Comparative Neutron & Proton Single Event Effect Testing and International Standards

Clive Dyer

Space Department,

QinetiQ Farnborough

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NPL

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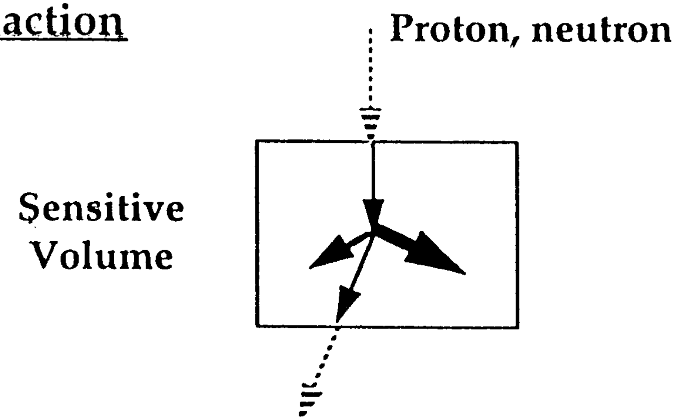
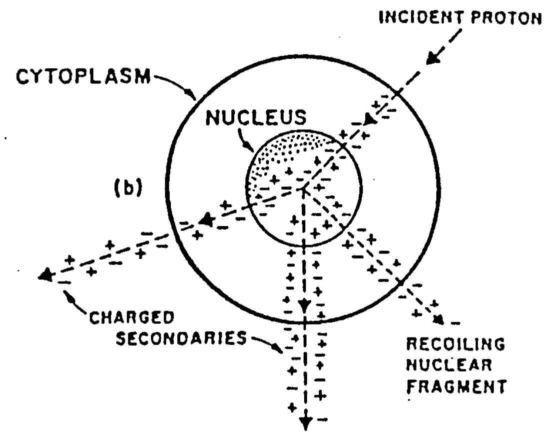
SEE in COTS Microelectronics

- **Single event effects** are induced by **single ionising particles**
  - Data corruption - single event or multiple-bit upsets
  - Device failure - eg Single Event Latchup (SEL), Gate Rupture (SEGR)
- SEEs are a growing problem for modern microelectronics:
  - Decreasing feature size and lower voltages - smaller critical charges
  - Higher frequency operation - previously transients from particle ionisation were too fast to be latched
  - Miniaturisation means more transistors affected by single ion - increased number of multiple bit upsets
  - Thinner gates - increased risk of gate rupture
- Growing evidence of such effects in aircraft and ground-based equipment as well as from spaceflight

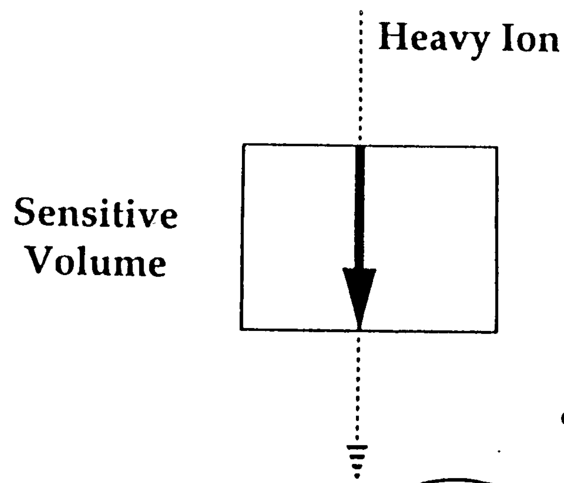
SINGLE EVENT EFFECTS & RADIOBIOLOGICAL EFFECTS

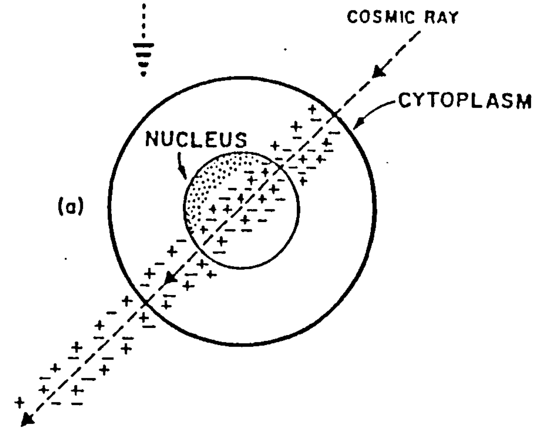
Nuclear Reaction





Direct Ionization





SEE in COTS Microelectronics

- PERFORM computer withdrawn for tests in 1991 following accumulation of errors in SRAM memory.
- More than one upset per flight in 280 64K SRAMs on Boeing E-3 AWACS and NASA ER-2.
- Boeing-777 autopilot design altered after faults shown to correlate with altitude and latitude.
- Sun Enterprise Server crashes from upsets in L2 cache
- PCs on Shuttle and MIR required frequent reboot, typically every nine hours.

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SEE in COTS Microelectronics

- Activities
  - Develop and validate atmospheric SEE threat models
  - Test microelectronics and compare with model results to better understand process which drive SEE susceptibility and trends with device technology
  - Modelling of nuclear interactions, energy deposition and charge collection in devices
  - Develop, with industry, standards for environment, test methodologies, and guidelines
- Complementary programmes funded by MOD (QinetiQ) and DTI (MBDA, BAE SYSTEMS, Goodrich, Smiths, Universities of Lancaster, Central Lancashire, Surrey).

