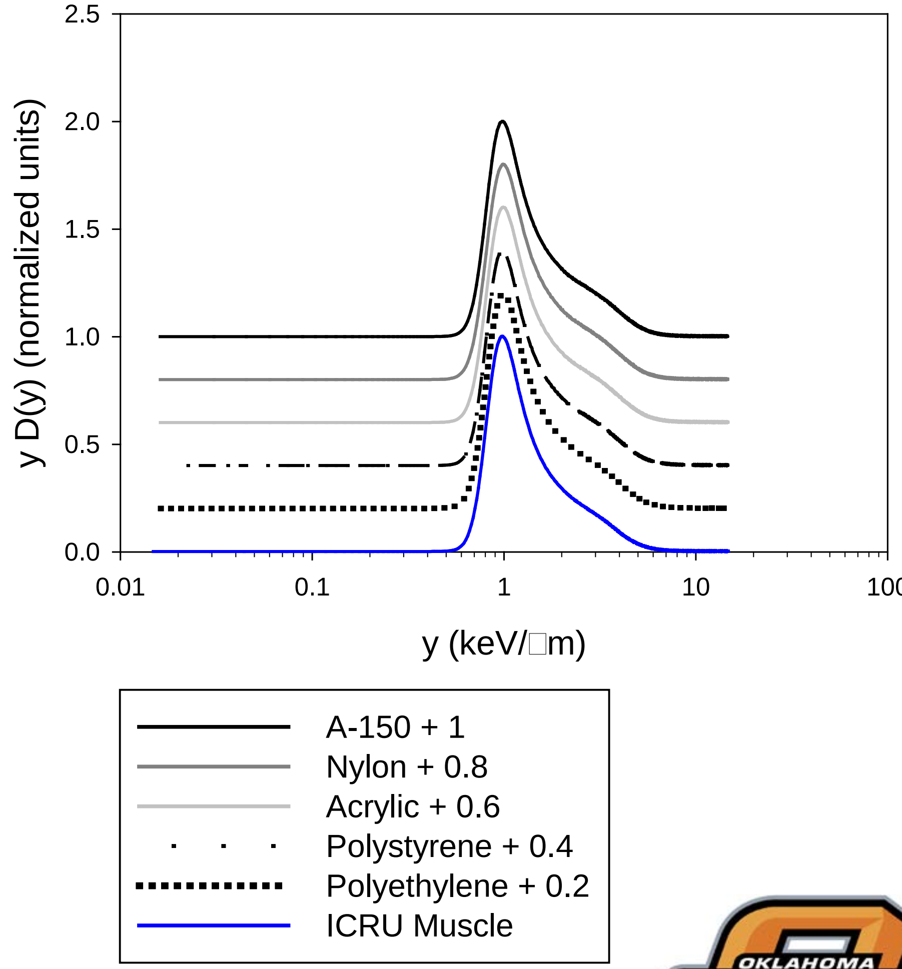




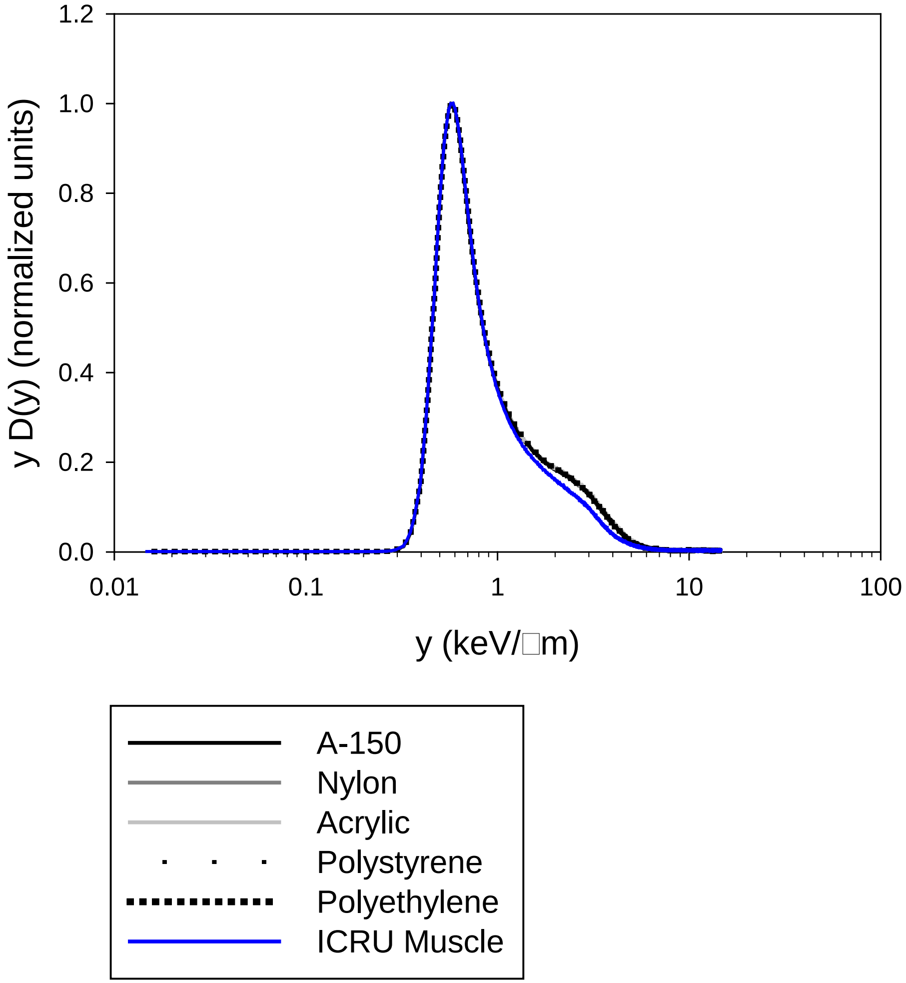


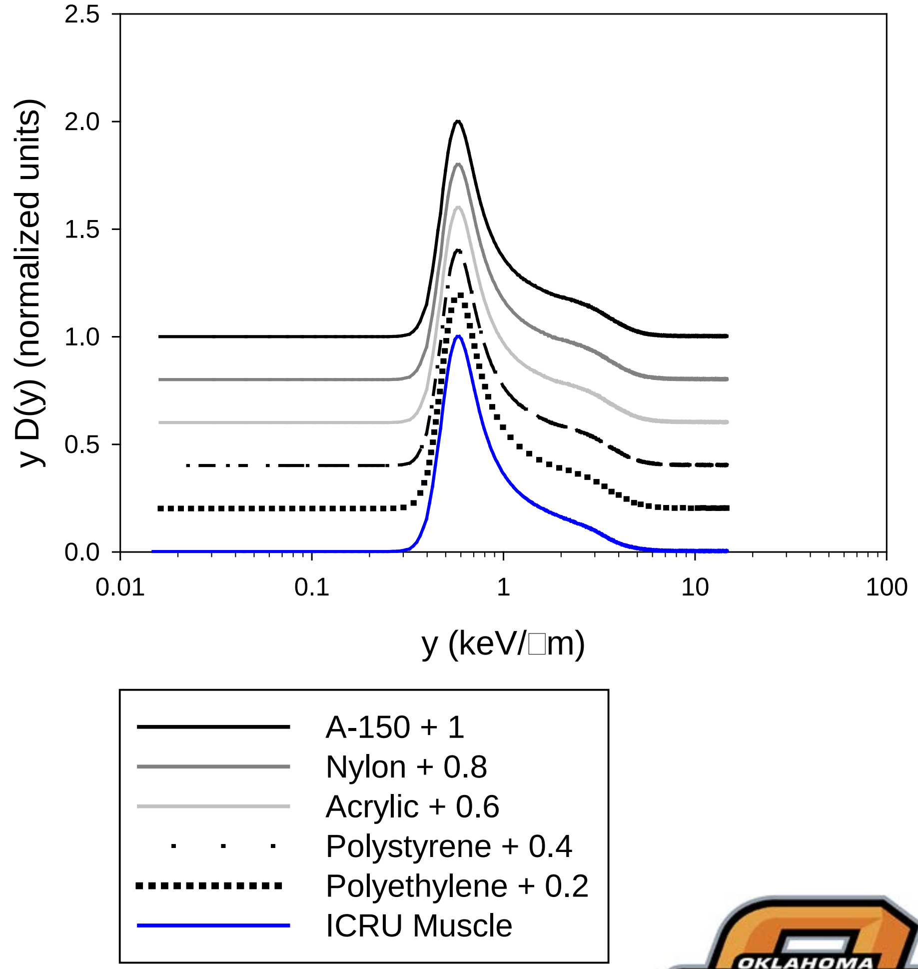
87 MeV Protons
FLUKA Simulation



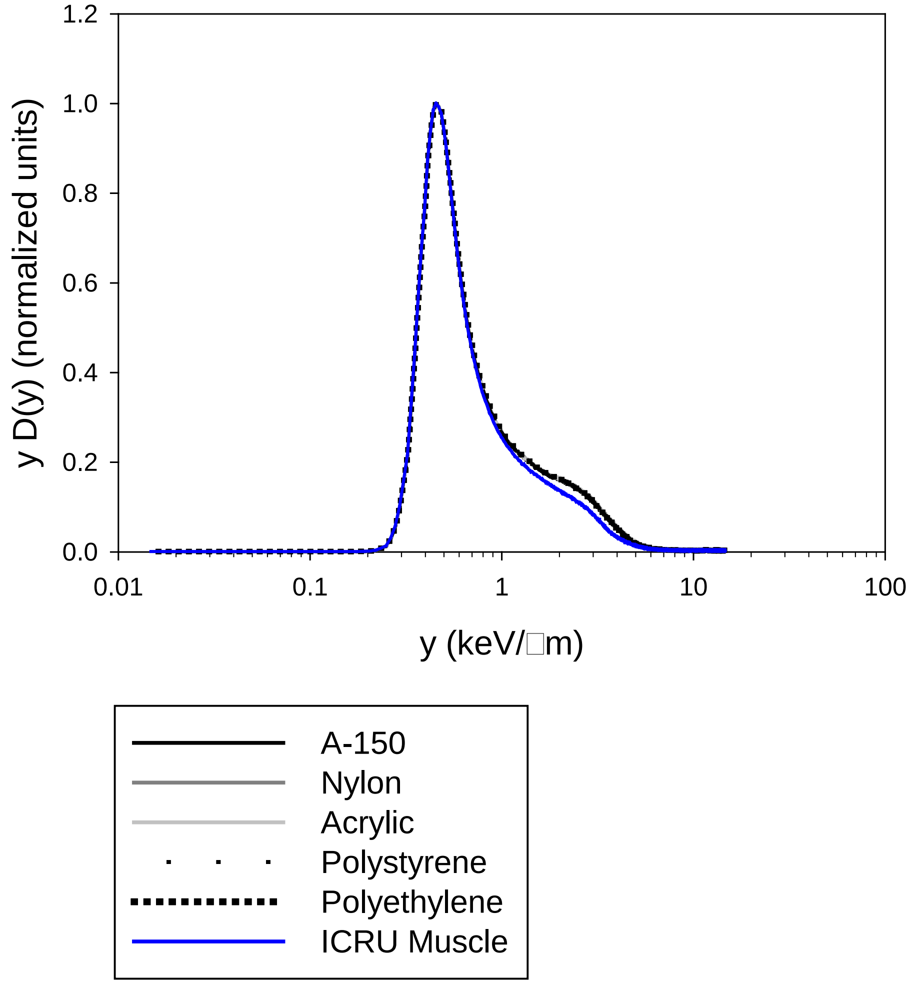


