

Single Event Effect (SEE) Test Planning 101

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Unclassified



Outline

- **Introductory Comments**
 - Scope of course
- **Requirements**
 - Flight Projects
 - Research
 - Programmatic constraints
- **Device Considerations**
 - A word on data collection
- **Test Set Considerations**
- **Facility Considerations**
- **Logistics**
- **Contingency Planning**
- **Test Plan Outline**
- **Summary**



Introduction

- **This is a course on SEE Test Plan development**
- **It is NOT**
 - How to test or testing methodology
 - A detailed discussion of technology
 - New material on new effects
- **It is**
 - An introductory discussion of the items that go into planning an SEE test that should complement the SEE test methodology used
- **Material will only cover heavy ion SEE testing and not proton, LASER, or other though many of the discussed items may be applicable.**



Course Abstract

- **While standards and guidelines for how-to perform single event effects (SEE) testing have existed almost since the first cyclotron testing, guidance on the development of SEE test plans has not been as easy to find.**
- **In this section of the short course, we attempt to rectify this lack.**
- **We consider the approach outlined here as a “living” document:**
 - **mission specific constraints and new technology related issues always need to be taken into account.**
- **We note that we will use the term “test planning” in the context of those items being included in a test plan.**



Requirements – Dual and Competing Nature(s)

- **Programmatic**
 - Cost
 - Schedule
 - Personnel
 - Availability
 - Criticality
 - RISK!
- **Technical**
 - Device
 - Packaging
 - Beam/facility
 - Application
 - Data Capture

Dual Nature 2: Flight Project versus Research

How we plan and prepare for a test will also vary
with this trade space

All tests are driven by requirements and objectives in
one manner or another



Flight Project Requirements

- **When planning a test for a flight project, considerations may include:**
 - **Acceptance criteria**
 - **Error or fail rate (System or Device)**
 - System availability may be appropriate, as well
 - **Minimum device hardness level**
 - Linear Energy Transfer threshold (LETth), for example
 - **Error definition and application information**
 - **User application(s)**
 - **Circuit**
 - We note that “test as you fly” is recommended
 - **Criticality**
 - **Programmatic constraints**
- **The bottom line is that flight project tests are usually application specific and designed to get a specific answer such as:**
 - **Is the SEL threshold higher than X? or**
 - **Will I see an effect more than once every 10 days?**



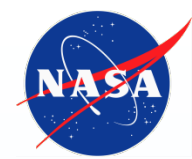
Research Requirements

- **These are less specific than requirements for flight projects and may include**
 - Generic technology/device hardness
 - Application range
 - Angular exploration
 - Frequency exploration
 - Beam characteristics such as ion/energy/range effects
 - Error propagation, charge sharing, etc...
 - Programmatic constraints
- **The bottom line is that all requirements and objectives should be “in plan”, i.e., considered prior to test and included in test plan development.**



Resource Estimation

- **Many factors will weigh in to actual resource (re: cost and schedule) considerations including:**
 - Complexity of device/test and preparation thereof
 - Facility availability (and time allotment)
 - Urgency of test
 - Funds availability, and so forth
- **We usually try to “pre-plan” facility access approximately three months prior to a test date and refine the list as flight project exigencies, test readiness levels, etc are evaluated.**
 - At NASA, flight projects receive priority in planning
- **Schedules should be developed and included that include all phases of testing from requirements definition to completed report.**



Cost Estimation Factors

- **Labor**
 - Principal investigator/team lead
 - Test engineers/technicians
 - Electrical, mechanical, VHDL, software, cabling, etc.
 - Test performance (pay attention to overtime needs)
 - Data Analysis
 - Report and plan writing
- **Non-recurring engineering costs**
 - Board fabrication and population
 - Device thinning/delidding
 - Cables, connectors, miscellaneous
 - Test equipment purchase/rental
- **Facility Costs**
 - Note that estimating the amount of beam time required is non-trivial: modes of operation, ions, temperature, power, etc. all factor into the test matrix and need to be prioritized
- **Travel**
- **Shipping**



Device Constraints

- **Devices under test (DUTs) can range from very simple transistors to the most complex systems on a chip (SOC)**
 - This range implies test set implementations can vary just as widely
- **At the top level, the following are the key items to begin planning with:**
 - Datasheet and
 - Application requirements (mission specific or range for “generic” research)
- **We note that implementing a test set hinges greatly on the DUT type and requirements, however, detailed discussion of this is out of scope for this talk.**
 - Certain key features will be delineated later



DUT Parameter Space

- **DUT parameter space may include multiple items found on datasheets:**
 - **Electrical performance**
 - Frequency, timing, load, drive, fanout, IO, ...
 - **Application capability/ operating modes**
 - Processing, configuration, utilization...
 - **Power**
 - **Environmental characteristics, and so on**
- **Mission specific testing will limit the space as part of the requirements**
 - **Research tests must consider the overall application space of the DUT and determine priorities for configuration of tests**
- **We note that device sample size is also considered and may be limited due to resource or other constraints.**
 - **Good statistical methods are still recommended**
 - **Lot qualification issues should be considered**
- **Key features, device markings, etc. should be included**