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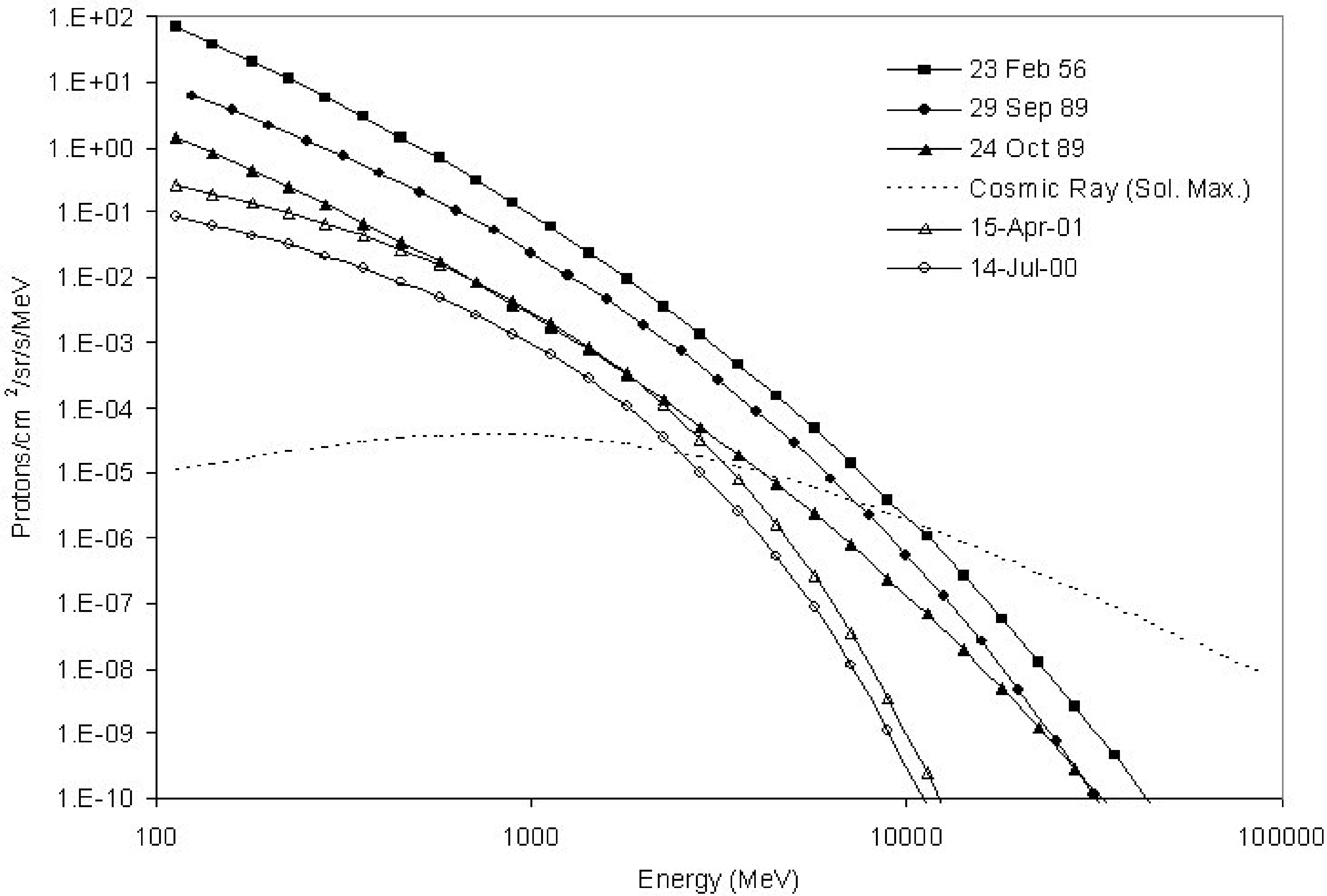
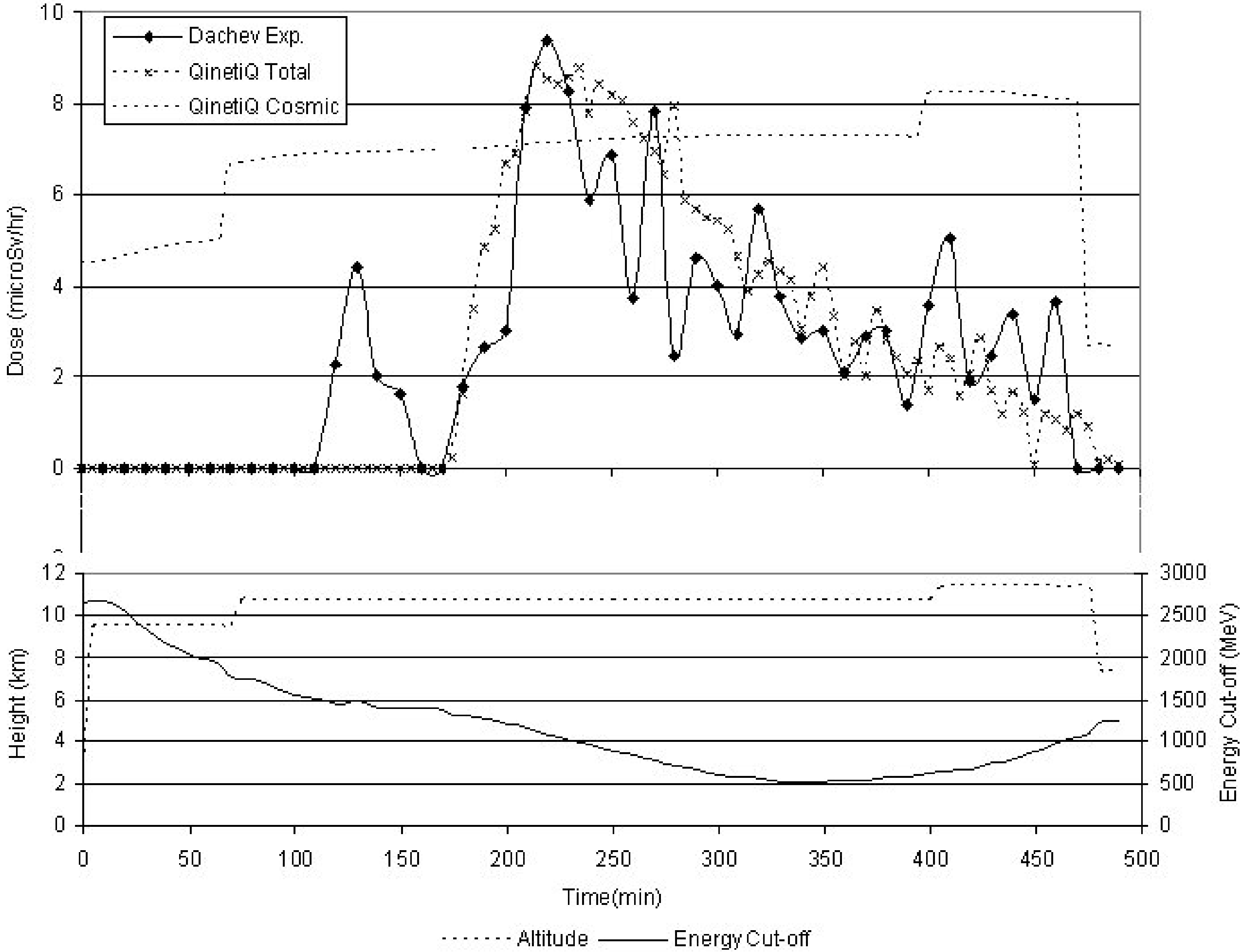
WP1 Environments

- Monte Carlo codes have been used to generate a database of atmospheric secondary particle production as a function of incident cosmic ray energy
- Ground level neutron monitor data have been obtained for the major solar particle events of the current solar maximum.
- These have been combined with space data to generate the solar particle spectra and particle fluxes throughout the atmosphere.
- Flights of the CREAM monitor have been made to 49000 ft.
- A prototype compact monitor has been built and calibrated at The Svedberg Laboratory in Sweden.

Spectra of large solar particle events cf cosmic rays



Comparison with experimental data



Prague – JFK
15th April 2001

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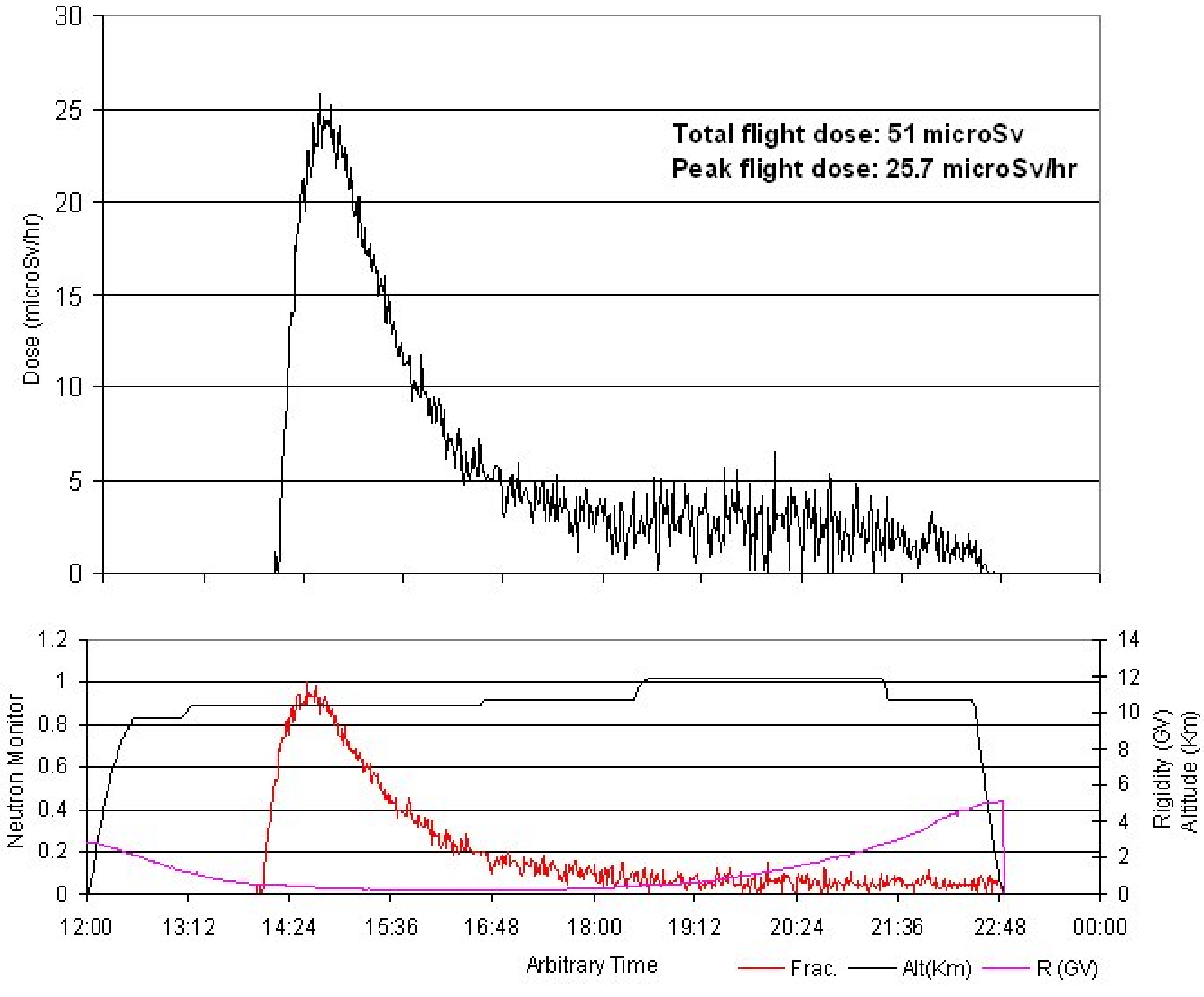
Consequences of 15th April 2001 event for LHR-LAX flight