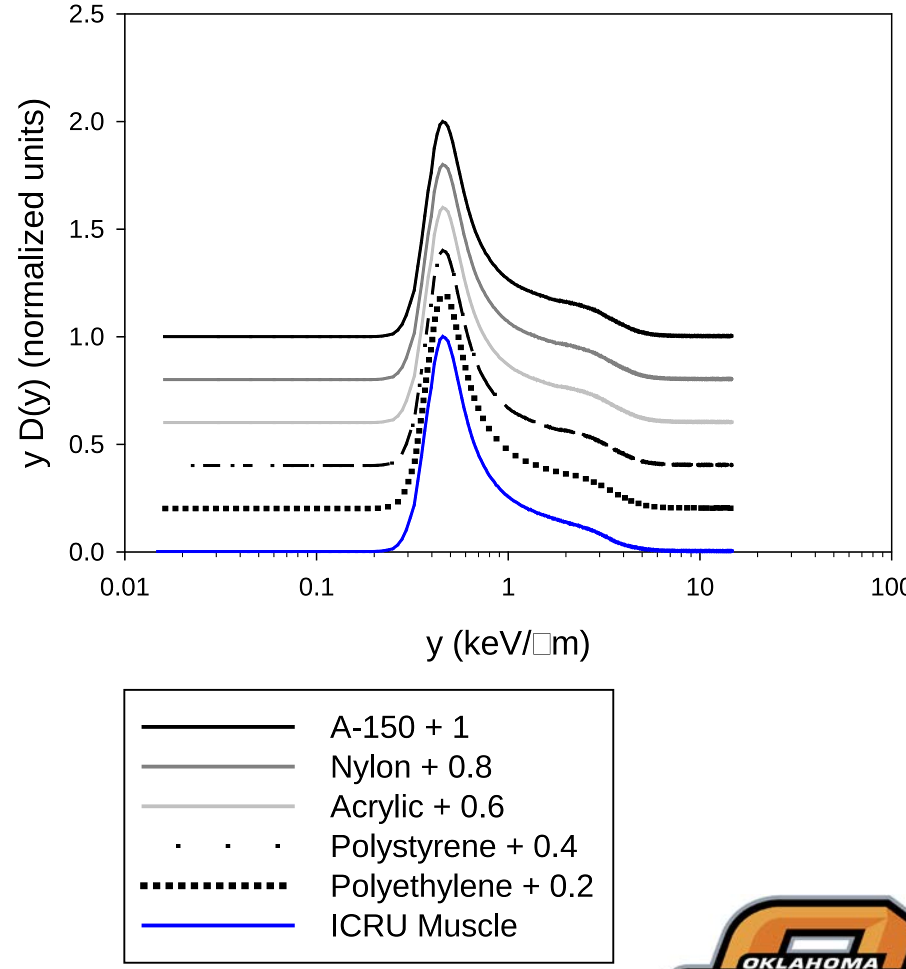
162 MeV Protons
FLUKA Simulation





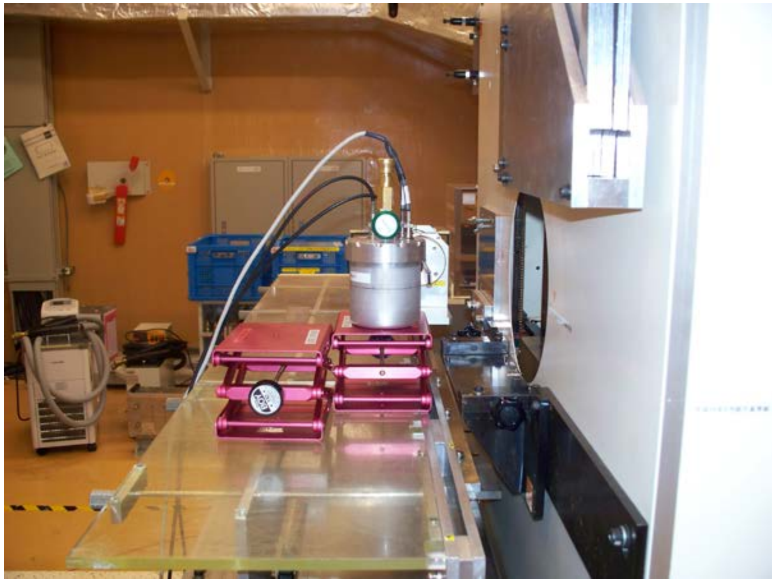
222 MeV Protons FLUKA Simulation

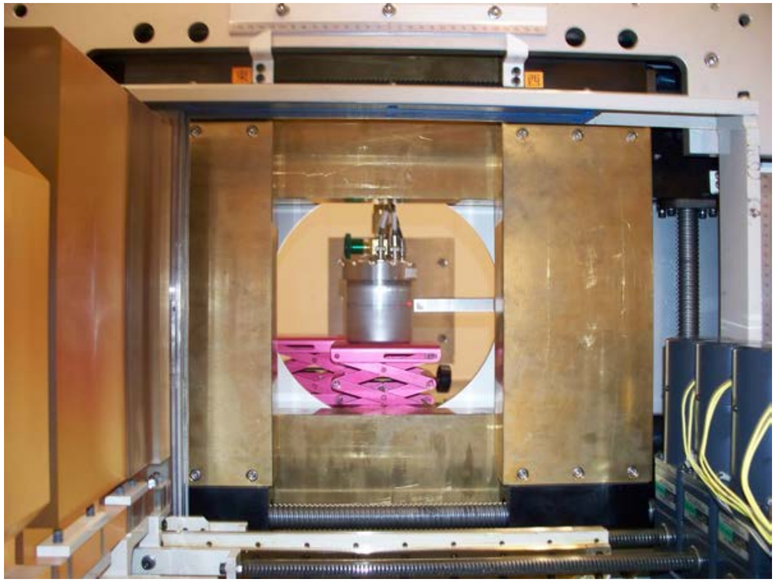




