Automotive Semiconductor
Safety Innovation Conference

ASSIC 2021

반도체 가속 평가 최신 동향과 평가용 빔의 중요성

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QRT Inc., Korea

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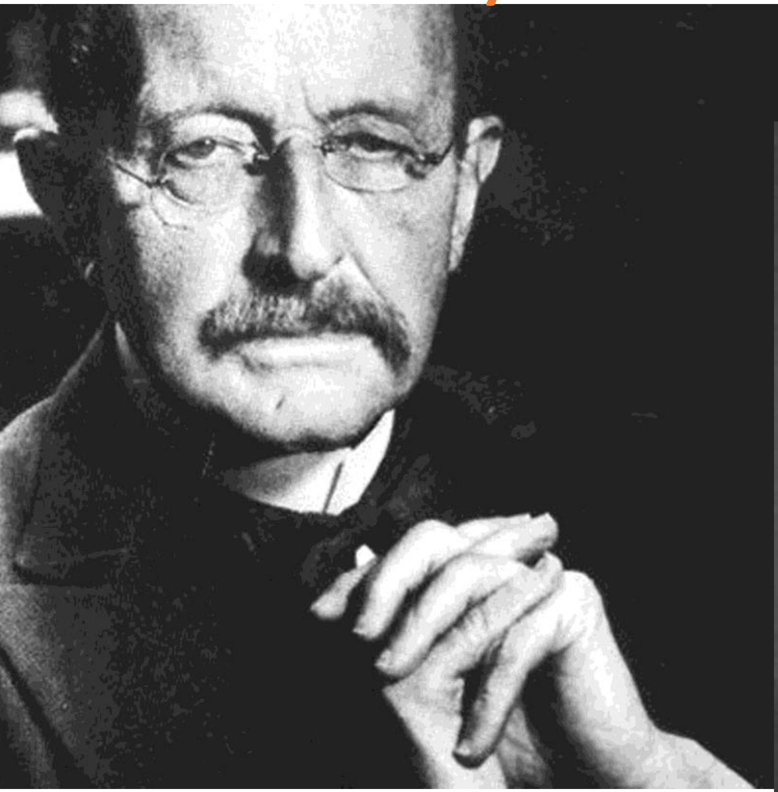
00

Status: Opening Thoughts

Quantum Mechanism and Quantum Effects

Where it all started 110 years ago

Black Body



Max Plank coined Quanta and Quantum in 1900 but he dismissed the idea

Einstein found Quanta of Light in 1905

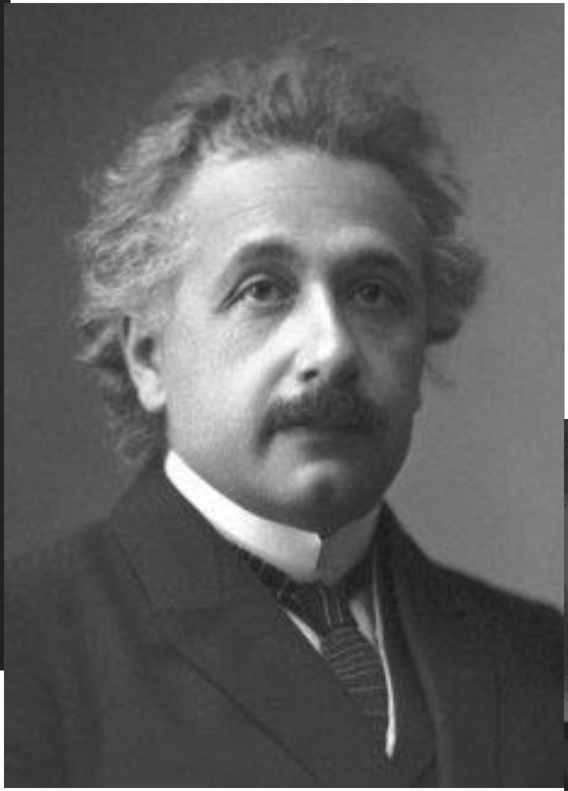
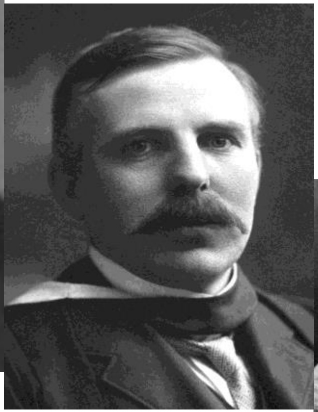


Photo Electric Effect

Rutherford proposes Solar System of the atom in 1910

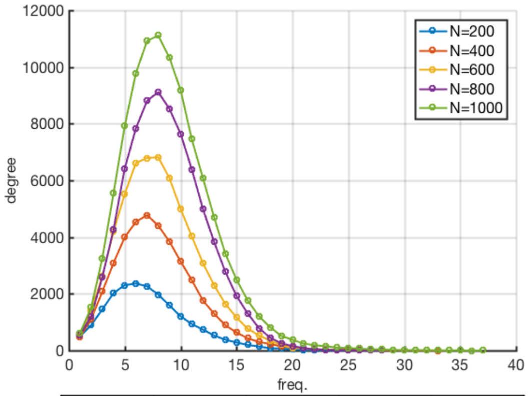


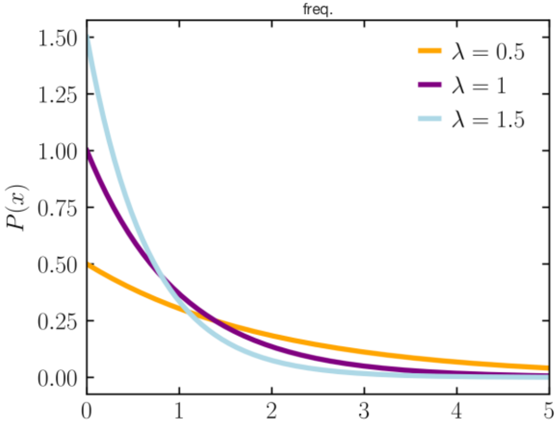
Atomic Model

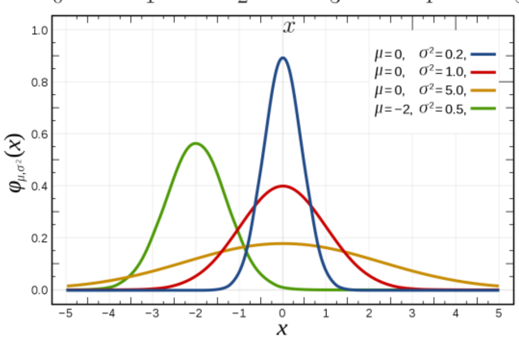
Bohr proposes Orbital Electrons in 1911

Quantum Mechanics

Distribution Functions







- Poisson Distribution
  - Neutron Spallation
  - Single Event Effects
  - Soft Error Arrival Time
- Exponential Distribution
  - Time between each particle arrives
  - Time between soft error happens
- Uniform Distribution
  - Particle profile
  - Error bit map
- Radiation test confirms these functions