Upset Rates in 1 Gbyte of SRAM (Cross-Section of 5×10^{-14} cm^2 per bit)

Event	Neutron Flux /(cm^2-sec)	Upset Rate (/hr)	MTBU (sec)
1GV - 17km			
23-Feb-56	2893	1164	3.1
29-Sep-89	487	196	18.4
19-Oct-89	39.1	15.7	229
22-Oct-89	70.4	28.3	127
24-Oct-89	79.7	32.1	112
GCR (Sol. Max)	9.3	3.6	1003
1GV - 12km			
23-Feb-56	1113	493	7.3
29-Sep-89	191	84.7	42.5
19-Oct-89	16.1	7.1	504
22-Oct-89	28.2	12.5	288
24-Oct-89	31.5	13.9	258
GCR (Sol. Max)	5.8	2.5	1468

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WP2 Ground Irradiations

- Comparative results on SRAMs obtained using :
  - protons (13.5 to 490 MeV) at TRIUMF,Vancouver.
  - ions (xenon, argon) at UCL, Belgium.
  - neutrons (20-180 MeV) at TSL, Sweden
  - neutrons (14 MeV) from D-T at NPL, UK.
  - thermal neutrons at NPL, UK.
  - spallation neutrons at LANL, USA (Nov 2003).
  - pulsed laser via collaboration with MBDA Bristol.
  - flash X-ray at EROS. AWE (April 2003)
  - new devices tested at TSL in May 2004.

Old 4-MEGABIT SRAM PARTS now comprehensively tested

manufacturer	reference	date code	minimum feature size (µm)
Hitachi	HM628512ALP-7	9809	0.5
Hitachi	HM628512BLP-7	9925	0.35
Toshiba	TC554001FL-70L	9827	0.5
Toshiba	TC554001AF-70L	9929	0.4
Mitsubishi	M5M5408AFP-70LL	9839	0.4
Samsung	KM684000BLP-7L	9844	0.4

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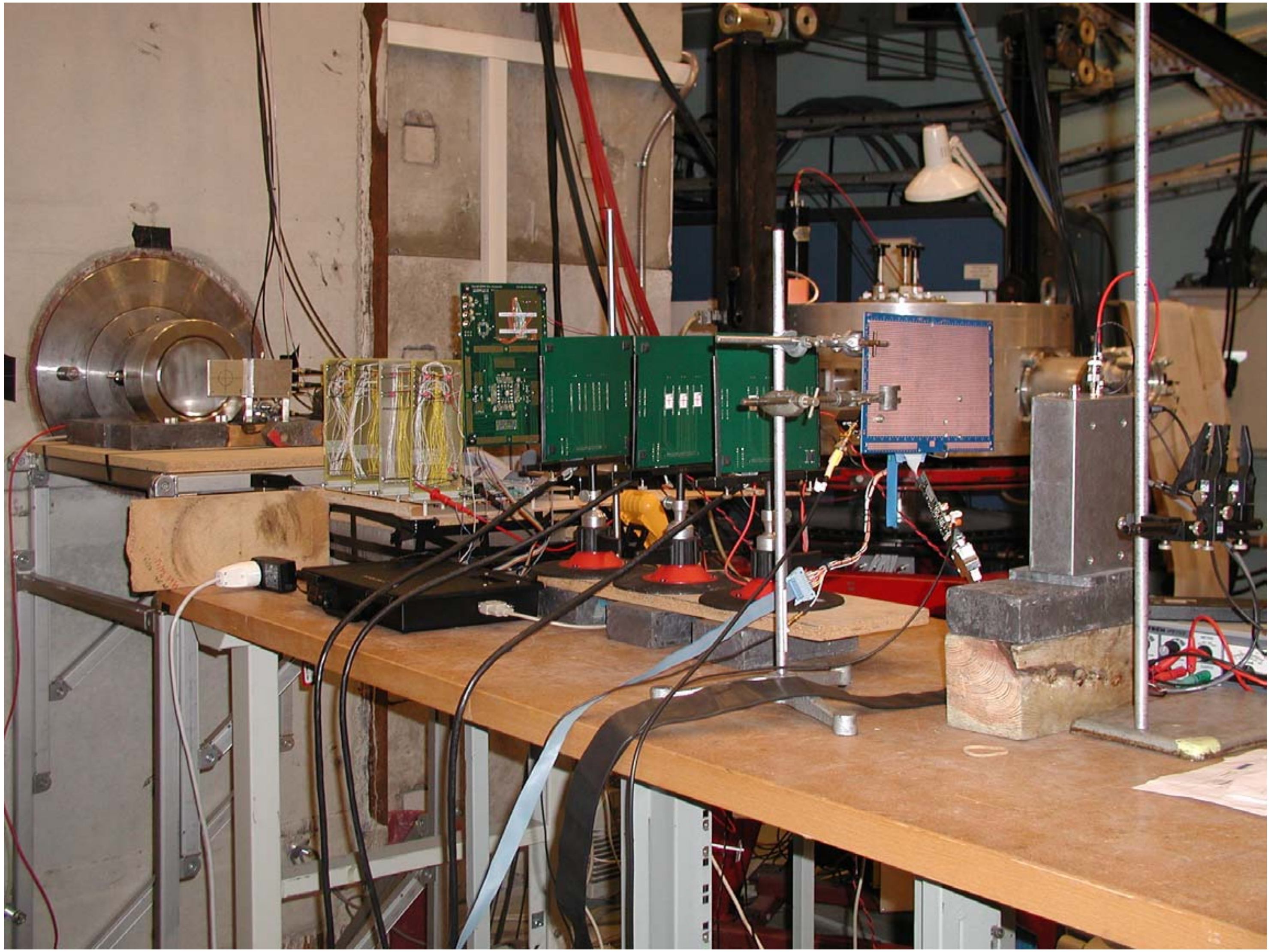
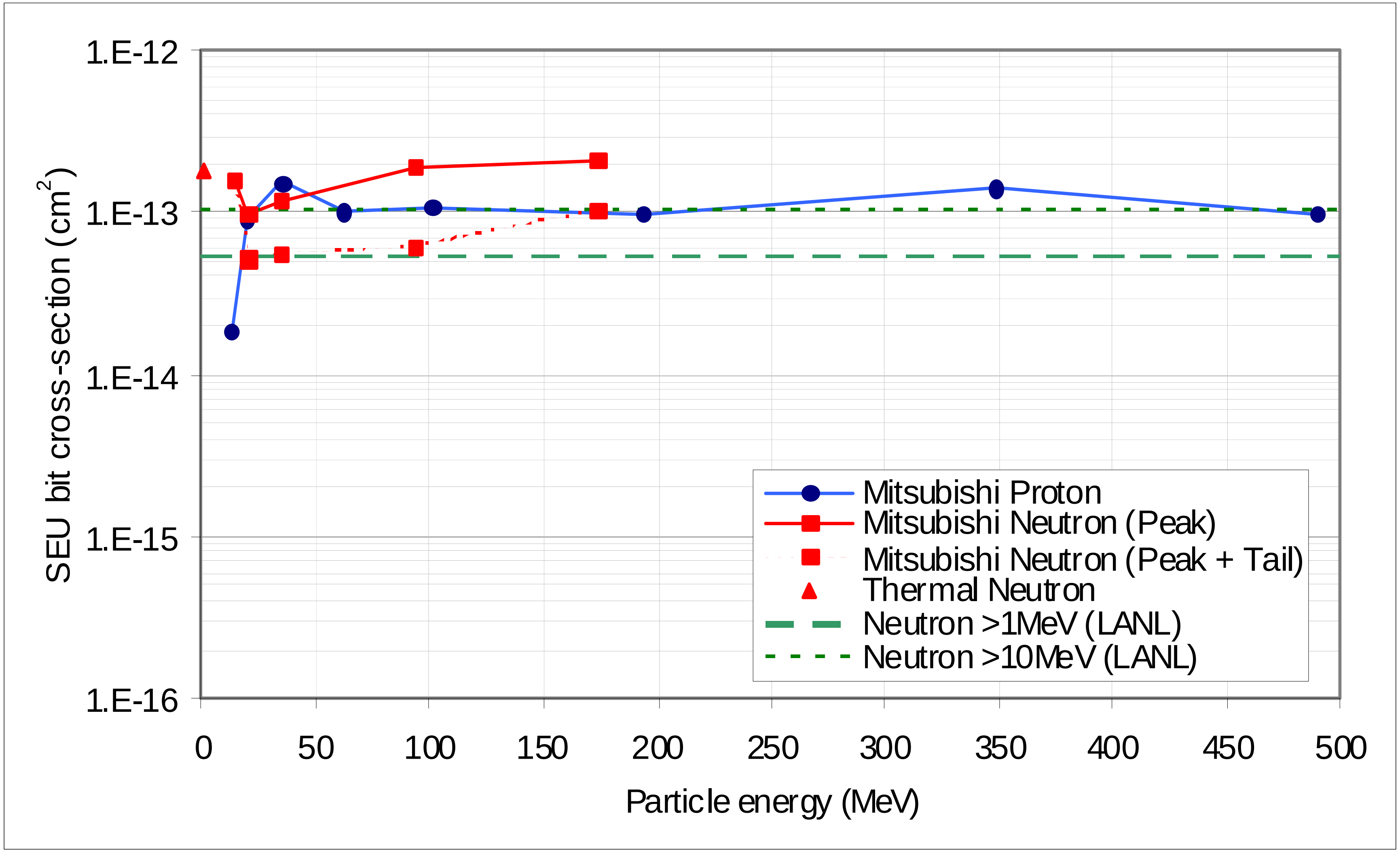
Testing at The Svedberg Laboratory May 2004