Predicting DUT SEE Categories

- **An analysis of the types of SEE the device might observe during irradiation is required.**
 - This may be called a error/failure mode analysis
 - Predicted type and even frequency of SEEs will drive the data capture requirements discussed later as will error propagation/visibility
- **An analysis should include**
 - Upset (single, multiple, transient, functional interrupts, etc..) and destructive issues, as well as,
 - Mission specific objectives (Ex., application requirements or destructive test only)
- **Looking at existing data on similar device types and technologies may help in this process**



DUT Data Capture - Sample SEU Capture Signatures

- **Upsets can be as simple as a short glitch/transient in an output or an incorrect output state**
- **Upsets can be complex:**
 - **Bursts: streaming upsets that are time limited (i.e. occur from time τ_n to τ_{n+k})**
 - Burst vs uncorrectable error?
 - **One particle strike may cause an oscillation between known good and bad values (metastable)**
- **Difficulties**
 - **Differentiate between a single event versus accumulation:**
 - Multiple effects may occur from one particle strike
 - Multiple effects may occur from an accumulation of particle strikes
 - **Differentiate between hard errors and soft errors**
 - Is it bus contention?
 - Is it a micro-latch? Or...



Test Set Requirements

- **Test set requirements are a set of derived requirements from the mission/DUT/facility requirements**
 - **Example: requirement for a test in vacuum may be different than one in air**
- **Knowing how a DUT performs is one thing, but defining requirements for a test system is clearly separate**
 - **Test set requirements should encompass actual application range or have sufficient flexibility such that modifications can be made on site easily**
- **Mission Requirements generally have ranges of operation.**
 - **The test set should accommodate this range in areas such as:**
 - **Min, max, and typical (speed, temperature, voltage)**
 - **Vary inputs**
 - **Note the difference between static tests and dynamic tests**
 - **Output loading**
- **We note that a test plan should provide full details, schematics, figures, photos, etc. of test method/set**



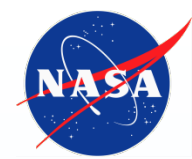
Test Set Considerations

- **Test Set Development challenges**
 - Visibility of upsets may be restricted with complex devices
 - Testing the expected state of the device may be impossible
- **Test Set considerations**
 - May be necessary to separate tests for various portions of the device
 - Example: FPGA (configuration, data paths, and SEFIs)
 - Understand and note test restrictions when determining SEU cross sections and error rates
 - Be aware of the separation of tester, user equipment, and DUT during testing.
- **Boards for DUTs: roll your own or ???**
 - DUT mounting can be performed by: wiring, soldering, or socketing
 - Wiring will only work for slow devices with minimal I/O count
 - Soldering onto a board will increase the range of angular testing and improved speed/noise performance
 - Socketing provides flexibility: if DUT dies, another can easily replace it
 - Potential signal integrity issues must be considered (ground bounce, transmission line effects, etc...)



Data Requirements

- **Data requirements may be broken into two categories**
 - **Data capture, and,**
 - **Data analysis**
- **Data capture, in this context, is not how you capture the data, but the requirements/items that should be considered for capture**
- **Data analysis is the other end of the picture: everything from the system-wide flow of the data, what format it is being captured in, and what are the requirements for analyzing this data (real-time and post-testing, as well as planning how this should be implemented.**
- **We suggest treating radiation data much like a spacecraft treats science data: a telemetry and command system**
 - **Utilize as many reliable design practices as possible to have confidence in the results**



Data Capture

- **Multiple facets are included in data capture including**
 - **Data volume and storage**
 - **Maximum error capture rates should be planned as well in order ensure the TBD system can keep up**
 - **Resolution of measurements**
 - **This includes “housekeeping” data as well at the “scientific” information**
 - **Timetagging**
 - **Supply currents**
 - **Temperature**
 - **Beam/facility run information,**
 - **Accumulated dose, and so on...**
 - **We note that capture criteria per beam run may hinge upon beam “stop” criteria**
 - **X number of errors**
 - **Beam fluence**
 - **Current limit**
 - **Anomaly**
 - **Other**



