Geant4 Software Development and Application at QinetiQ

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Contents

- Background
- ESA contracted activities
- MOD and in house activities
- Experiences and new user requirements

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Background

- QinetiQ: Largest R&D organization in Europe, ~ 7000 scientists and engineers
- Formerly the Defence Evaluation and Research Agency, UK
- Cover of all areas of non-nuclear defence research
- Space environment and protection group in the Space department

Main areas of our simulation activities

- Simulation of whole spacecraft system: XMM, INTEGRAL etc.
- Simulation of the radiation environment: terrestrial/space/artificial
- Radiation effect analysis at system and component level
- Crew/Passenger radiation dose estimate
- Simulation of radiation beam tests
- Microdosimetry /Device simulations

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Geant4 activities:

- Joined the Geant4 collaboration in 1998 with the SPARSET project funded by ESA.
- Carried out 5 ESA funded projects so far.
- Significant (~50%) supports from MOD.

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ESA Supported Projects

- SPARSET (completed)
- REAT (~ completed)
- SpaceGRID (completed)
- SEPTIMESS (on-going)
- IONMARSE (~ completed)
- XMM simulation support (completed)

SPARSET:
Space Radiation Shielding and Effect Toolset

Collaborator: University of Southampton

WWW: http://www.space.qinetiq.com/geant4/geant_mn.html

Completed in 2001

Products:

- Sector Shielding Analysis Tool (SSAT)
  - http://reat.space.qinetiq.com/ssat
- CAD front-end tool (MGA)
- Radioactive Decay Physics (RDM)
- Internal Conversion Physics

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SPARSET(II)

Products:

- General Particle Source Module (GPS)
  - Released the first version
- Low energy electromagnetic processes

Specific studies:

- Comparison of G4 hadron physics with FLUKA/GCALOR/MCNPX
- X-ray fluorescence from basalt

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REAT: Radiation Effect Analysis Tools

Collaborator: SIRA Electro-Optics Ltd.

WWW: http://reat.space.qinetiq.com/reat

Products:

- Report on the detailed analysis of the requirements:
  Space Radiation Effects For Future Technologies and Missions
  http://reat.space.qinetiq.com/Reat/wp1_tn
- MULASSIS: MULtiple LAyered Shielding SImulation Software
  http://reat.space.qinetiq.com/mulassis/
  Also available under SPENVIS
- GEMAT: GEant4 Microdosimetry Analysis Tool
  - Incomplete and not available to the general public yet!

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SpaceGRID:

- A major ESA project to investigate the applications of GRID technology in Space Researches.
  - Consortium lead by DATAMAT (Italy)
  - Completed in 2003.

  http://www.spacegrid.org
- Radiation Transport Simulation (RTS) was one of the potential area.
- Collection of User Requirements, Infrastructure requirements.
- Application Prototyping
  - MULASSIS/G4

All documents and code available at:

http://reat.space.qinetiq.com/spacegrid

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SpaceGRID:

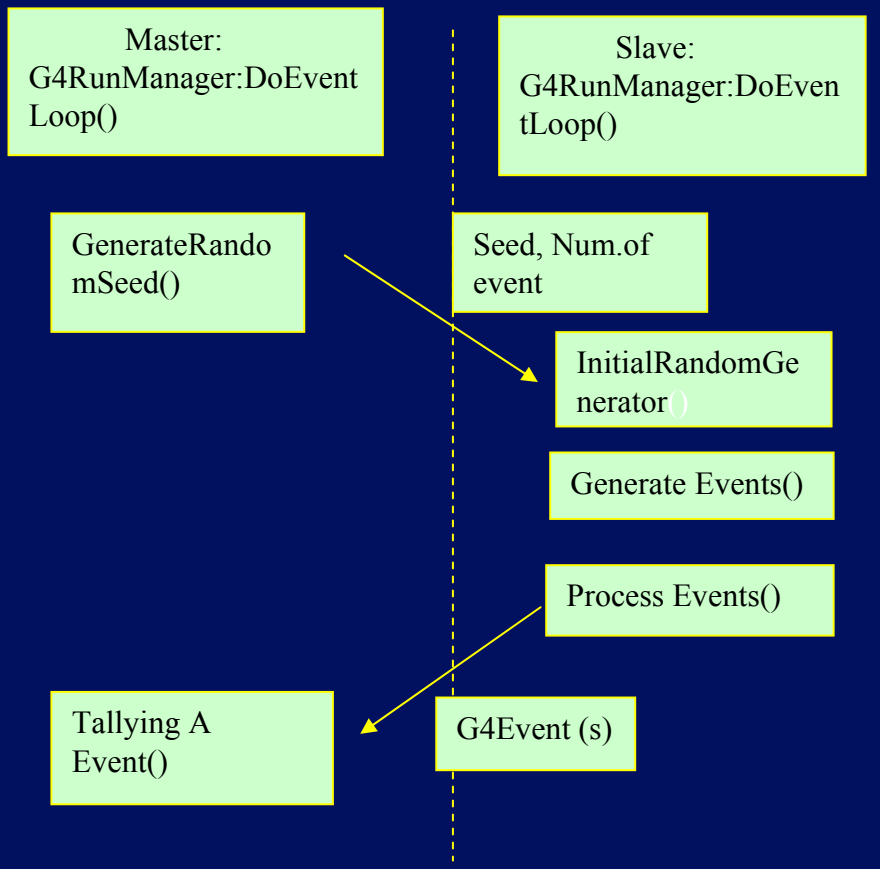
MULASSIS

Geant4 toolkit

TOP-C

GLOBUS

Integration of software layers



Master/Slave task split

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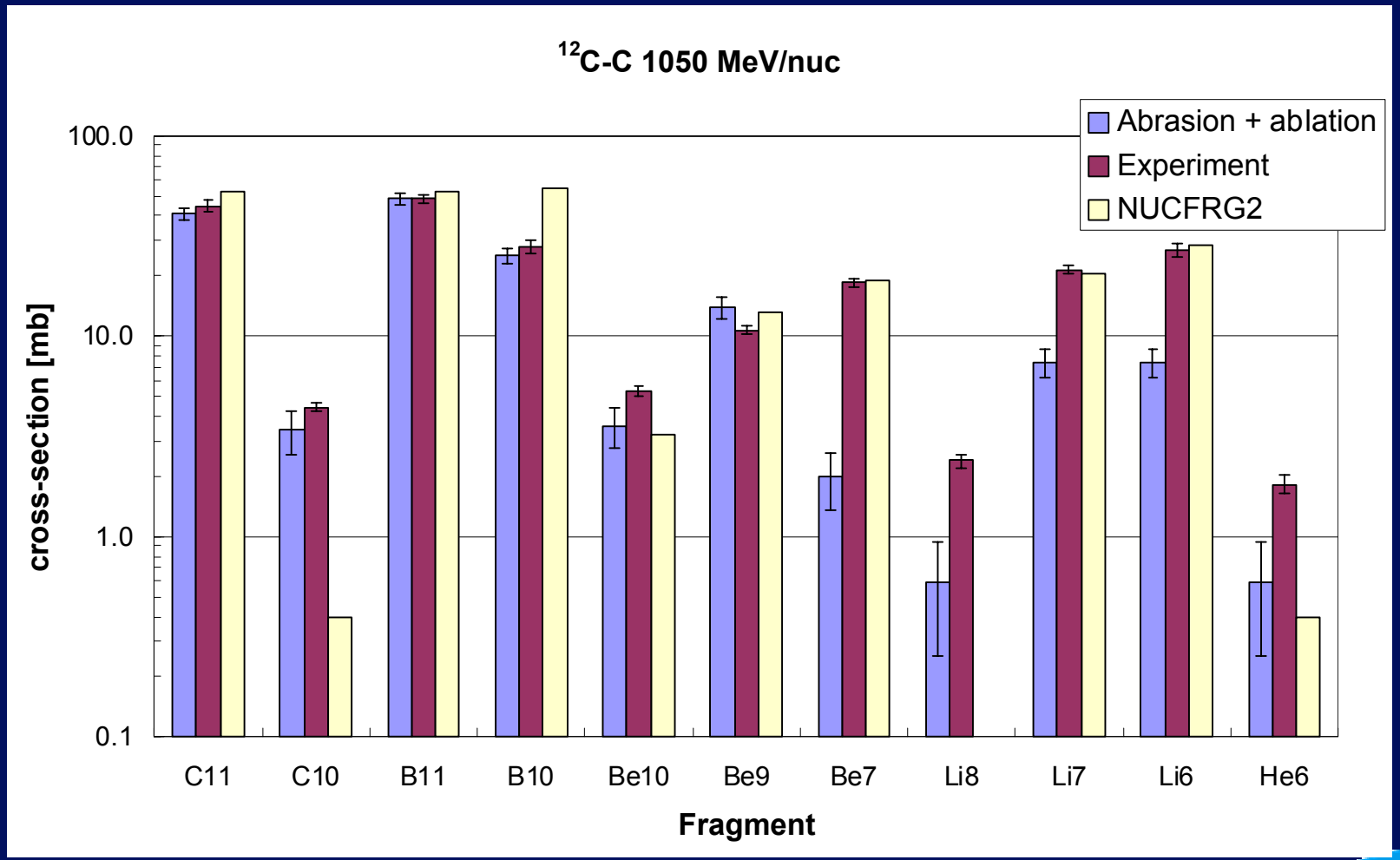
IONMARSE(I)

