Evaluation and Application of U.S. Medical Proton Facilities for Single Event Effects Test

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Outline

- Discuss challenges of using new medical proton therapy cyclotrons for SEE tests in the 200 MeV regime.
- Solutions are discussed to utilize these facilities as a replacement for the Indiana University Cyclotron Facility
- Part data response to conventional scattered proton beams are compared to newer scanning beam configurations
- A common dosimetry system for fluence and beam uniformity cross calibration is also discussed

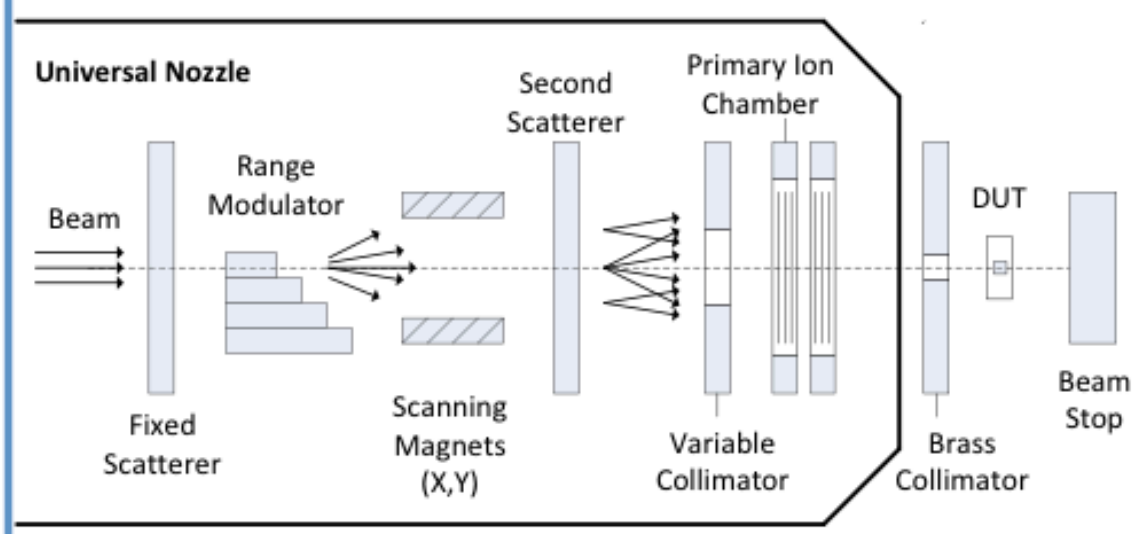
Background

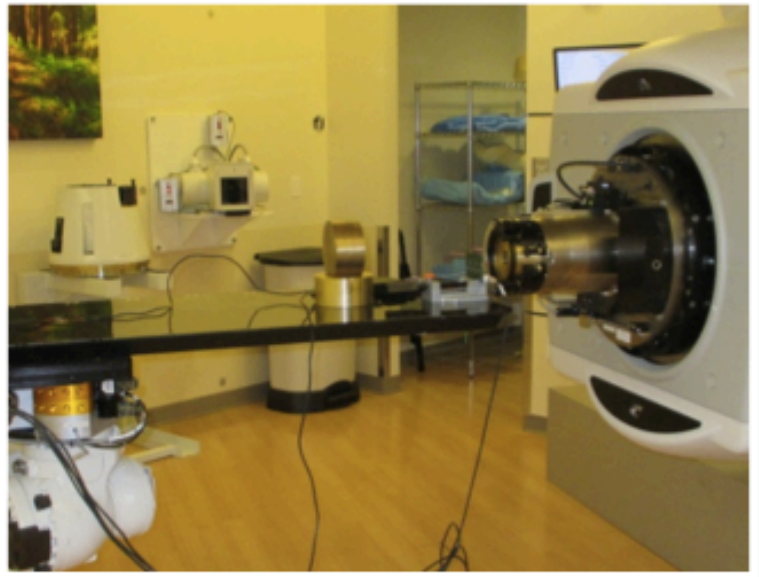
- IUCF has been a primary source of 200 MeV protons for the space community since 1994
- The closure has resulted in a critical shortage of high energy proton test capability in the United States
- To fill this gap, the authors have undertaken an evaluation of proton cancer treatment centers to understand whether they have the ability to provide proton beams suitable for SEE testing
- Test results from these new facilities are presented and compared to data previously collected at established proton test facilities

