SOFT ERROR RATE TEST METHODOLOGY FOR ADVANCE PROCESS NODES UNDER NEUTRON BEAM AT CHIPIR

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AGENDA

- Motivation
- Previous Experiments, New Design
- Experimental Setup
- The Math
- Results
- Issues/Future Work

MOTIVATION

- FIT(Failures In Time) is a measurement of soft defects induced in silicon in the presence of high energy Neutron Particles found naturally.
- JEDEC Spec defines methodology and formulation for FIT rates.
- Nvidia Collects FIT data and does correlation to Foundry data.
- FIT rates help us determine
  - The amount of ECC logic to be added in a design.
  - Qualify
    - failure rate in the presence of bitcell interleaving for SRAMs.
    - process node and provide accurate FIT rates to our customers.
  - Find any design related issues causing skewed FIT rates for different data patterns.

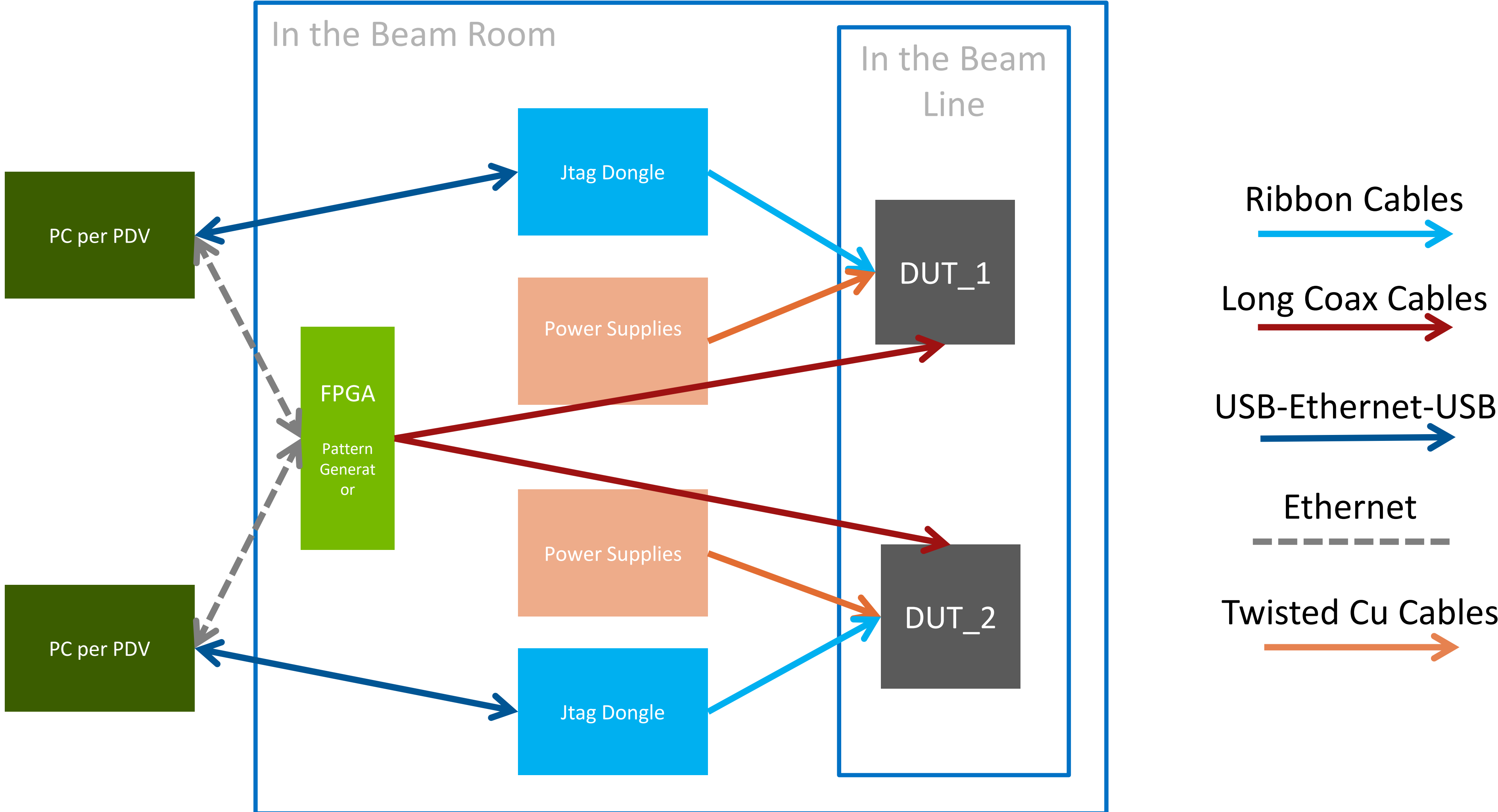
DESIGN CHOICES

- ChipIR Beam –
  - Mimics energy spectrum of Neutron particles in the environment
  - Flux is $1e^9$ X of Environment
- Full PC with GPU in Beam Line –
  - Complex setups
  - excessive Flux causes peripheral components to fail
- Process Design Vehicles (PDVs) –
  - Has dedicated hardware to find FIT rate
  - Works at very high flux
  - FIT for both SRAM and Logic Storage elements (Flops)
  - Similar design across process nodes

EXPERIMENTAL SETUP

1) Load the scan chains with Data Pattern D (scan enable high, clk and SI on for 15K cycles)
2) Load the Srams with Data Pattern M (SE=0, free running clk)
3) Soak the die for 5 Minutes
4) Unload the Mbist failure count data
    1) If fails observed, then bitmap and collect all the bit fails – Single bit and Multi bit
5) Unload the Scan Chain XOR Counters –
6) Repeat Steps 1-5 for
    1) D=0000,1111,0101,1010
    2) M=WR-0,WR-1,W/R-Checkerboard, W/R-Inverse Checkerboard
7) Repeat Step 6 for 600-700 Minutes across multiple Voltages