Proton and Neutron Experimental Data for the Mitsubishi Device



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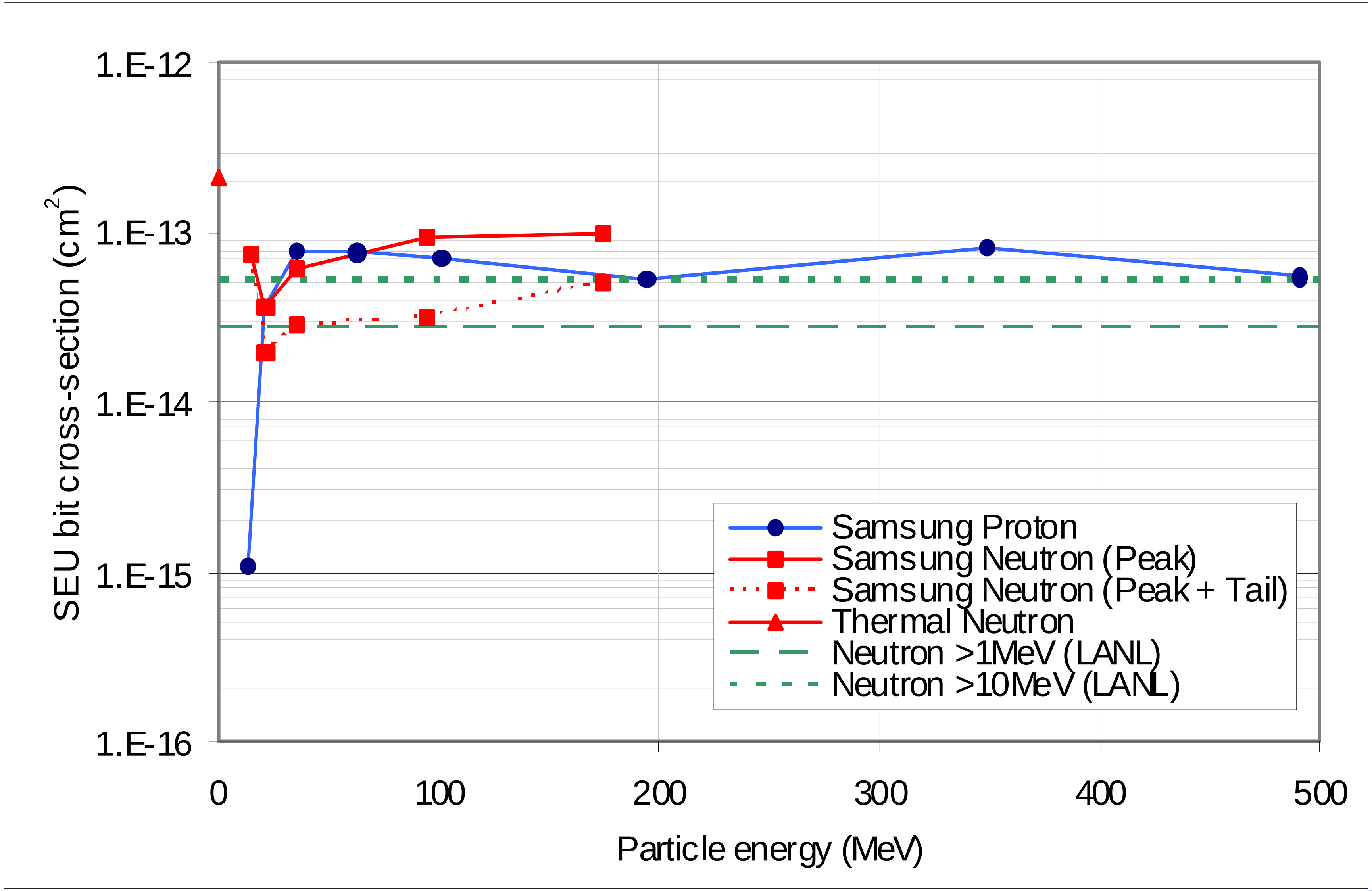
Proton and Neutron Experimental Data for the Samsung Device



