Single-Event Upsets in Photodiodes for Multi-Gb/s Data Transmission

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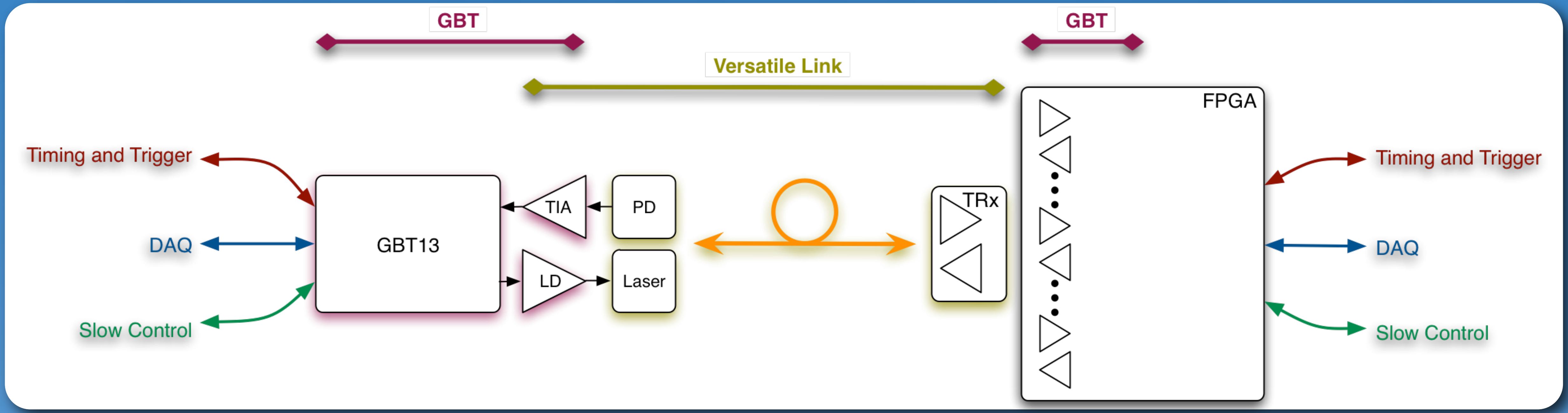
Multi-Gb/s optical links for SLHC

- Increased luminosity at SLHC leads to a need for higher bandwidth optical links for several reasons:
  - More data are produced
    - Detectors either remain the same size and contain more hits at increased luminosity
    - Or the hit occupancy kept constant per detector module thus more modules needed
  - Better use of available bandwidth in fibre is desirable
- In the context of the CERN Workpackage of the Versatile Link project, we are developing a bi-directional optical module for use in the detector front-ends
  - Our testing thus includes radiation testing to ensure that the Versatile Transceiver and its sub-components will operate inside SLHC Tracker and Pixel environments



Why SEU Testing

- Literature widely reports that Photodiodes are also good particle detectors (!)
  - Charge is deposited via direct ionization and nuclear recoils
- Bit Error cross section scales with data-rate (linearly)
  - i.e. Bit Error Rate is independent of data-rate
- (almost) All papers argue that particle-induced SEU only upsets single bits
  - Or with a much smaller probability two adjacent bits

❖ Prediction of SEU rates without testing not well established

❖ If we would like to mitigate SEU using Error Correction then we need to know something about the statistics of the process - mostly the time between errors and the nature of any bursts