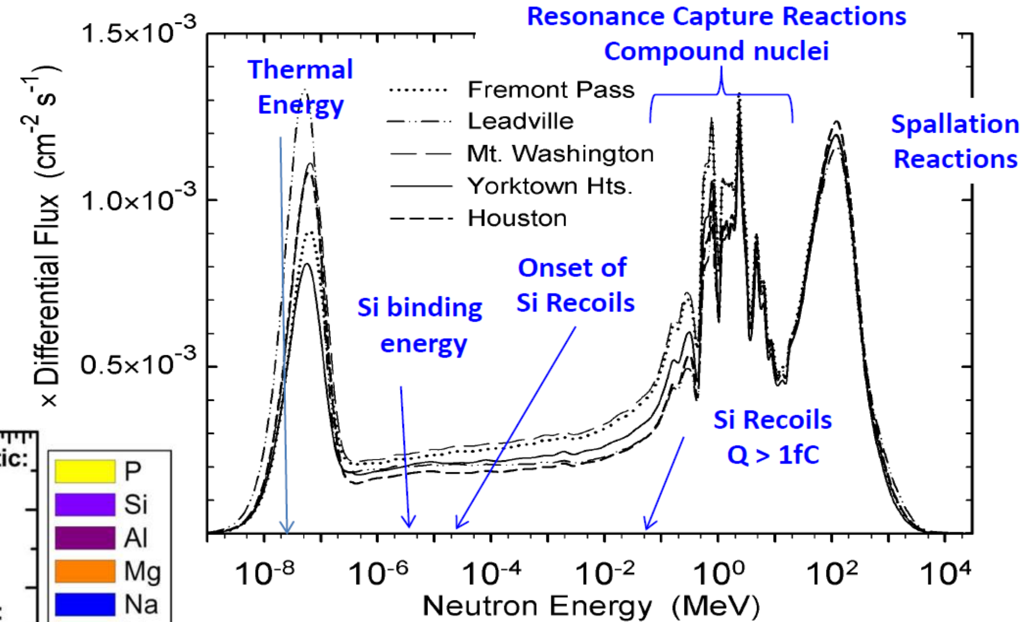
01

Status: Neutron Beam and Soft Error Rate

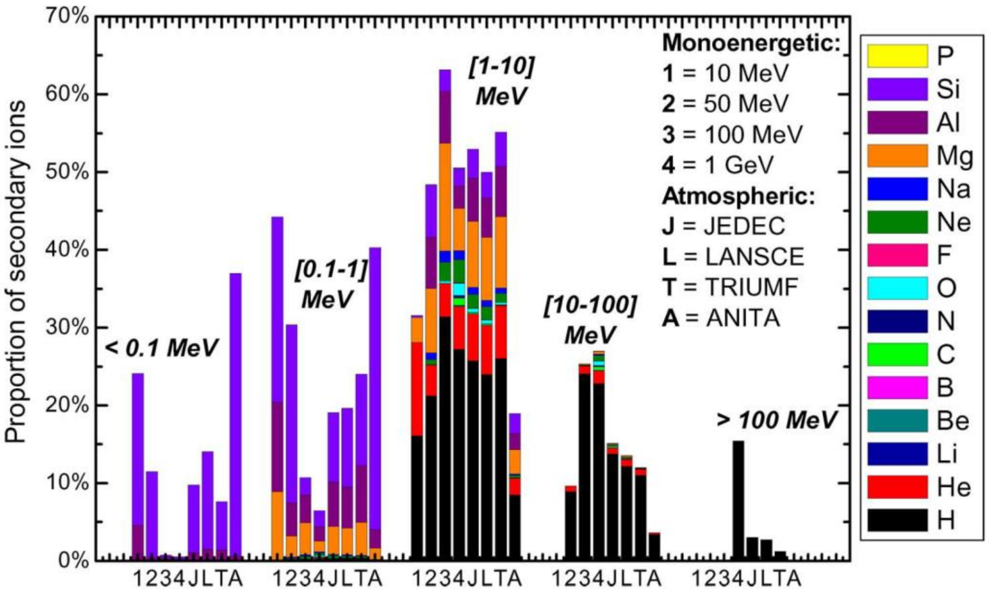
Nuclear Particle and its Effects

Energy histogram for the secondary ion

Terrestrial Neutron Lethargy Spectrum



Neutron Energy and Silicon Interaction



Energy histogram for the secondary ion cocktails produced by n-Si interactions for the different neutron sources considered.

Serre, S., et al,. "Geant4 analysis of n-Si nuclear reactions from different sources of neutrons and its implication on soft-error rate." IEEE Trans on Nuclear Science 59, no. 4 (2012): 714-722

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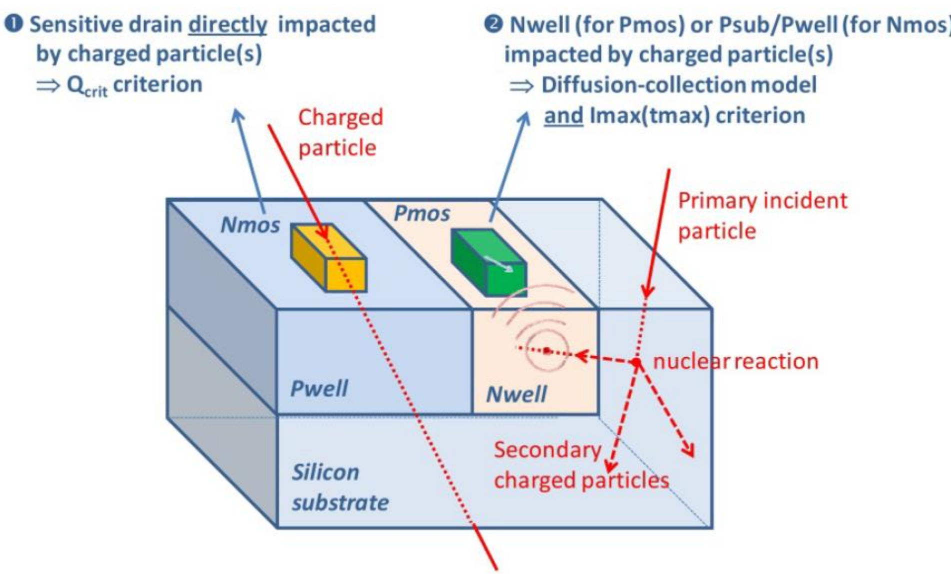
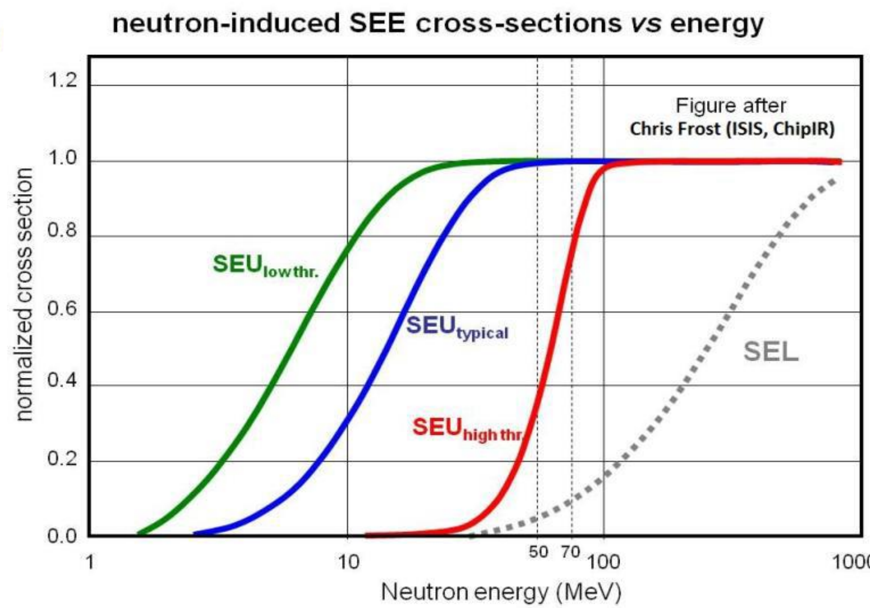
SEU and Neutron Threshold Energy

- Charged and Non-charged Particle Interaction with Silicon
- Normalized cross-section curves for current electronic devices' SEU and SEL per neutron energy