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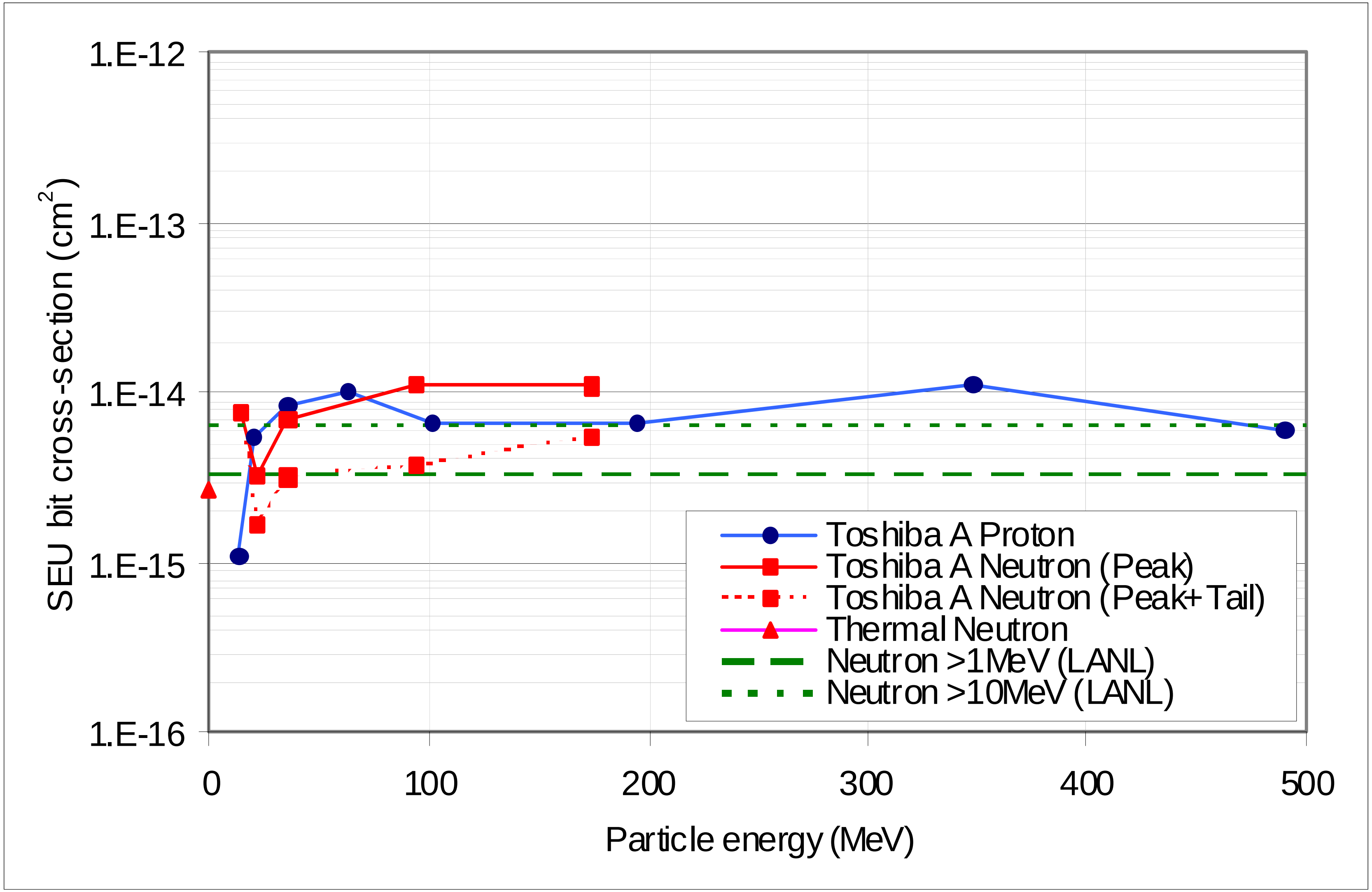
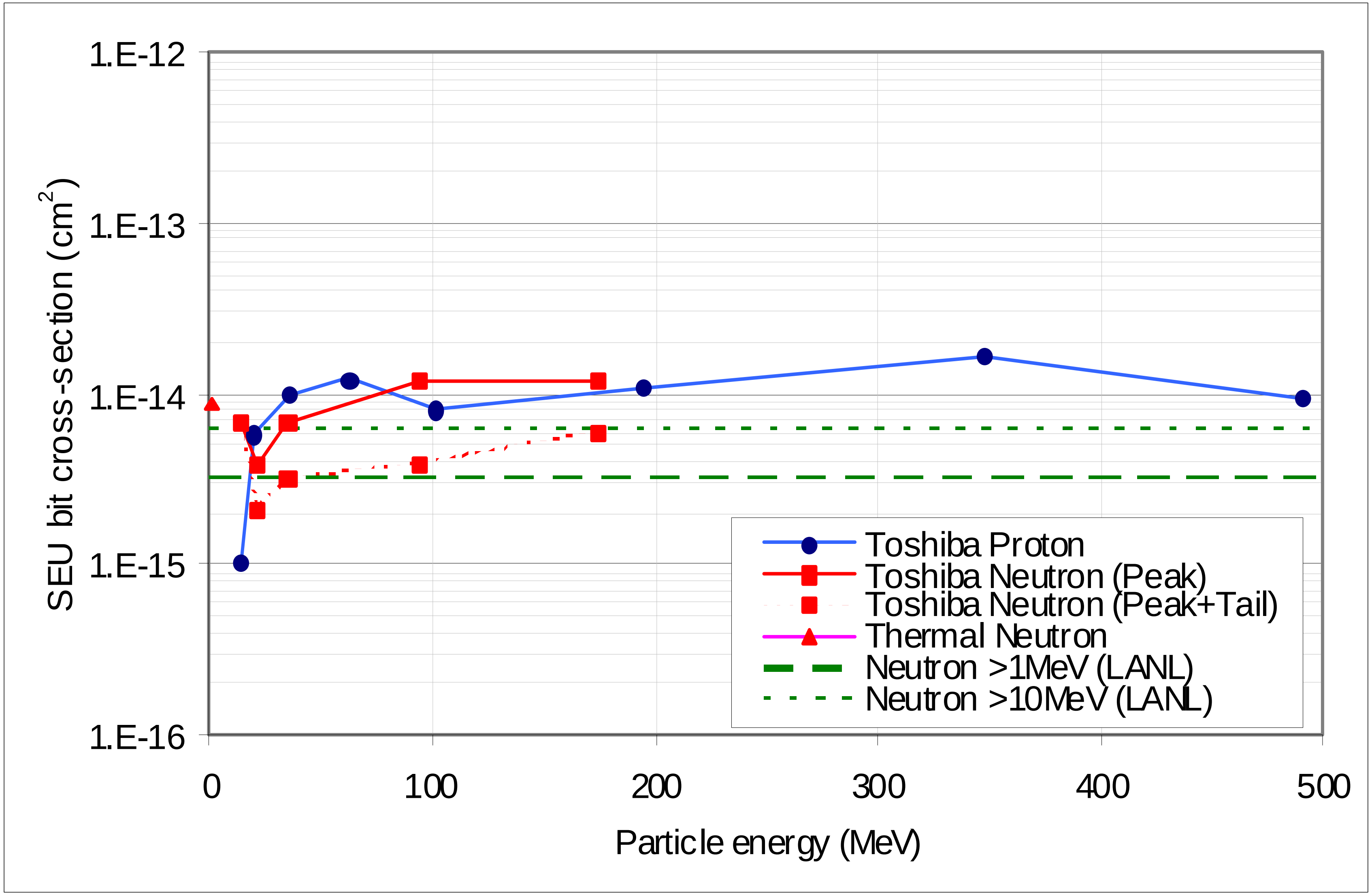
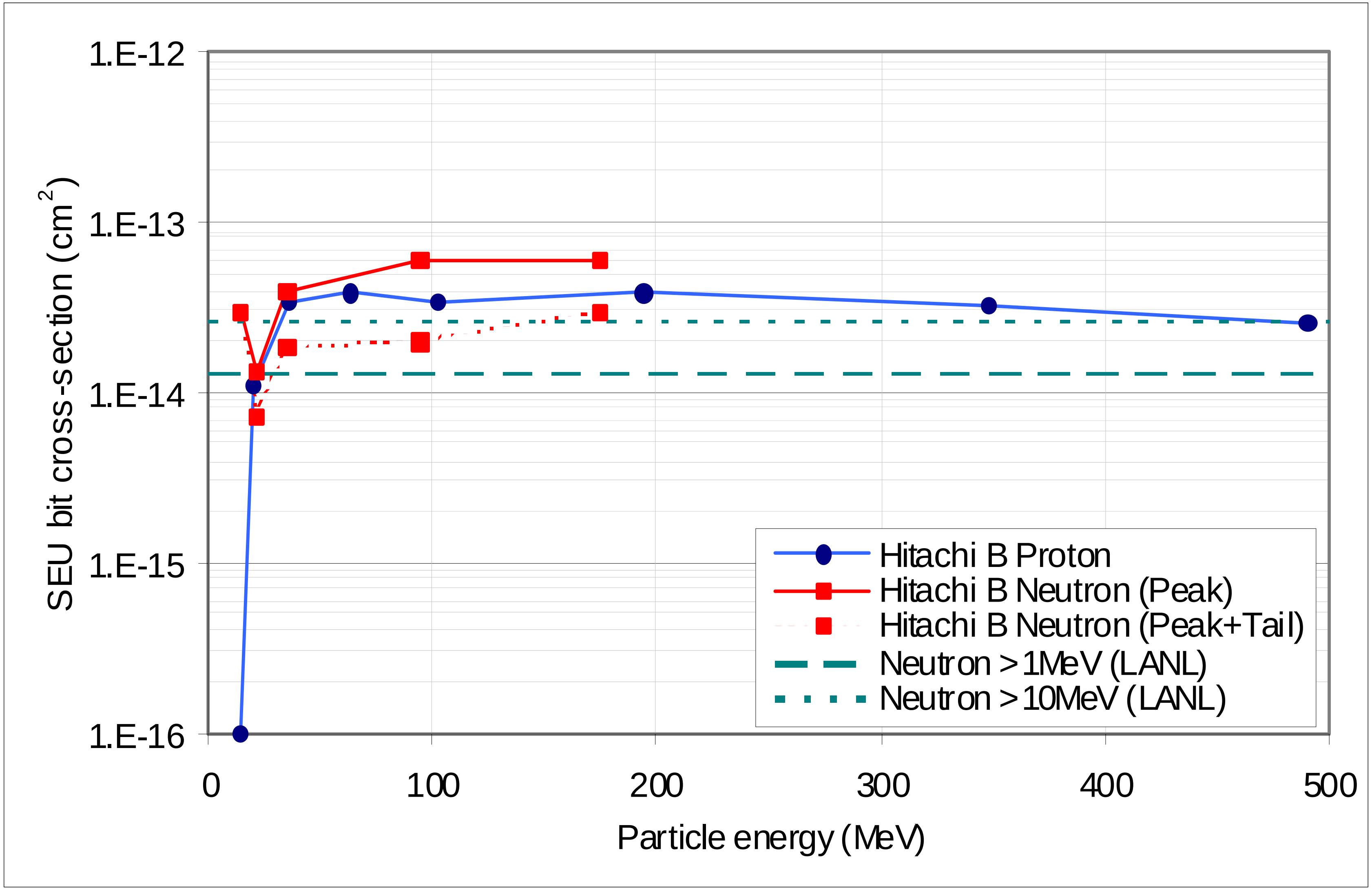
Proton and Neutron Experimental Data for the Toshiba A Device



