Neutron Single Event Effects Testing at LANSCE

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Single Event Effects Symposium

Military and Aerospace Programmable Logic Devices Workshop

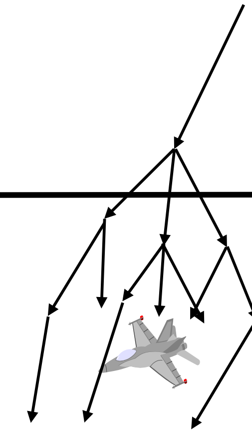
October 6, 2020

LA-UR-20-27633

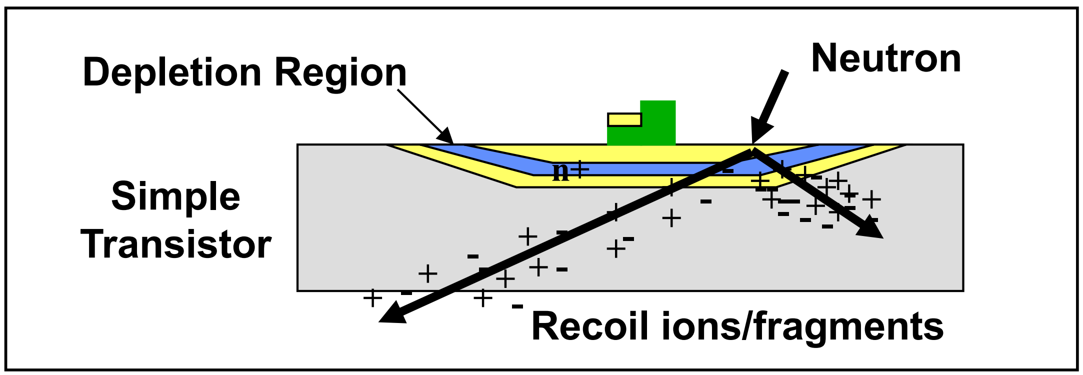
Outline

- The terrestrial particle flux
- LANSCE terrestrial neutron radiation testing facility
- Time-of-Flight measurements
- A recent measurements on MOSFETs

Neutron Single Event Effects (SEE)