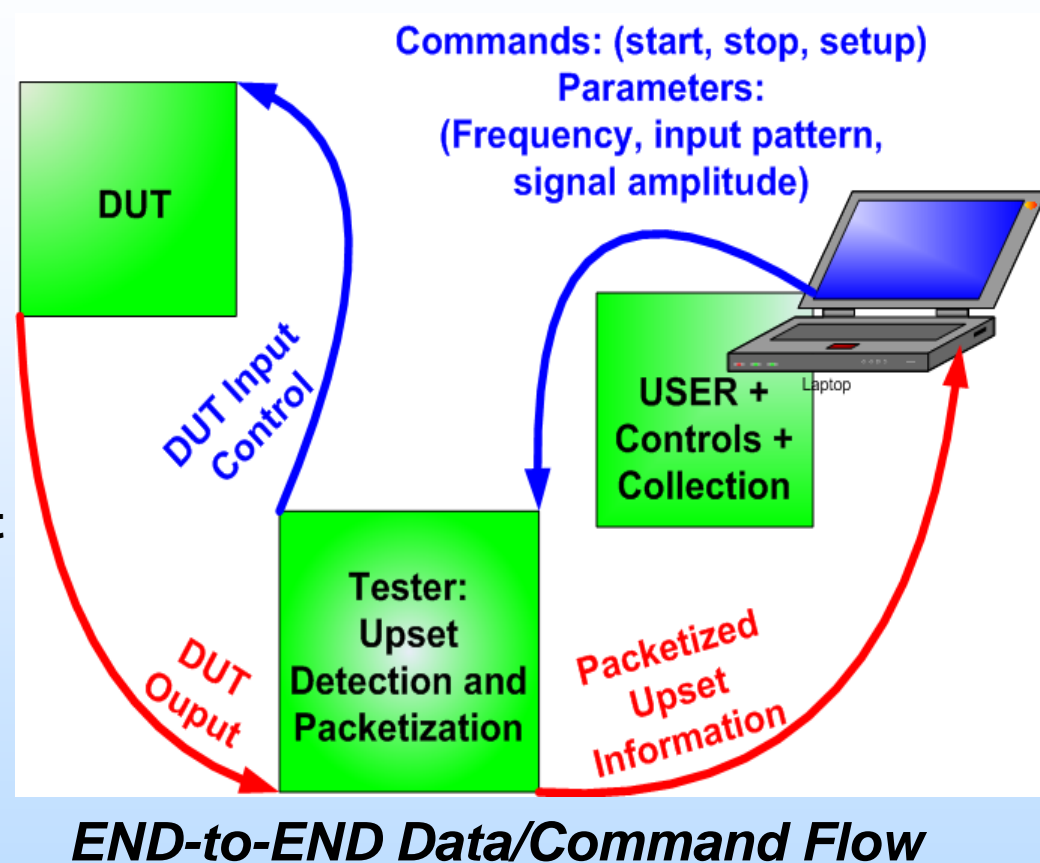
Data Capture – Reliable!

- **Some suggested implied requirements for reliable data capture**
 - **Must abide by datasheet requirements (timing diagrams, DUT output drive, etc...)**
 - **Might require the capability to observe short duration upsets**
 - **Should readily capture random errors**
 - **Should be able to determine changes in current**
 - **Should be able to keep up with the upset rate by:**
 - **Storing upset data locally (fastest method – but can be restricted by amount of storage)**
 - **Bandwidth limitations of communications links**
 - **Some mix of the above two options – alleviates the storage and bandwidth issues**
- **Flexibility to adapt to unexpected “events”**



Data Analysis

- The early definition of the data/command flow and structure is key to performing a successful test
 - Developing an end-to-end data/command flow diagram, and,
 - Defining data and command packet structure at each point along the path
 - Headers (run number, etc...)
 - Word formats and length
 - Insertion of housekeeping information
- Note: Geographical (DUT layout) and temporal information often aid determining root cause of error



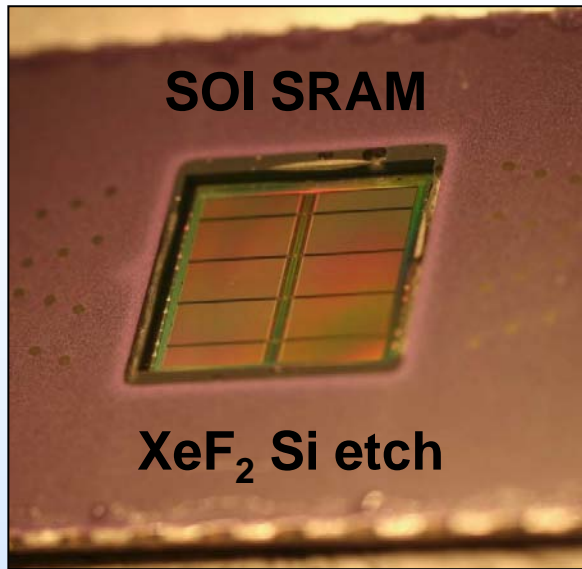


Processing the Data

- **Every plan should include a discussion of how the data will be processed whether it's for**
 - Full width half max (FWHM) for transients,
 - Physical mapping of errors and multiple bit events, or
 - Any of the myriad of data events in between.
- **Requirements for what needs to be viewed/processed real-time in order to make informed decisions at the site as well as what should be done as part of post-processing should be clearly delineated.**