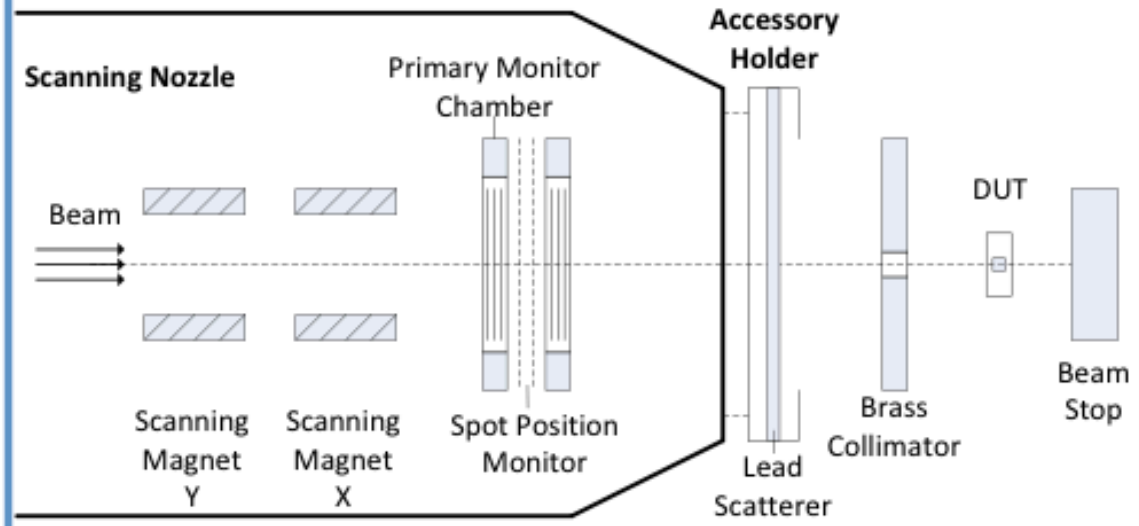
Proton SEE Test Requirements

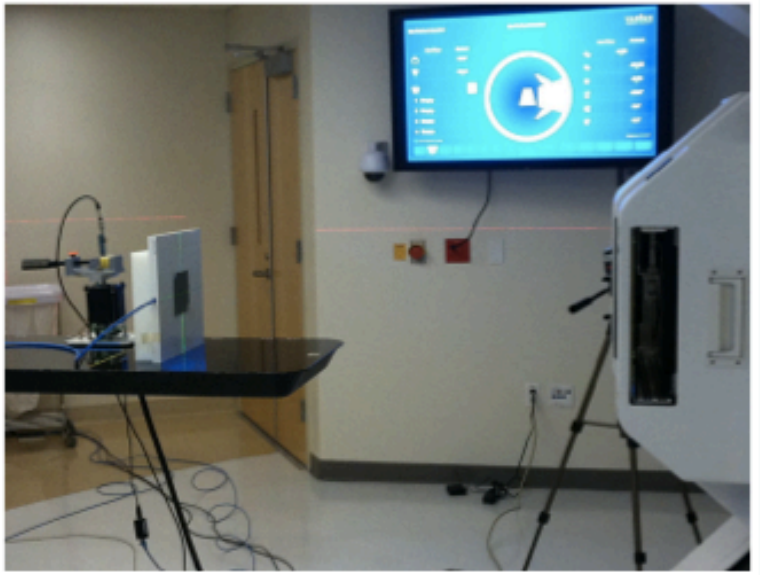
Energy	125 MeV to > 200 MeV
Flux	10^7 to 10^9 p/cm^2/s
Fluence	10^9 to 10^{12} p/cm^2
Field Size	1cm x 1cm (small IC) to 15cm x 15cm (Board)
Beam Uniformity	> 80%
Beam Structure	Cyclotron, Fixed spot or scatter