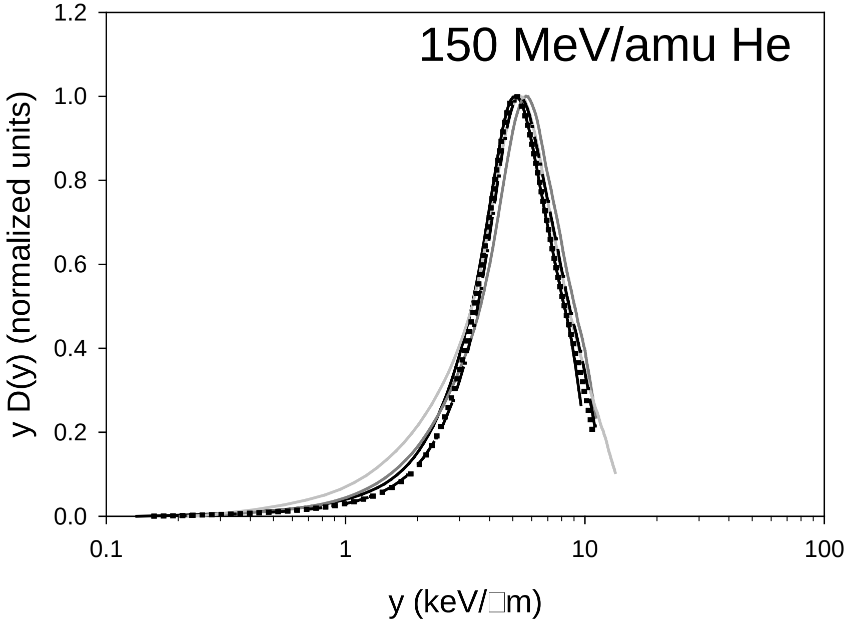
Heavy Ion Beam Experiment

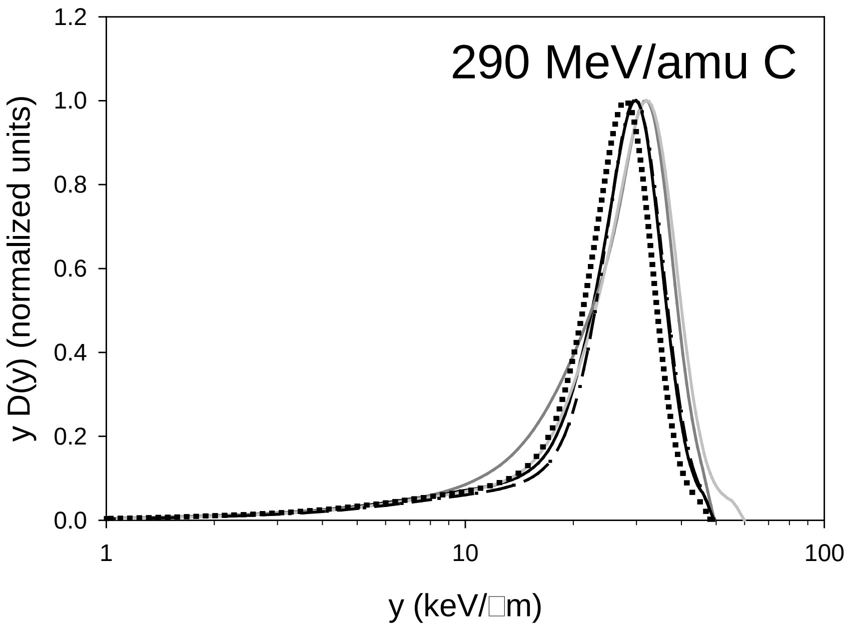
- Heavy Ion Medical Accelerator in Chiba (HIMAC) at the National Institute for Radiological Sciences (NIRS) in Japan
- Five beams:
  - 150 MeV/amu He
  - 290 MeV/amu C
  - 490 MeV/amu Si
  - 500 MeV/amu Ar
  - 500 MeV/amu Fe
- Low flux field (~1000 particles $cm^{-2}\ s^{-1}$)