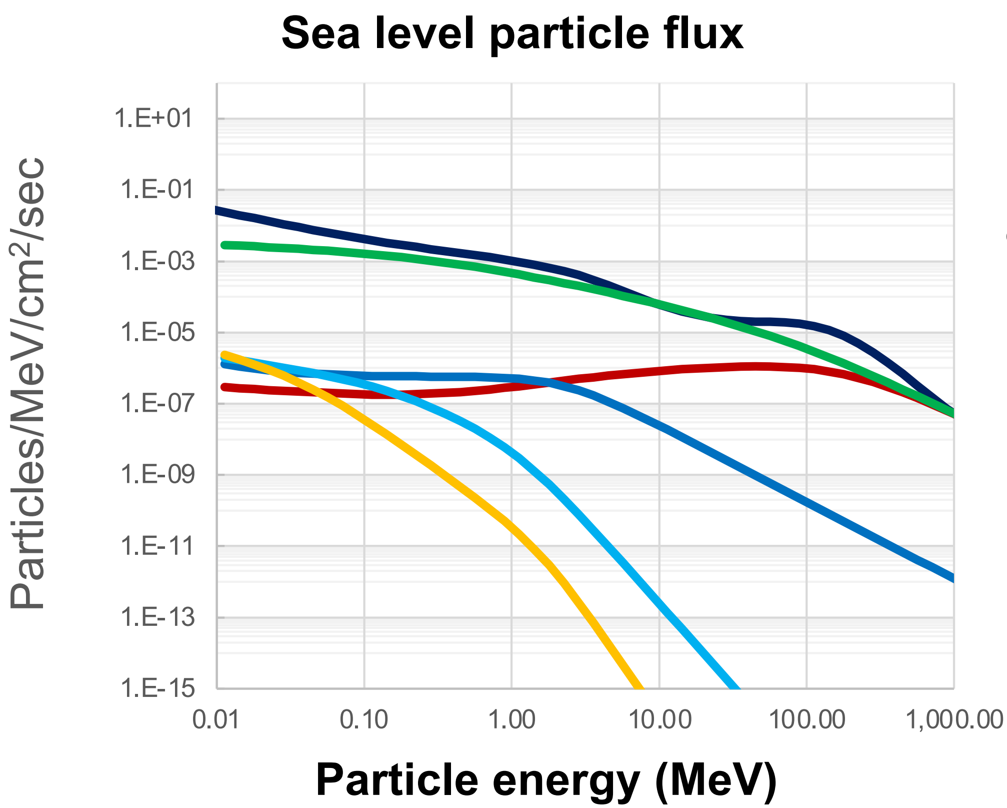


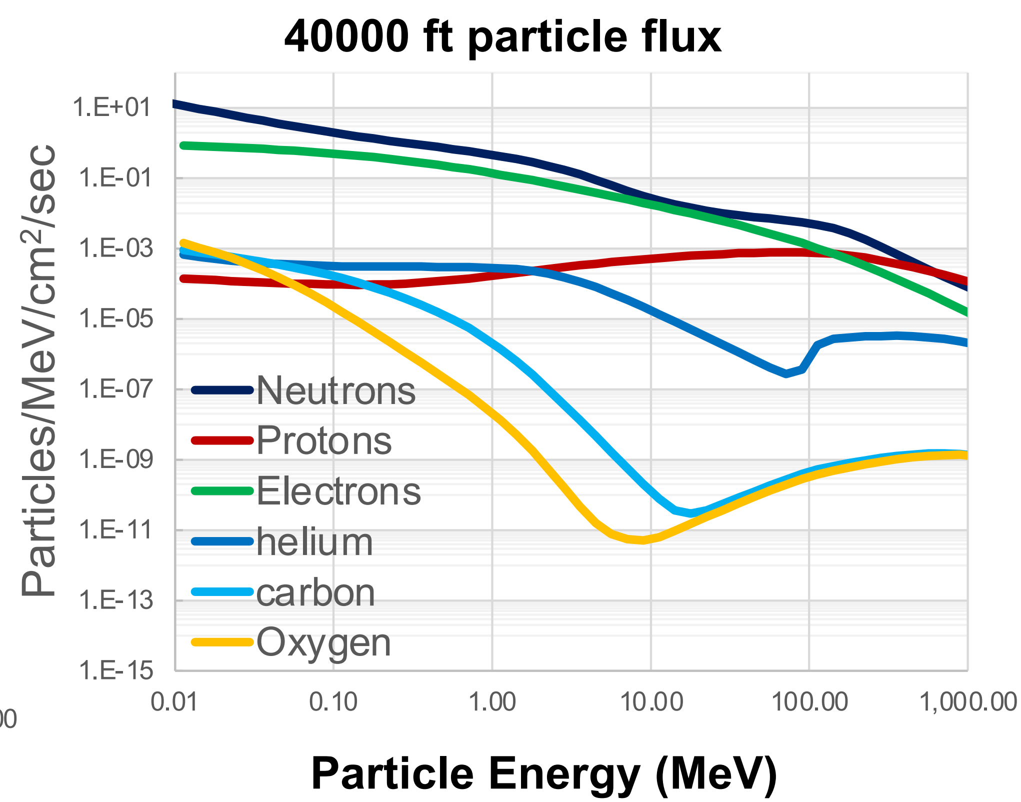
- *Neutrons are the greatest threat* ***at sea level and aircraft altitudes***
  - Produced by cosmic ray interactions in upper atmosphere
  - Penetrate to low altitudes – long mean free path
  - Interact indirectly with devices through nuclear interactions
  - SEE include soft errors (SEU, MBU) and hard errors (SEL, SEGR)
- *Neutrons also present in local spacecraft environment through cosmic ray spallation*



Neutrons need nuclear reaction to create charged particles. Charged recoil ions (elastic collisions) and fragments (inelastic) ionize device material and deposit charge in the sensitive volume where it can cause an upset.

Terrestrial radiation flux





- Terrestrial radiation flux is mostly neutrons and electrons
- Protons contribute at higher altitudes
- Heavy ions get important in space and very high altitudes
- Calculations from EXPACS spreadsheet
  - Research Group for Radiation Transport Analysis
    Environment and Radiation Sciences Division, Nuclear Science and Engineering Center, Sector of Nuclear Science Research, Japan Atomic Energy Agencyhttps://nsec.jaea.go.jp/ers/radiation/en/rpro/index.htm

Failure rate is convolution of a Flux with a cross section

- The failure rate due to cosmic-ray events is given by:

$$F/t = \sum_p \int \sigma_p(E_p) * \Phi_p(E_p)\, dE$$

Particle flux depends on:
Particle type
Altitude
Latitude
Solar activity
Local geometry

Cross section depends on
Device characteristics
Particle type
Particle energy

F/t is the number of fails / time

p is the particle type (neutron, protons, pions,…)

