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

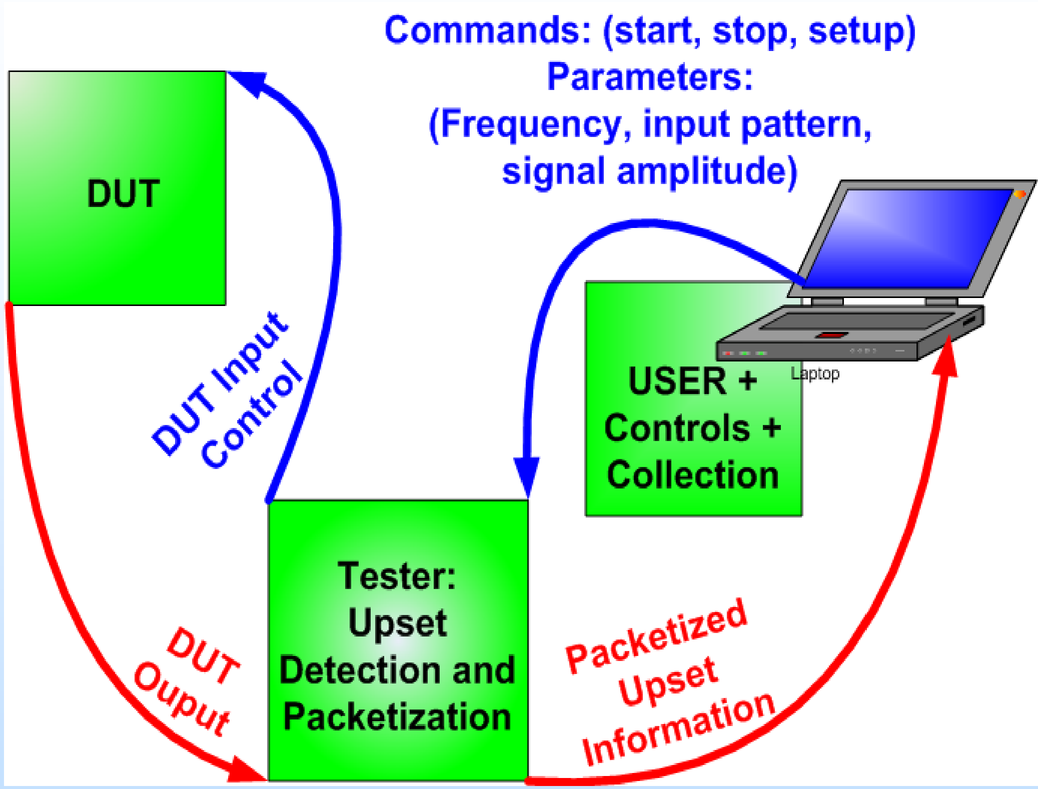
- Multiple facets are included in data capture including
  - Data volume and storage
    - Maximum error capture rates should be planned as well in order ensure the TBD system can keep up
  - Resolution of measurements
    - This includes “housekeeping” data as well at the “scientific” information
      - 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