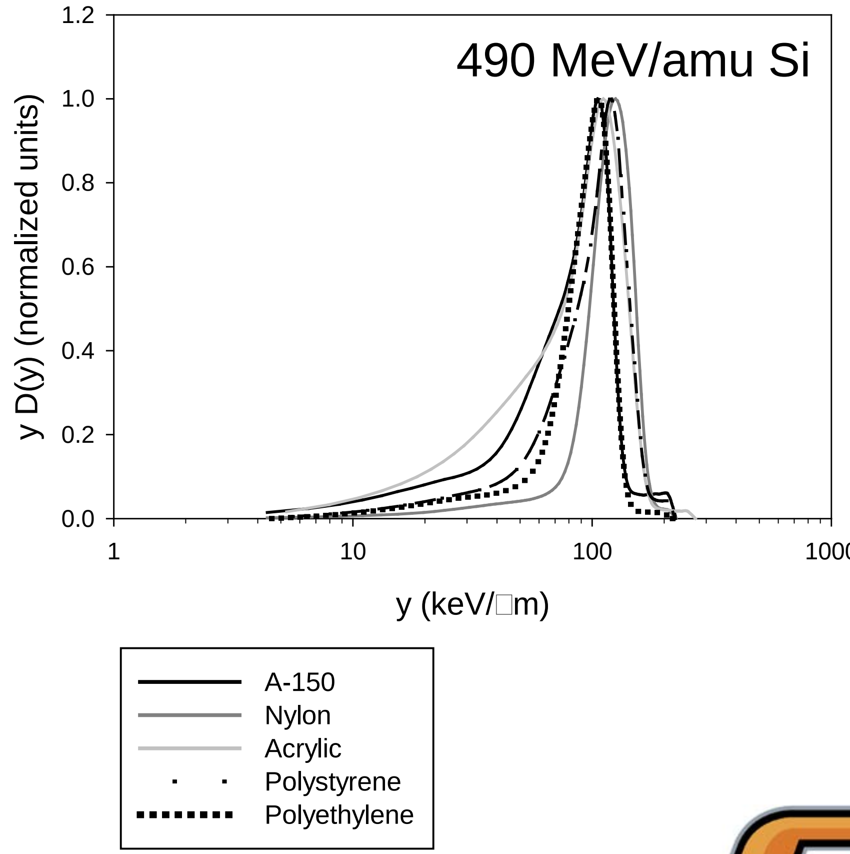




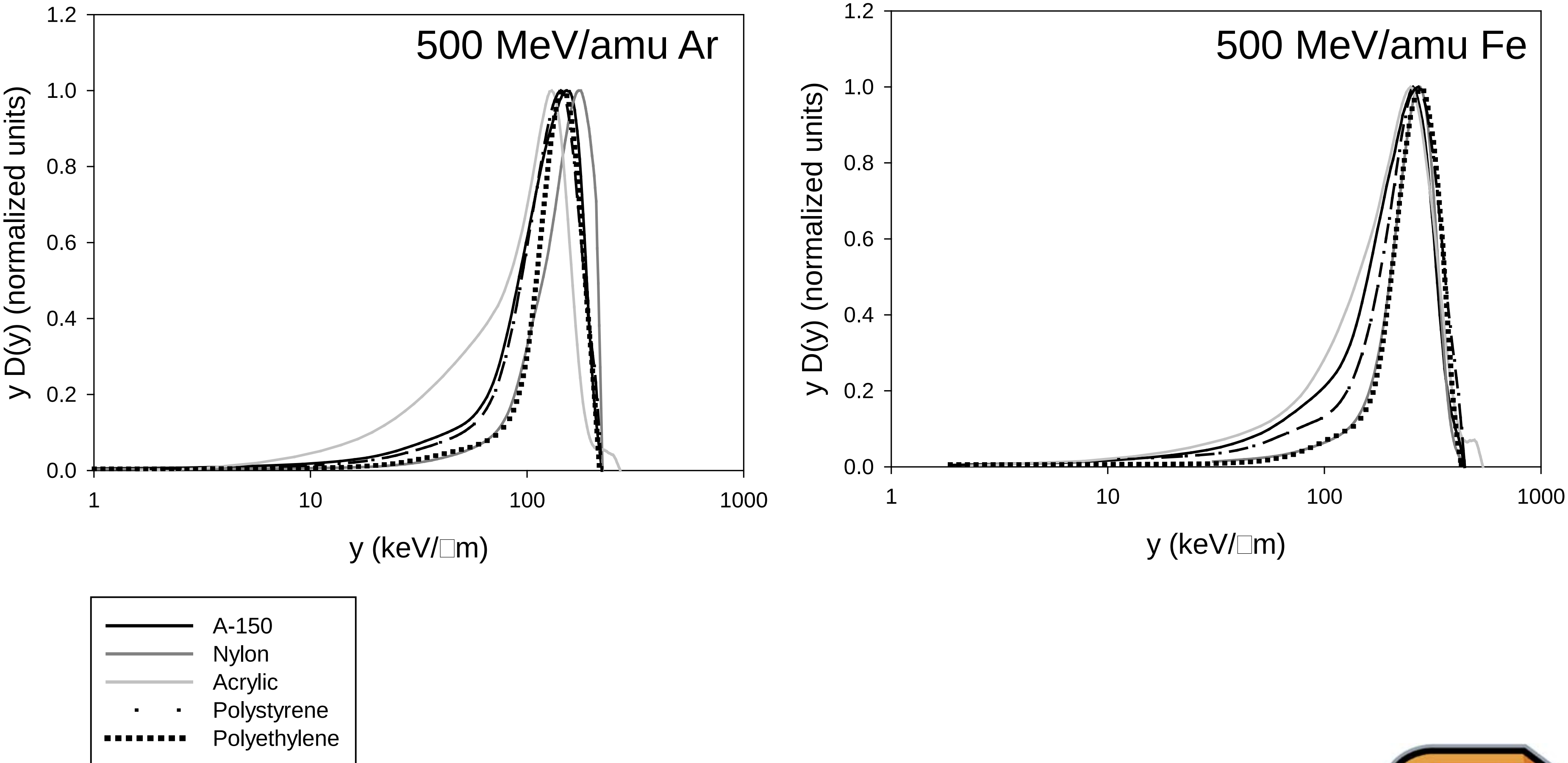
Experimental Results



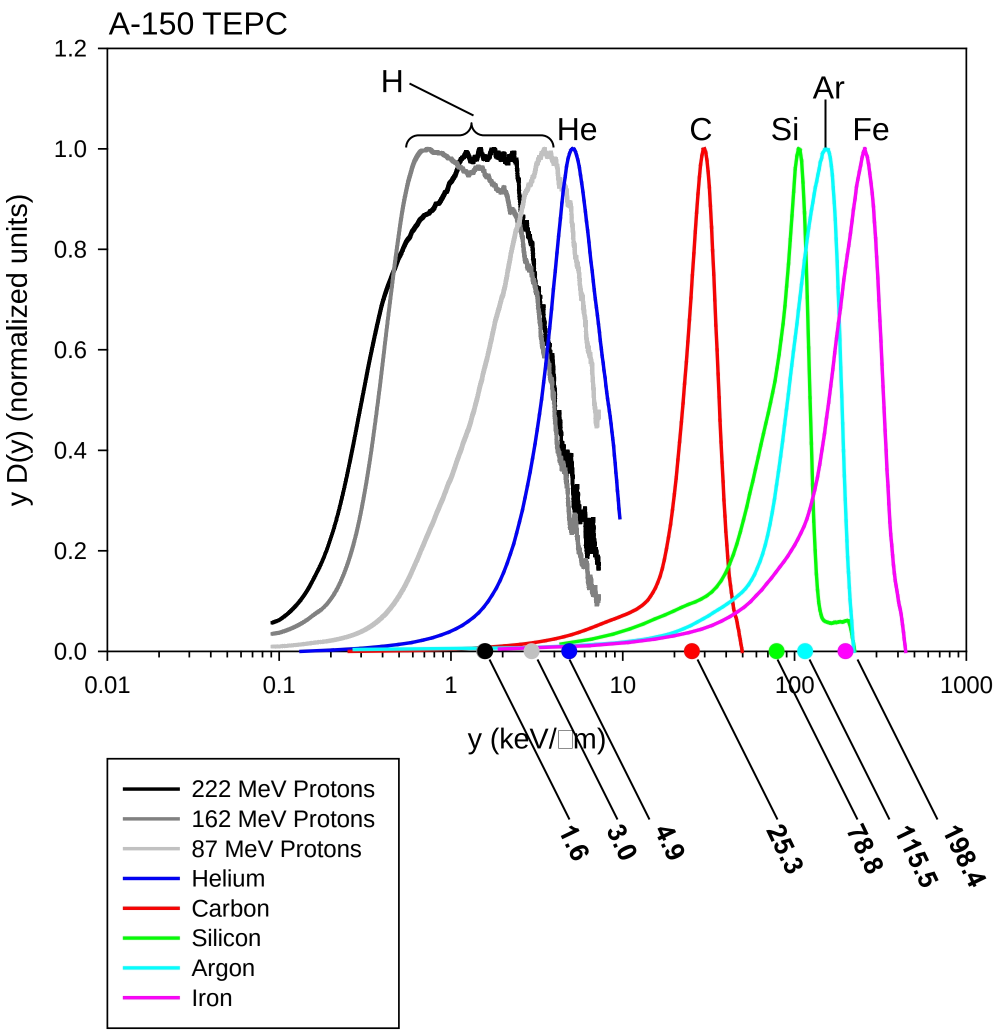