$\sigma_p(E_p)$ is the number of upsets /particle with energy E_p

$\Phi_p(E_p)$ is the number of particles/sec with energy E_p

Los Alamos Neutron Science Center (LANSCE) User facility

800 MeV proton linear accelerator (linac)
Linac is approximately 1 km long

Weapons Neutron Research High-energy Neutrons

Proton source 200-800 MeV Linac and PSR beam

Lujan Center Low-energy neutrons

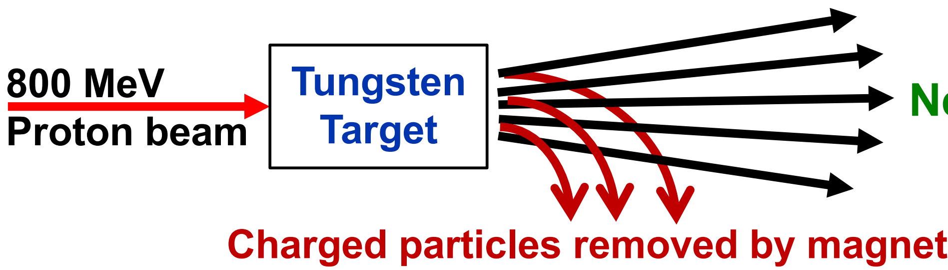
Isotope Production Facility

Proton Radiography

Future Proton Source