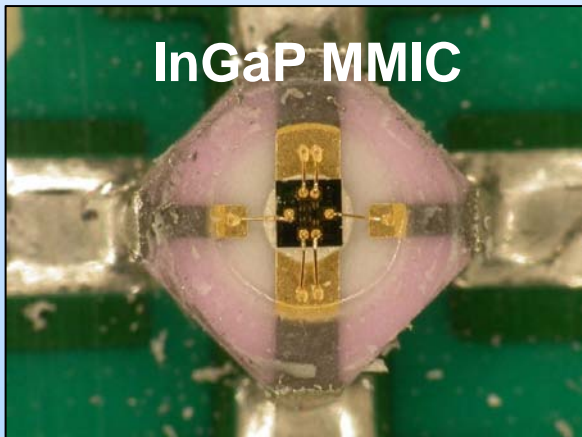


Facility Issue - Device Preparation

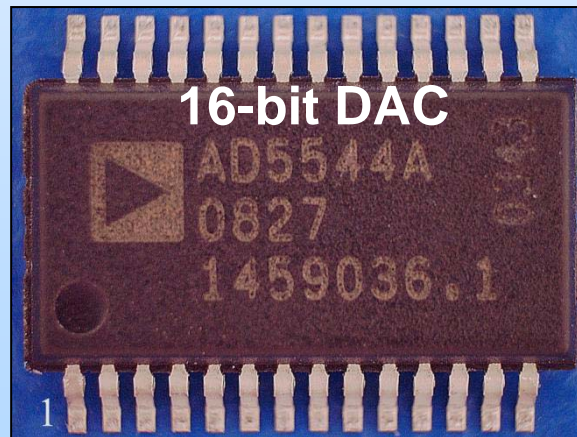


M. R. Shaneyfelt, et al., *SEE Symposium*, 2011.

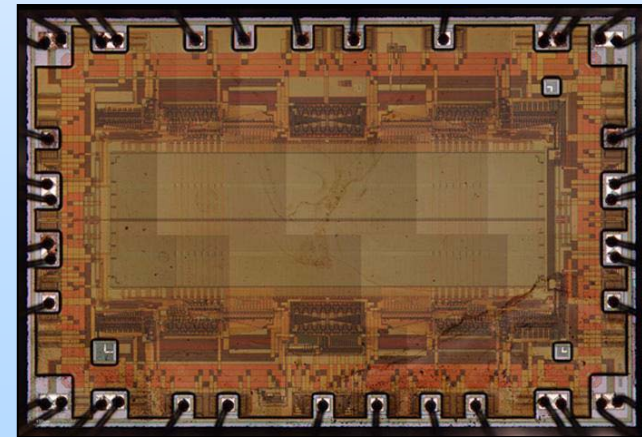
- If only everything was hermetic!
- Ion's range of penetration is short compared to packaging materials
 - Cannot use protons for everything
- What is the package style and die material?
 - Are there heat sinks?
- Methods: mechanical, chemical, and electromagnetic (ablation lasers)