- Assessment and implementation of improved nuclear-nuclear interaction models
- Physics implemented:
  - ***G4TripathiLightCrossSection***: improved total inelastic cross-section model for protons and light nuclear projectiles/target
  - ***G4ESAGeneralNNInelasticCrossSection***: General cross-section model selector for proton/nuclear-nuclear interactions
  - ***G4WilsonAbrasionModel*** : Abrasion (macroscopic) interaction model
  - ***G4WilsonAblationModel***: Ablation+evaporation model as an alternative to standard Geant4 de-excitation (evaporation / break-up / fission)
  - ***G4EMDissociation***: Electromagnetic dissociation model

IONMARSE(II)



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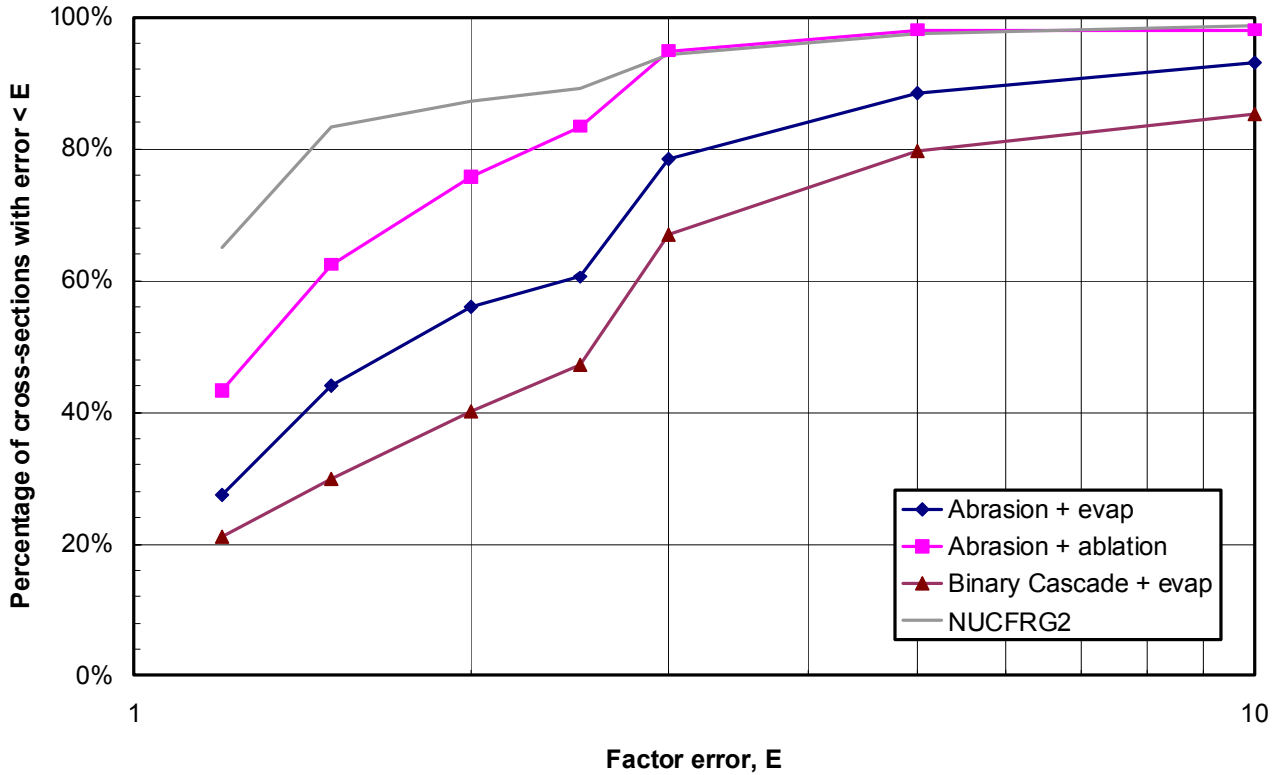
Comparison of the percentage of times the predicted cross-section for fragment production is within a factor of E of the experimental value (for various projectile nuclei on carbon target).



Projectile	Energy [GeV/nuc]	Product from EMD	G4EMDissociation [mbarn]	Experiment [mbarn]
Mg-24	3.7	Na-23 + p	124 ± 2	154 ± 31
Si-28	3.7	Al-27 + p	107 ± 1	186 ± 56
	14.5	Al-27 + p	216 ± 2	$165 \pm 24^{\dagger}$ $128 \pm 33^{\ddagger}$
O-16	200	N-15 + p	331 ± 2	$293 \pm 39^{\dagger}$ $342 \pm 22^{*}$

Comparison of predicted and experimental EM dissociation cross-sections

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SEPTIMESS(I)

Collaborators: Imperial College, Uni. of Southampton, INFN(Genova)/CERN, Uni. of Geneva, Uni. of Bern.

- Radiation effects analysis for ESA science missions
  - Payload and instruments
  - Simulation requirements
- Geant4 developments
  - Implementation of new physics process: G4FirsovScattering
  - Improvement to existing ones: Atomic relaxation and Radioactive decay.
  - Utilities and tools: Hadron data format and data set; Statistic testing toolkit; G4GeneralParticleSource.

SEPTIMESS(II)

- Mission specific Geant4 simulations
  - XMM-Newton
  - INTEGRAL
  - LISA
  - SMART-2
  - Bepi-Colombo
- Other Geant4 applications
  - Atmocosmics
  - Magnetocosmics
  - Advanced Example for Radioactive Decay

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Non-ESA Geant4 Activities

- Radiation Environment modeling
- Shielding, total dose and NIEL analysis at design phase
- Operation phase analysis
- Simulation of proton/neutron SEUs in SRAMs
- Radiation beam test simulations
- Passenger and crew radiation dose calculations
- Microdosimetry: interface Geant4 to microelectronics device physics simulators

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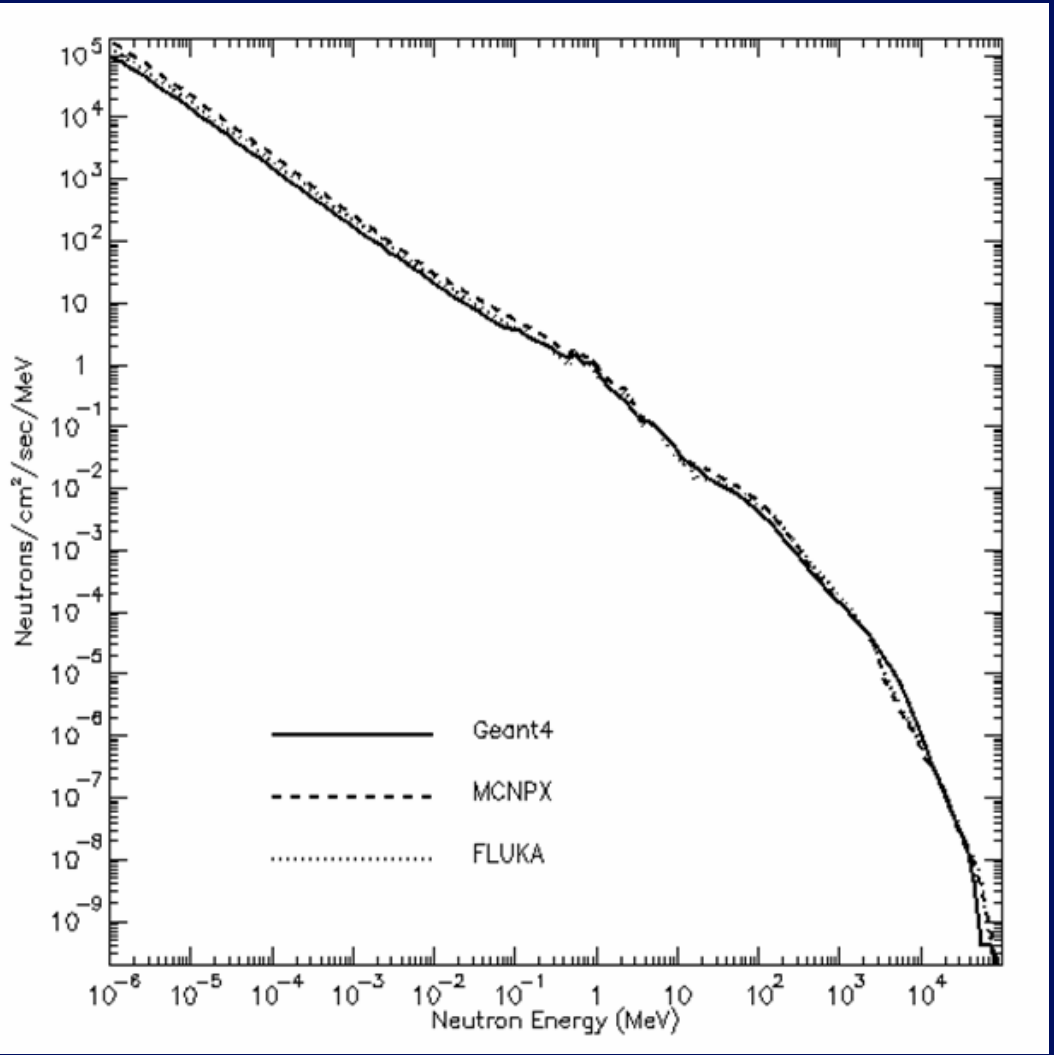
Radiation Environments

- Radiation Environments:
  - Atmospheric radiation model (ARM)
    - Response matrices (Geant4 or MCNPX)
    - cosmic ray and solar particle models
  - Influence of aircraft structure to the radiation field
    - Thermal neutron fluxes
  - Mars radiation fields
  - Rigidity cut-offs and effects of geomagnetic condition
    - Linked to ARM



ARM: Comparison of response Matrices

- Atmosphere model: MSISE90
- Neutron spectra at 15 km
- 0 GV cut-off
- Cosmic ray proton Contribution only