Beam Setup

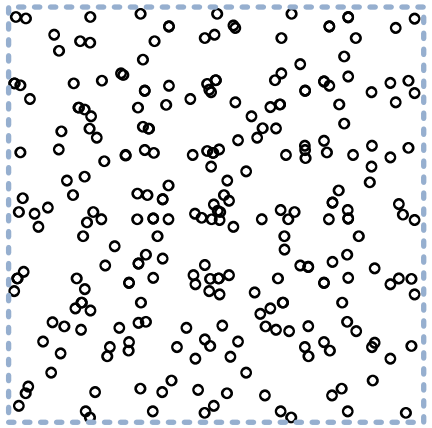

Universal Nozzle
Beam
Range Modulator
Second Scatterer
Primary Ion Chamber
DUT
Fixed Scatterer
Scanning Magnets (X,Y)
Variable Collimator
Brass Collimator
Beam Stop



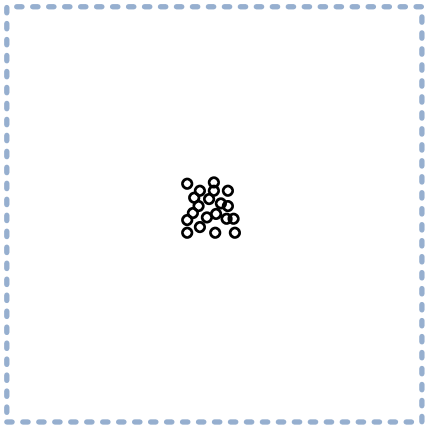

Scanning Nozzle
Primary Monitor Chamber
Accessory Holder
Beam
DUT
Scanning Magnet Y
Scanning Magnet X
Spot Position Monitor
Lead Scatterer
Brass Collimator
Beam Stop