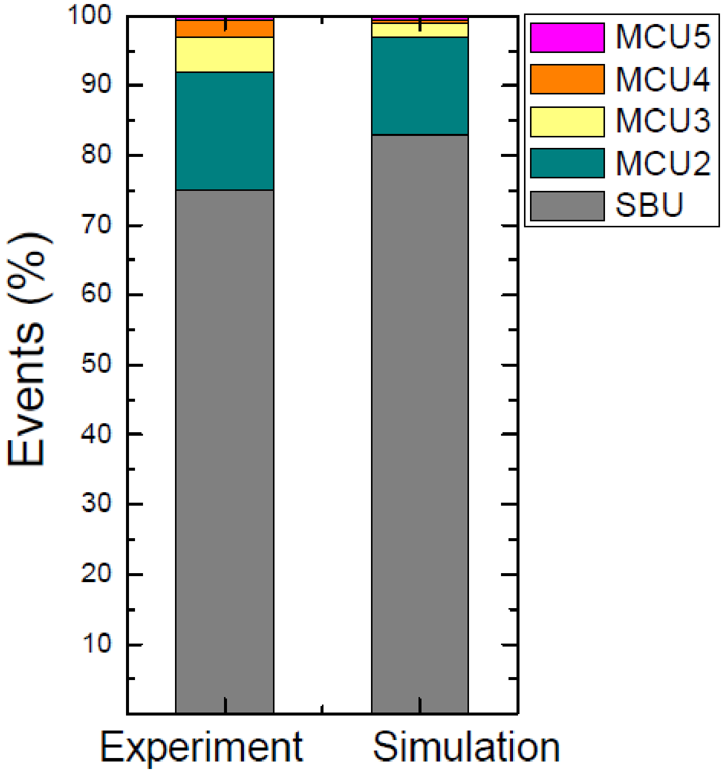


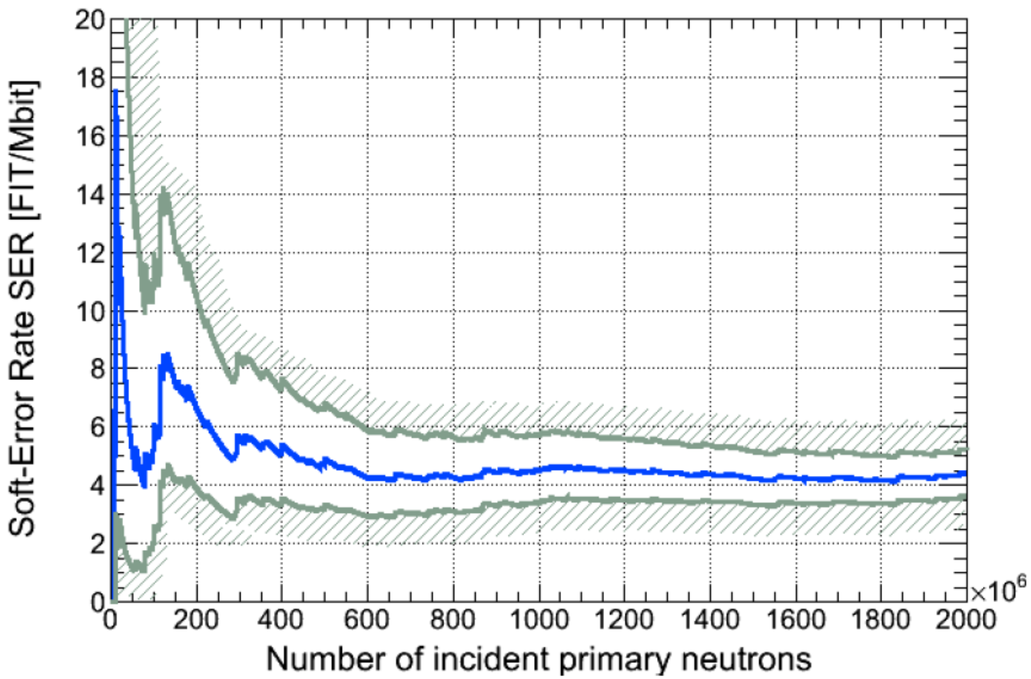


Neutron production targets for a new Single Event Effects facility at the 70 MeV Cyclotron of LNL-INFN

SER Simulation

Comparison between Simulation vs. Experimental Result of Soft Error Rates





$$SER = \frac{N_r}{AF \times \Sigma_r} \times 10^9 \ (\mathrm{FIT/MBit})$$

Autran, Jean-Luc, et al., "Soft-error rate of advanced SRAM memories: Modeling and monte carlo simulation." Numerical Simulation-From Theory to Industry (2012): 309-336.

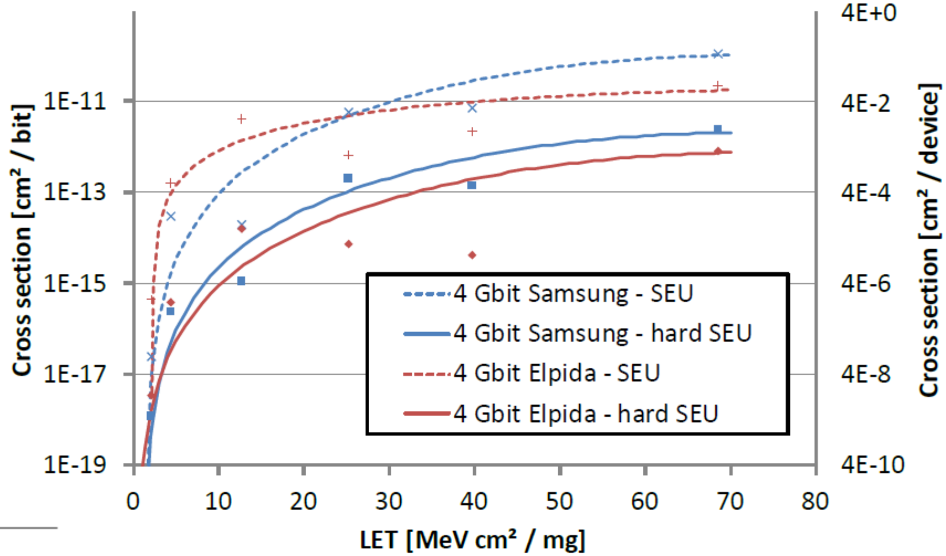
02

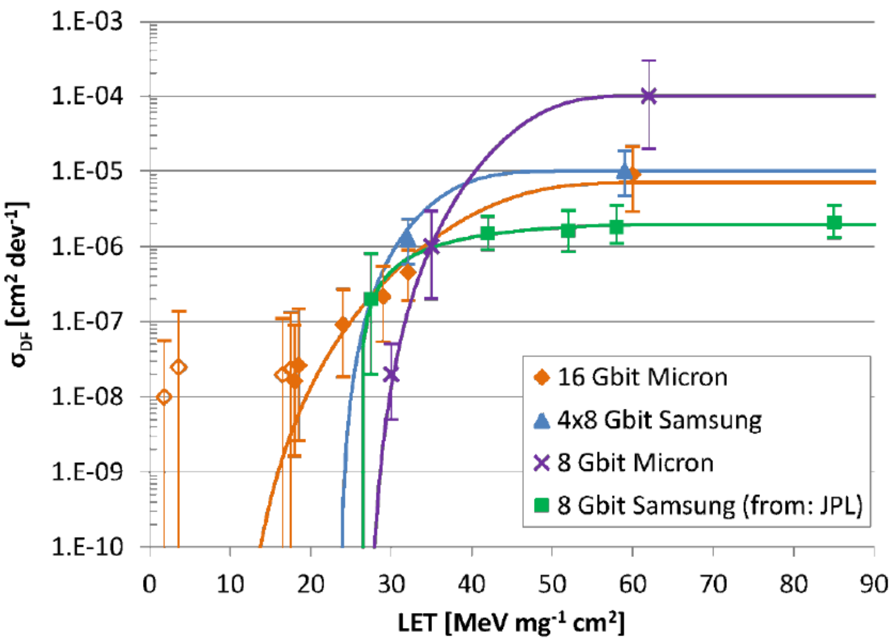
Status: Device Soft Error Rate General Trends