Open a can

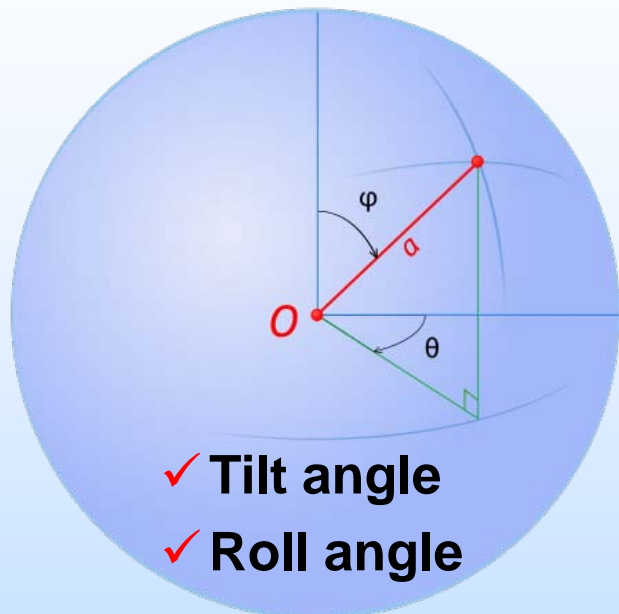


Acid etch/de-pot plastic encapsulated microcircuits



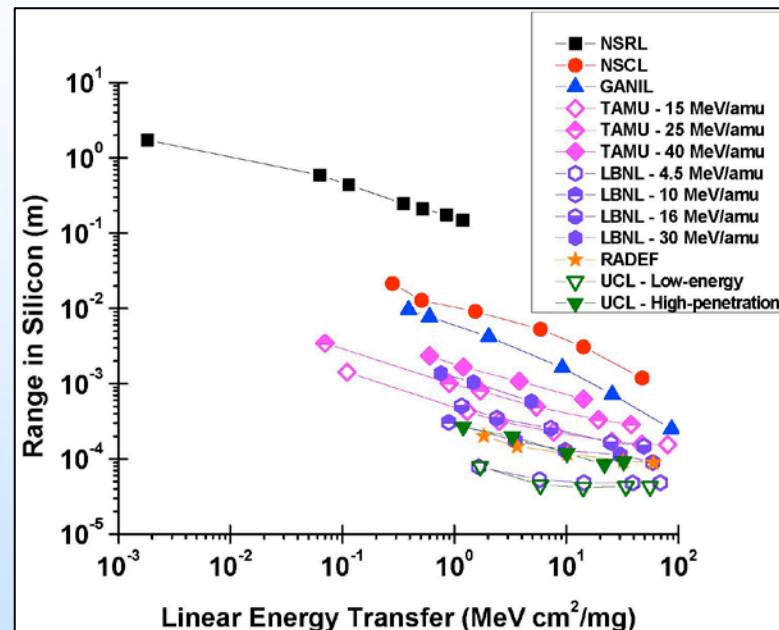


Facility Considerations – Angles and Ion Choice



http://en.wikipedia.org/wiki/Spherical_coordinate_system

Heavy Ion Facility Comparison



J. A. Pellish, et al., *IEEE Trans. Nucl. Sci.*, vol. 57, no. 5, pp. 2948-2954, Oct. 2010.

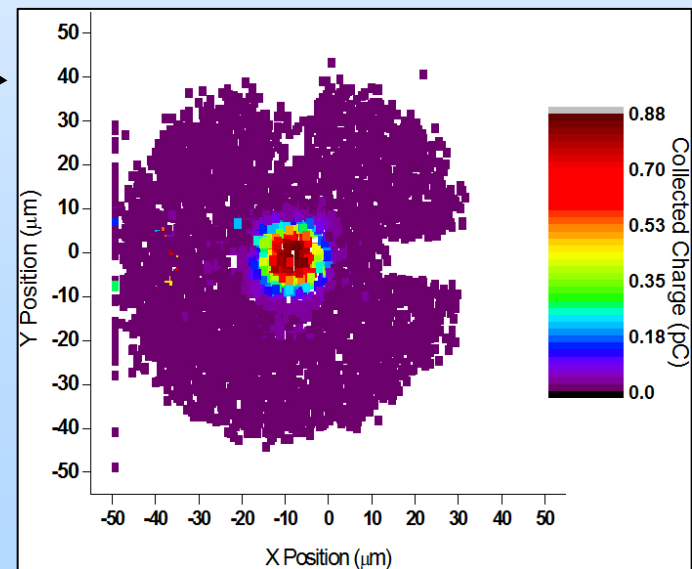
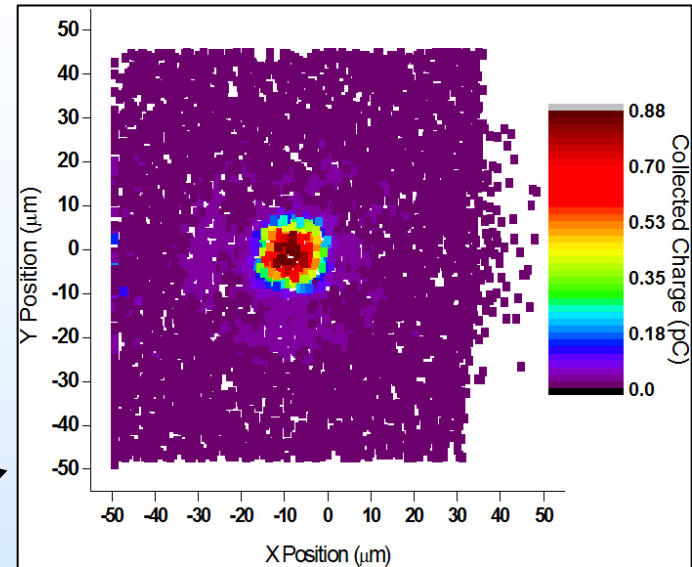
- What's the sensitive area(s) geometry and are there any hardening techniques (design and/or process) employed?
- Is ion range or dE/dx (ionization/length) more important?

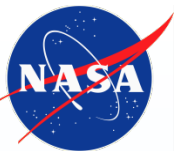


Facility Considerations – Dosimetry

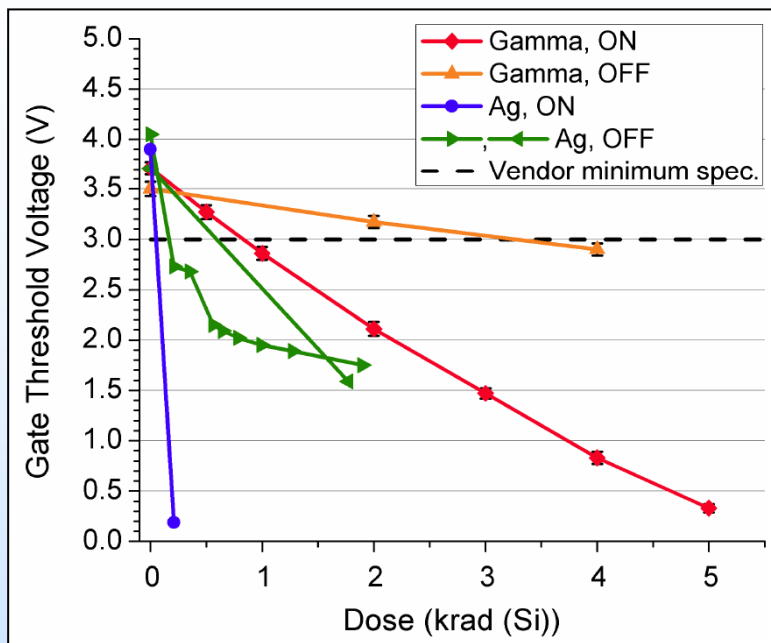
- SiGe HBT transistor under microbeam irradiation at Sandia National Laboratories
- 36 MeV oxygen
 - Surface LET = 5.3 MeV-cm²/mg
- 60 scans in total
 - Early = first 12 scans
 - Late = last 12 scans
- Note the large diffusion component

- Dose/damage from heavy ions can be a significant factor
- Is my device susceptible to this?