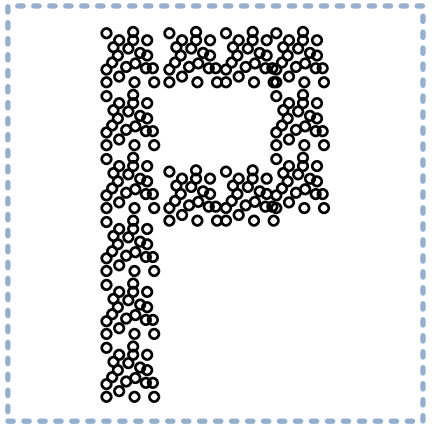
Proton Beam Configurations



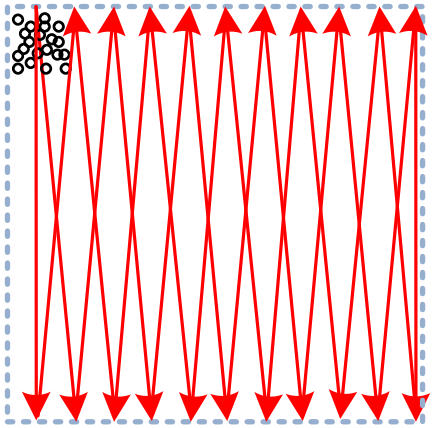
a) Single/Double Scatter



b) Fixed Beam



c) Pencil Beam Scan



d) Uniform scan

Beam Profiles

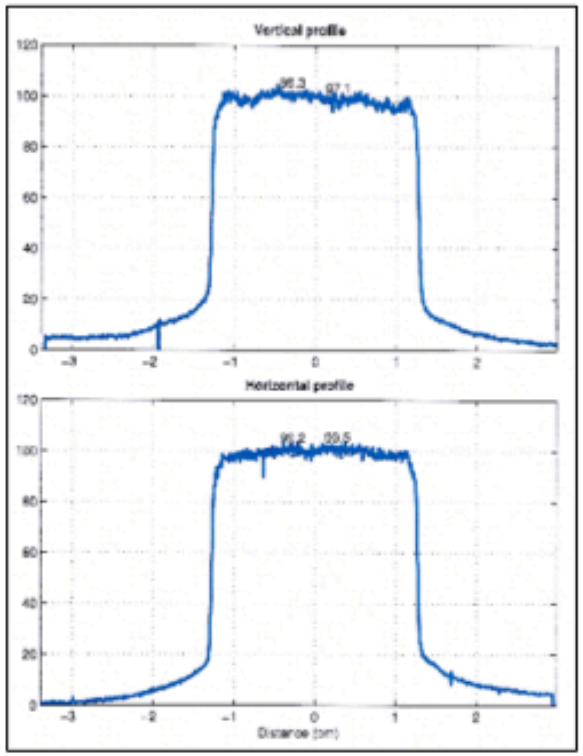


Fig. 3. Uniform Scan Beam Profile

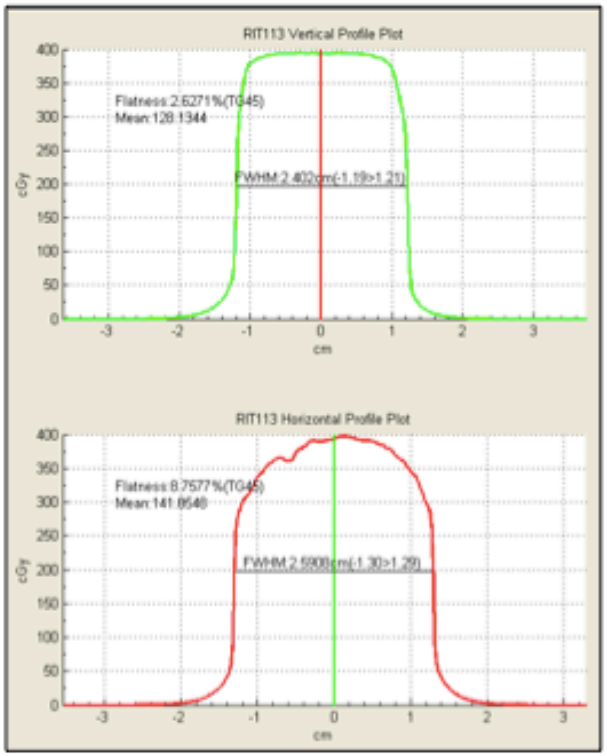


Fig 4. Double Scatter Beam Profile

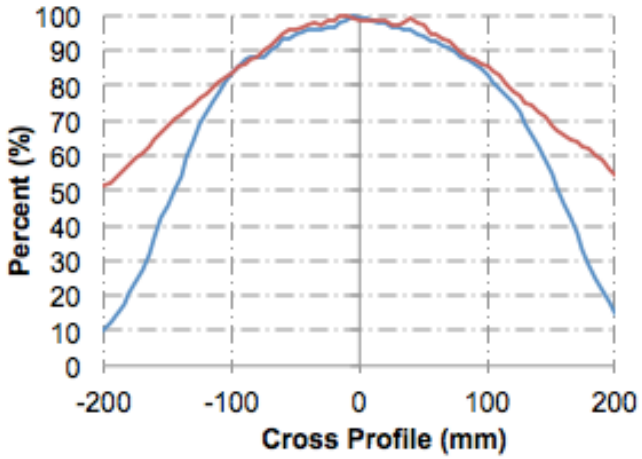


Fig 5. Single Scatter Beam Profile

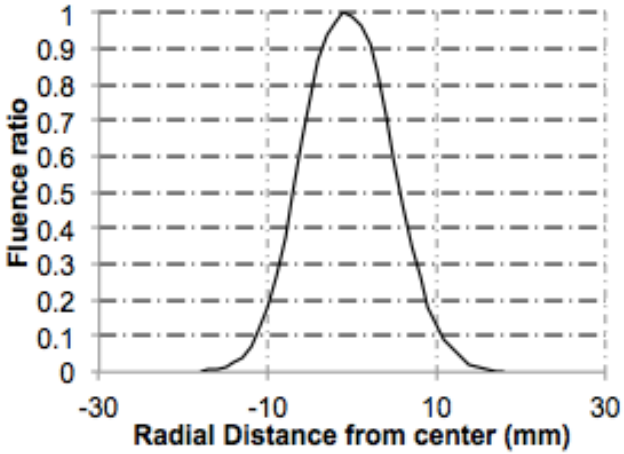


Fig 6. Fixed Beam Profile

Facility	Max Energy/Type	Beam Type
Northwestern Medicine Chicago Proton Center	230MeV/ IBA Cyclotron	Uniform scan, double scatter, single scatter, pencil beam scan
Scripps Proton Therapy Center	250MeV/ Varian Cyclotron	Single scatter, pencil beam scan
Seattle Proton Center	230MeV/ IBA Cyclotron	Uniform scan, double scatter, single scatter, pencil beam scan
Hampton University Proton Therapy Institute	230MeV/ IBA Cyclotron	Uniform scan, double scatter, single scatter, pencil beam scan
OK City ProCure Proton Therapy Center	230MeV/ IBA Cyclotron	Uniform scan, double scatter, single scatter
University of Florida Proton Therapy Institute	230MeV/ IBA Cyclotron	Uniform scan, double scatter, single scatter,
Provision Center for Proton Therapy	230MeV/ IBA & Sumitomo Cyclotron	Uniform scan, double scatter, single scatter, pencil beam scan
Maryland Proton Treatment Center	250MeV/ Varian Cyclotron	Single scatter, pencil beam scan
TRIUMF	500MeV/ Cyclotron	Double Scatter
Loma Linda University Medical Center – Slater	250MeV/ Synchrotron	Uniform scan, double scatter, single scatter, pencil beam scan
Francis H. Burr Proton Therapy Center	230MeV/ IBA Cyclotron	Uniform scan, double scatter, single scatter, pencil beam scan
NASA Space Radiation Lab	2500MeV/ Synchrotron	Single Scatter