EXPERIMENT SETUP



Ribbon Cables

Long Coax Cables

USB-Ethernet-USB

Ethernet

Twisted Cu Cables

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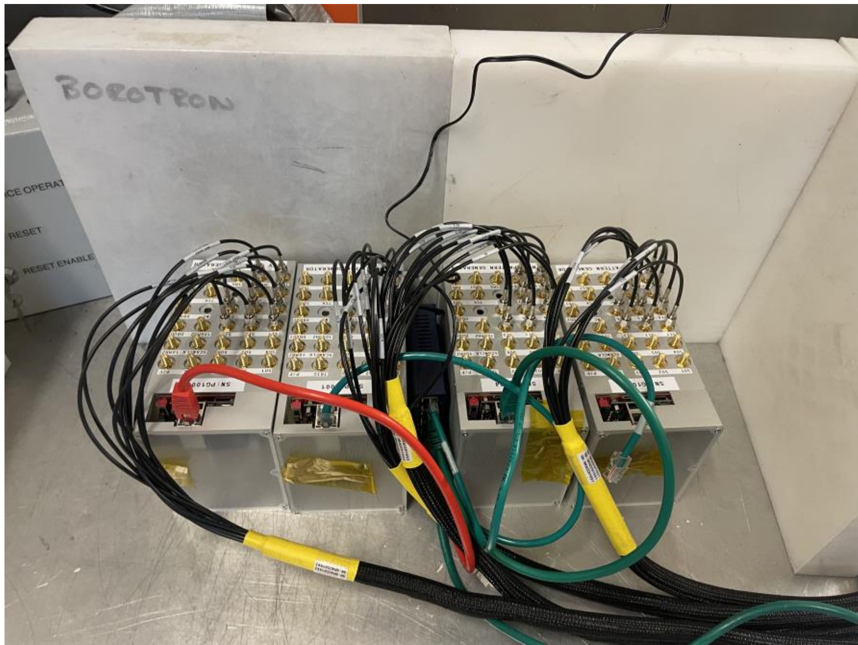
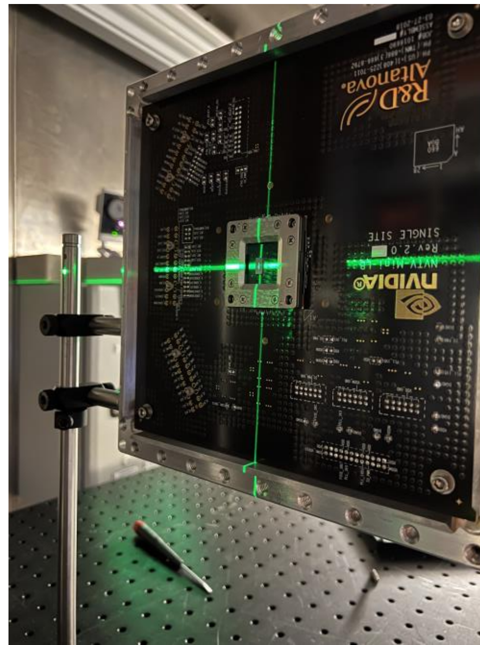
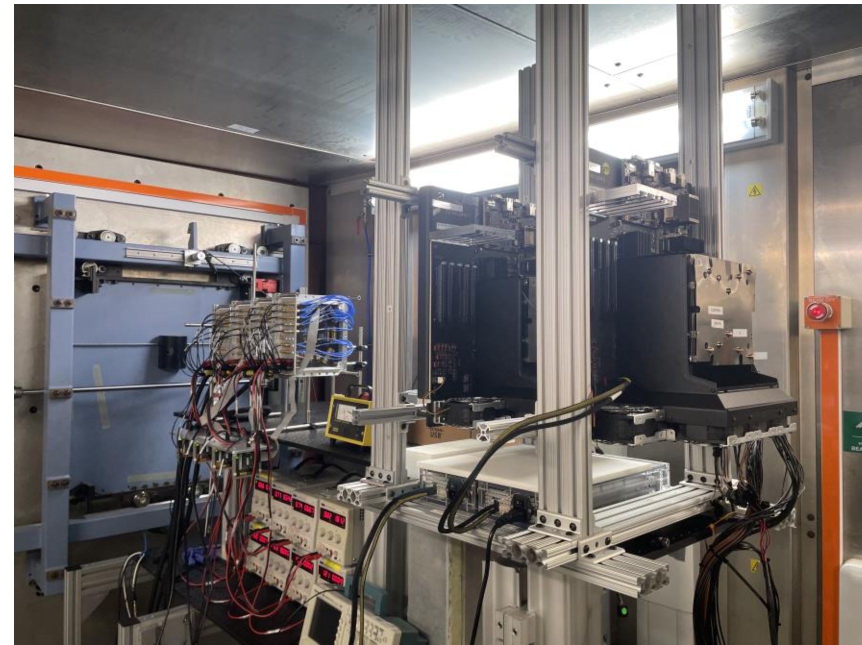
- 4 load boards hooked up with 4 Pattern Generators
- We are able to test 4 die in parallel
- All the Pattern Generators were placed in a Cadmium box along with added shielding to avoid secondary thermal Neutrons
- Other than the DUT, no active components exist in the beam line







THE MATH

FIT: Failures In Time (caused by soft errors) - Unit-of-measure for Soft Error Rate (SER) - 1 FIT == 1 Failure per 1 Billion Hours

$$FITs/_{Mbit} = (Total\,\#\,Events)\times\left(\frac{1}{Total\,\#\,n/_{cm^2}}\right)\times\left(13n/_{cm^2 \times hr}\right)\times\left(10^9/_{Billion}\right)\times\left(1/_{\#\,Mbit}\right)$$

Total # of measured events* | Total # neutrons during exposure | n flux at New York City | per billion hrs conversion | per Mbit conversion

*# events instead of # bits corrupted- 1 event can cause more than 1 bit to flip

Flux = Delta Fluence/Delta Time (3s at chipIR)

Delta Fluence –

- New Sensor = count * 2.63e5 (for spectrum > 10MeV) – New Sensor at chipIR since 2022
- New Sensor = count * 2.63e5 * 1.84 (for Full spectrum)