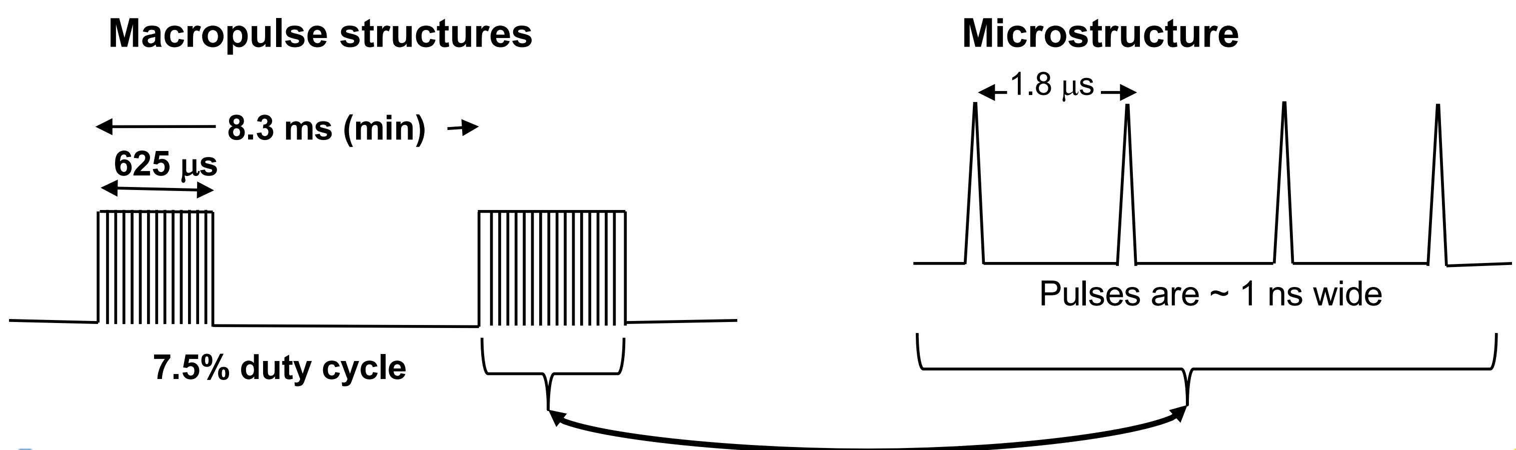
Ultra Cold Neutrons

Neutrons at LANSCE are produced by spallation reactions



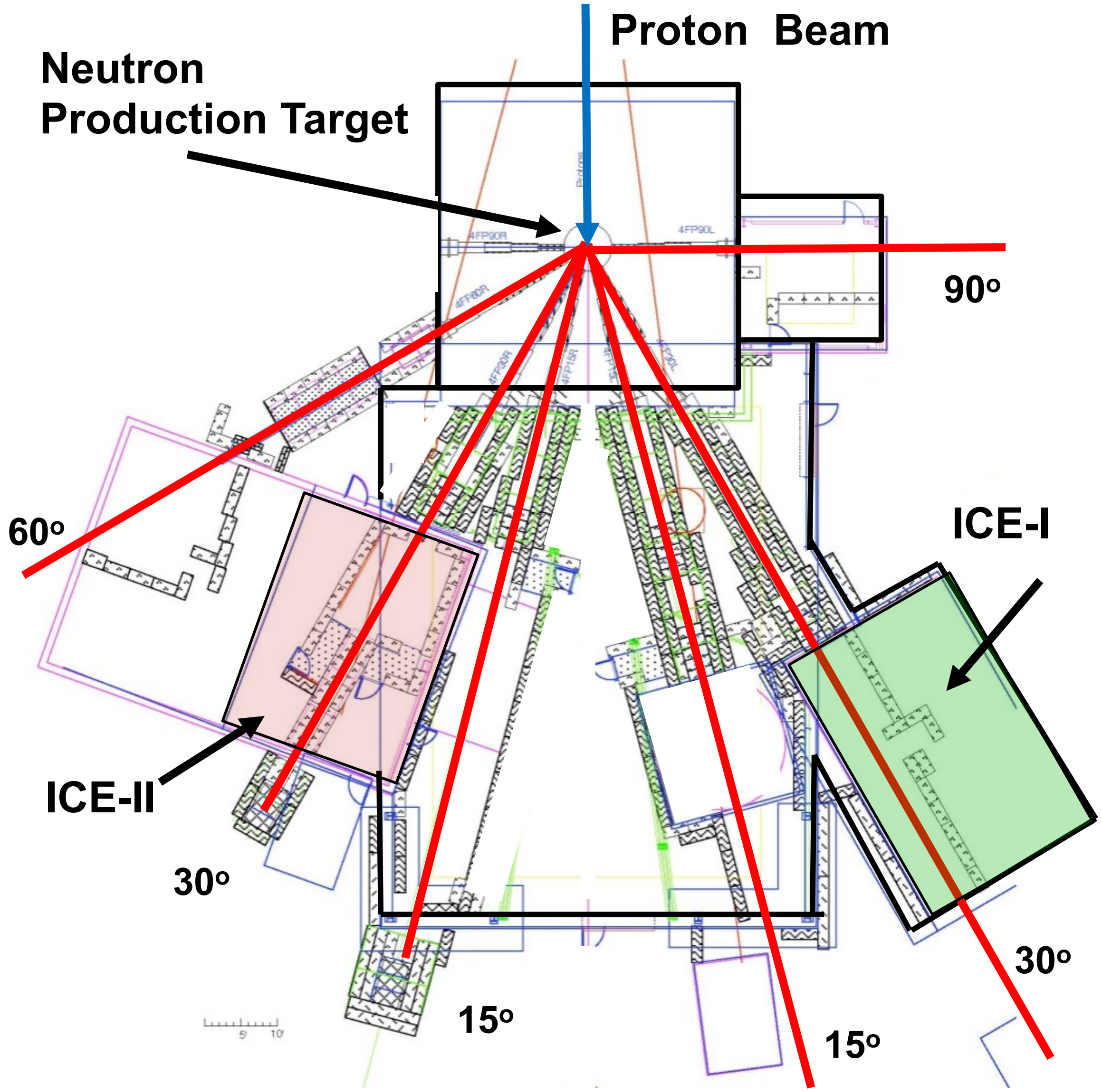
- 1 proton yields ~18 neutrons

- Neutrons have no charge so can't be accelerated, have to be made at by nuclear reactions
- Proton spallation reactions on a high-Z target produce a wide range of output particles
- The proton beam is pulsed so time-of-flight techniques are possible



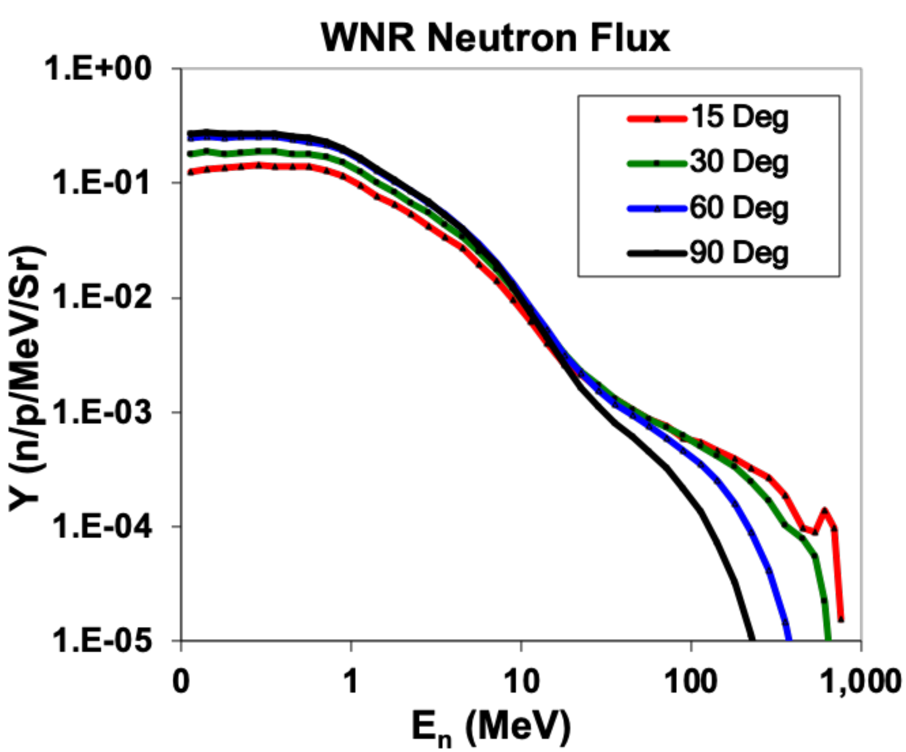
High-energy neutron experimental (WNR) area