Single Event Effects and Soft Errors

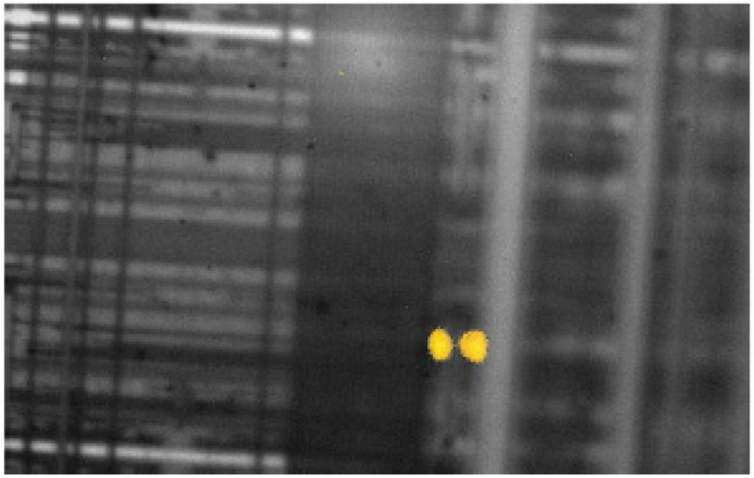
Hard and Destructive Events

- DRAM Hard Error
- Destructive events in NAND-Flash





Thermal picture charge pump region



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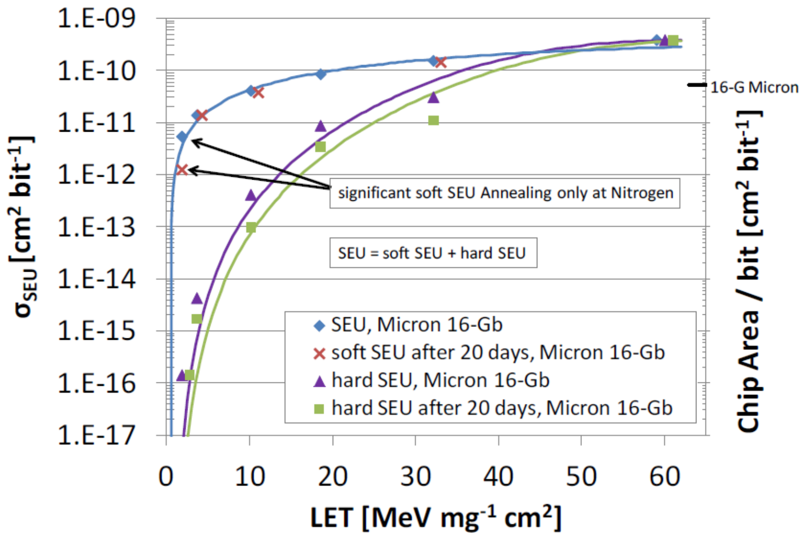
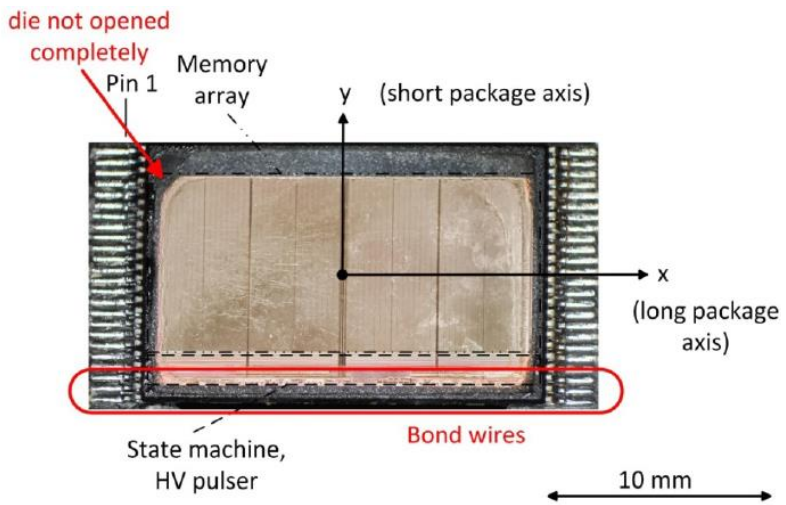
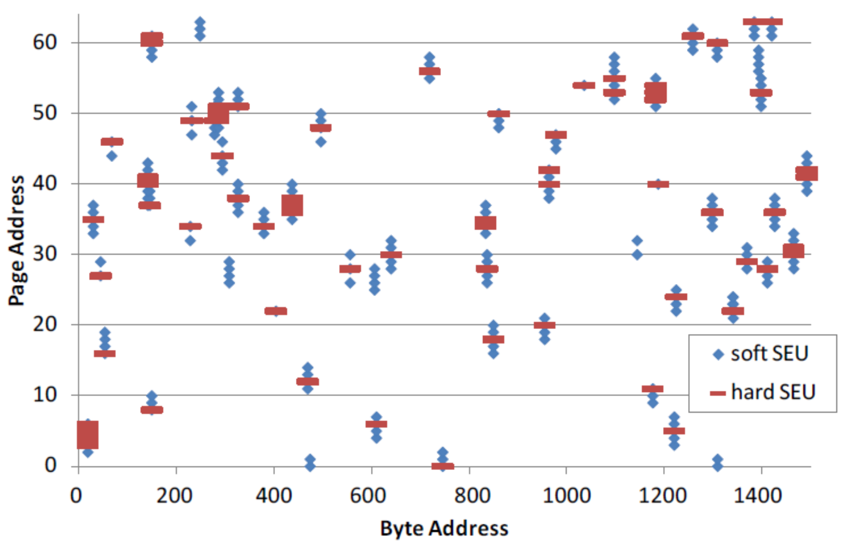
Stuck bits in NAND-flash

- Soft Error to Hard Error
- SSD has provisioning and ECC to accommodate these issues

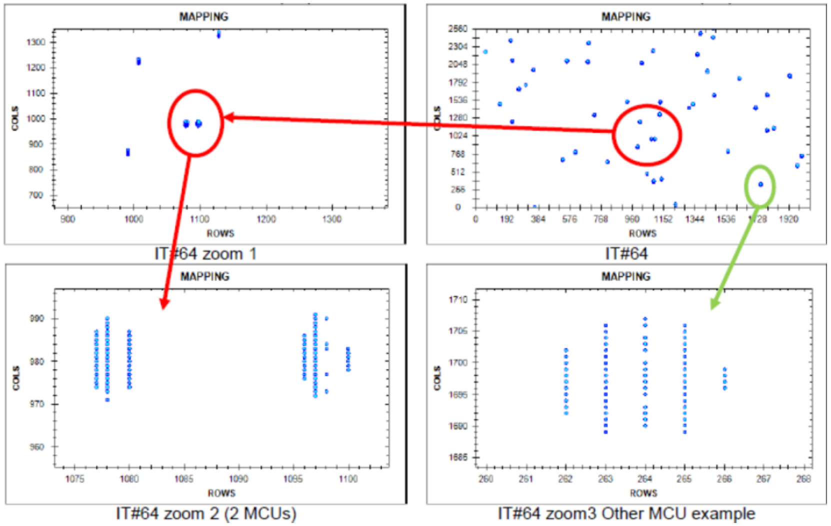




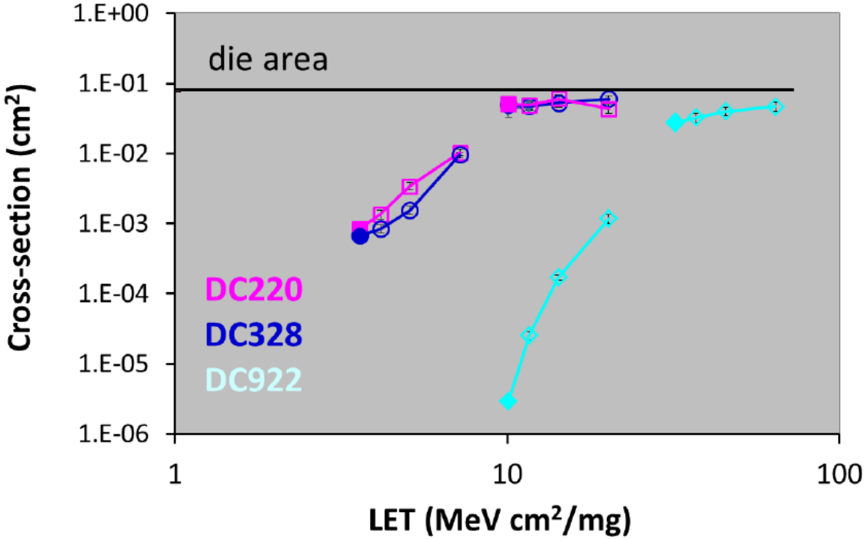


MCU and Lot to Lot Variation

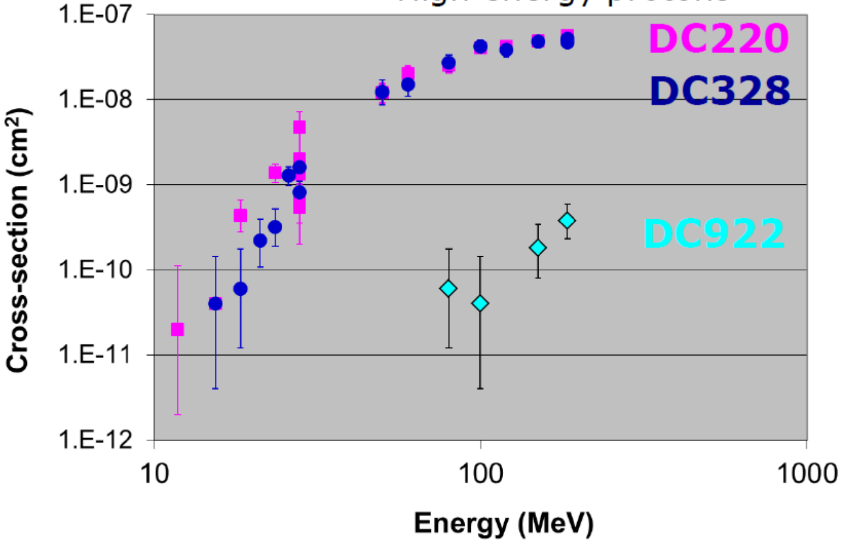
- Multi-cell Upset: One particle strike can induce more than 100 upsets
- SER Variation of the given DRAM device



Heavy ions



High energy protons



Ferlet-Cavrois, D. V. "Overview of radiation test activities on memories at ESA." *European Space Agency* (2015).