Experimental Results (cont.)



Average Lineal Energy



Frequency Averaged

Lineal Energy

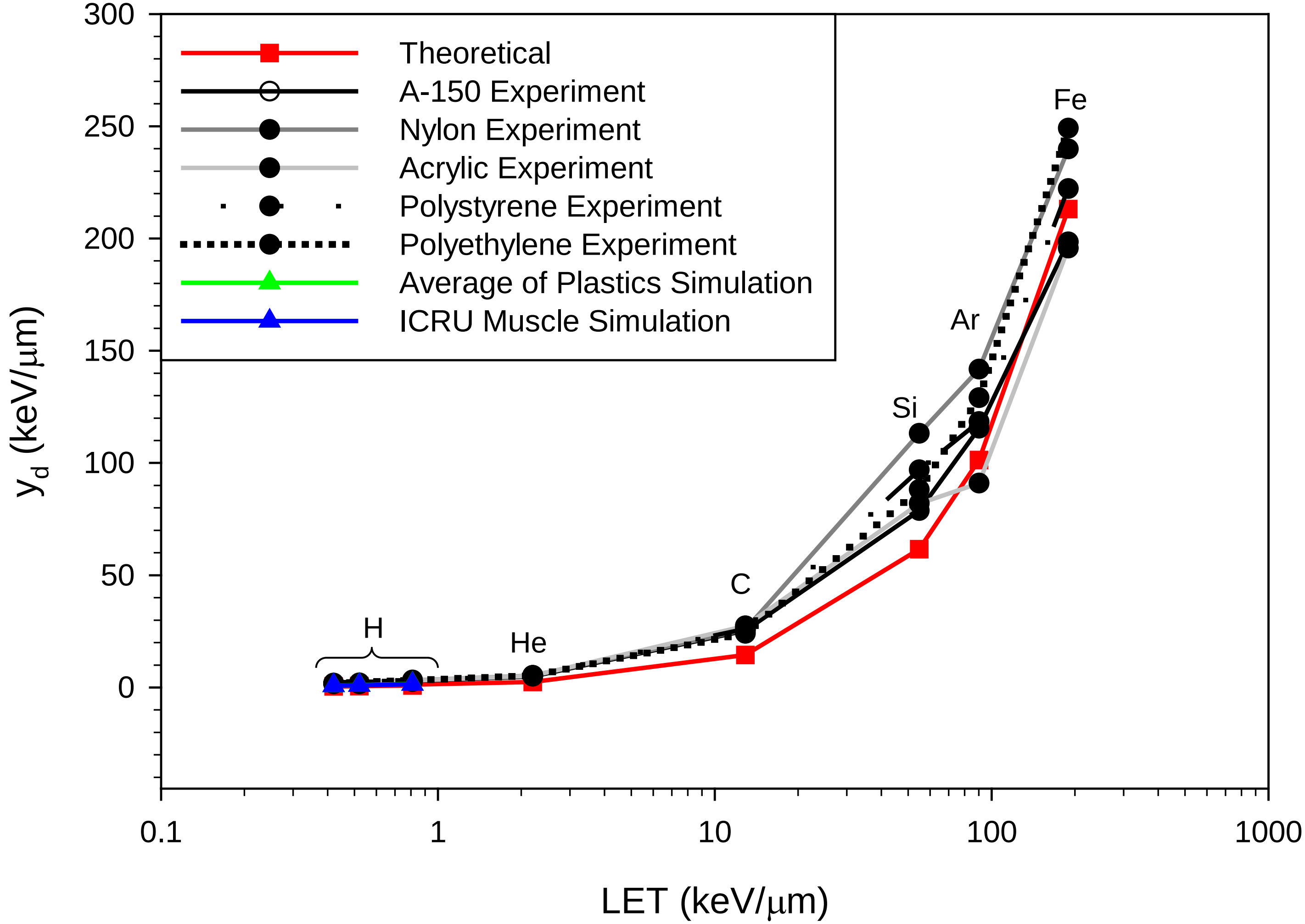
$$\bar{y}_F = \int_0^\infty y\, f(y)\, dy \qquad \bar{y}_F = \frac{\sum_{y=0}^{y=y_{\max}} y\, f(y)}{\sum_{y=0}^{y=y_{\max}} y}$$