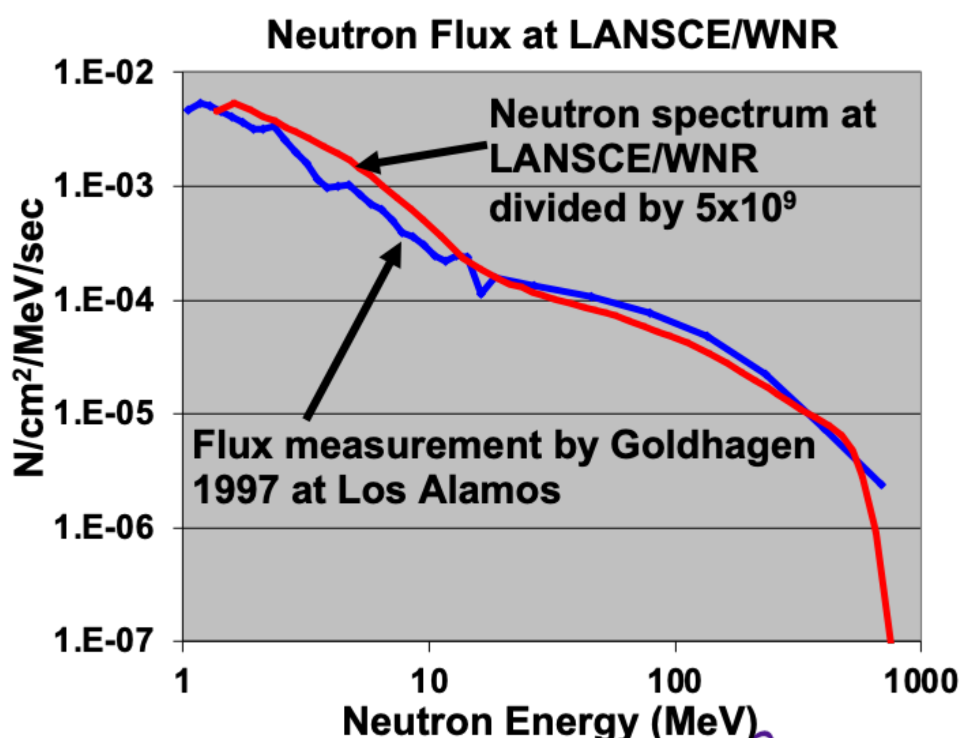
- ~4 μA (1 KW in target) of proton beam current is used for high- energy neutron production
- Six flight paths operate simultaneously
- The first area for neutron testing was developed in 2004 (ICE House, 30-L). The second area was developed in 2012 (ICE-II, 30-R)



The high-energy neutron spallation source at LANSCE

- The shape of the neutron spectrum depends on the angle of the flight path with respect to the proton beam
- The best match to the cosmic-ray produced neutron spectrum is at 30^0

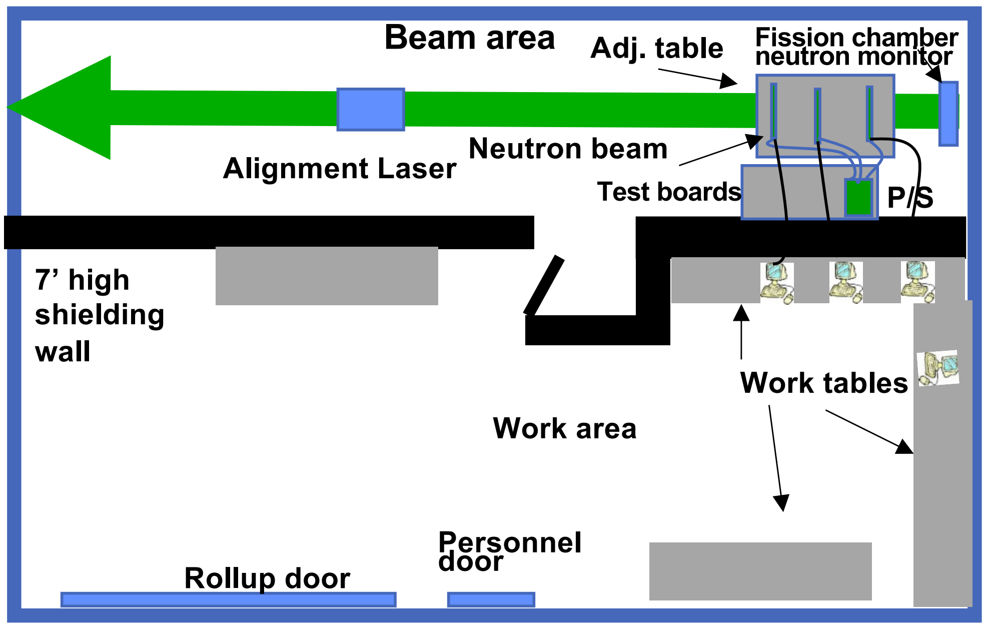




ICE House experimental area

ICE-I experimental area

800 sq ft building   40' x 20'