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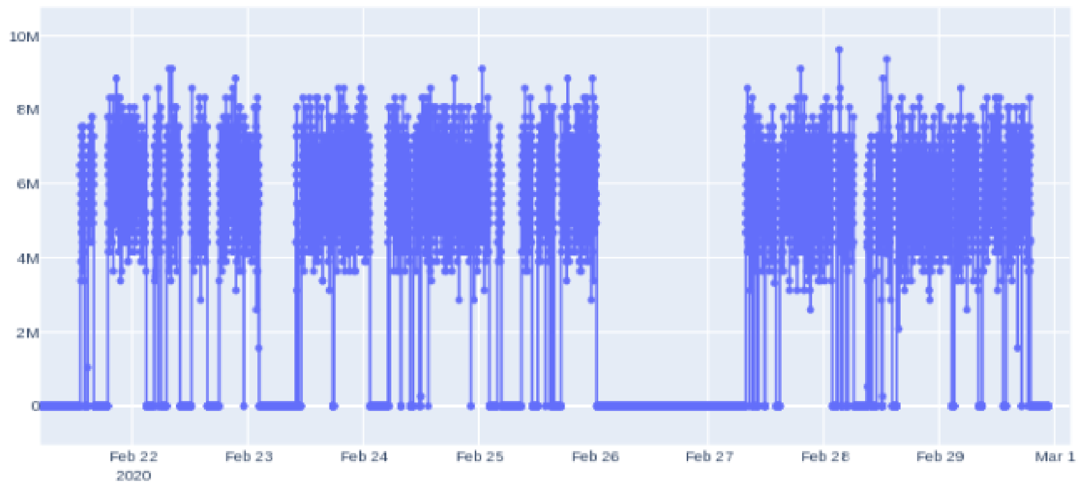
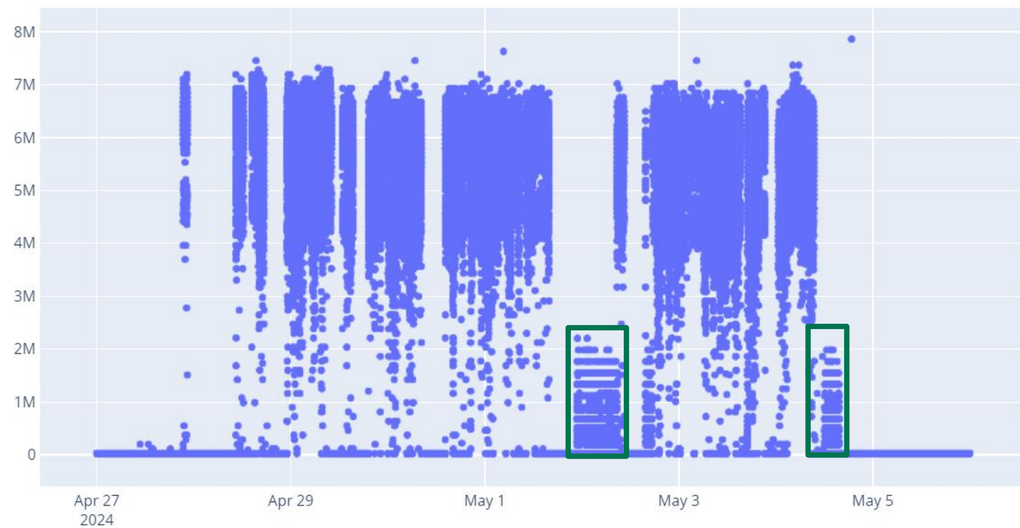
FLUX LOG AT CHIP-IR 2020 AND 2024