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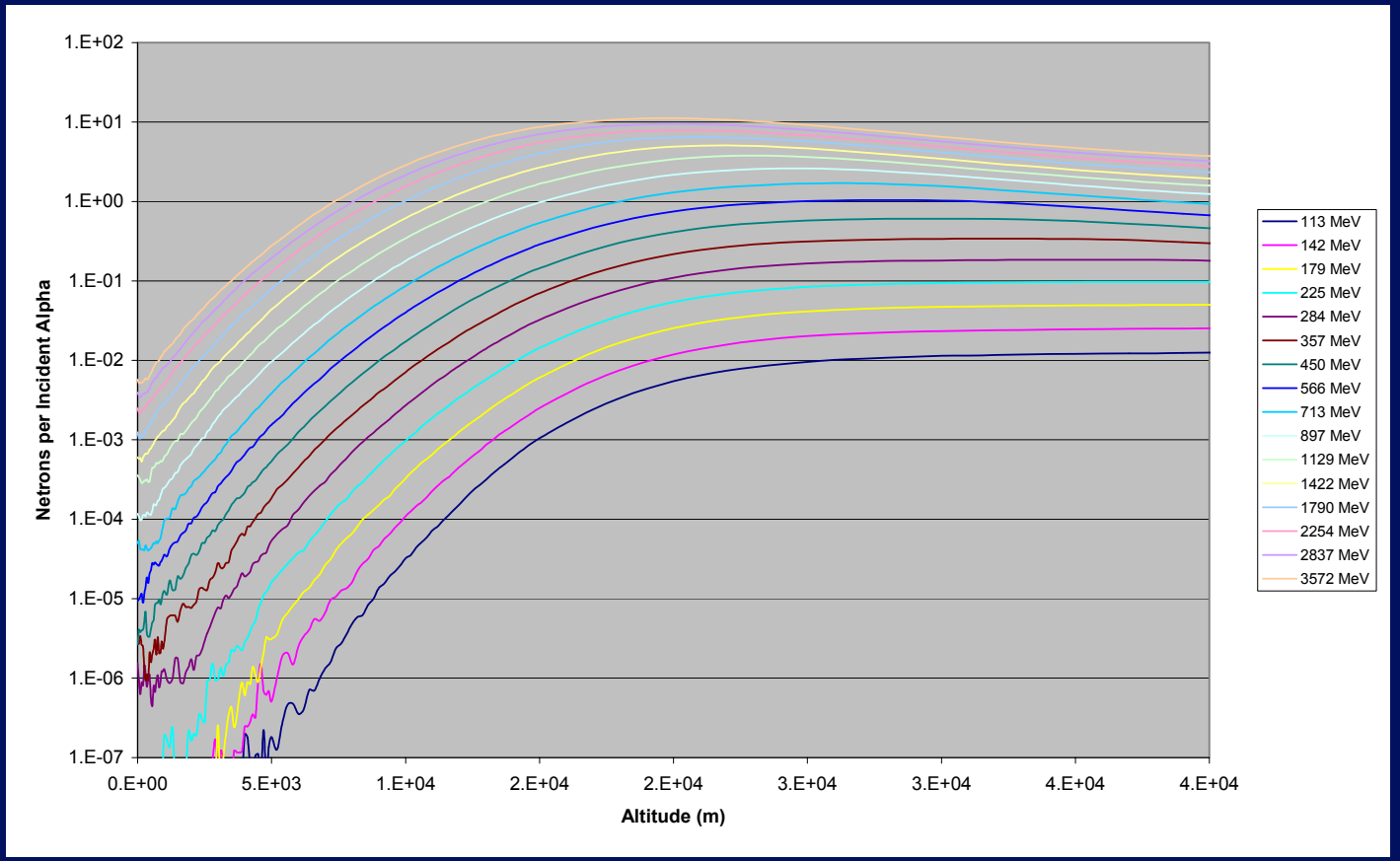
ARM: Response matrix example



Secondary Neutrons at Various Altitudes

Incident particle: alpha

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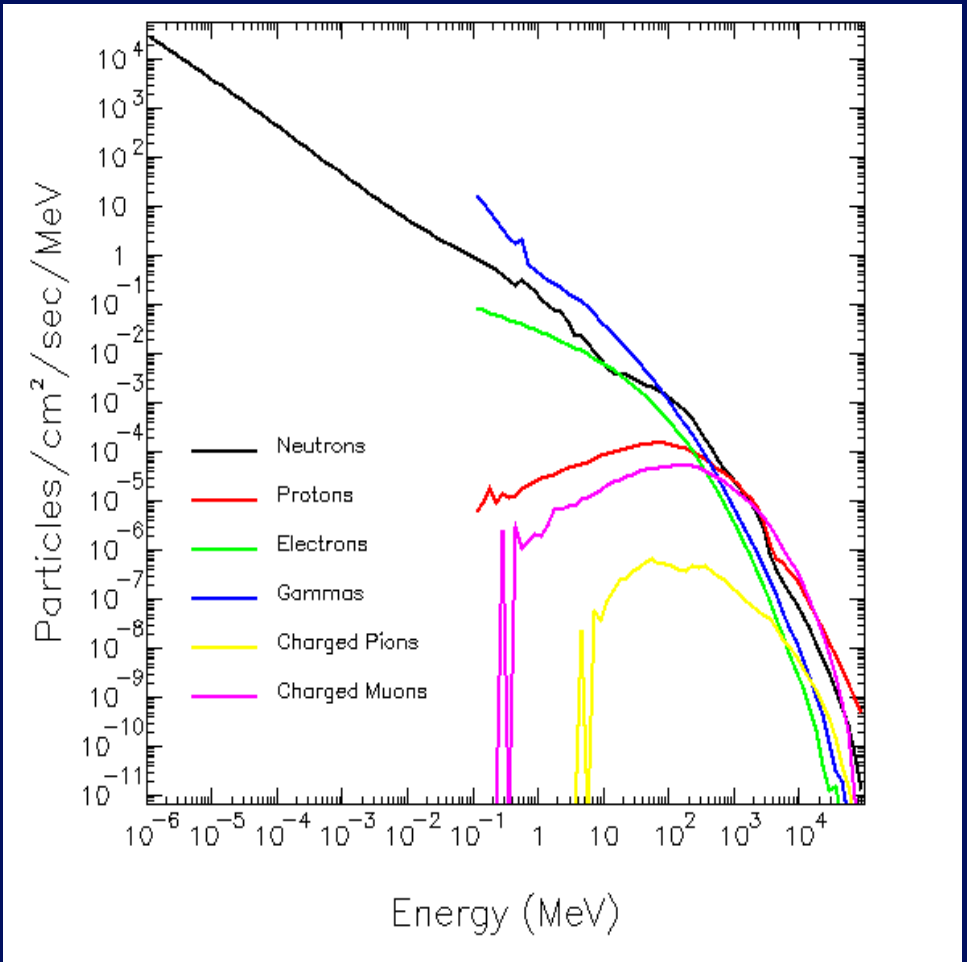
ARM: Example of particle spectra



Date: 01-Aug-1988

Altitude: 10 km

Cut-off: 1 GV

GMC: kp = 0

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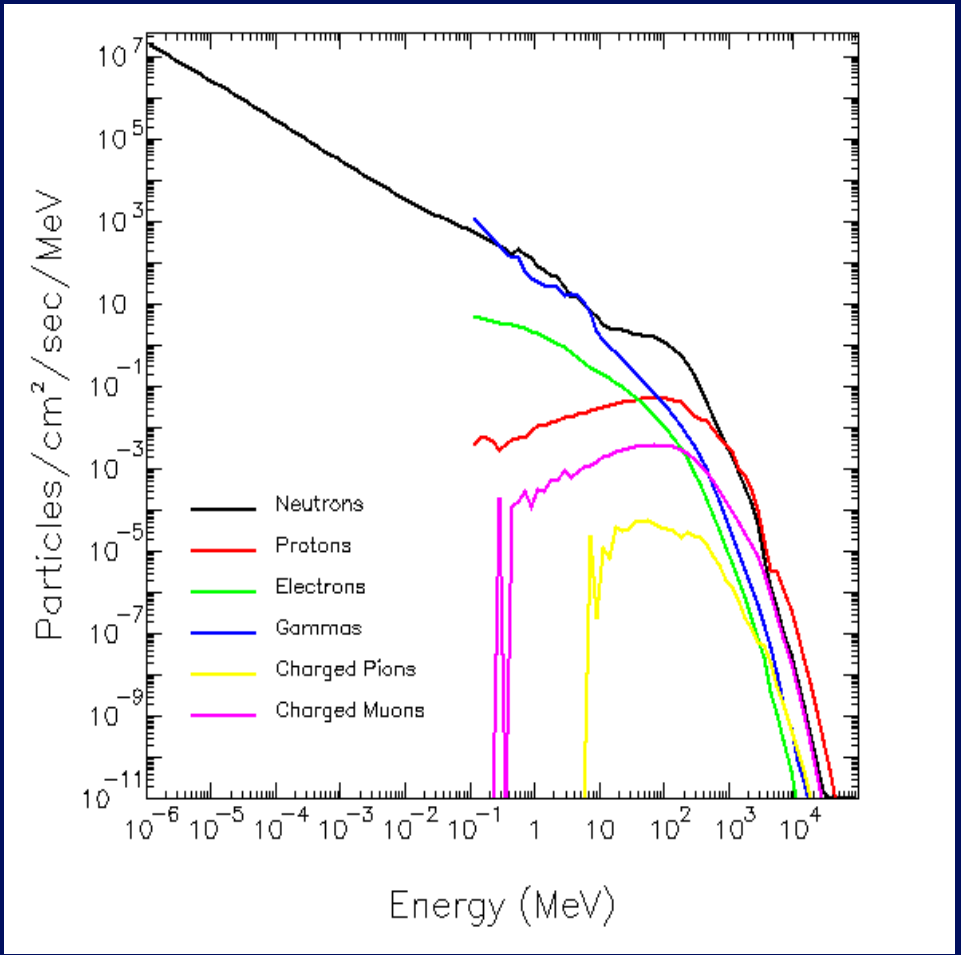
ARM: Secondaries from GLE 23/02/1956