03

Status: Proton Beam and Degrader Simulation

Proton Beam Characterization for Radiation Test

Target Simulation: Transported Particles

- Types of Particles transported are similar in both cases
- Particle counts are not similar

Aluminum Target

Pb Target

```
------------------------------------------------------------
List of transport particles
------------------------------------------------------------
    Name        kf-code        mass       charge    baryon
    proton         2212       938.3          1         1
    neutron        2112       939.6          0         1
    photon           22         0.0          0         0
    deuteron    1000002      1875.6          1         2
    triton      1000003      2808.9          1         3
    3he         2000003      2808.4          2         3
    alpha       2000004      3727.4          2         4
```

Produced Particles

Aluminum Target

prod. particles	number	weight
proton	166338.	1.6633800E+05
photon	136270.	1.3627000E+05
neutron	81204.	8.1204000E+04
alpha	18838.	1.8838000E+04
deuteron	7289.	7.2890000E+03
3he	1090.	1.0900000E+03
triton	693.	6.9300000E+02

Pb Target

prod. particles	number	weight
photon	297418.	2.9741800E+05
neutron	256270.	2.5627000E+05
proton	75309.	7.5309000E+04
deuteron	1828.	1.8280000E+03
alpha	987.	9.8700000E+02
triton	603.	6.0300000E+02
electron	291.	2.9100000E+02
fission	229.	2.2900000E+02
3he	106.	1.0600000E+02

Source Particles are 0.5 Million Protons

- More neutrons than protons produced by Pb target
- Neutron produced in Pb target are **3.1X** more than Al Target
- Neutron produced in Al target are half of the Protons produced
- Neutron produced in Pb target are **3.4X** more than Proton produced

Stopped Particles (Trapped)

Aluminum Target

stop. particles.	number	weight
proton	520575.	5.2057500E+05
nucleus	178737.	1.7873700E+05
alpha	18833.	1.8833000E+04
deuteron	7207.	7.2070000E+03
3he	1088.	1.0880000E+03
triton	689.	6.8900000E+02
electron	554.	5.5400000E+02
photon	64.	6.4000000E+01
neutron	1.	1.0000000E+00

Pb Target

stop. particles.	number	weight
proton	476195.	4.7619500E+05
nucleus	196700.	1.9670000E+05
electron	117425.	1.1742500E+05
deuteron	1780.	1.7800000E+03
alpha	977.	9.7700000E+02
triton	596.	5.9600000E+02
3he	104.	1.0400000E+02
photon	57.	5.7000000E+01

Source Particles are 0.5 Million Protons

Aluminum Target

- 500,000 (primary) + 166338 (secondary) = 666,338 (total) Protons
- **520,575** protons stopped inside Al Target (**78%**)

Pb Target

- 500,000 (primary) + 75309 (secondary) = 575,309 total Protons
- **476,195** protons stopped inside Pb target (**83%**)

Escaped Particles (Emitted)

Aluminum Target

leak. particles	number	weight
photon	117982.	1.1798200E+05
neutron	43792.	4.3792000E+04
proton	143.	1.4300000E+02
deuteron	14.	1.4000000E+01
alpha	4.	4.0000000E+00
triton	2.	2.0000000E+00
3he	1.	1.0000000E+00

Pb Target

leak. particles	number	weight
neutron	150093.	1.5009300E+05
photon	38175.	3.8175000E+04
proton	2223.	2.2230000E+03
deuteron	30.	3.0000000E+01
alpha	10.	1.0000000E+01
triton	4.	4.0000000E+00
3he	1.	1.0000000E+00

Escaped Particles are from Proton Spallation

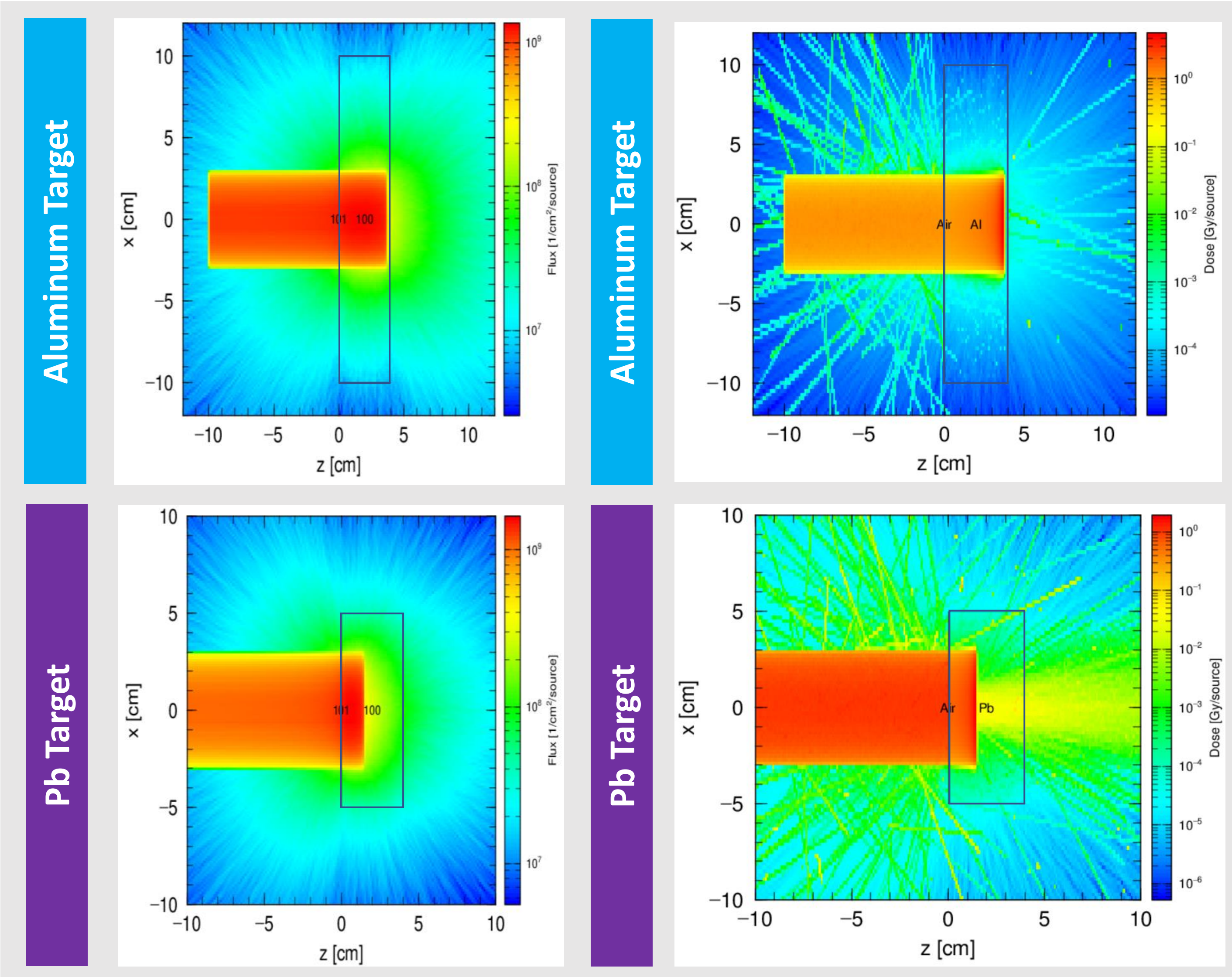
Aluminum Target

- For Al target, **43792** neutrons escape

Pb Target

- For Pb target, **150093** neutrons escape, **3.4** X more than Al target

Particles Track and Energy Deposit



- Track and fluence of the proton beam inside target
- Energy deposition by the proton beam inside target