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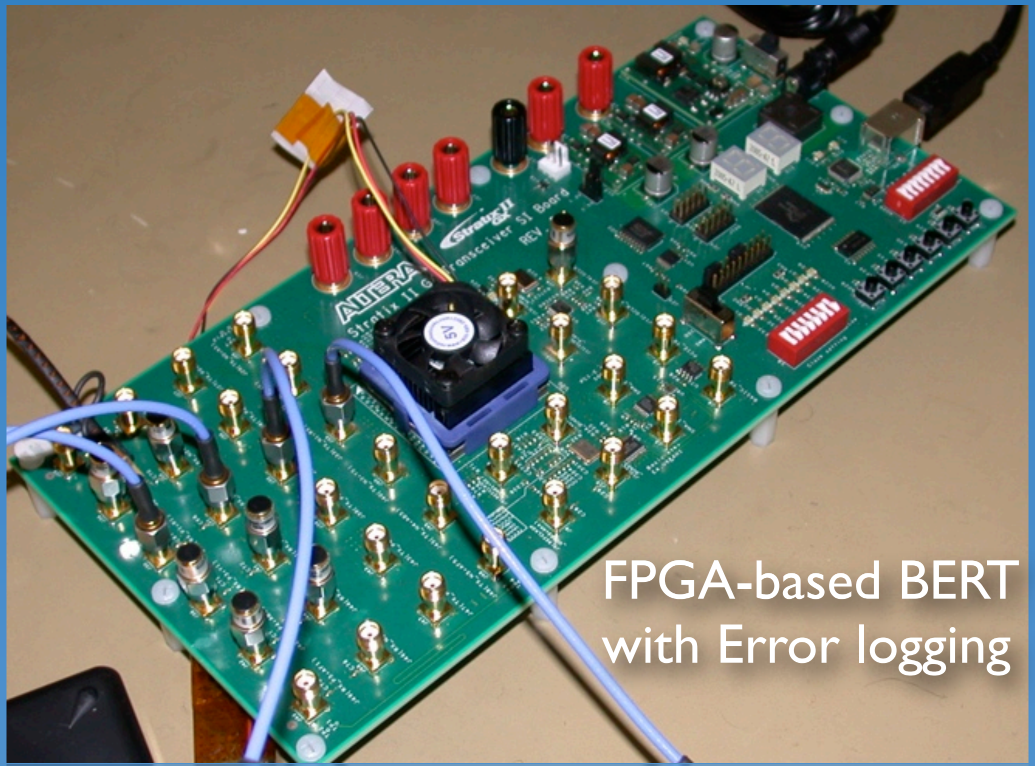
Aims of SEU test

- Survey as wide a range of devices as possible
  - Multiple wavelengths
  - Photodiode only vs. ROSA with integrated TIA

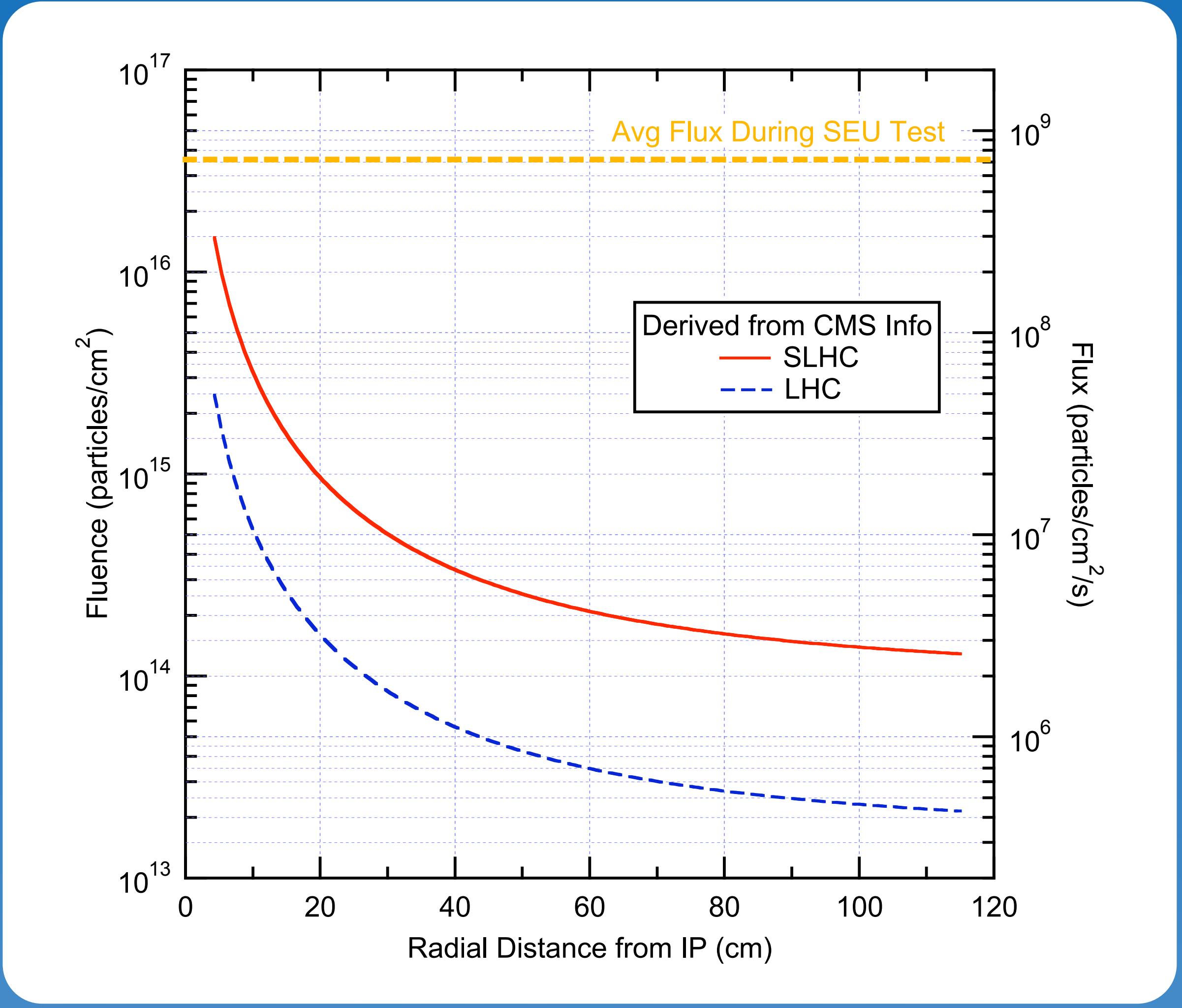
Family	Wavelength	# Device Types (# tested)
PIN MM	850nm	2 (4)
ROSA MM	850nm	1 (2)
PIN SM	1310nm	7 (14)
ROSA SM	1310nm	1 (2)
MSM MM	850nm	1 (2)