Time: Peak of SPE 23/02/56

Altitude: 10 km

Cut-off: 1 GV

GMC: kp = 0

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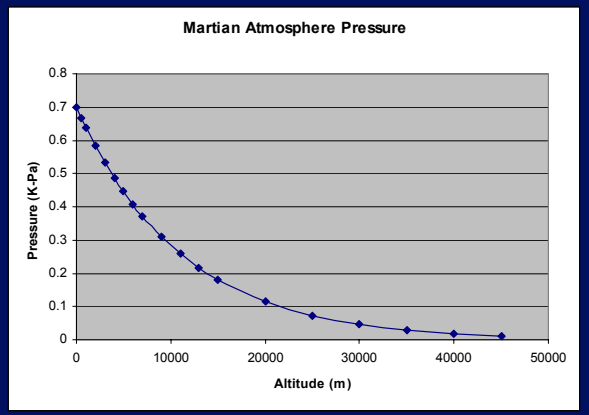
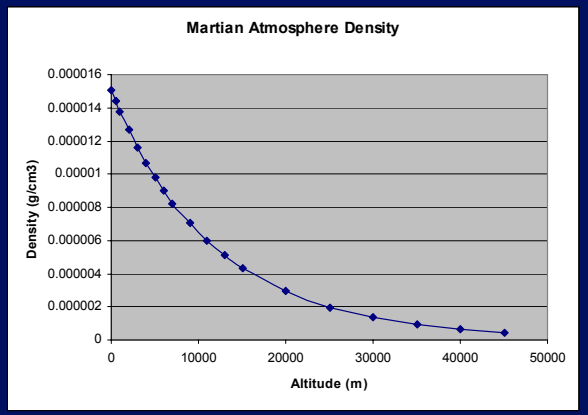
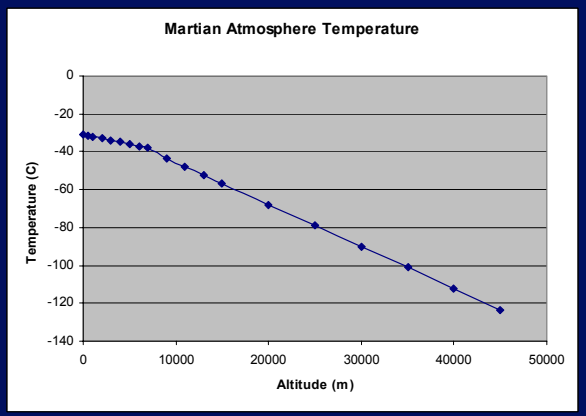
Model of the Mars atmosphere & ground







Air Composition	
O	19100
C	9539
N	540
Ar	160
H	6

Soil Composition	density = 1.4 g/cm3
O	16700
Mg	1620
Si	5830
Ca	781
Fe	1800

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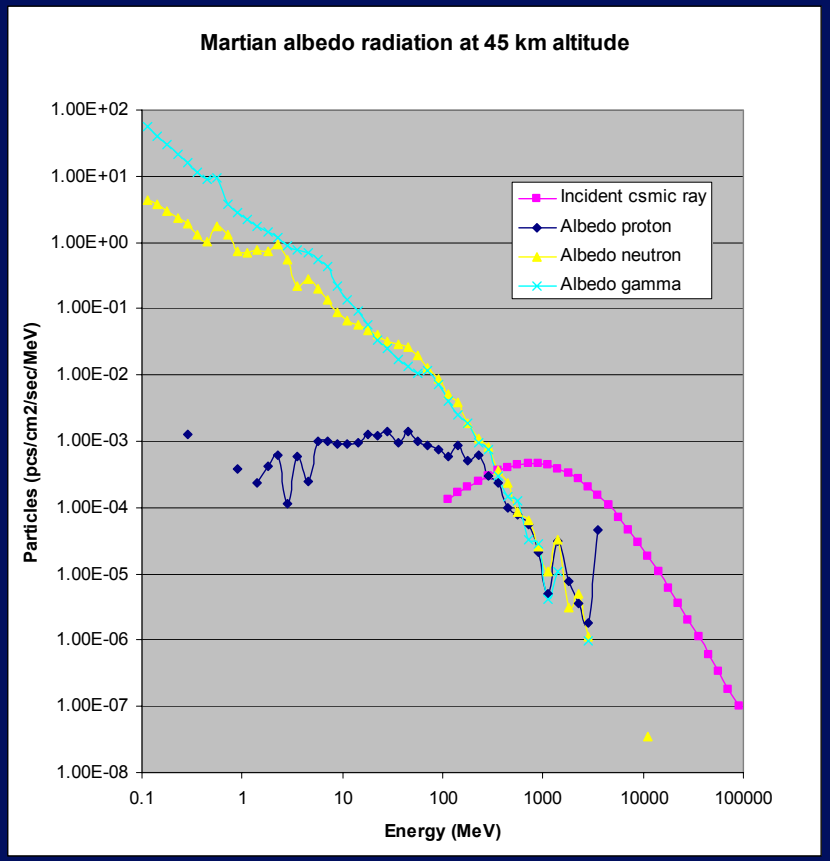
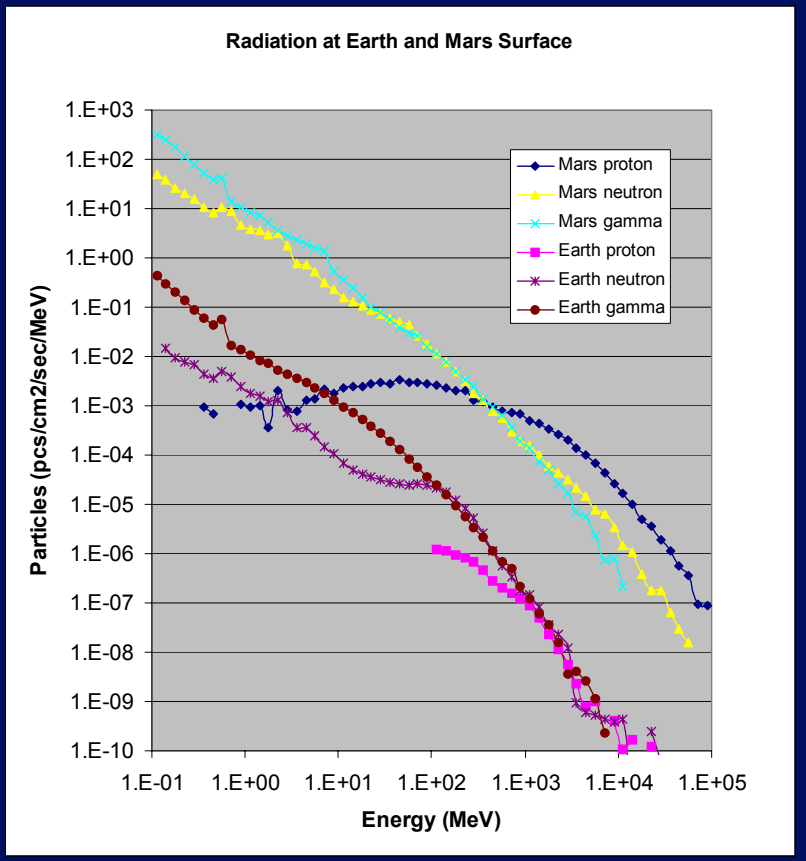
Examples of radiation on Mars