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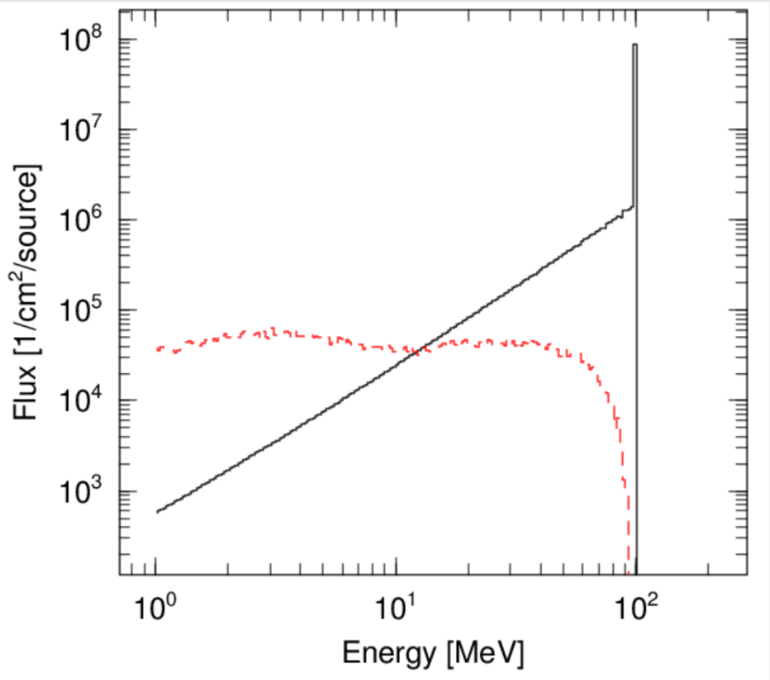
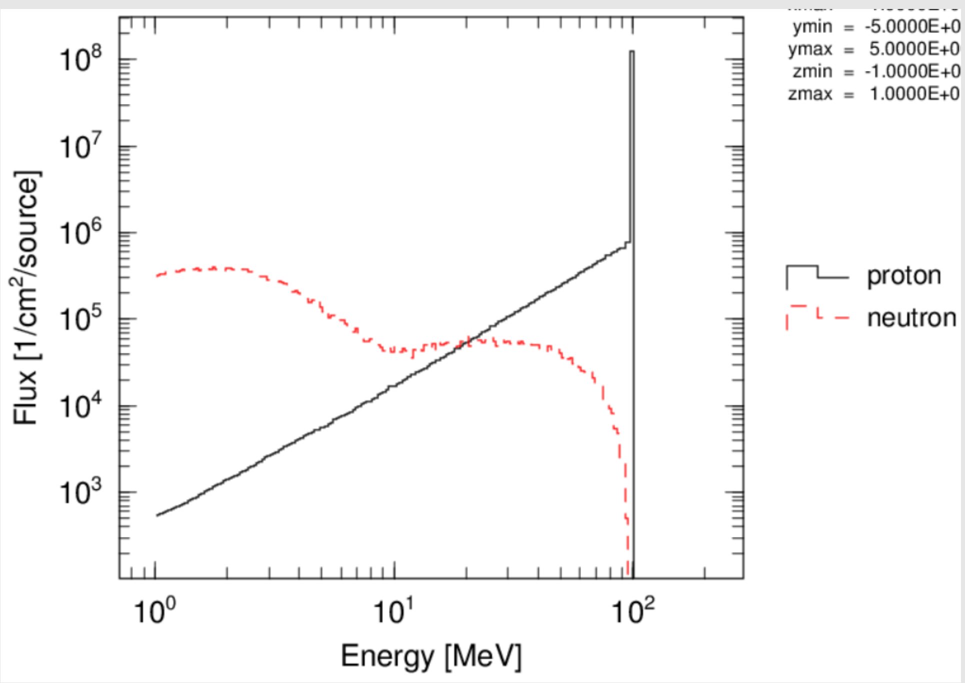
Particle Fluence

Aluminum Target



Pb Target



- Particle fluence with its energy distribution
- Total Fluence for all Particles = 5 x 10^{10} particles