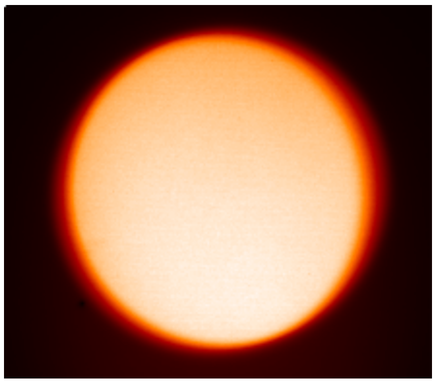
E_n >1 MeV
2×10^6 neutrons/cm^2/sec   ICE-I
4×10^6 neutrons/cm^2/sec   ICE-II

E_n > 10 MeV
1×10^6 neutron/cm^2/sec   ICE-I
2×10^6 neutrons/cm^2/sec   ICE-II

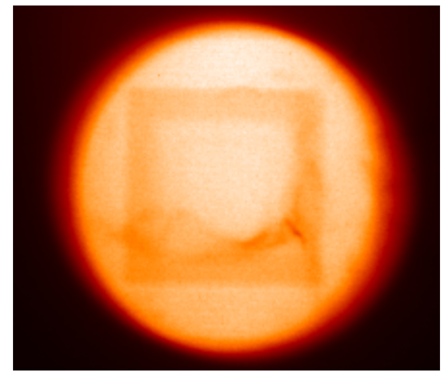
An image plate of the beam spot shows uniform exposure

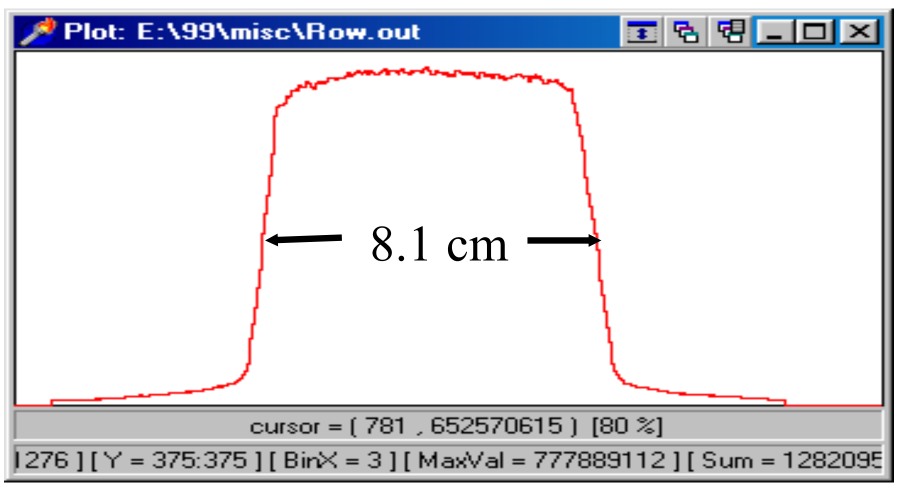
- Neutron beam spot size is determined by steel collimation (~ 3 feet long)
- Presently we have collimation for 1” to 4” spot sizes