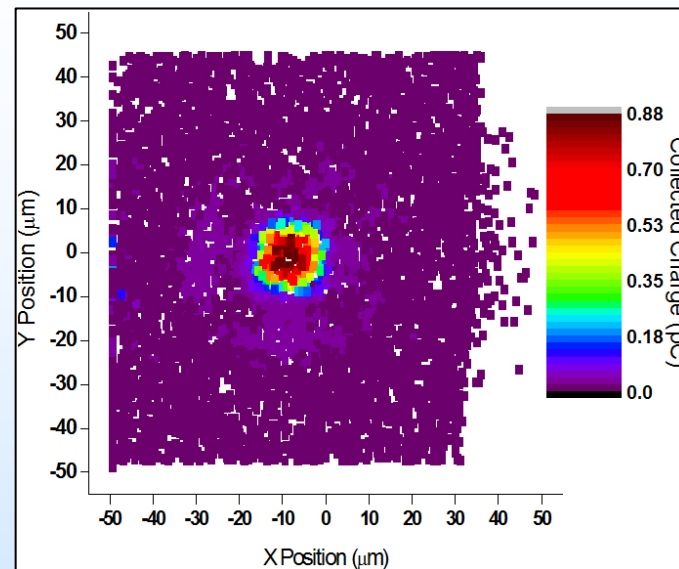
Facility Considerations – Dosimetry



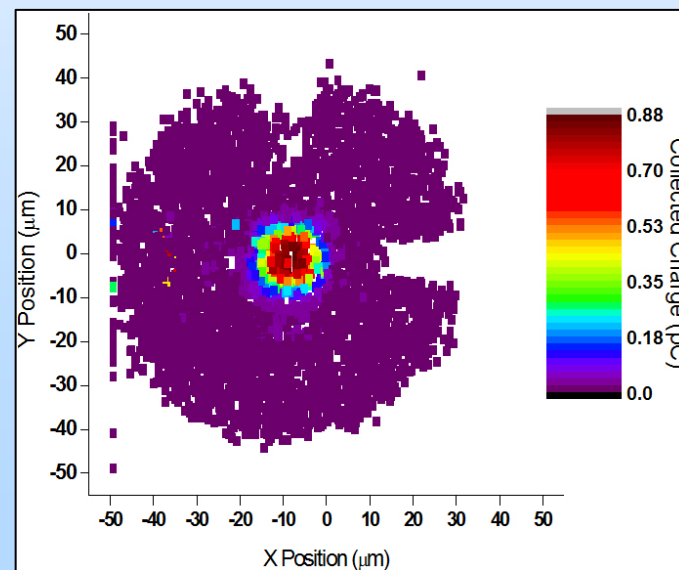
J.-M. Lauenstein, Ph.D. Dissertation,
U. Maryland, 2011.

Dose type and bias effects on power MOSFET V_{th}

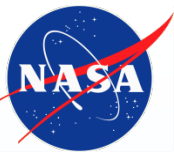
- Dose/damage from heavy ions can be a significant factor
- Is my device susceptible to this?



Early

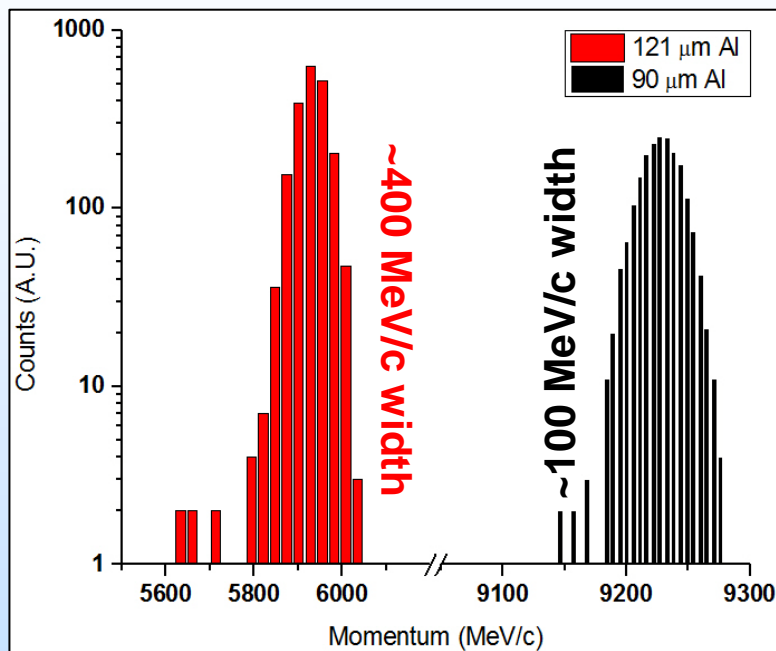


Late



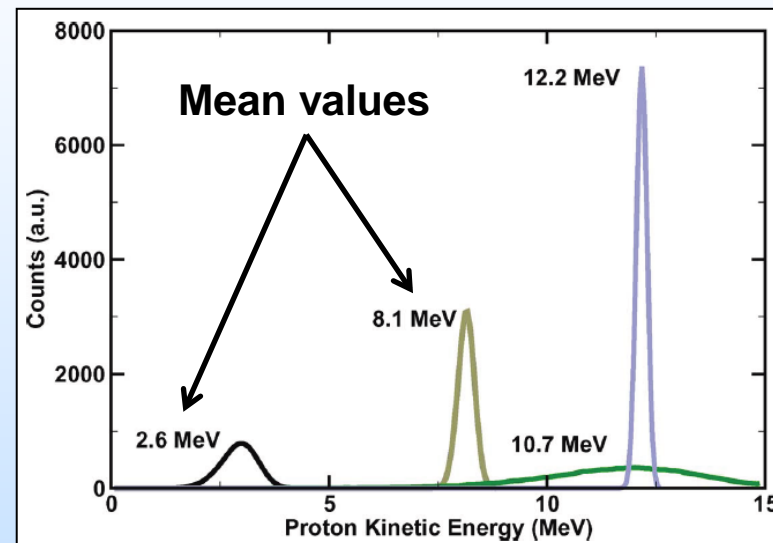
Facility Considerations – Beam Profile and Purity