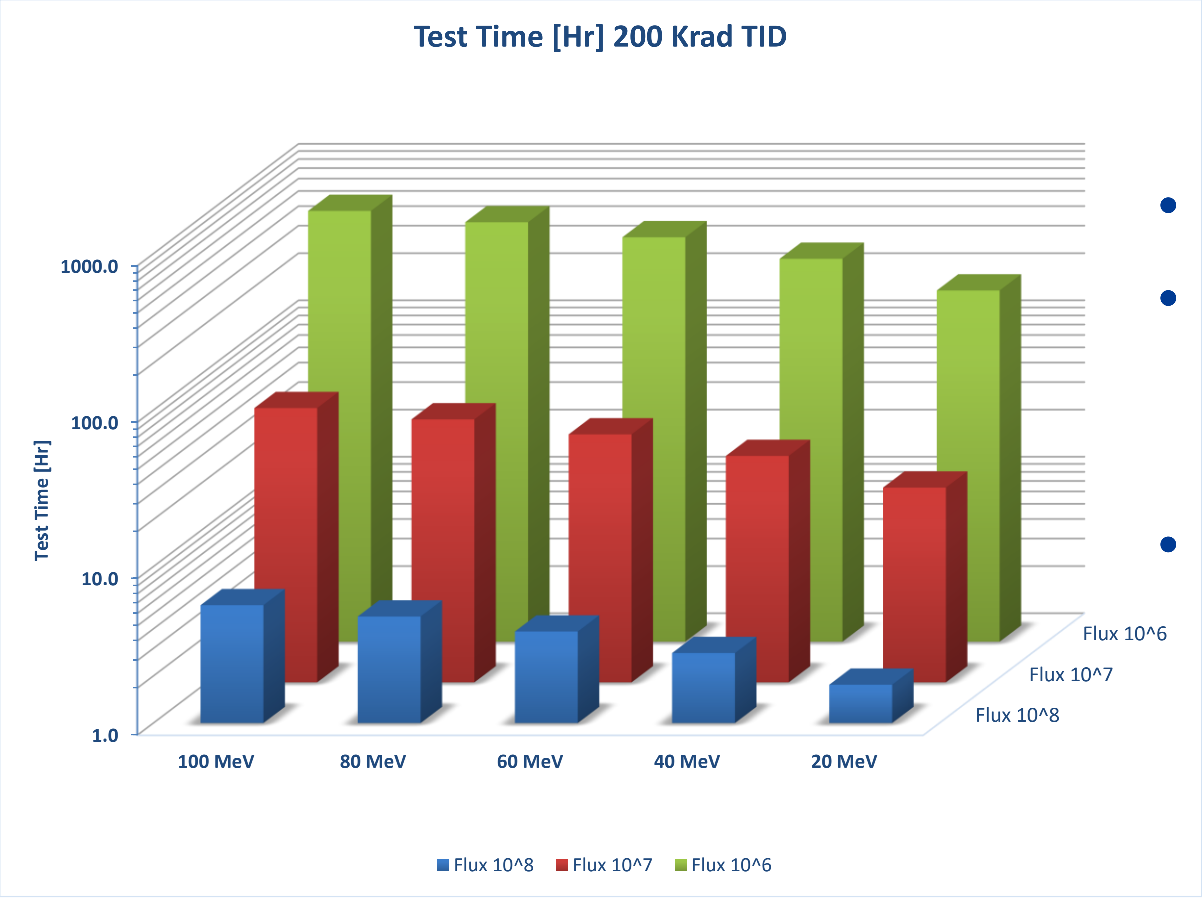
04

Status: Proton Radiation Test and TID Effects

Ionizing Dose Effects from Proton Irradiation

Beam Energy, Test Time, and TID Effects

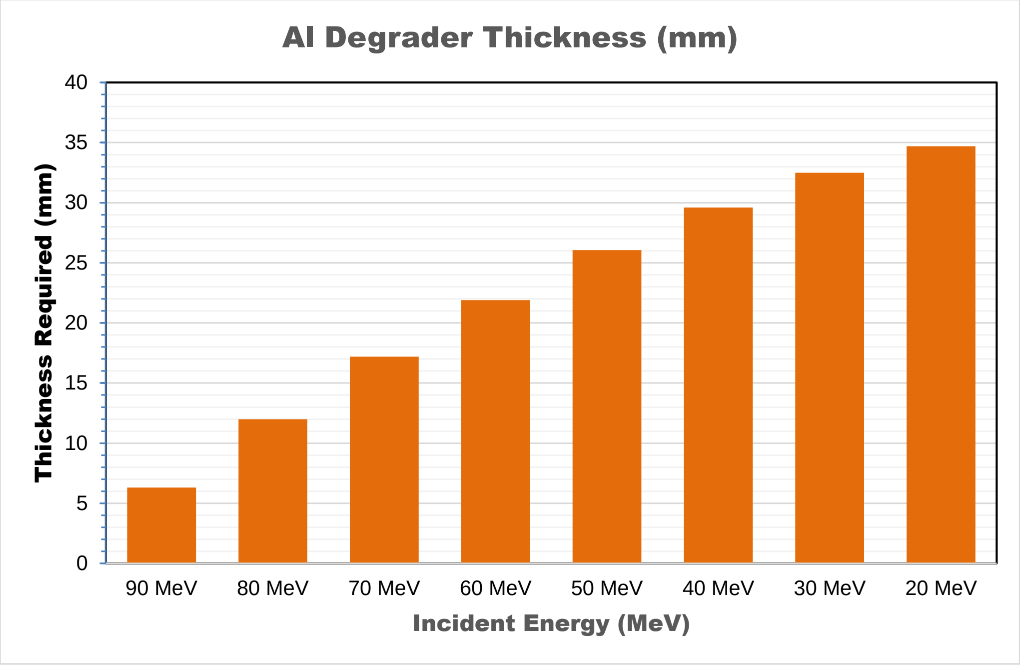
Total Ionizing Dose Effects (TID)

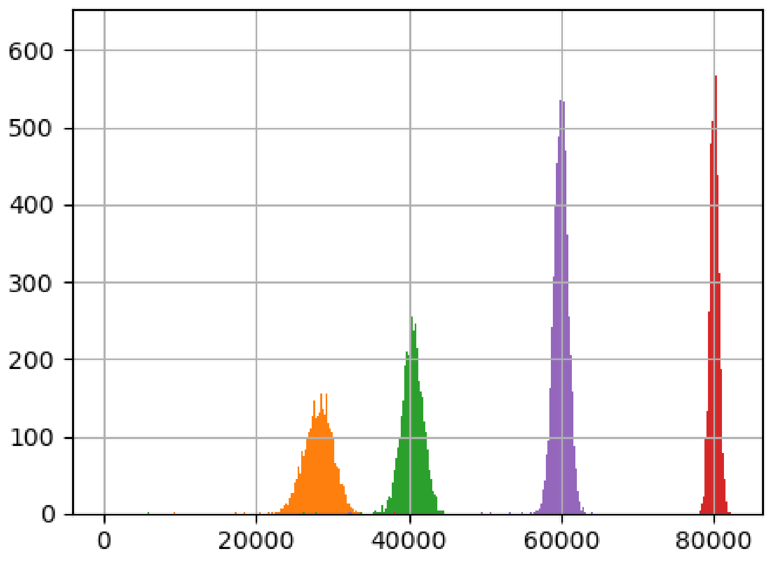


- TID impact test result
- High energy proton dumps more charges than lower energy
- The Test Time must consider upper limit of proton fluence and corresponding TID limit

Beam Energy and Al Degrader

- Thinner degrader is better for SEU cross-section test
- As the degrader get thicker, it causes more “range and energy” straggling
- Avoid using thicker degrader; it changes threshold energy of the cross-section





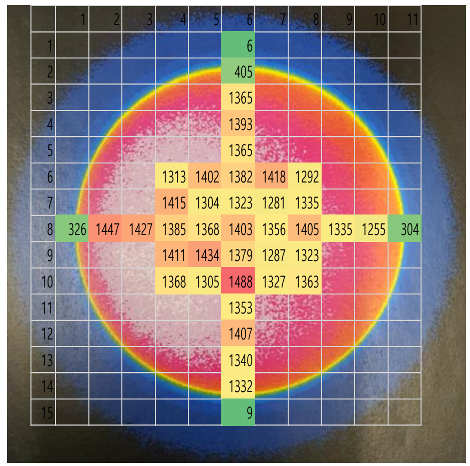
05

Status: Beam Profile and Device SER Variation

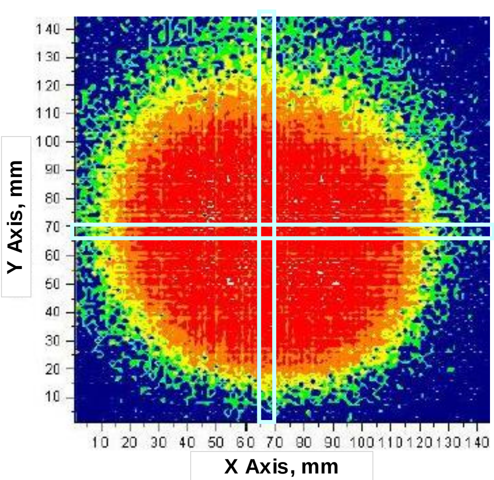
Variability of Beam and Sample During Test

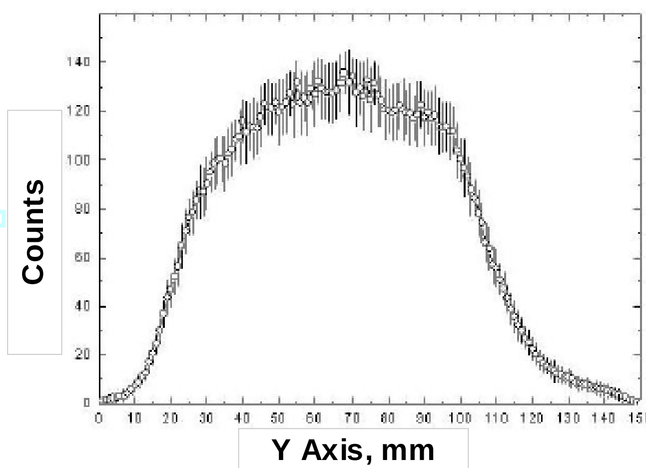
Beam Profile and Soft Error Rate

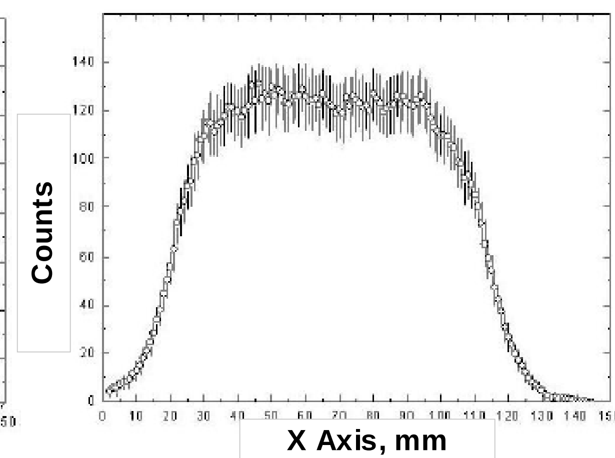
Beam Profile and Test Scenario



- Beam Profile has ±10% Fluence variance.
- Devices have more than ±10% SER variance
- Combined result can mislead SER up to ±20%