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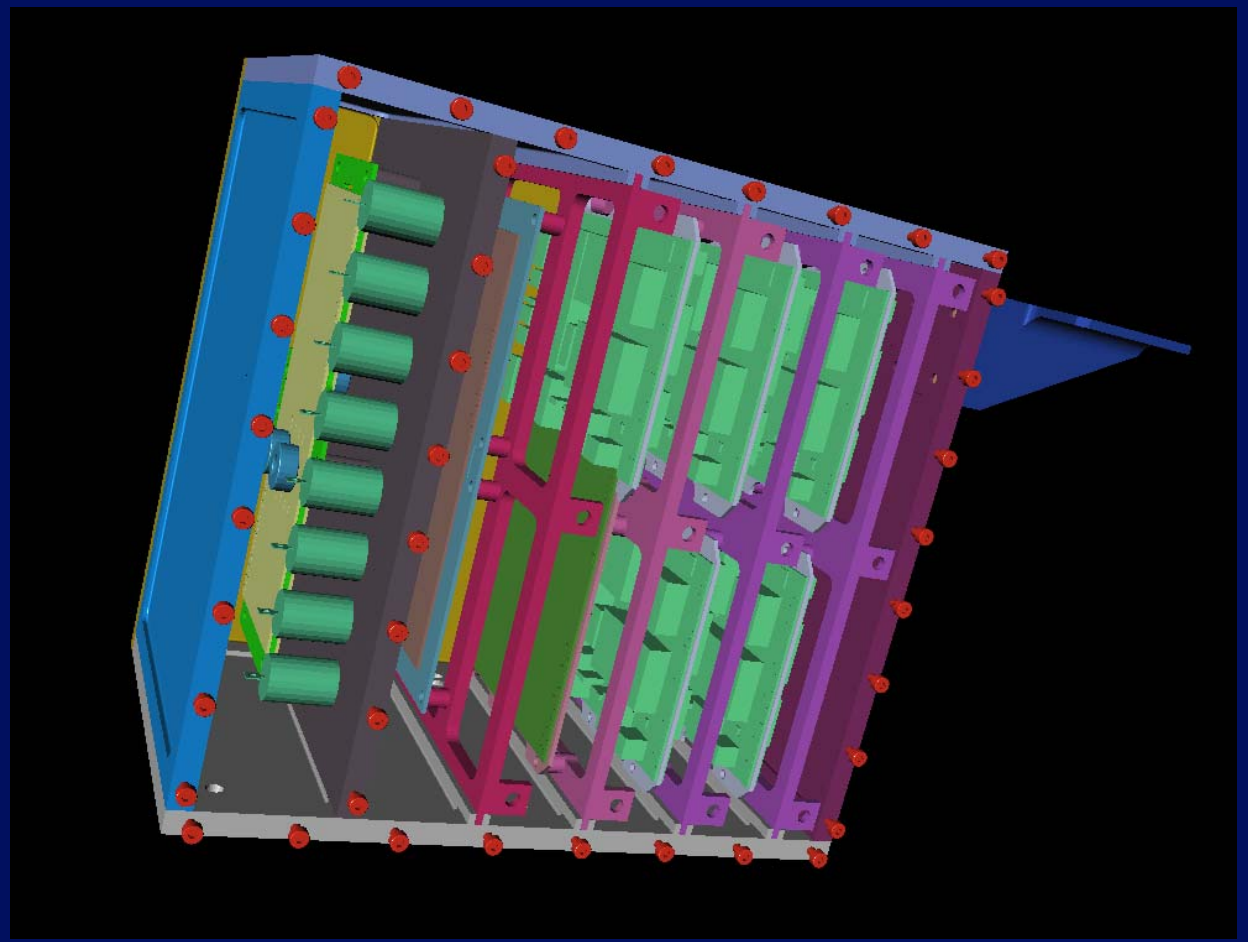
Shielding, TID & NIEL analysis

- Standard radiation analysis at mission level:
  - G4 (MULASSIS) was used to derive TID and NIEL dose depth curves for Si and GaAs.
  - Shielding distributions obtained with SSAT.
- Component level analysis at design and operation phases:
  - TID analysis.
  - Secondary particle fluence.
  - Shielding distributions.

Example of Shielding Analysis:



- Left picture from a CAD/STEP file
- G4STEPReader and MGA worked with this file, but
- G4Brep surface classes are incomplete

→ Labour intensive re-modeling

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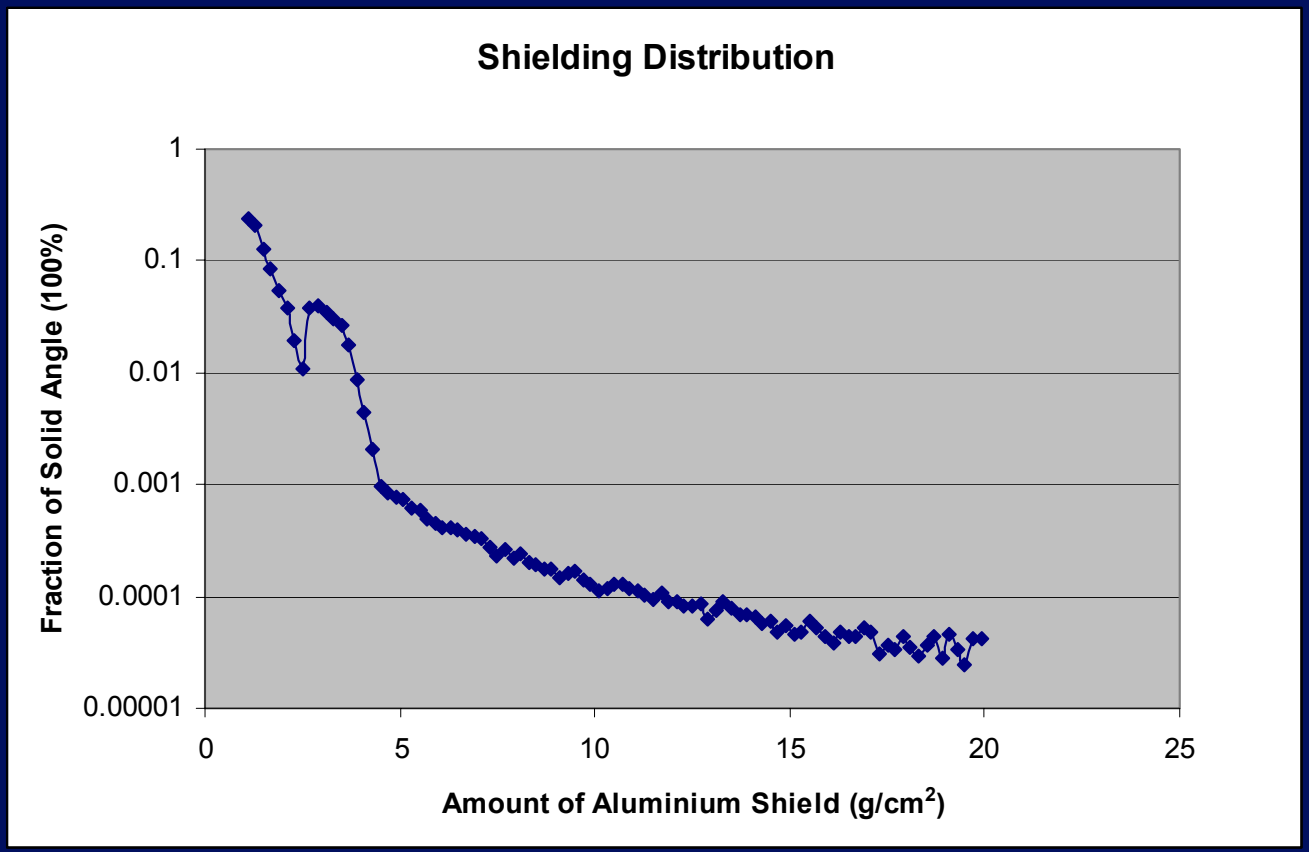
Example of SSAT results:



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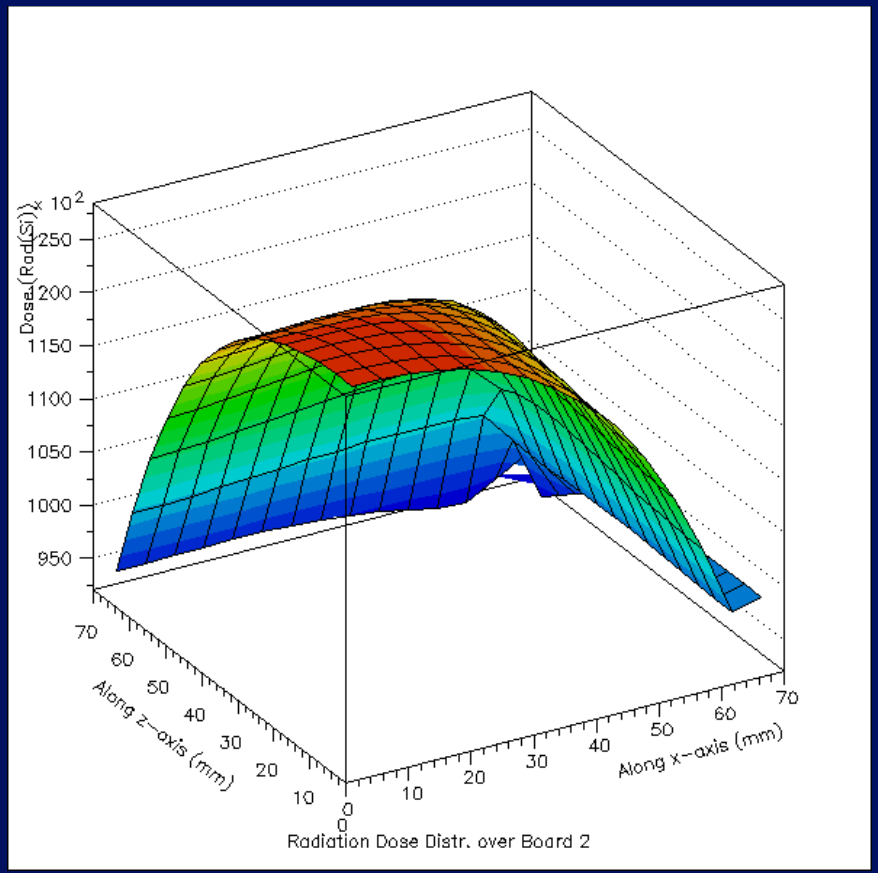
Example of G4 dose analysis at PCB level



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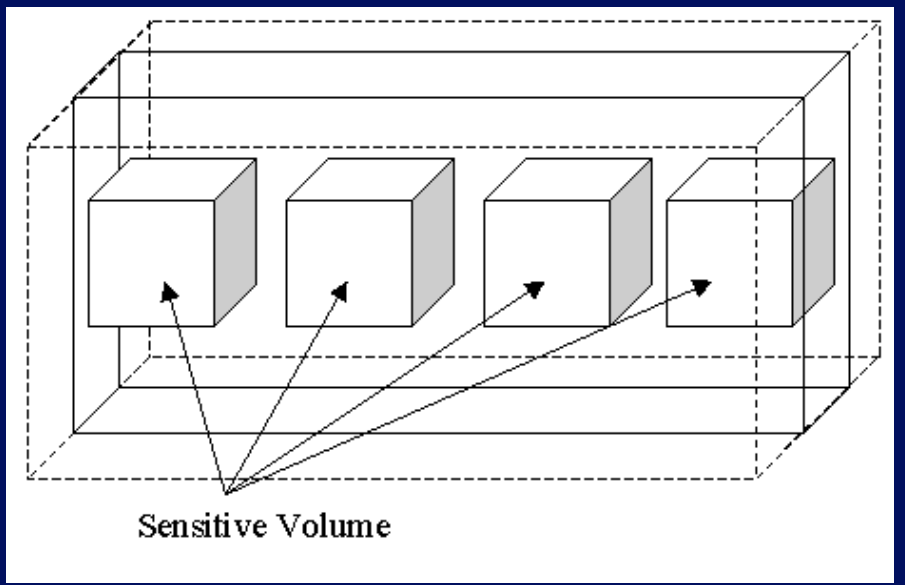
Example: Simulation of SEUs In SRAMS