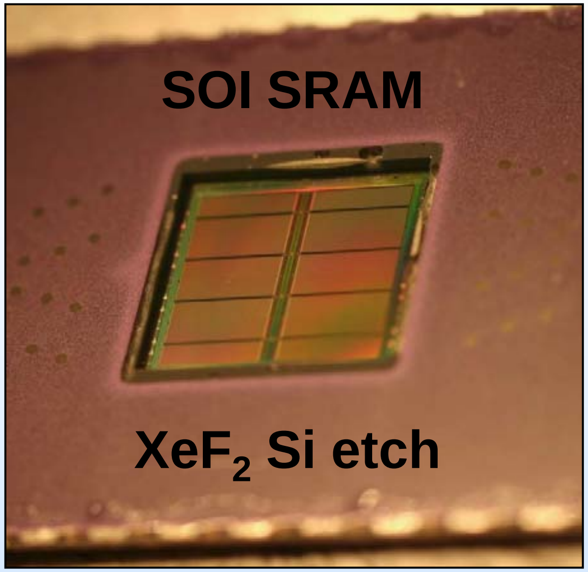


END-to-END Data/Command Flow

Processing the Data

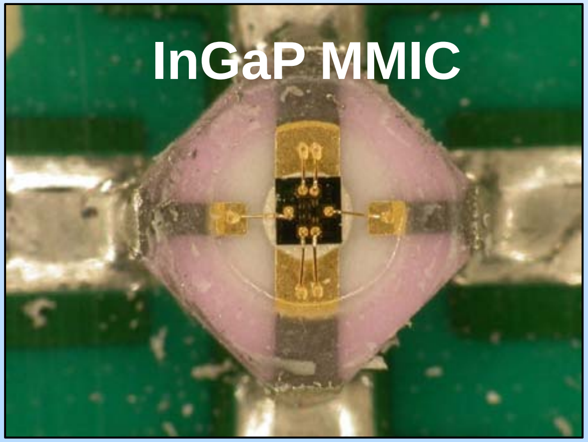
- Every plan should include a discussion of how the data will be processed whether it's for
  - Full width half max (FWHM) for transients,
  - Physical mapping of errors and multiple bit events, or
  - Any of the myriad of data events in between.
- Requirements for what needs to be viewed/processed real-time 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

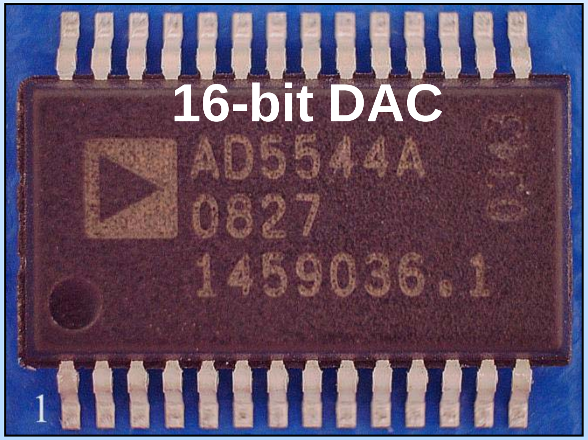


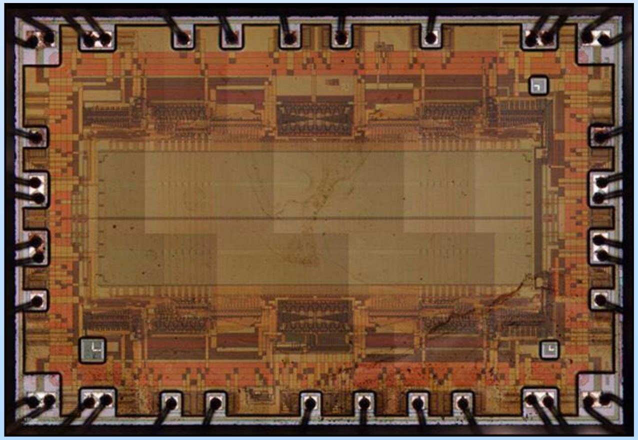
M. R. Shaneyfelt, et al., *SEE Symposium*, 2011.