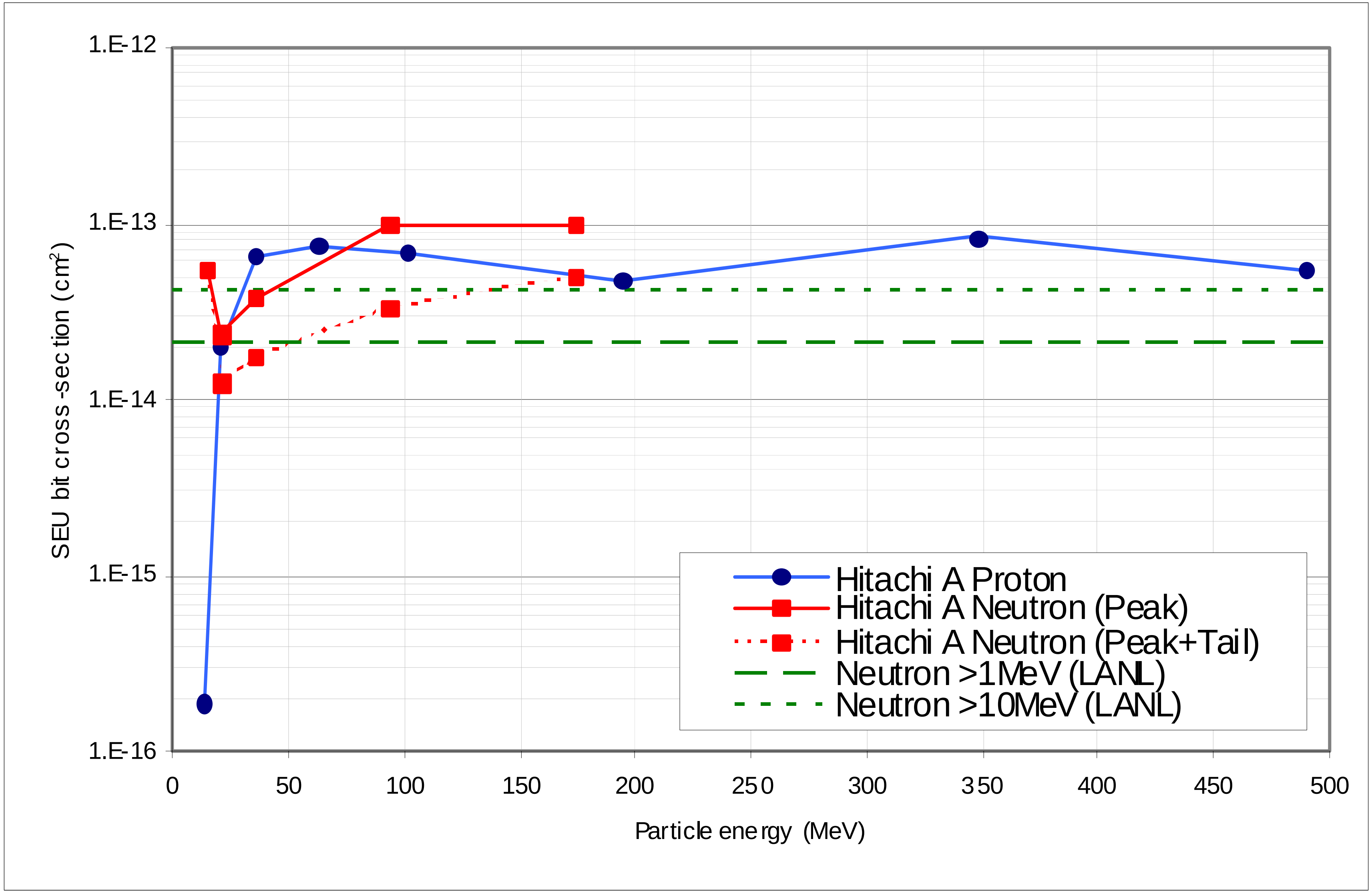
Proton and Neutron Experimental Data for the Toshiba Device