- Geant4 and IRTS/IMDC predictions of neutron and proton SEU and MBU over the range 1 to 500 MeV based on ion test data for a Hitachi 4-Mbit SRAM.
- Comparisons with test data.
- Sensitive volume: 4.5x4.5x0.5 μm



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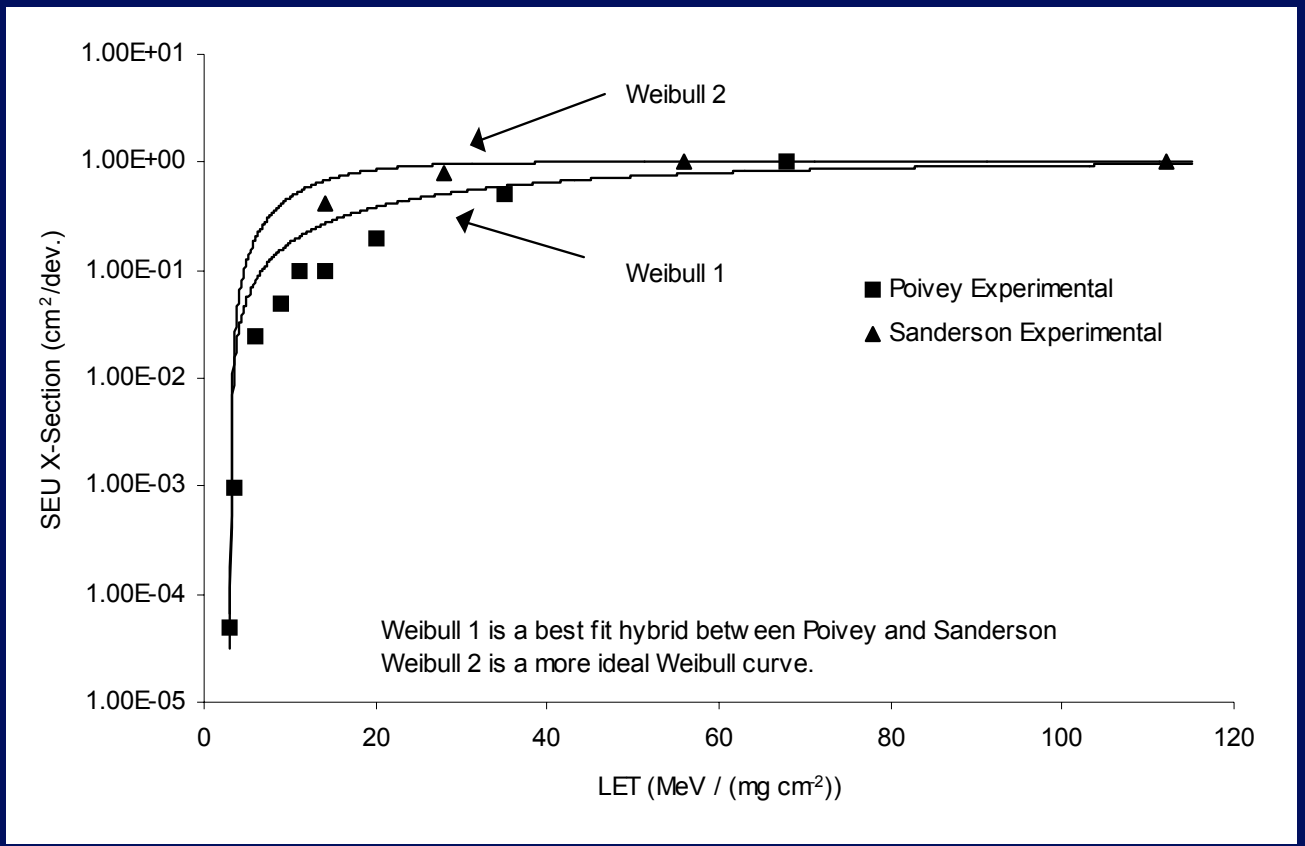
Two Possible Weibull Fits to Ion data for Hitachi-A Used as Input to Simulations for Proton & Neutron Cross-Sections



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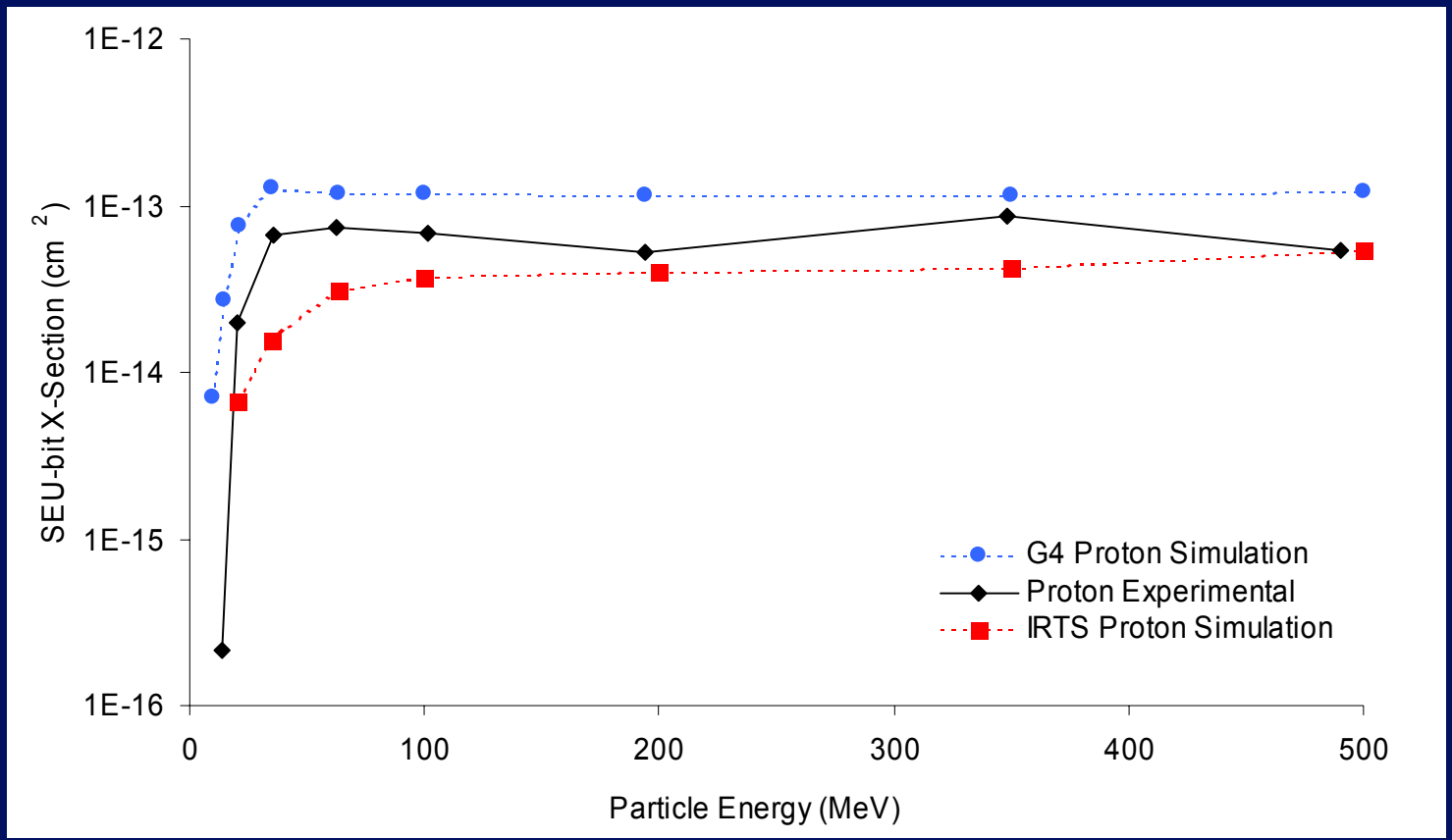
Proton Cross-Sections: Experimental and Simulation Comparison