- Measure statistics of SEU events
  - Multiple-bit errors
  - Error-free Interval
  - Fraction of 0-to-1 errors



Choice of Beam

- Low Energy Proton Irradiation Facility at PSI (PIF-NEB)
  - 63MeV protons
  - High flux: 10^8 p/cm^2/s
  - Large sample area in beam - 5cm Ø
  - Convenient from CERN
- Irradiation took place over the weekend before Christmas in 2007
- Very good flux stability over the entire test



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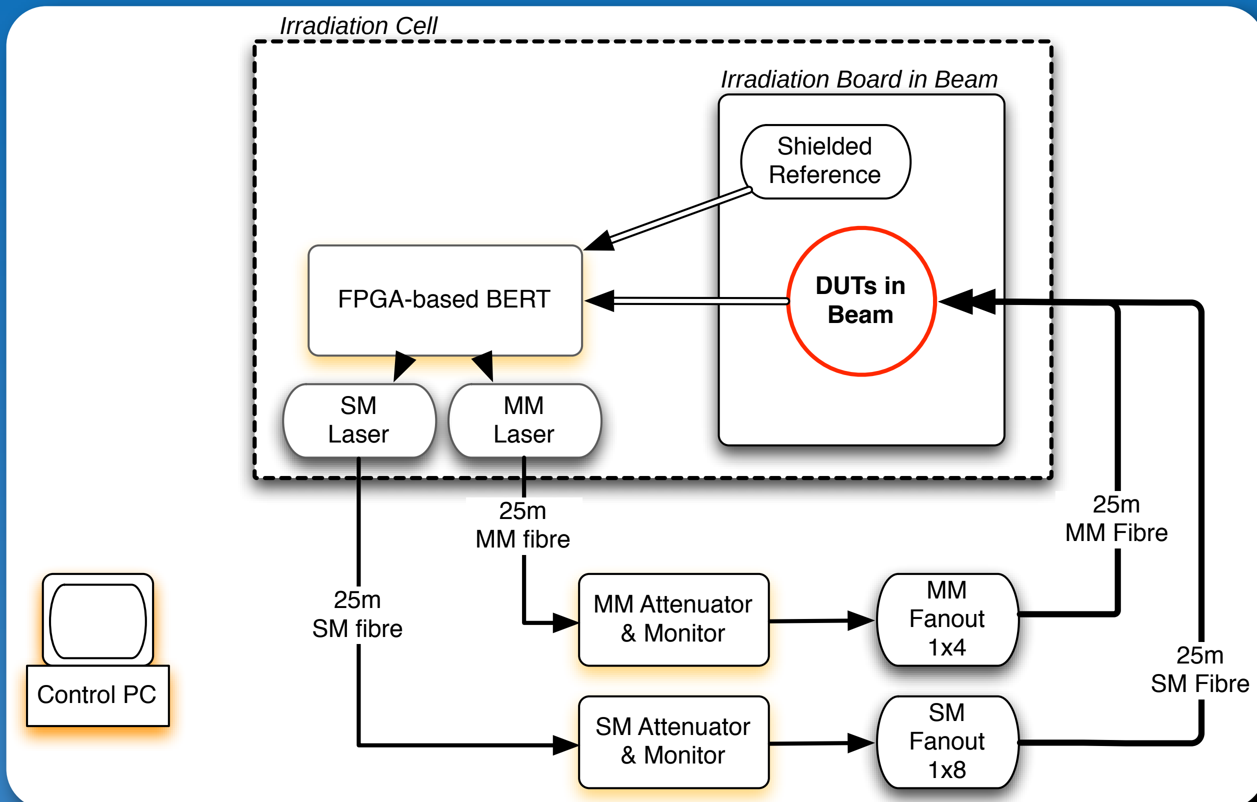
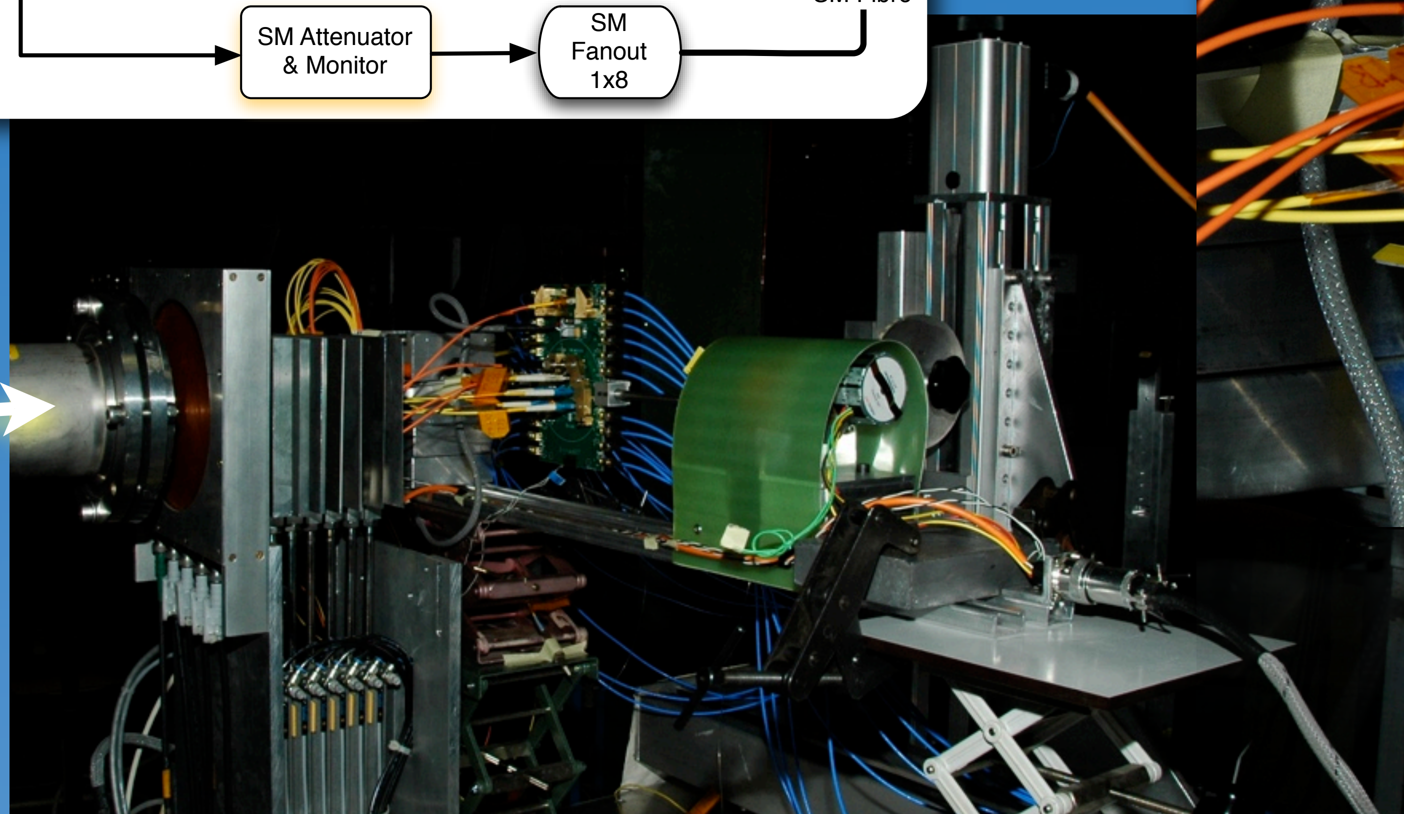
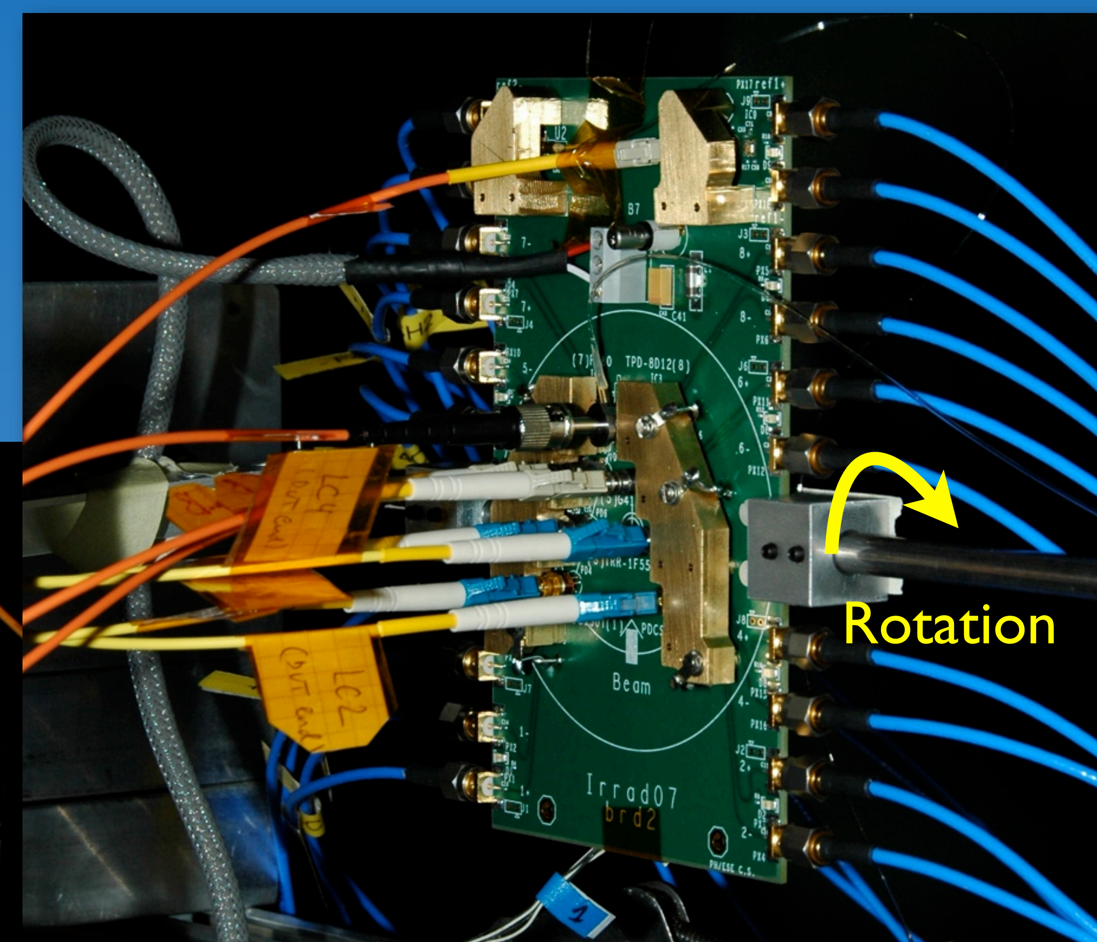
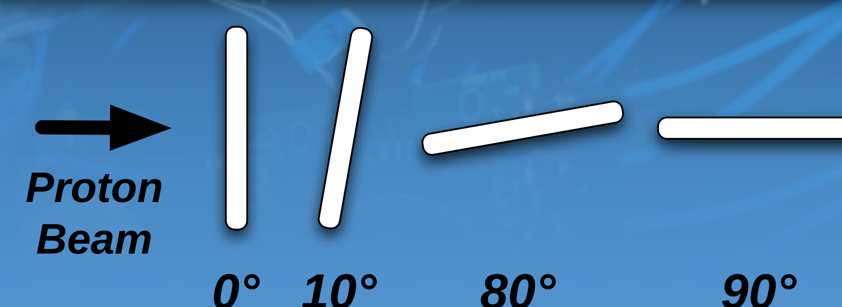
Test Setup in Beam