Dose Averaged

Lineal Energy

$$\bar{y}_D = \frac{1}{\bar{y}_F} \int_0^\infty y^2\, f(y)\, dy \qquad \bar{y}_D = \frac{\sum_{y=0}^{y=y_{\max}} y^2\, f(y)}{\sum_{y=0}^{y=y_{\max}} y\, f(y)}$$

Dose Averaged Lineal Energies



Conclusions

Average Experimental Percent Difference (y_d values)
with A-150 Tissue Equivalent Plastic

Nylon	Acrylic	Polystyrene	Polyethylene
18.2%	6.6%	9.9%	10.8%

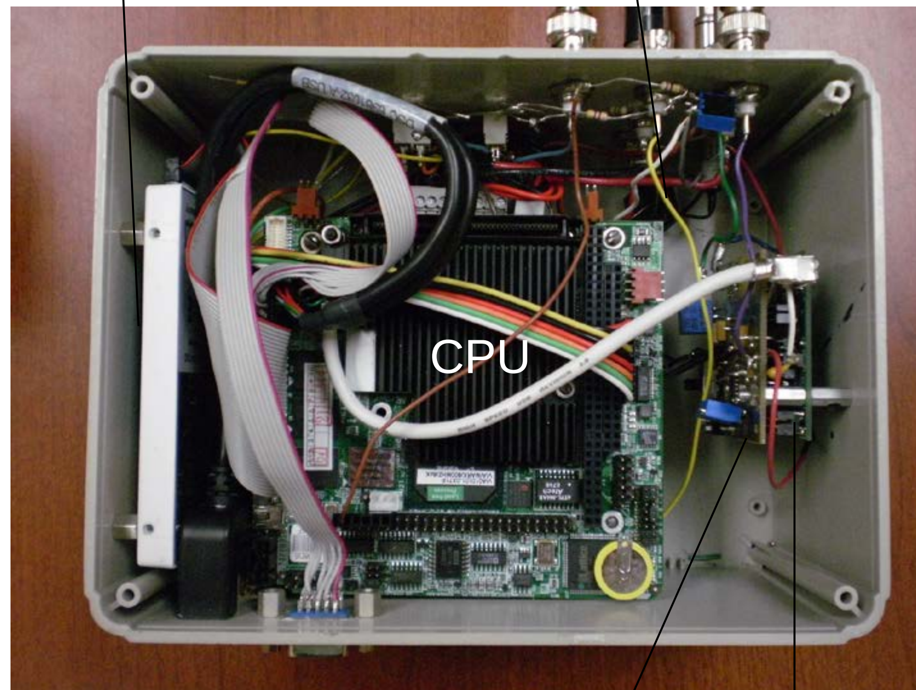
- Acrylic showed the most similar response to that of A-150
- However, simulation showed a difference of less than 1% between all five plastics for each proton beam
- This would imply that the larger differences between experimental values are more likely due to difference in geometry and fabrication of the detector and not the response of the plastics

Future Work

- Complete heavy ions simulations
- Irradiations in neutrons field
  - Experimental
  - Simulation
- Balloon flight

Flight Version

- Integrated components
  - CPU
  - MCA
  - HV power supply
  - Battery
  - Linear Amplifier
- Weight: ~2.4 kg
- Size:
  - 15X20X10 cm^3 CPU container
  - 9 cm diameter, 10 cm tall TEPC



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  - HIMAC staff
- ProCure
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- OSU machine shop staff