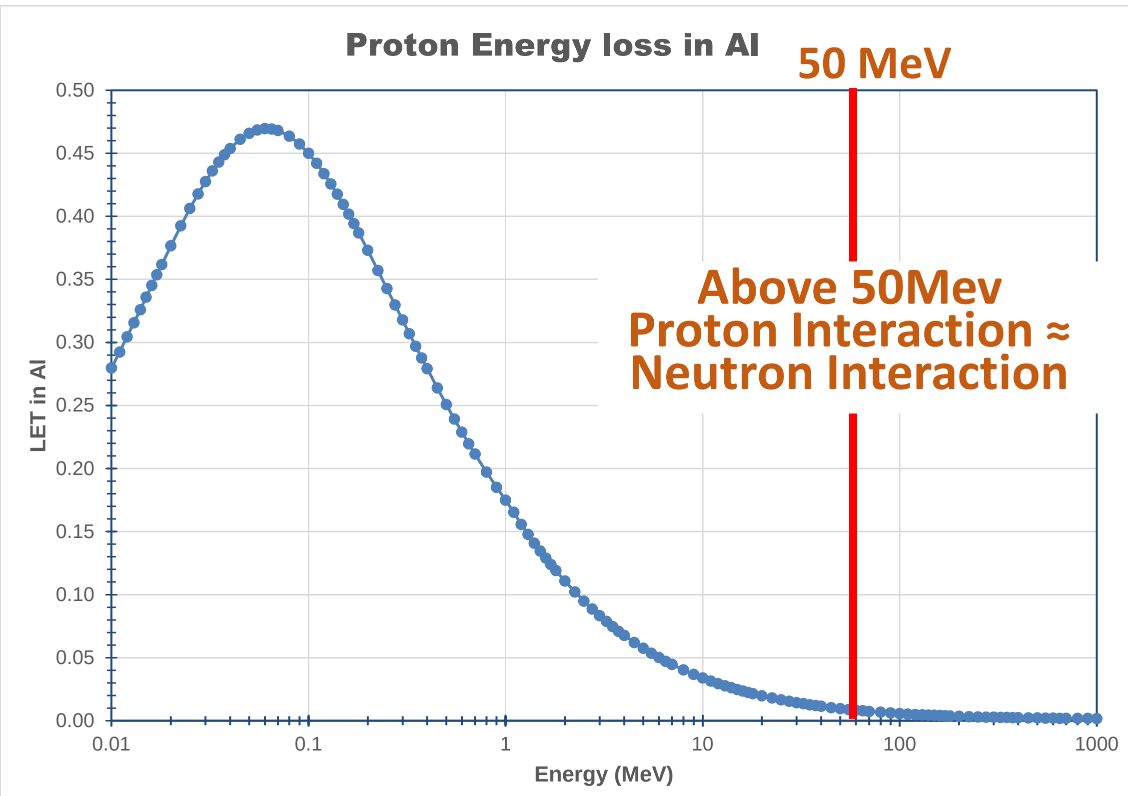




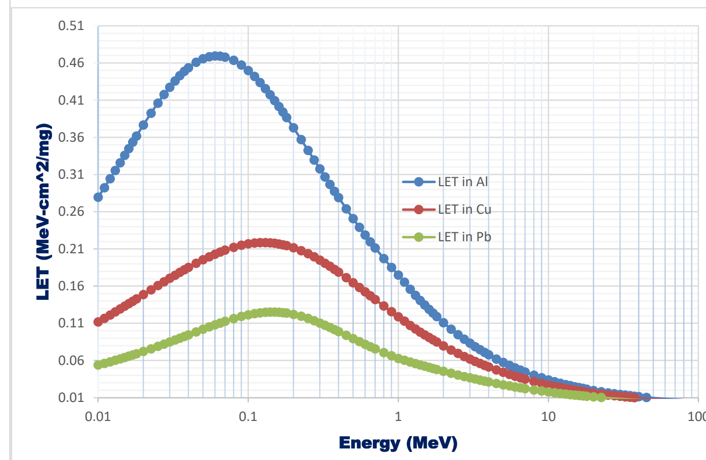


Proton Energy Loss in Silicon

- Ionization: Electron and Hole Pair Generation
- Recombination and Thermalization
- Elastic and Inelastic Interaction
- Secondary Particle Interaction



How to get meaningful test result from 100MeV Proton Beam?



LET for Al, Cu, and Pb

06

Status: Conclusions

Good Beam gives Good Test Result

How to get the most out of 100MeV

- **Good Dosimetry** and Beam Profile
  - Fluence variation impacts more then than energy variation
  - Yearly measurement of Beam Profile
  - Dosimetry Data application note for test data analysis
- **Proton** produces **secondary Neutrons** and Protons
  - Beam degraders and beam stoppers are the sources for the dirty particles contaminating the test results
- Customers are not well versed in Quantum Physics
  - Better documentations and guidelines help customers to produce better test results
- 100 MeV proton beam can do a lots of contributions to the SEE test

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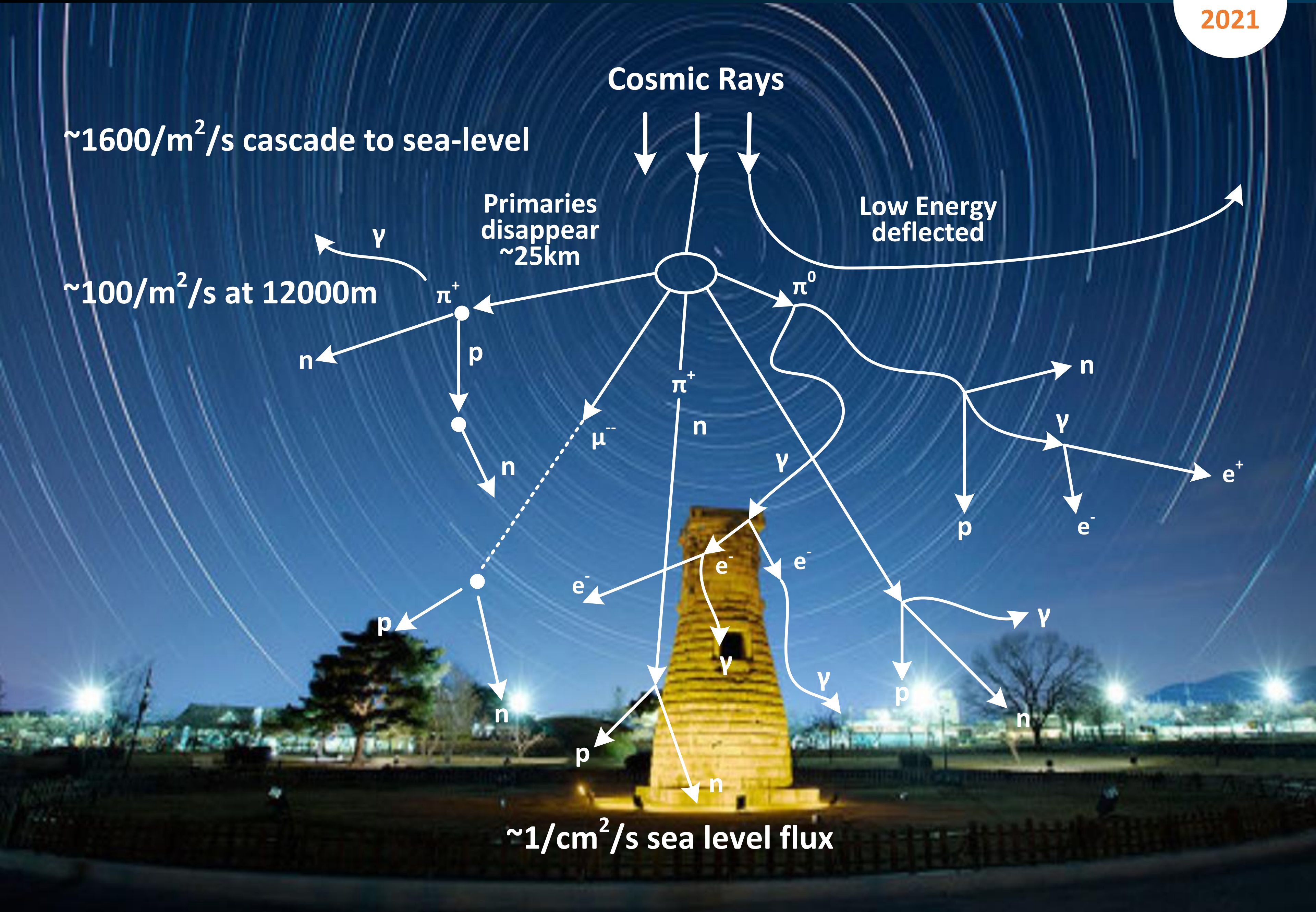
Cosmic Rays
~1600/m²/s cascade to sea-level
Primaries disappear ~25km
Low Energy deflected
~100/m²/s at 12000m
γ
π+
π0
n
p
n
μ--
π+
n
γ
n
γ
e+
p
e-
e-
e-
e-
γ
p
n
γ
γ
p
n
p
n
~1/cm²/s sea level flux