1.26 GeV ^{84}Kr Primary Beam



SRIM-2008.4

Degraded Proton Energy Distributions 14.6 and 63 MeV primaries



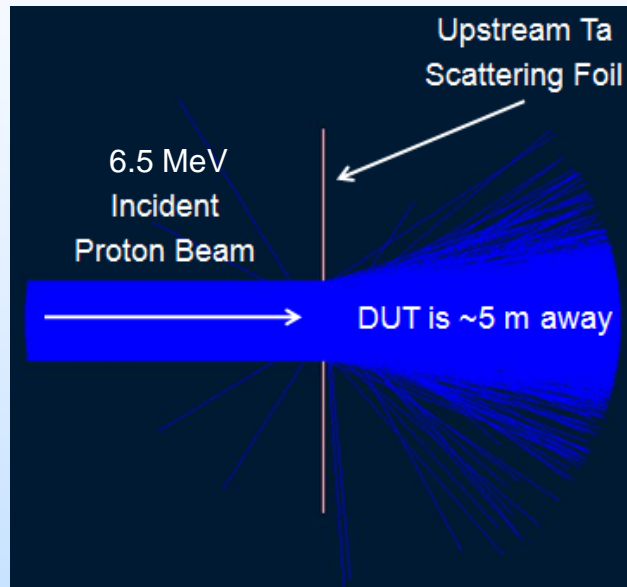
B. D. Sierawski, *et al.*, *IEEE Trans. Nucl. Sci.*,
vol. 56, no. 6, pp. 3085-3092.

- What is the beam's emittance (space and momentum)?
- Where are the sensitive areas on my device under test?
- How big are the sensitive areas?
- Am I sensitive to destructive effects?



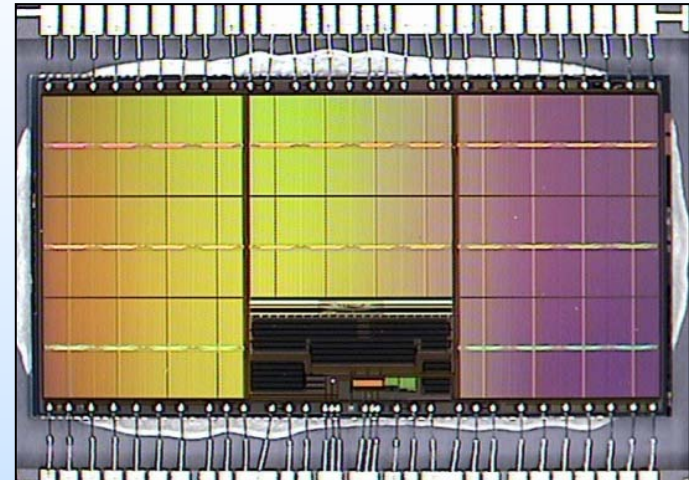
Facility Considerations – Beam Profile and Purity

Low-Energy Proton Scattering



J. A. Pellish, *et al.*, *SEE Symposium*, 2011.

ESA SEU Monitor



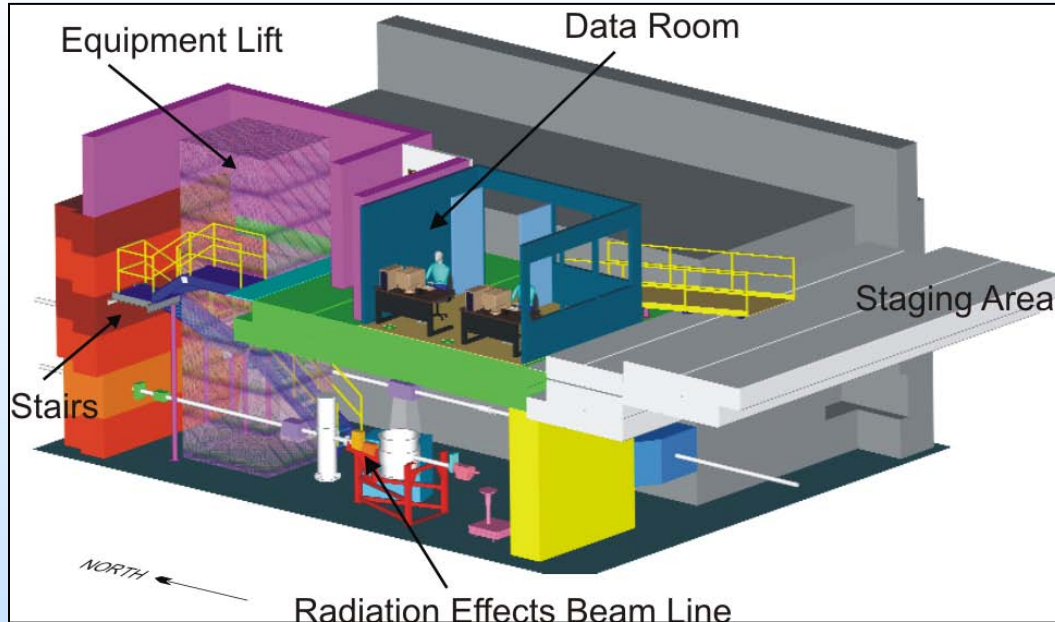
R. H. Sørensen, *et al.*, *Proc. RADECS*, 2005.