Used the new 10x attenuator in this time window

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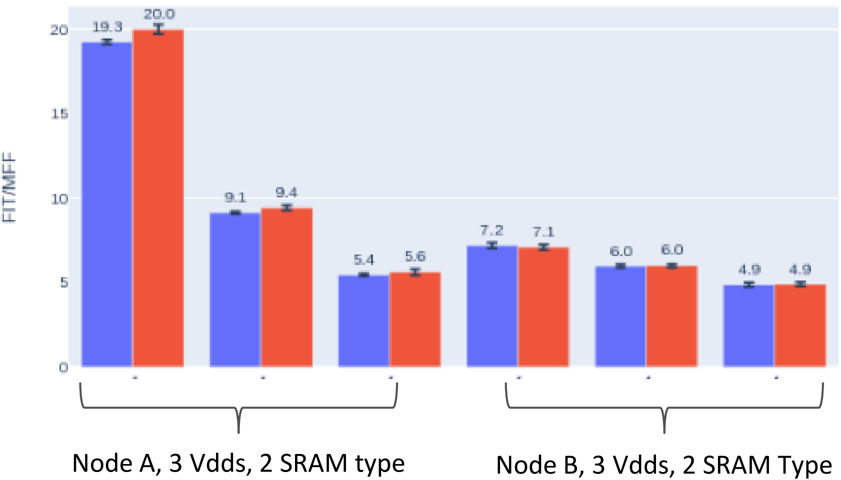
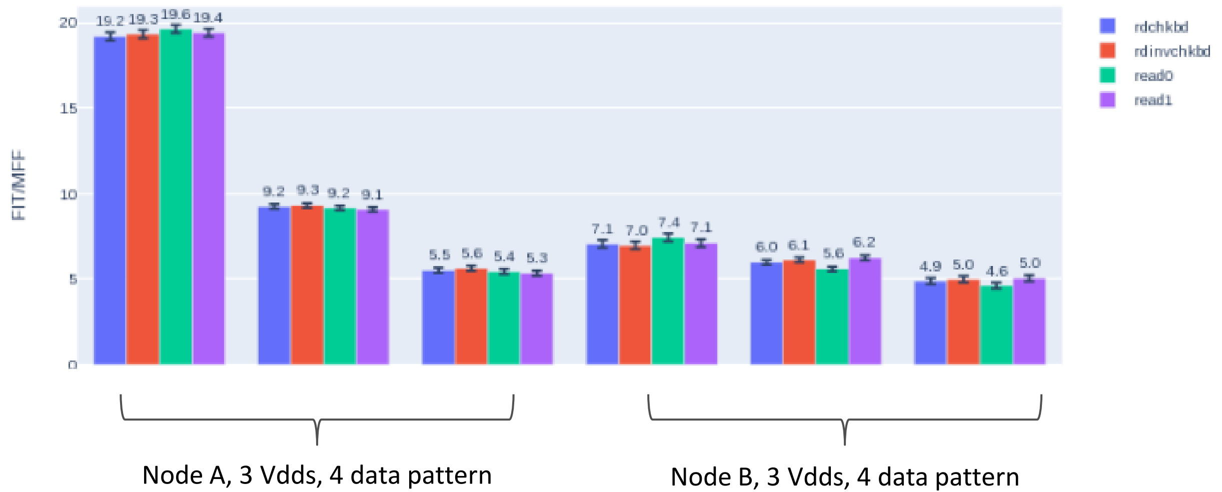
FIT RATE DATA - SRAM