- **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)**



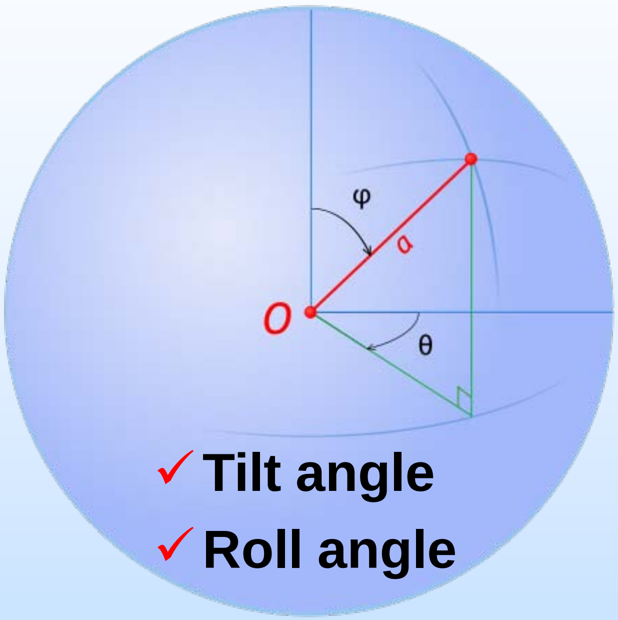
Open a can





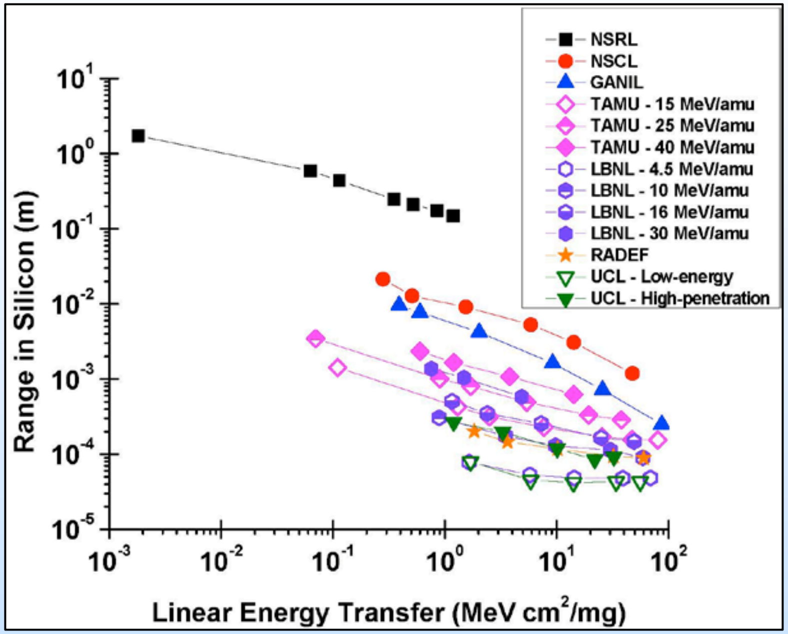
Acid etch/de-pot plastic encapsulated microcircuits