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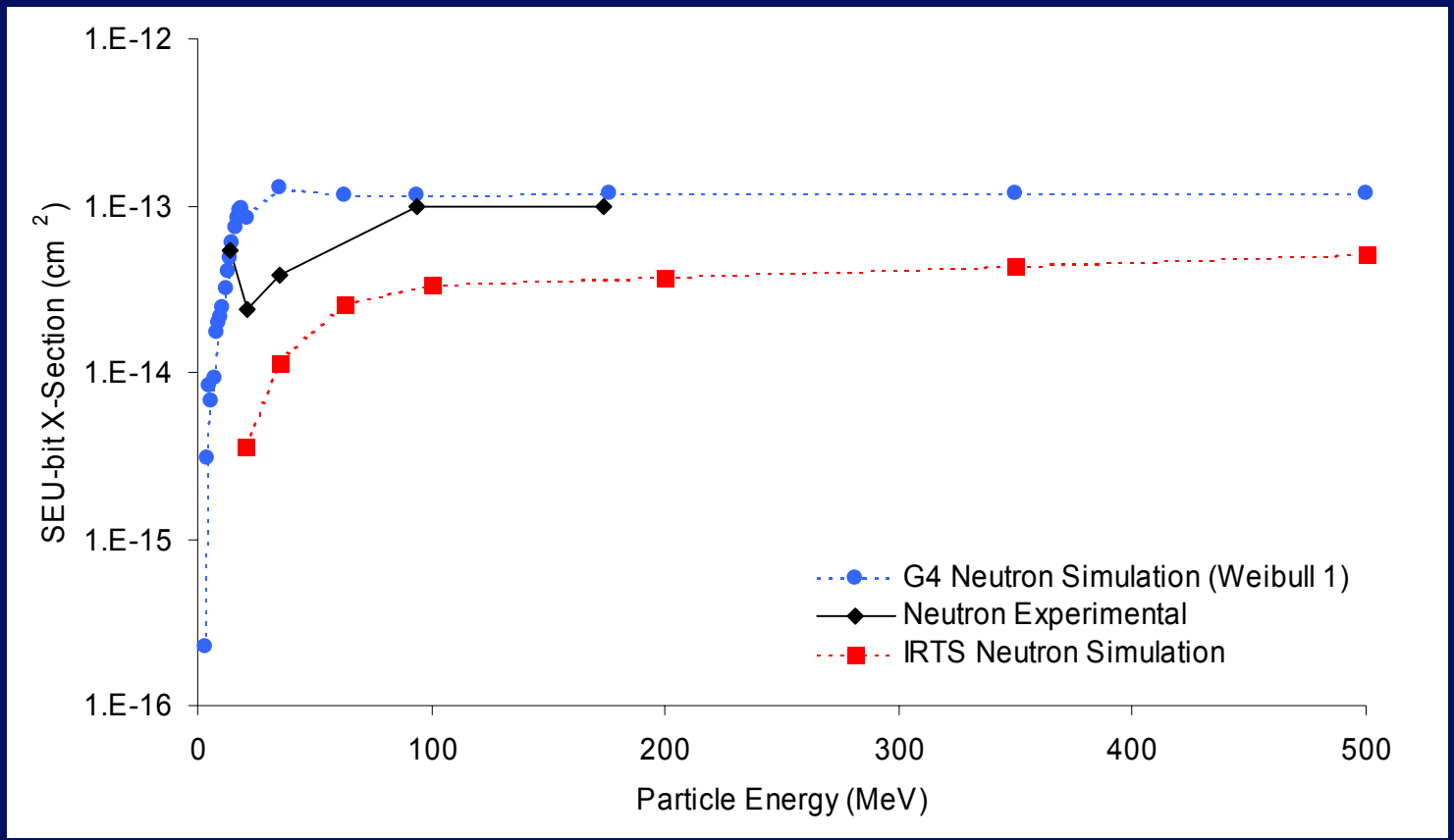
Neutron Cross-Sections : Experimental and Simulation Comparison



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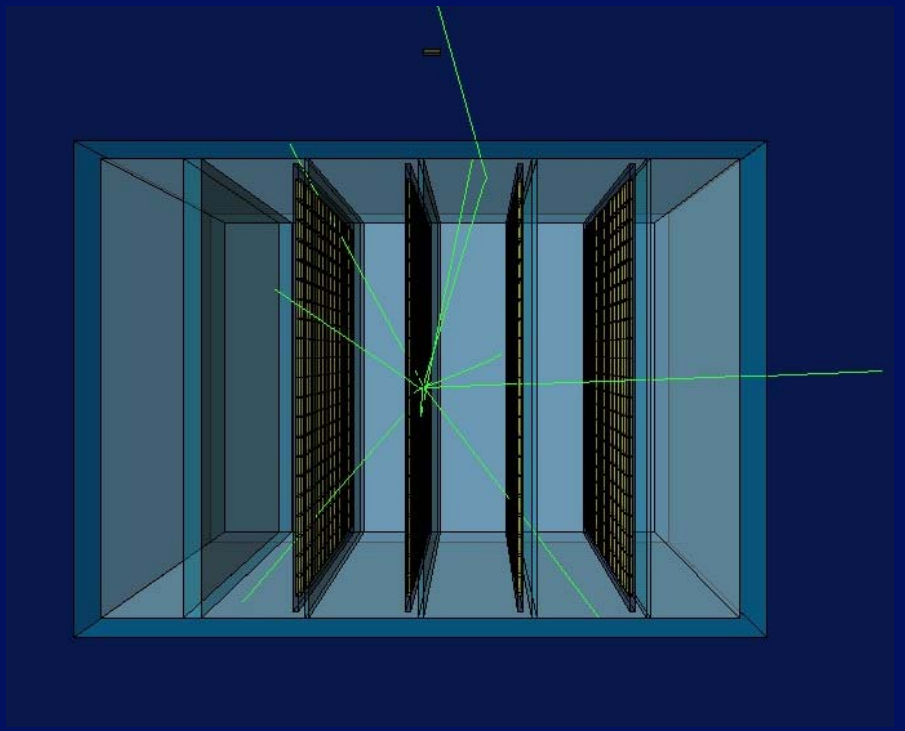
Example: Simulation of radiation beam exposures

- Components in the module have to be tested to a specified dose level, with exposures from different angles
- G4 simulations were used to estimate the dose rate, hence the exposure time required.



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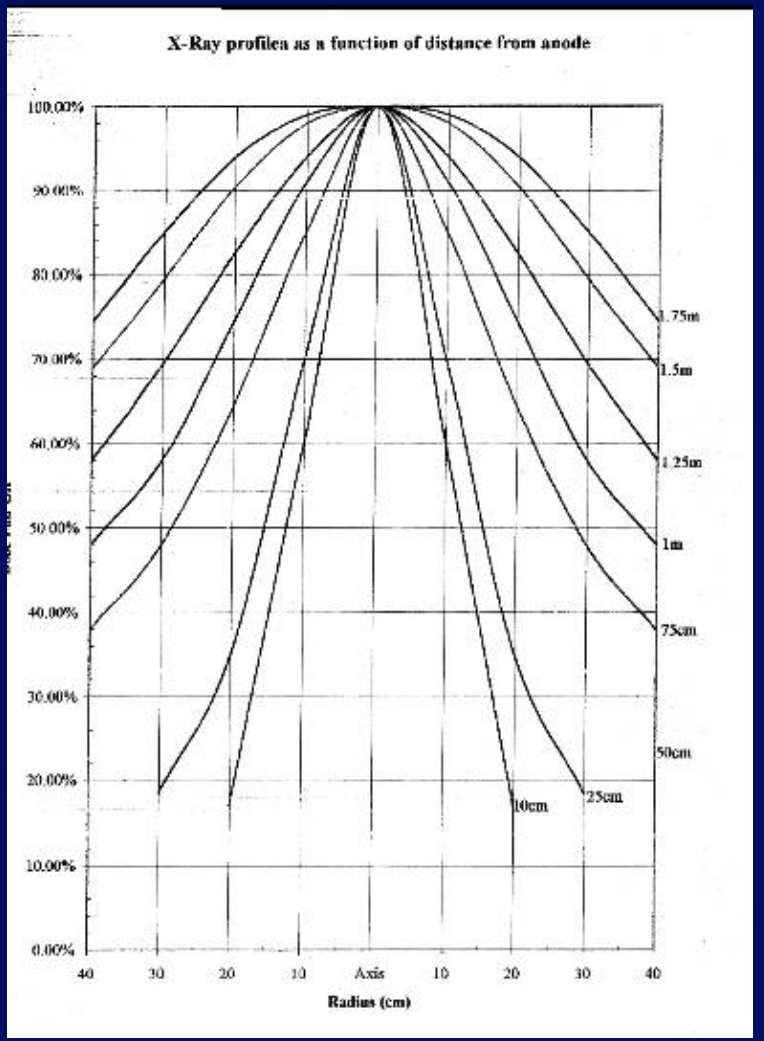
Beam profile

- The beam intensity falls steeply with increasing radius
- At 10 cm distance it can be approximated by a Gaussian function
- The beam is assumed not parallel, with a 10 degree divergence angle