Fit across different ramtypes



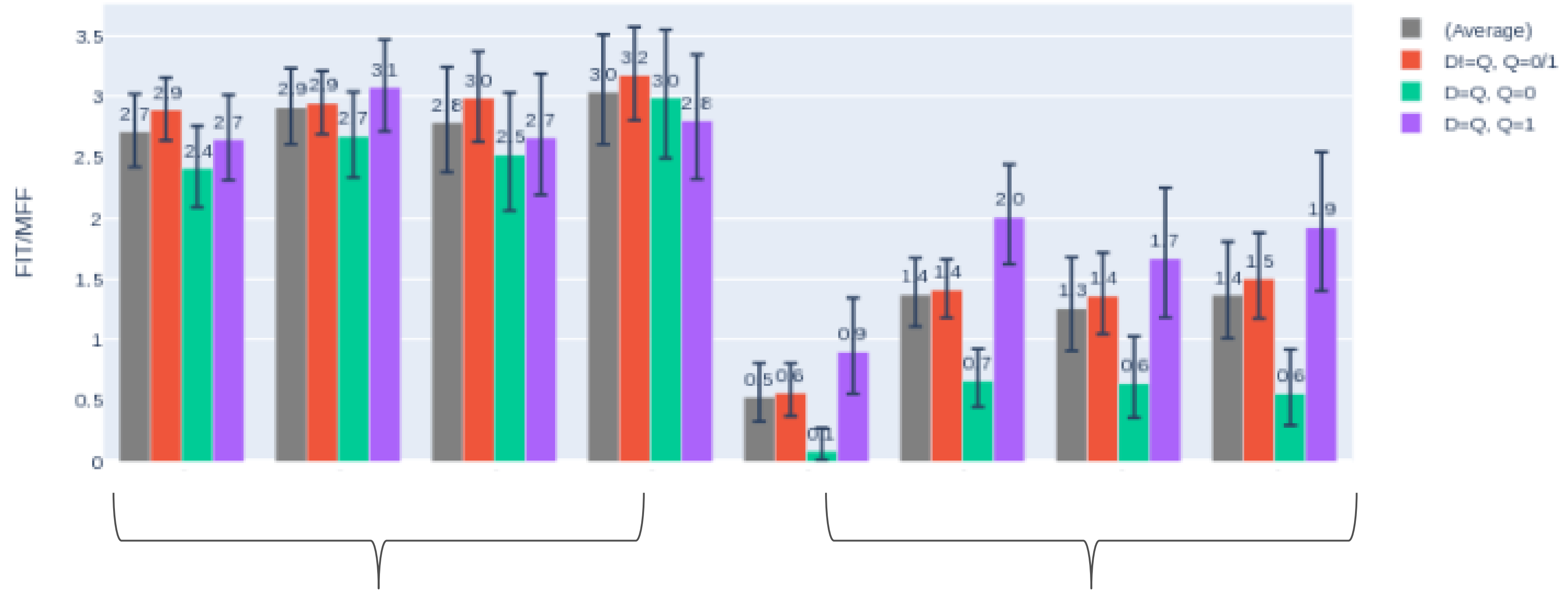
Fit across different data patterns



Fit Rates across voltage and nodes and SRAM type

Fit Rates across voltage and nodes and Data Pattern

FIT RATE DATA - FLOPS

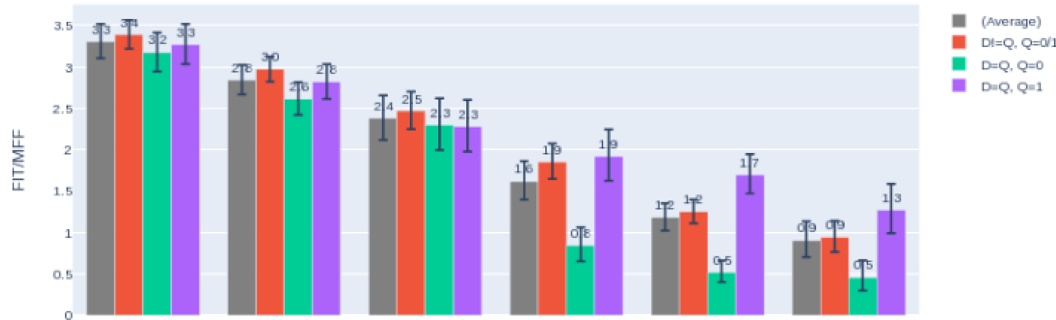


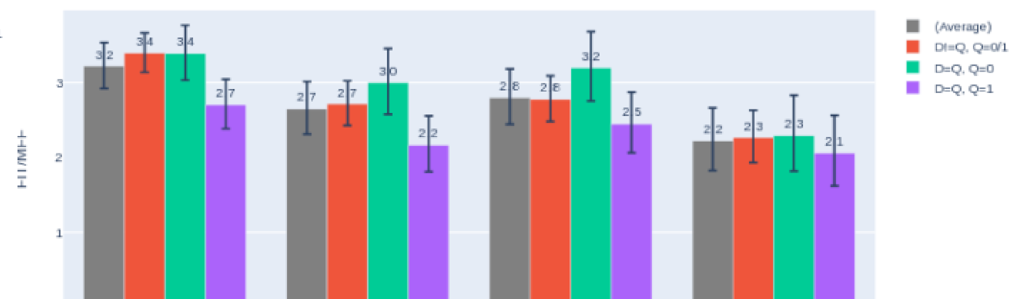
Node A, 4 gate types, 3 Data Pattern

Node B, , 4 gate types, 3 Data Pattern

Fit Rates across Different Gate Types

FIT RATE DATA – FLOPS –MASTER VS SLAVE



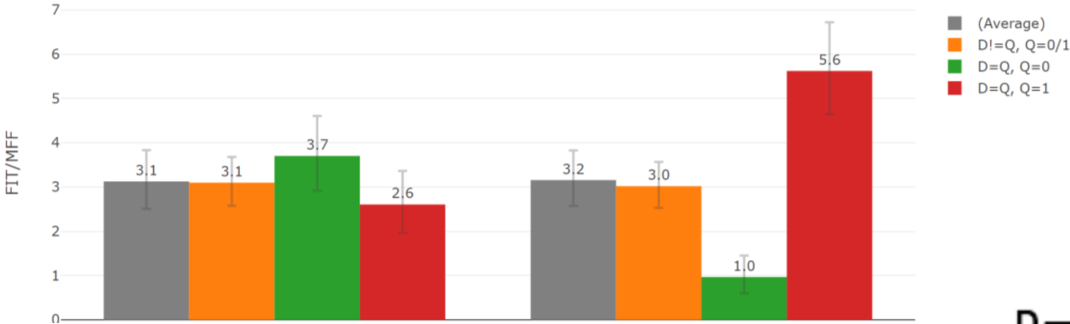


Clk was held low during the 5 minutes soak period

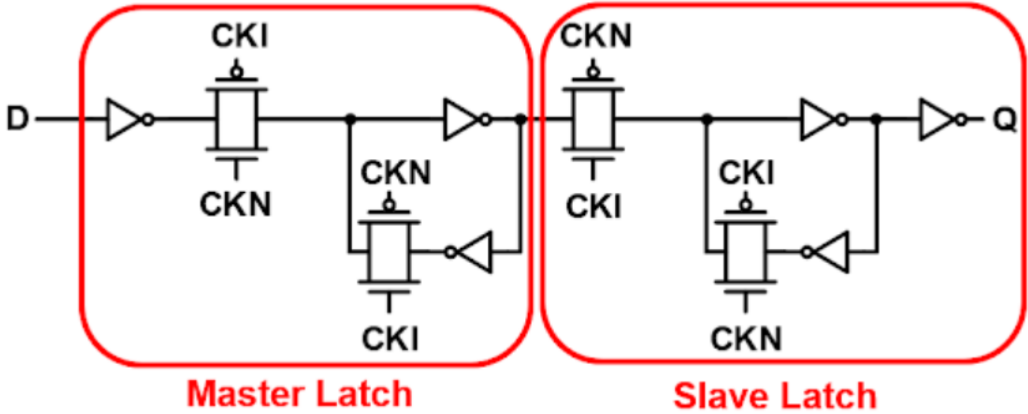
Clk was held high during the 5 minutes soak period

- Over the past 7 years, we have made 3 trip and collected data across 8 different PDVs.
- Results are consistent from trip to trip based on control experiments.
- Results match the expected data very closely
- Beam up time is very high

FIT RATE DATA FLOPS



Fit rate for NodeA and Node B with different data patterns for flops.



- FIT rate for Node B for pattern 0000 is much lower than the other data pattern
- Root Cause - Node B flop design had a larger feed fwd inverter and a parasitic pmos device on the feedback pulldown path

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ISSUES/ENHANCEMENTS

- With 10X attenuators on
    - Flux reduced by 10x
    - Expected FIT was 10x lower.
    - We see much higher FIT numbers.
- With lower geometries, we need better ways to characterize lower energy spectrum
- Is it possible to selectively choose the desired energy spectrum Neutrons?

CLOSING REMARKS

- ChipIR provides an excellent infrastructure to evaluate FIT rates for all our advance nodes processes.
- The facility is well equipped with all the tools and equipment needed for a successful trip.
- Beam is very consistent and has a high availability factor.
- Our dedicated PDVs provide with very accurate FIT data across various parameters with extremely low error bars.
- The staff at chipIR (Maria, Carlo and Chris) are phenomenal to work with.

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