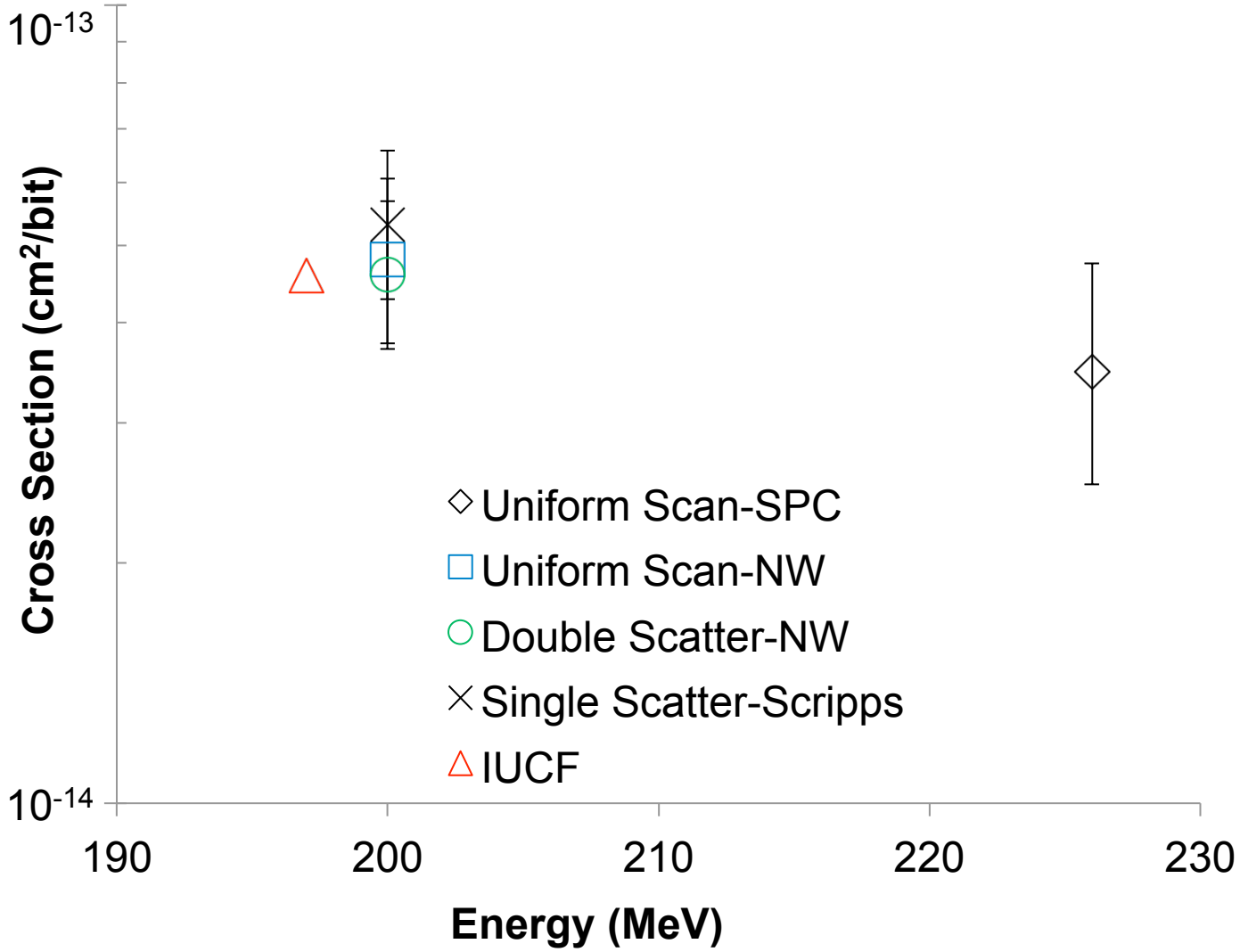
Dosimetry Considerations

- Proton therapy facilities measure the energy of the proton beam:
  - Determining the thickness of water needed to stop the beam as detected by a parallel plate ion chamber
  - Correct the energy for material thicknesses in the beam that differ from the standard configuration using tabulated stopping power with LET as a function of energy data
- Fluence at the DUT position is determined using a Markus ion chamber
  - Placed at the DUT location centered on the beam and exposed to a number of Monitor Units (MU) as measured by the ion chamber in the beam nozzle
  - The ratio of the dose(H2O) in Gray (Gy) measured by the Markus chamber to the number of monitor units from the beam monitor chamber is the monitor unit calibration in Gray(H2O)/MU.
  - This is the Fluence/MU at the center of the beam profile. The Fluence/MU at other locations in the beam profile is yet to be determined.
- Beam profile is determined by exposing a sheet of GafchromicTM film taped to the upstream surface of the Markus ion chamber located at the DUT position when performing a monitor chamber calibration
  - Film for each calibration exposure is then scanned and analyzed with FilmQA Pro or similar software to create a 2D Dose(H2O) distribution from which 2D Dose(Si) and Fluence distributions are readily calculated.
  - Absolute dosimetry for carefully calibrated GafchromicTM film may be as good as 2 to 4%