Proton and Neutron Experimental Data for the Hitachi B Device

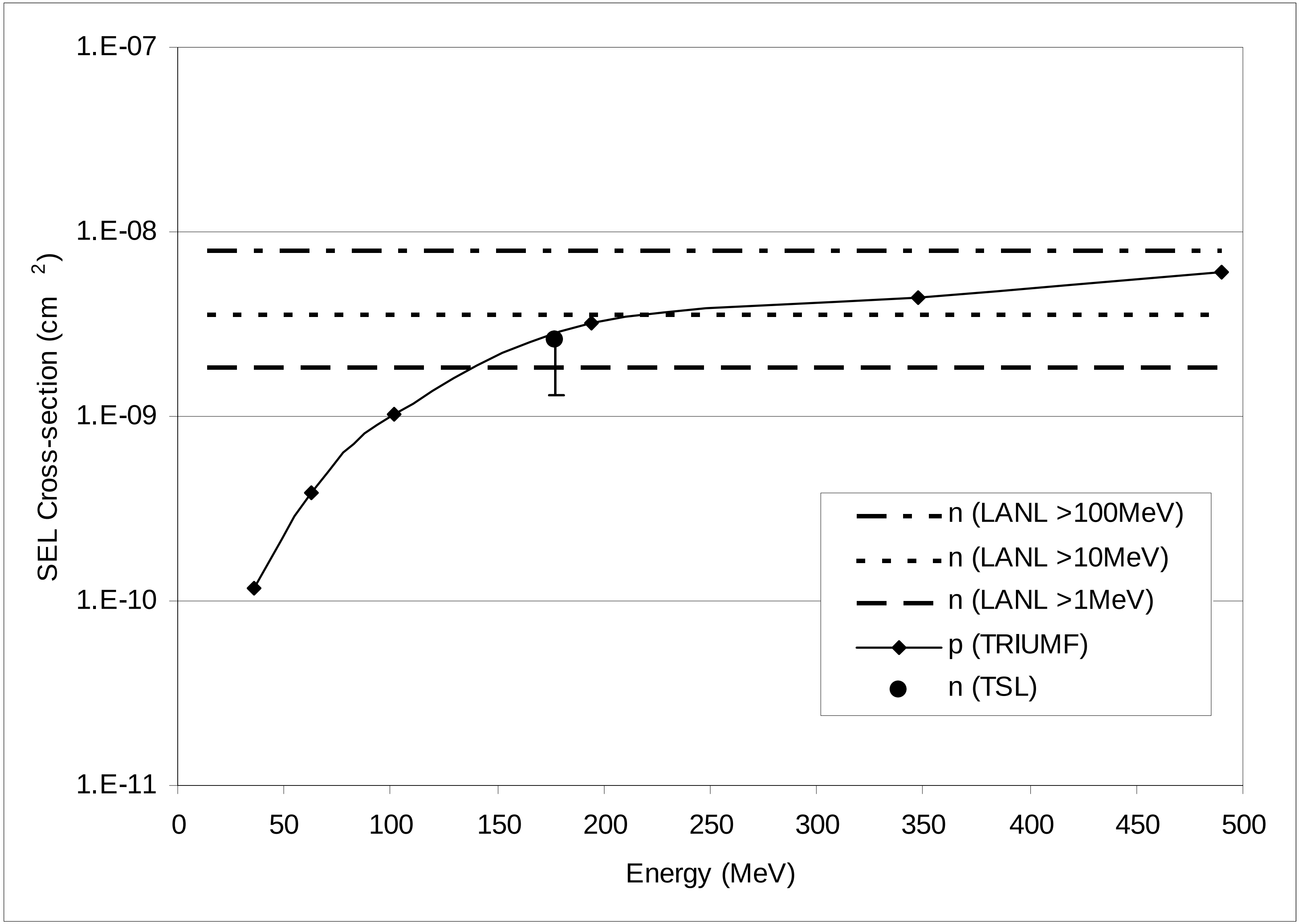


Proton and Neutron Experimental Data for the Hitachi A Device

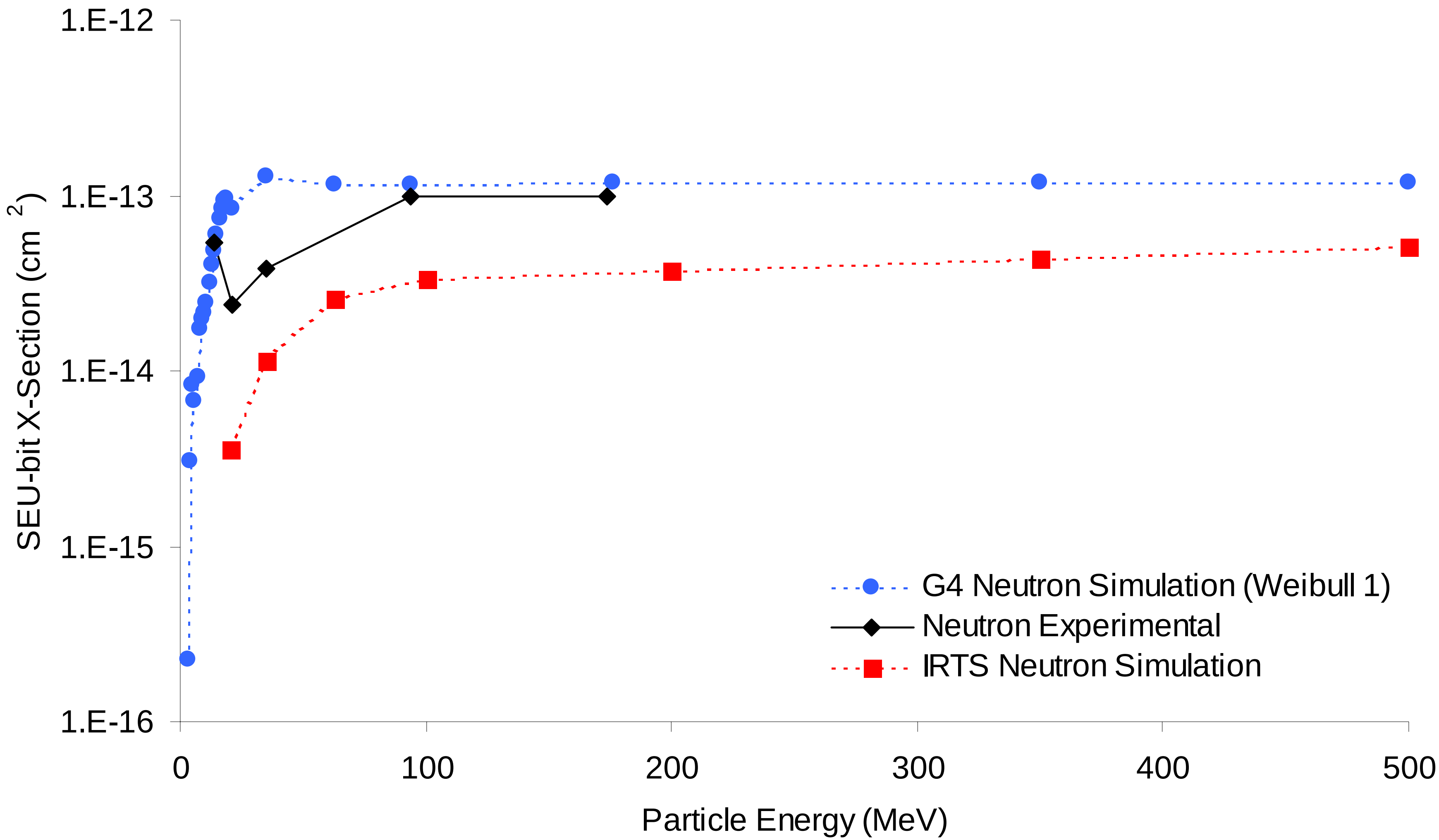


Device	Thermal neutron bit cross-section (cm^2)	Fast neutron bit cross-section (cm^2)	Thermal-fast ratio
Hitachi A	0	7.06×10^{-14}	-
Hitachi B	0	4.24×10^{-14}	-
Toshiba	8.7×10^{-15}	8.35×10^{-15}	1.04
Toshiba A	2.7×10^{-15}	7.75×10^{-15}	0.35
Samsung	2.1×10^{-13}	7×10^{-14}	3
Mitsubishi	1.8×10^{-13}	1.41×10^{-13}	1.28