Facility Considerations – Angles and Ion Choice



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

Heavy Ion Facility Comparison

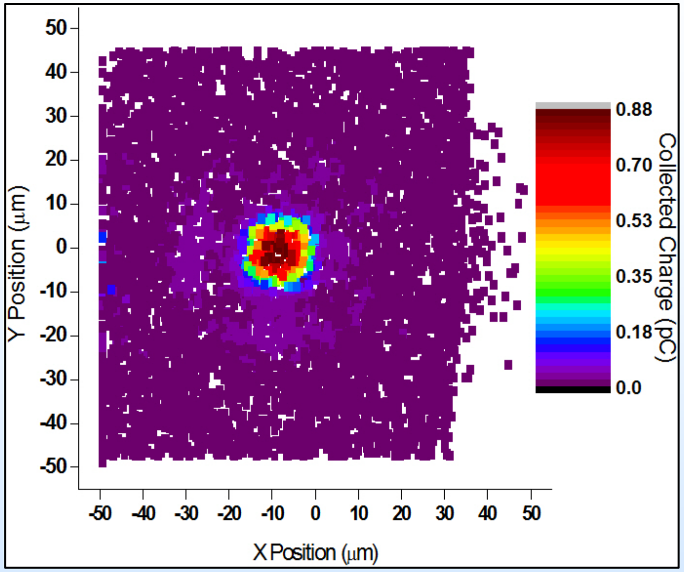


J. A. Pellish, et al., *IEEE Trans. Nucl. Sci.*, vol. 57, no. 5, pp. 2948-2954, Oct. 2010.

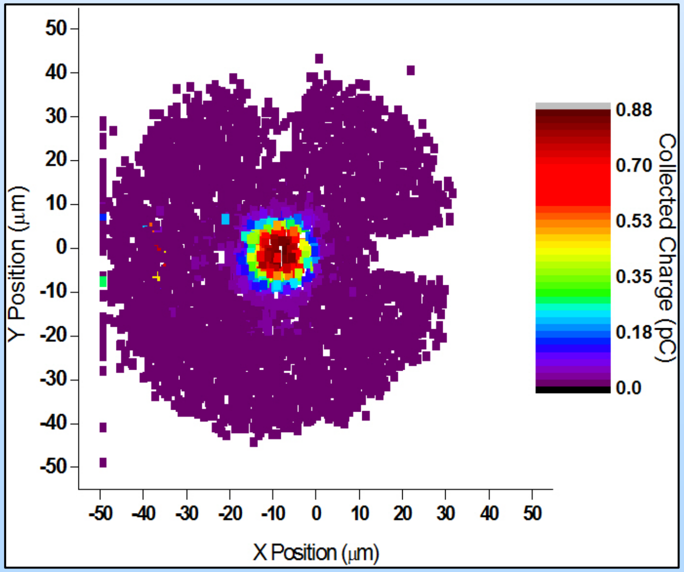
- **What's the sensitive area(s) geometry and are there any hardening techniques (design and/or process) employed?**
- **Is ion range or d*E*/d*x* (ionization/length) more important?**

Facility Considerations – Dosimetry

- SiGe HBT transistor under microbeam irradiation at Sandia National Laboratories
- 36 MeV oxygen
  - Surface LET = 5.3 MeV-cm^2/mg
- 60 scans in total
  - Early = first 12 scans
  - Late = last 12 scans
- Note the large diffusion component