-> use GPS



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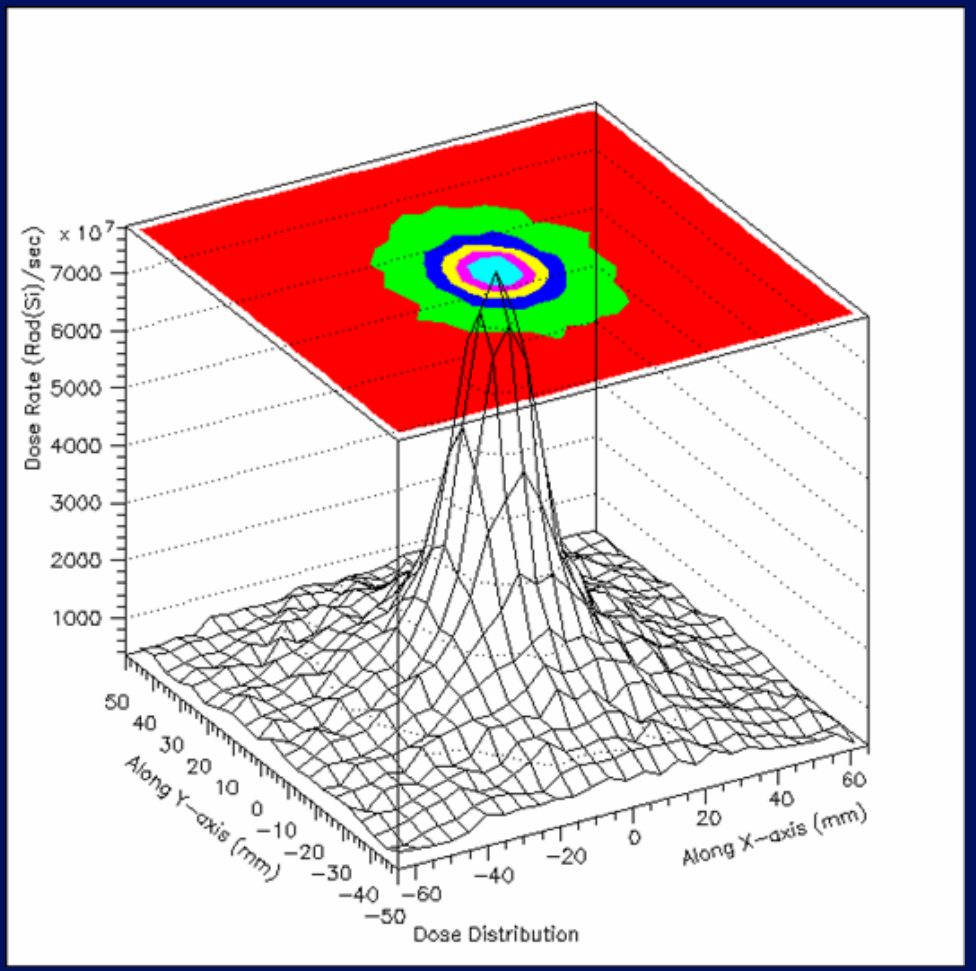
Board-0: Front illumination



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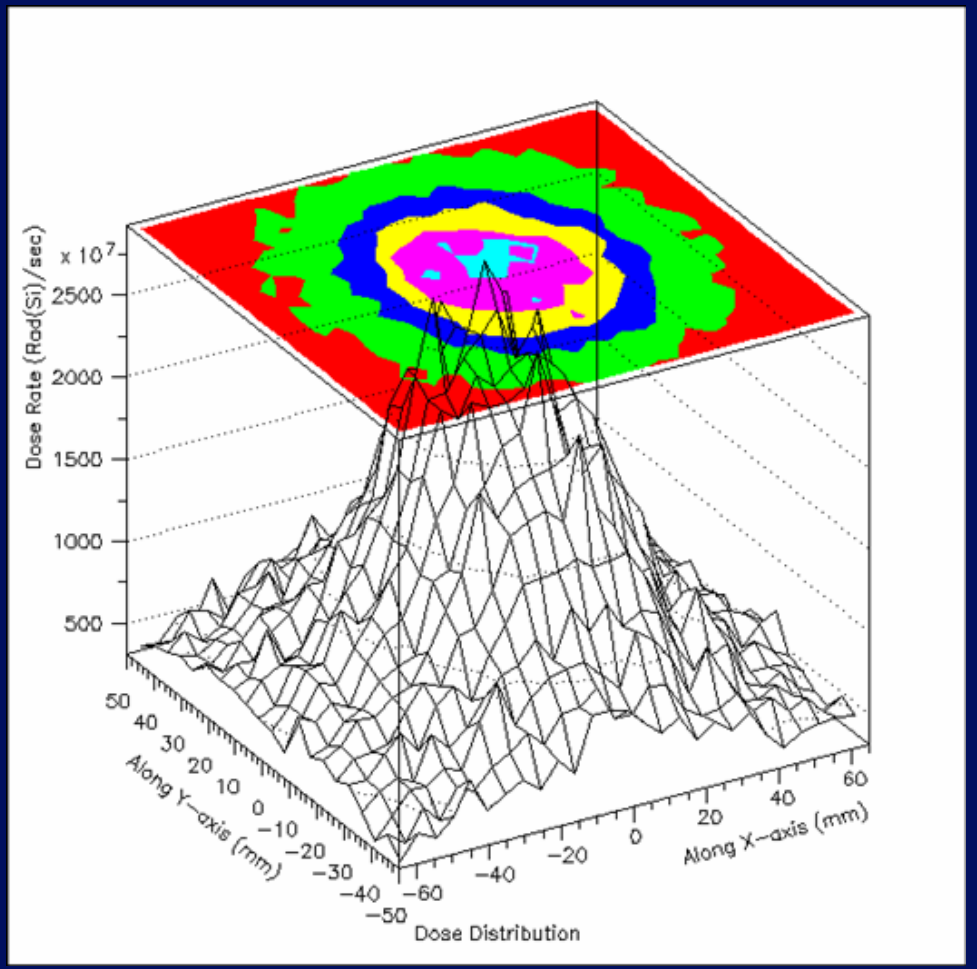
Board-0: Back illumination



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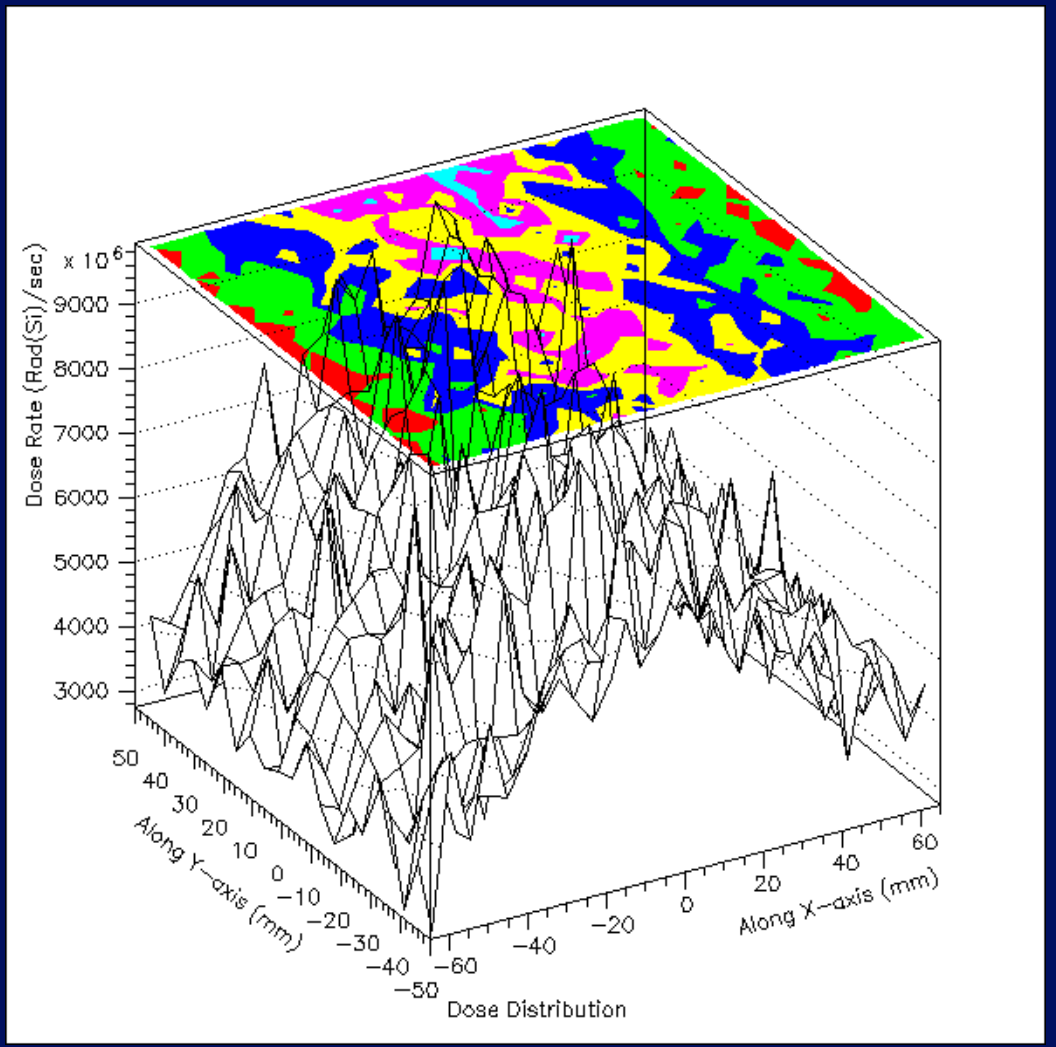
Board-0: Side illumination



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Board-0: Summary of dose rate

	High	Low	Average
Front	$7x10^{10}$	$1x10^{10}$	$1.25\ x10^{10}$
Back	$2.5x10^{10}$	$5x10^{9}$	$1.06\ x10^{10}$
Side	$9x10^{9}$	$3x10^{9}$	$5.91\ x10^{9}$

In units of Rads (Si)/sec

Microdosimetry

- Simulations of component/device beam tests, e.g. APS
- Interface Geant4 to ATLAS3D/SIVALCO simulator
  - G4 geometry model defined by the ATLAS3D device geometry file.
  - Options for adding packaging materials.
  - Various algorithms available for generating e-/h+ from G4 tracks.

  More details in Pete Truscott's talk next.

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Discussions (I)

- Geometry:
  - GUI to allow quick construction of simple geometry model
  - A Standard to allow common geometry model for various analysis
  - Real need for CAD/STEP capability. Will be a big selling point for G4
- Detector/Hits:
  - Surface detector
  - Mesh tally
- Analysis:
  - AIDA/ANAPHE: long term prospect?

Discussions (II)

- Physics:
  - Ion nuclear interactions
  - Microscopic NIEL calculation
    - Recoils
    - Separation of the nuclear/electronic energy loss
- More Biasing:
  - point detectors,
  - cross-sections/process/forced interactions