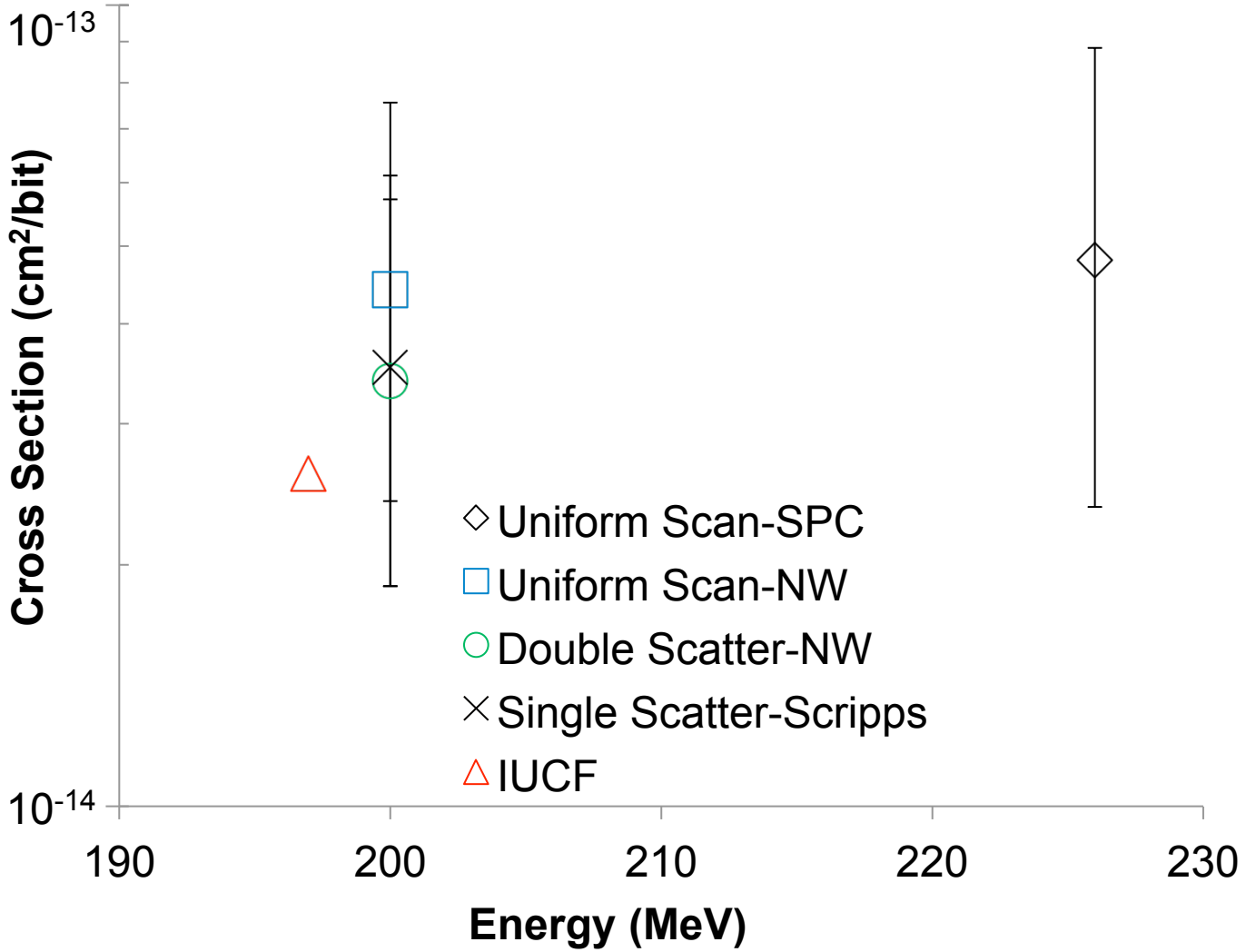
SEE Testing

- Beta tests have been conducted at
  - Seattle Proton Center (SPC),
  - Northwestern (NW) Medicine Chicago Proton Center, and
  - Scripps Proton Therapy Center in San Diego.
  - All measurement irradiations were performed in air at room temperature.
- Three beta tests :
  - Microsemi ProASIC FPGA
    - Single scatter, double scatter, and uniform scan modes of operation
    - Upset data on internal FPGA RAM memory in a static mode
    - Uspet data on dynamic shift registers clocked at 1 MHz
  - Microchip PIC microcontroller
    - Single scatter, double scatter, and uniform scan modes of operation
    - Latchup characteristics