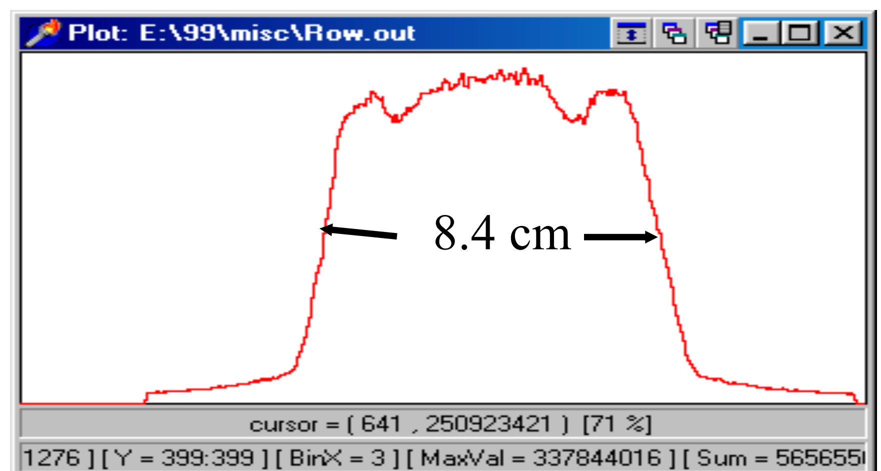
Upstream



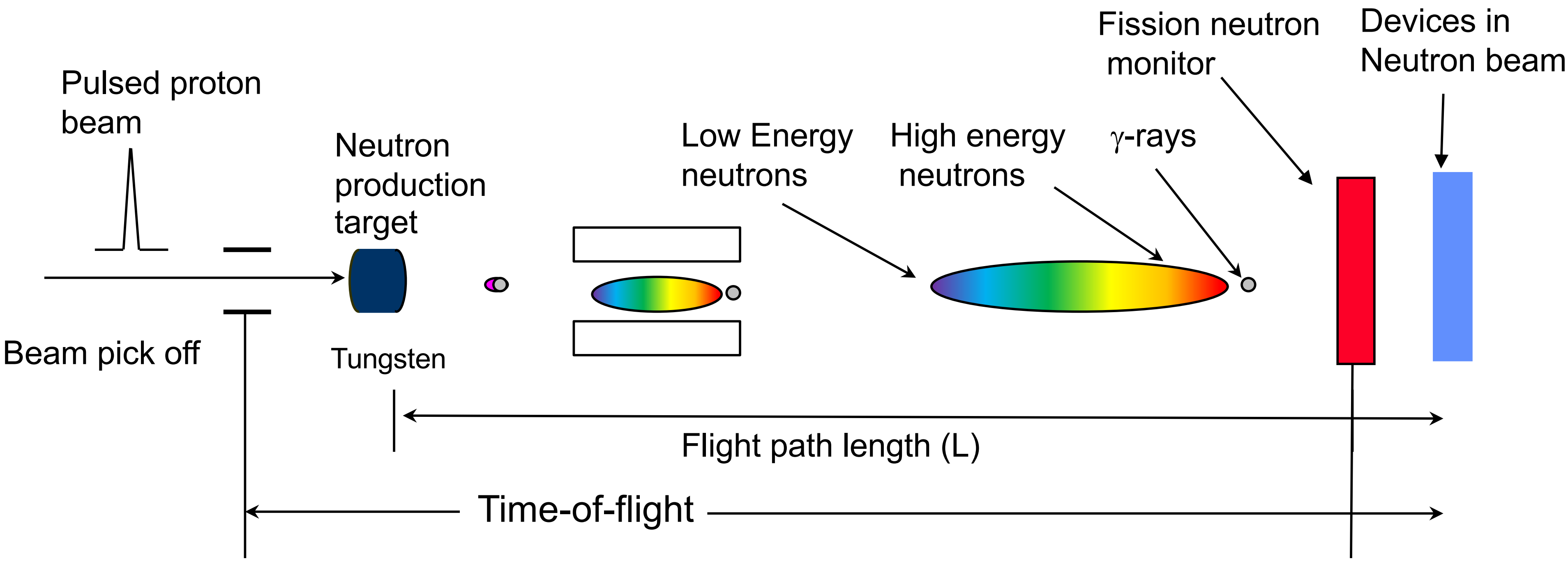
Downstream







Time-of-Flight techniques are used to measure the energy of the neutrons



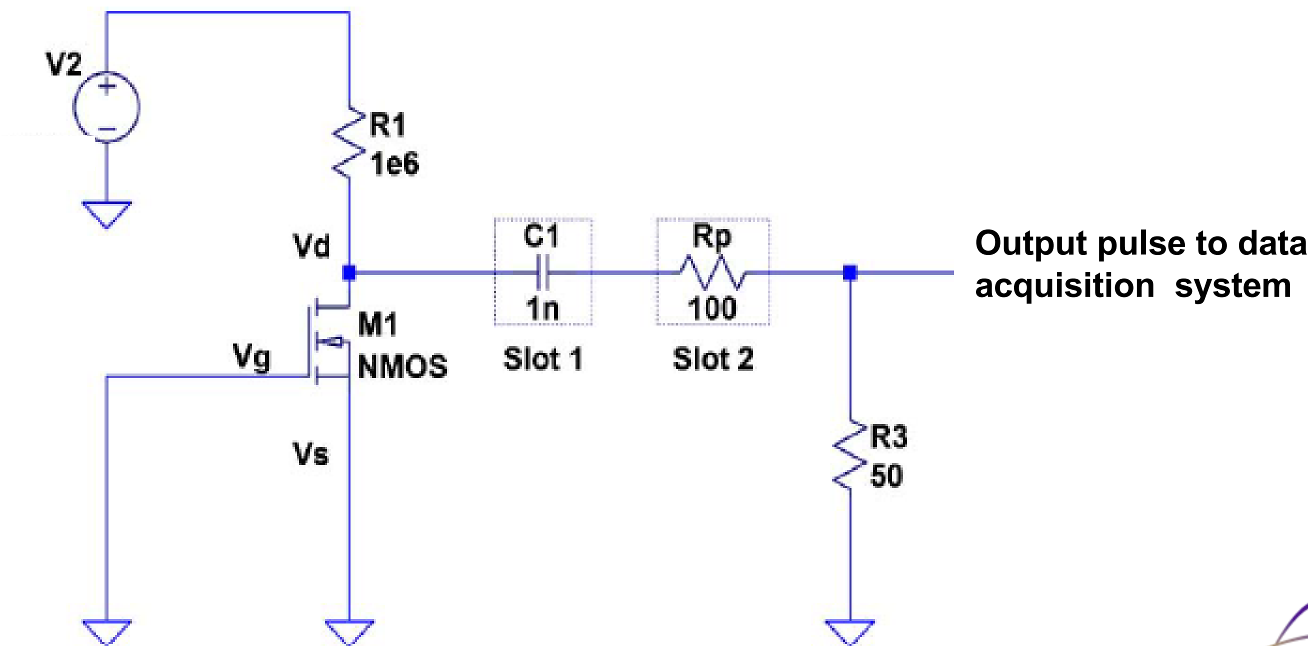
$$Neutron\ TOF = \frac{72.3\ L}{\sqrt{E_n}}$$ (Non-relativistic)