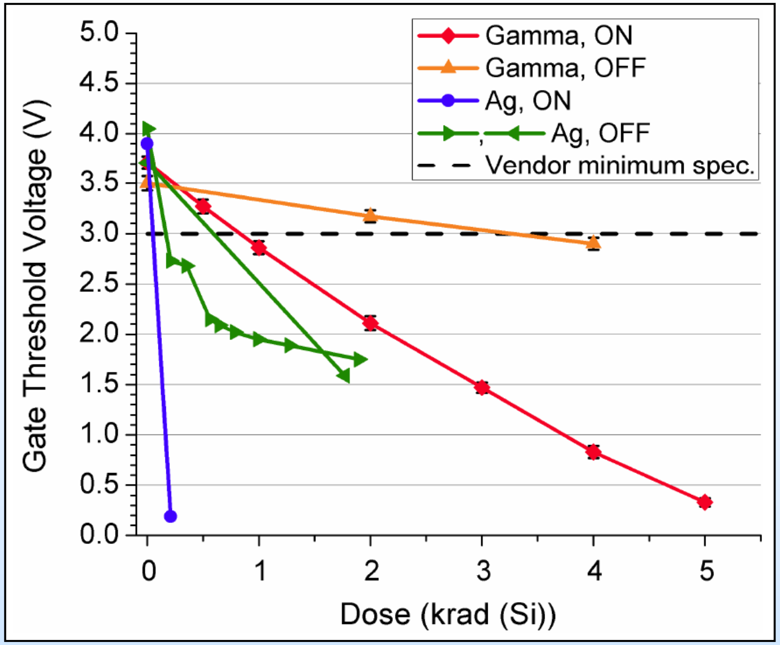
Early



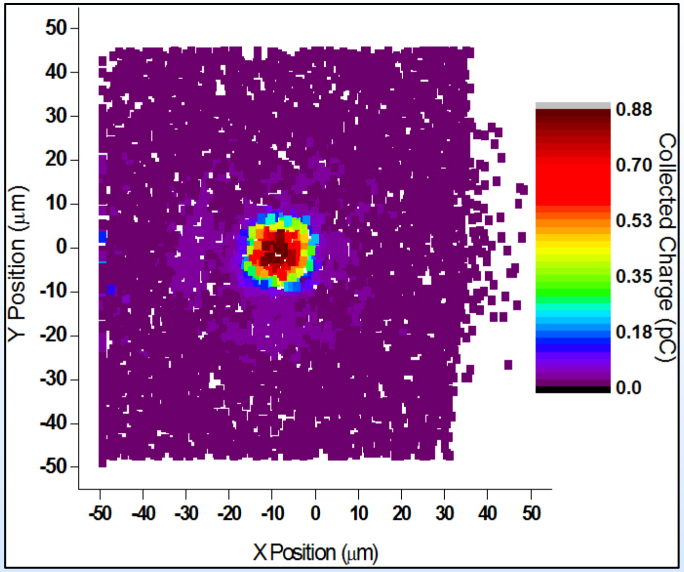
Late

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

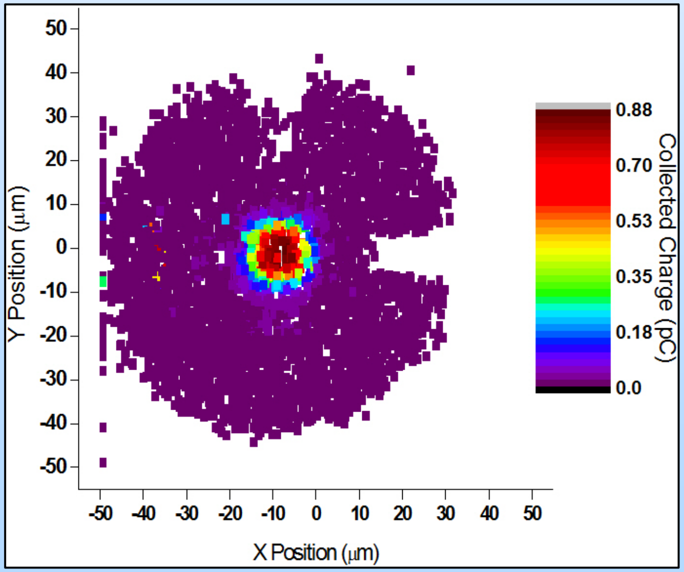
Facility Considerations – Dosimetry



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



Early



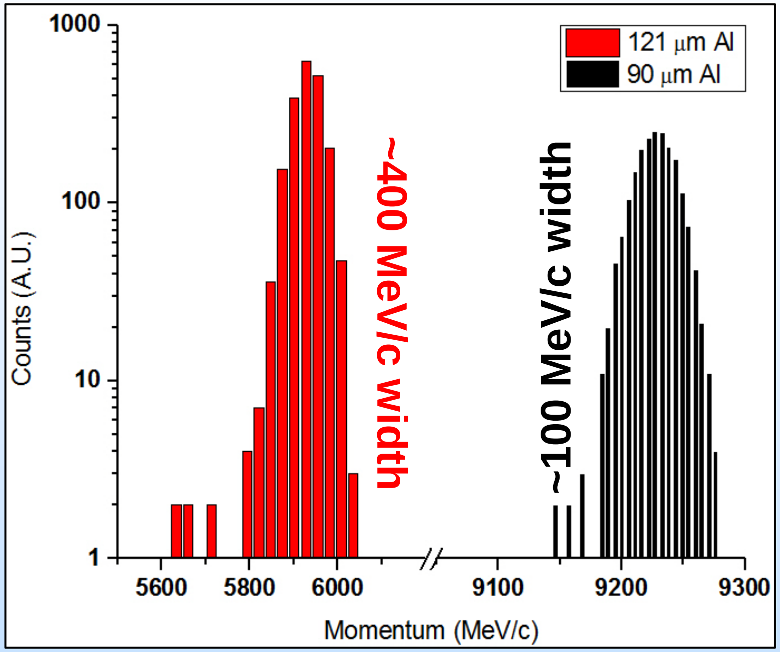
Late

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?**

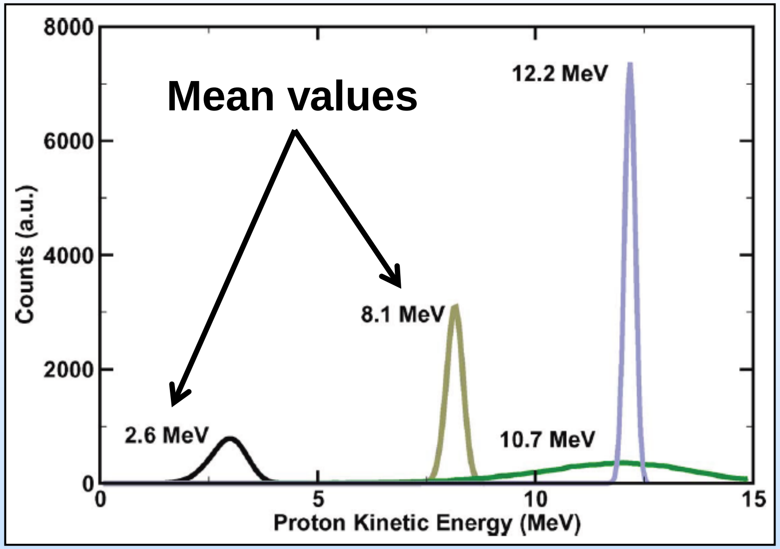