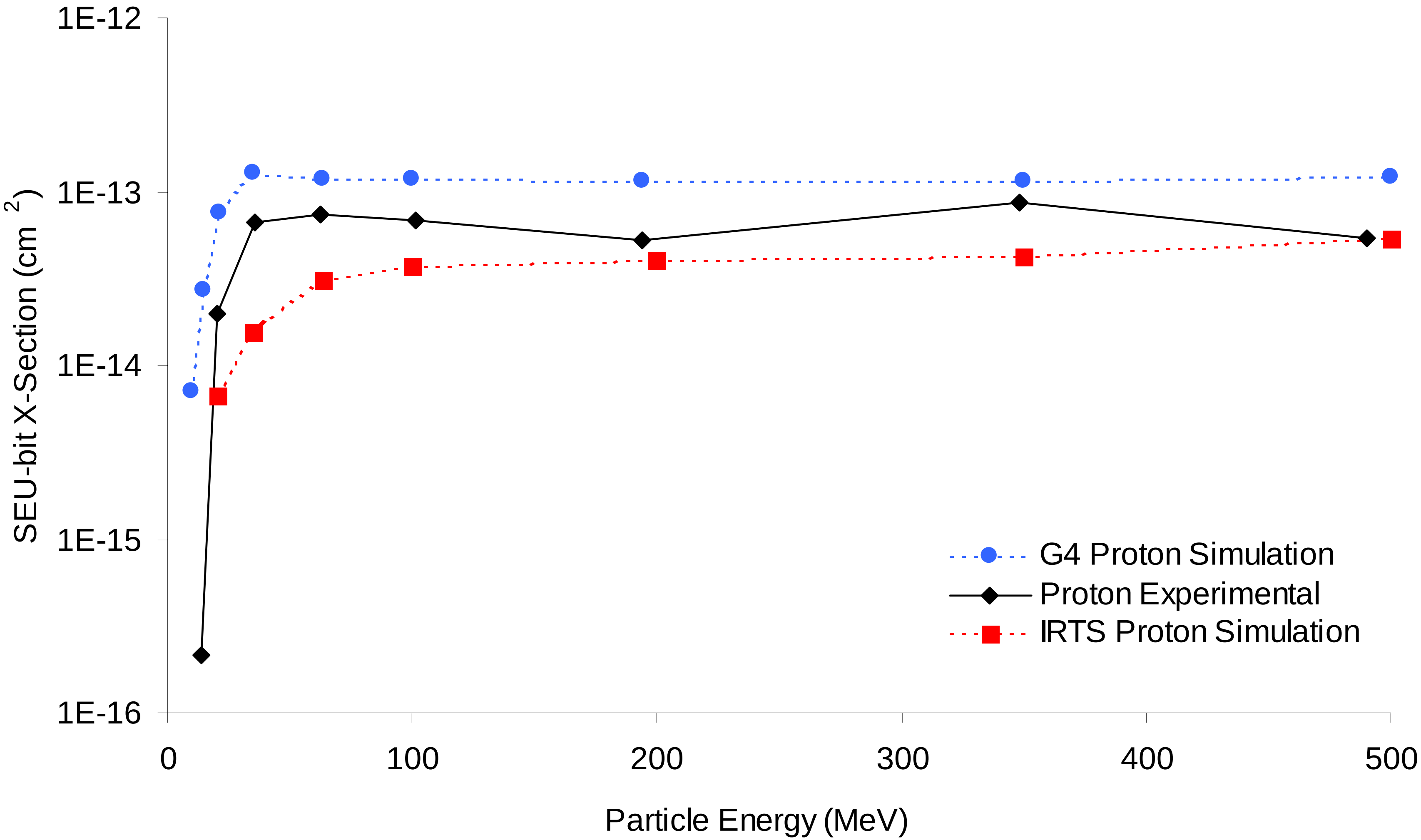
Proton & neutron latchup cross-sections for Hitachi-B 4Mbit SRAM



Neutron Cross-Sections for Hitachi-A 4-Mbit SRAM: Experimental and Simulation Comparison



Proton Cross-Sections for Hitachi-A 4Mbit SRAM: Experimental and Simulation Comparison



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WP4 SEE Predictions and Guidelines

- International Electrotechnical Commission TC107 “Standard for the Accomodation of Atmospheric Radiation Effects [SEE] within Avionics Electronic Equipment.”
  - Scope is avionics up to 60000 feet.
  - Main participants are Goodrich, Boeing, Honeywell, Airbus, Smiths, QinetiQ.
  - About to be issued as Committee Draft.
  - Paper at NSREC04 Workshop, July 2004.
- Work recently started on revision of JESD89 “Measurement and Reporting of Alpha-Particles and Terrestrial Cosmic-Ray Induced Soft Errors in Semiconductor Devices”
  - Sea level to 10000 feet.

IEC TC107 on Atmospheric Radiation Effects

- Contents:
  - Scope
  - Normative References
  - Terms and Definitions
  - Introduction
  - Radiation Environment of the Atmosphere
  - Effects of Atmospheric Radiation on Avionics
  - Guidance for System Designs
  - Determination of Avionics SEE Rates
  - Considerations for SEE compliance

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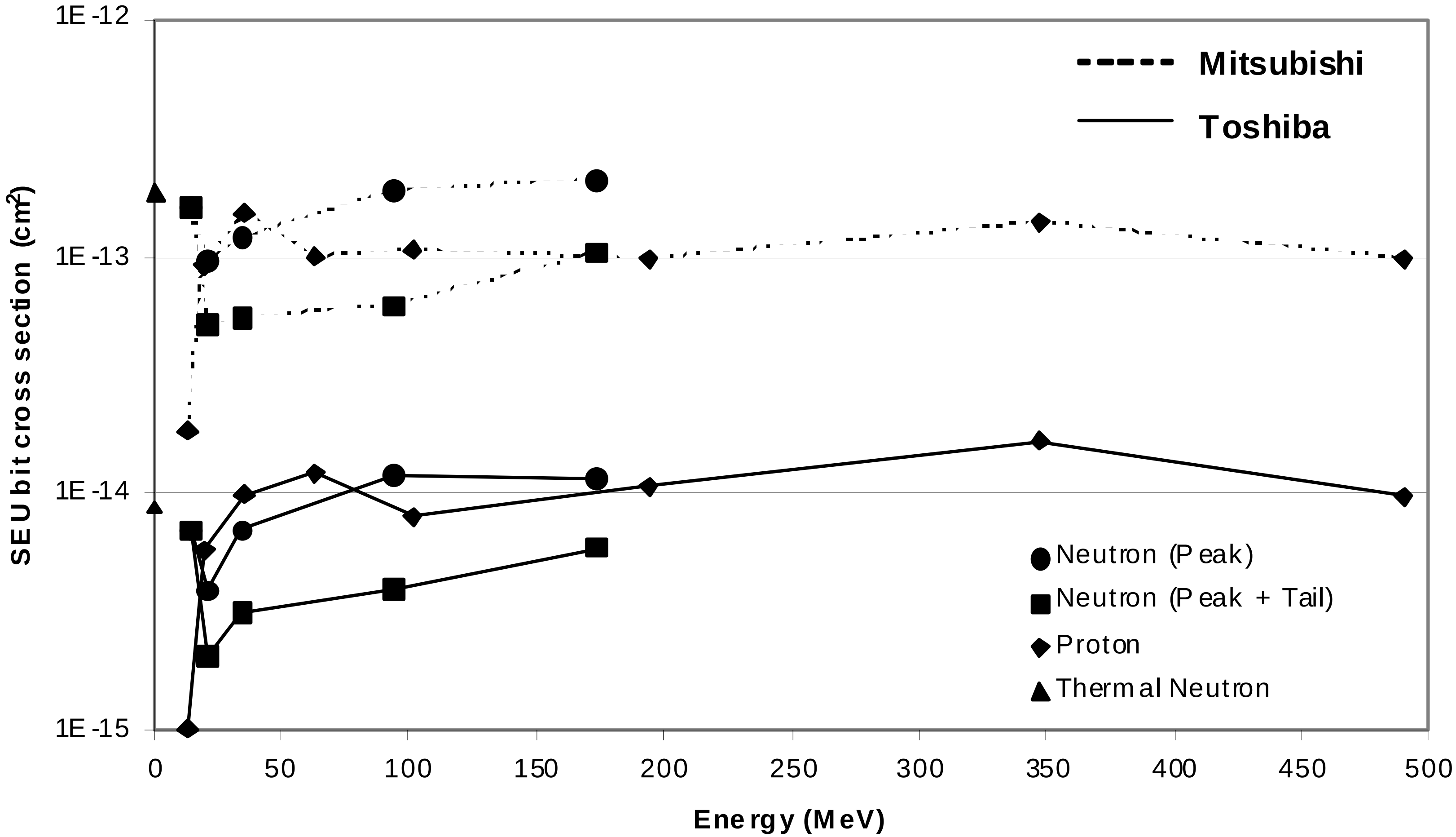
IEC TC107 on Atmospheric Radiation Effects (continued)

- Annexes:
  - Thermal Neutron Assessment
  - Methods of Calculating SEE Rates in Avionics
  - Review of Test Facility Availability
  - Tabular Description of Variation of Atmospheric Neutron Flux with Altitude and Latitude.
  - Bibliography
  - Technical References

Data from this work essential to comparing test methods



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Test Facility Needs

- Spallation neutron source
  - Los Alamos becoming difficult
  - TRIUMF limited test rate
  - CERF low intensity, ? availability
- Monoenergetic neutron sources; eg TSL
  - problems of low energy tail, intensity
- Low energy sources: D-T, D-D, fission, Am-Be, thermal
  - Problems of intensity, availability
- Protons are reasonable proxy at high energies but not at low (< 20 MeV).