- **What is the beam's emittance (space and momentum)?**
- **Where are the sensitive areas on my device under test?**
- **How big are the sensitive areas?**
- **Am I sensitive to destructive effects?**



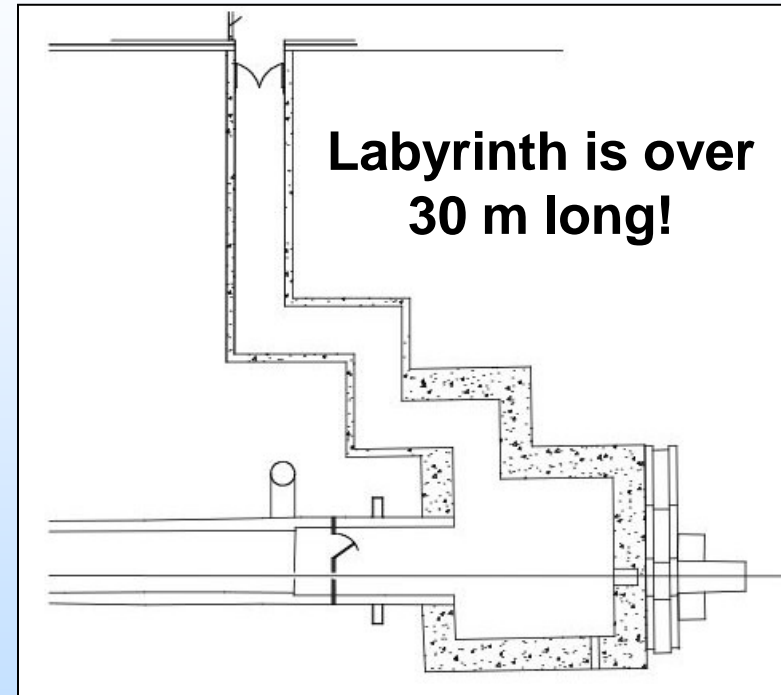
Facility Considerations – Setup and Cabling

Texas A&M Cyclotron Facility



http://cyclotron.tamu.edu/ref/pics/3d_new_reline.png

NASA Space Radiation Lab



http://www.bnl.gov/medical/NASA/CAD/NSRL_Facility_and_Target_Room.asp

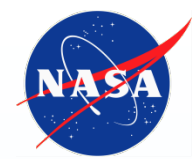
- **Is there a staging area?**
- **How large is the data collection/user room?**
- **What kind of cables/feedthroughs are present?**
- **How long is the cable run? (signal bandwidth, voltage droop, etc.)**



Facility Considerations – Setup and Cabling

**Avoid
the
dreaded
CABLE CADAVER**





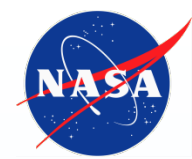
Configuration Management (CM)

- **The rule here is simple: know and document what you have, what you are using, and how you are using it. This ranges from cabling all the way to coding!**
 - **CM defines which version you have and making sure you bring the tools to modify if needed**
 - **Ex., which VHDL code is final one for either the test set or DUT (if applicable)?**
 - **Each team member is responsible for CM**
- **Data backup is related**
 - **Make sure you have a plan for storage of multiple copies of the data, who is responsible, and what happens for post-processing**



Logistics

- **While non-technical, logistics related to test planning and writing a test plan are no less important**
- **Areas for consideration in no particular order:**
 - **Test team member contact info (cell phones, hotels, flights, etc...)**
 - **Facility contact information including maps for newbies**
 - **Contact information for key people at home site**
 - **Equipment list including spares**
 - **Don't forget datasheets!**
 - **Shipping/transport of equipment (cost, tracking, ...)**
 - **Roles and responsibilities of the team**



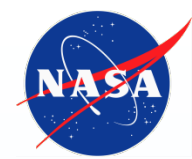
Contingency

- **Contingency is required for several reasons:**
 - Test set does not work
 - Test set does not work as well as expected
 - Error signatures are different than anticipated
 - Facility may have an “issue” such as the beam goes down
- **A good plan will include:**
 - Prioritization of tests planned (which devices, which tests)
 - Limits on debug time to make a decision to test, move to a later test timeslot, or ???
 - Example: if after 1.5 hours no significant progress is noted, go to backup device
 - Backup devices (in case test ends early or other device/test doesn't work properly)



SEE Test Plan Outline - Summary

- **Introduction and objectives**
- **Detailed Device Information**
- **Documentation**
 - Block diagrams, circuit diagrams, cabling diagrams, datasheets, etc...
 - Photos of device and test set
- **Equipment list**
 - Packing and shipping information (detailed)
- **Test Methodology and Data Capture**
 - Including Data Storage Structure
- **Configuration management**
 - Data backup and distribution plan
- **Personnel and Logistics**
- **Data Analysis Plan**
- **Contingency Plan**



Summary

- **This section of the short course was designed to provide the user the basic thought processes required to develop a successful test plan**
 - Technical issues,
 - Logistics issues, and,
 - Programmatic issues.
- **Further details are found in the full notes accompanying this presentation.**