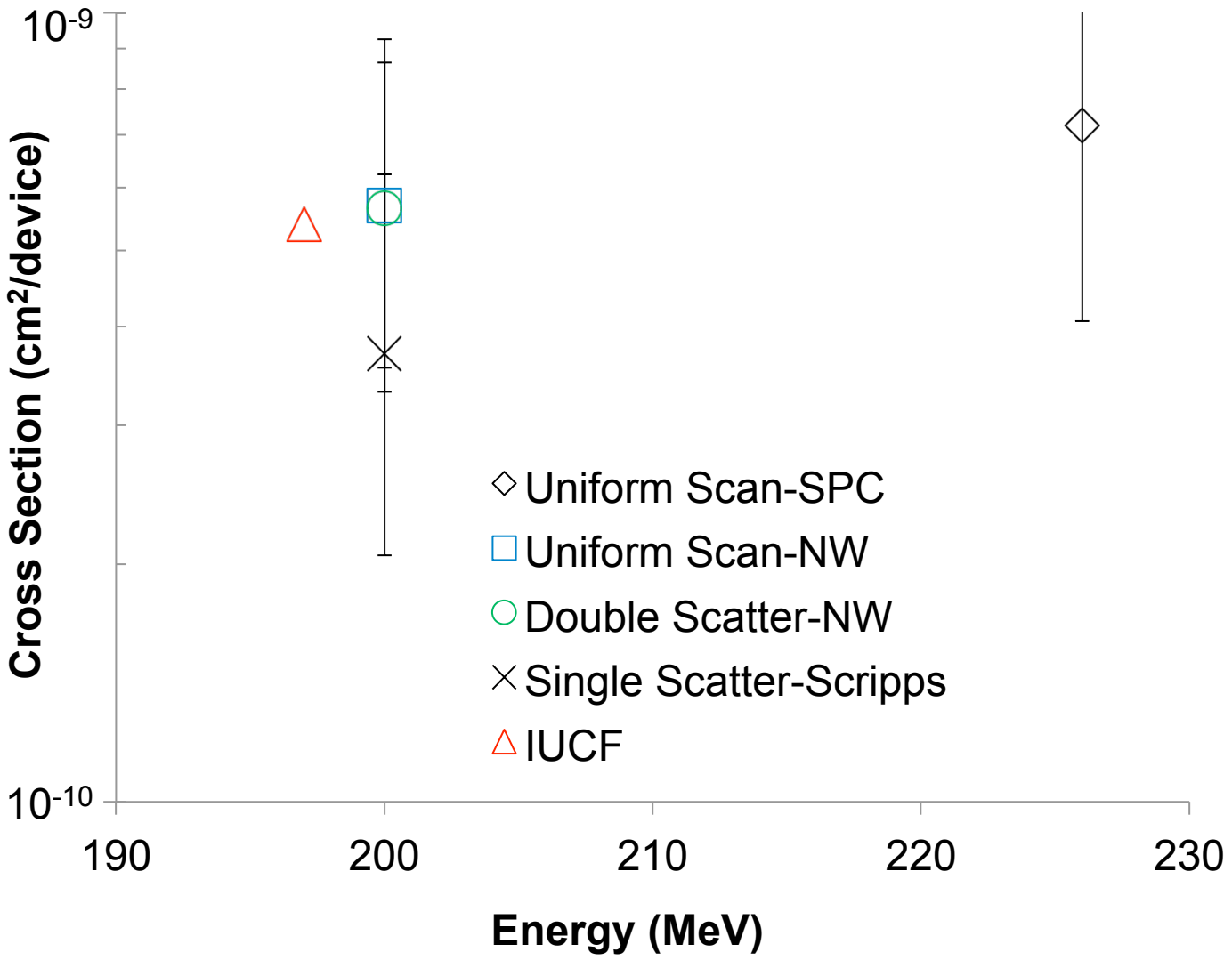
FPGA SRAM Cross Section



FPGA Shift Register Cross Section



Microcontroller Latchup Cross Section



Recommendations for Proton Testing

Test Type	Fixed or Scatter	Uniform Scan	Pencil Beam Scan
Static	x	x	x
Destructive	x	x	x
Dynamic (low proton sensitivity or slow operation)	x	x	x
Dynamic (high proton sensitivity or fast operation)	x		
System test (board/box)	x		

Conclusion

- With 14 proton therapy centers in operation and an additional 10 in development, an opportunity exists to utilize these facilities for single event effects testing
- The logistics and business model to support this new access is still in active development
- Initial tests have been conducted
  - Results to date indicate these new facilities provide equivalent results to IUCF and are usable by the space radiation effects community