Facility Considerations – Beam Profile and Purity

1.26 GeV ^{84}Kr Primary Beam



SRIM-2008.4

Degraded Proton Energy Distributions
14.6 and 63 MeV primaries

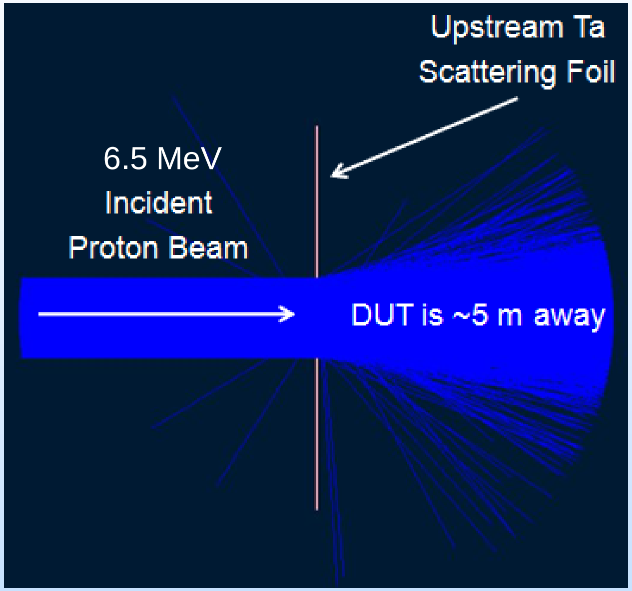


B. D. Sierawski, *et al.*, *IEEE Trans. Nucl. Sci.*, vol. 56, no. 6, pp. 3085-3092.

- **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?**

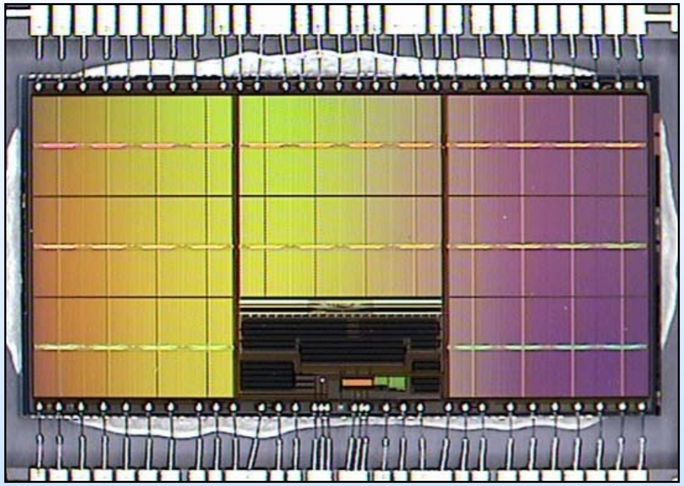
Facility Considerations – Beam Profile and Purity