$$\gamma\ TOF = \frac{L}{c}$$ (c is speed of light)

- For L=20m, the gammas arrive in 67ns
  - 1 MeV neutrons take 1.5 μs and 100 MeV neutrons take 150 ns to arrive
- If we can tag the time of the device upset within a few ns, we know the energy of the neutron that caused it

Measurement of SEE cross section for MOSFETs

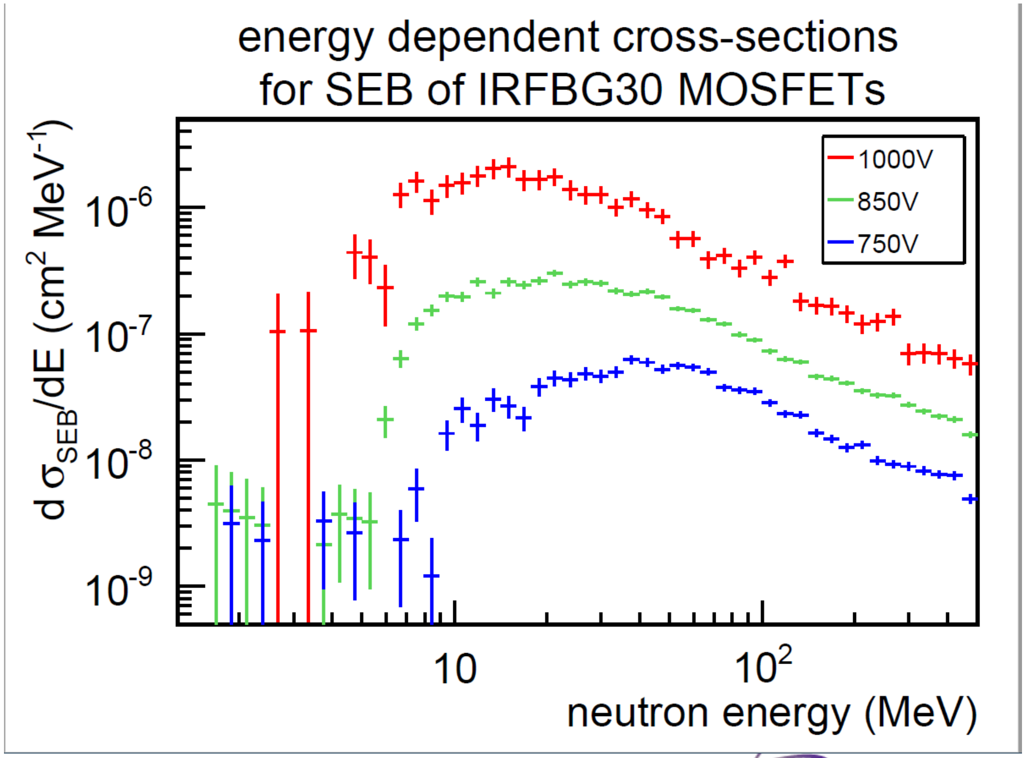
- A test circuit was designed to measure measure destructive single event burnout without destroying the device. R1 is a current limiting resistor.
- An output pulse is obtained when there is a SEE event in the MOSFET
- The time of this pulse and its amplitude is stored in our data acquisition system
- The TOF of the event is converted to neutron energy and divided by the neutron flux to obtain a cross section.



Results of MOSFET cross section measurement

- Full energy cross sections for SEB were acquired for IRFBG30 MOSFET at 1000, 850 and 750 volts in less than a day
- This is a differential cross section (per MeV). Plotting data as average over bin results in the familiar saturation plateau for high energy

- The SEB cross section depends strongly on applied voltage
- Expected behavior
- Bias changes both threshold and shape of the cross section



Summary

- LANSCE is an excellent place to test semiconductor devices in a terrestrial neutron spectrum
  - Good match for terrestrial level neutrons - acceleration factor ~ 10^8 compared to sea level
- TOF techniques allow direct and precise measurement of neutron energy
  - Energy-dependent cross sections from broad spectrum beam for devices with a fast upset signature
  - Have been applied to measure SEB cross section in power MOSFETs
- We are working on approaches to measure the energy-dependent cross section for digital devices
  - New techniques needed for devices with no fast timing signal