Low-Energy Proton Scattering



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

ESA SEU Monitor

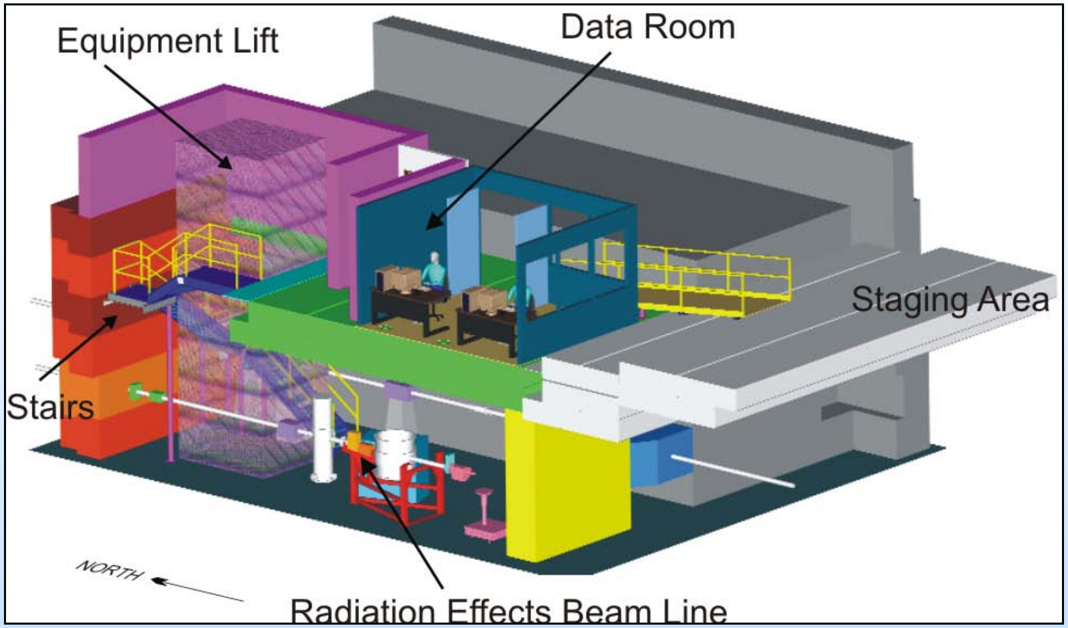


R. H. Sørensen, *et al.*, *Proc. RADECS*, 2005.

- **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?**

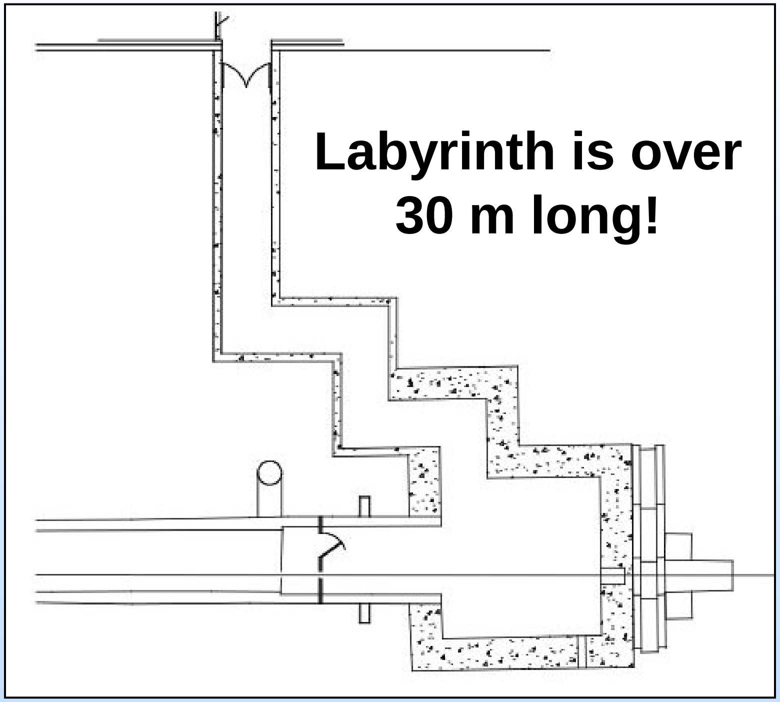
Facility Considerations – Setup and Cabling

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 <u>CABLE CADAVER</u>

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.