Beam







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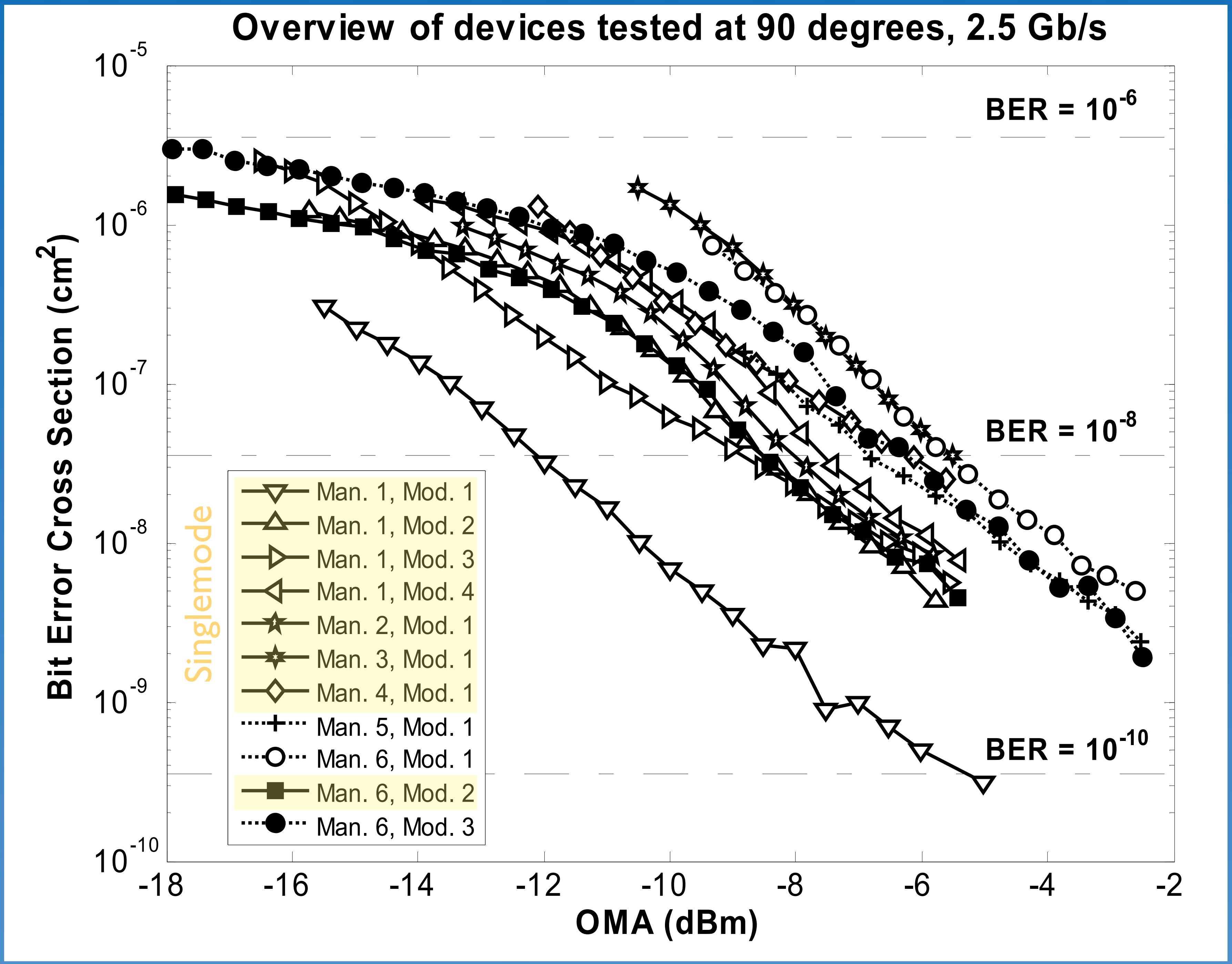
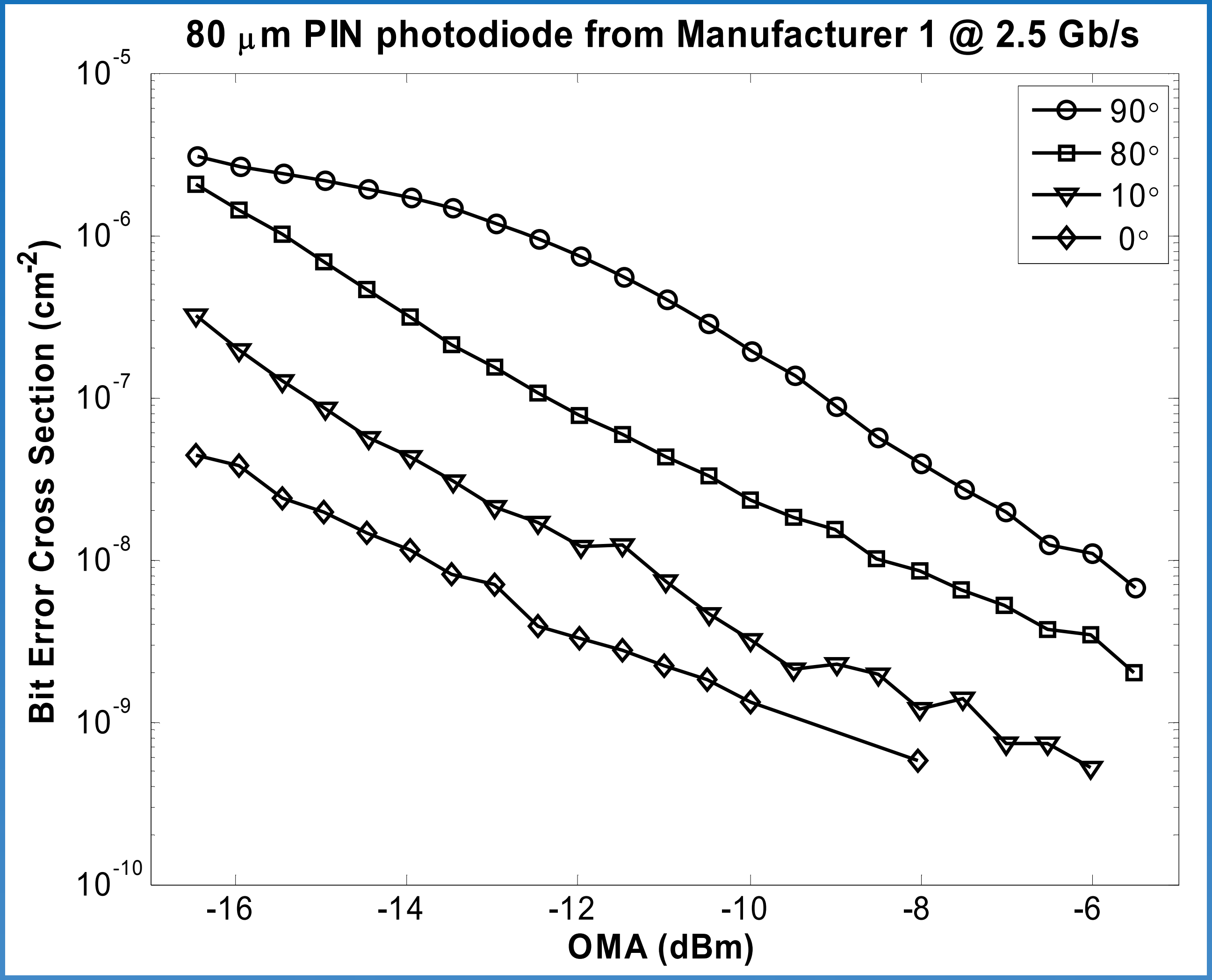
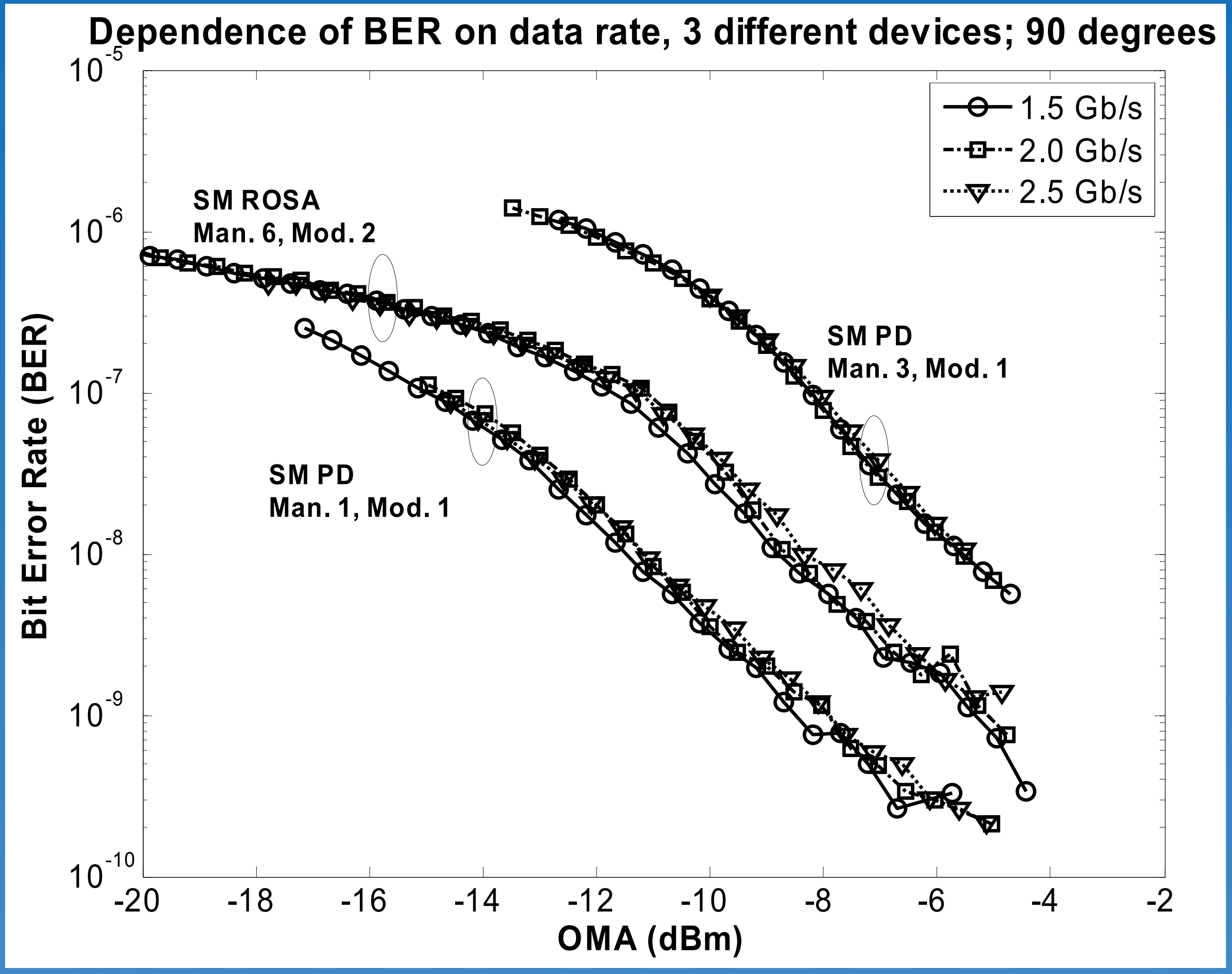
Global Result



- Plot shown for Grazing incidence, worst case
- Very Similar overall trend
  - ROSA (solid symbols) not much worse than bare PINs
  - SM and MM devices behave in similar ways
  - Several orders of magnitude difference in response between devices
- Best Performance from Smallest diameter device

Parameter variation





- Grazing incidence shows highest cross-section, as expected
  - x-sect. too low for low angles - devices shielded by test setup!
- BER independent of Data-rate
  - Cross-section linear with data-rate
  - Operating well within amplifier bandwidth

Error Statistics

- Parameters that define a burst:
  - Burst length
  - Error free threshold (EFT)
    - Maximum number of succesive correct bits inside burst
    - i.e. Any two bit errors separated by EFT or less correct bits are considered part of the same burst
    - Different settings of EFT lead of different burst histograms
      - Example: error word 0100111010000110
        - EFT = 0: 3 single, 1 double, 1 triple
        - EFT = 1: 1 single, 2 quadruple
        - EFT = 2: 1 quadruple, 1 octuple
    - and to different Error Free Interval (EFI) histograms
- Other parameters:
  - 'Occupancy' = (number of bits flipped) / burst length
  - 0→1 fraction = (number of sent 0's mistaken as 1's at rx) /(number of bits flipped)

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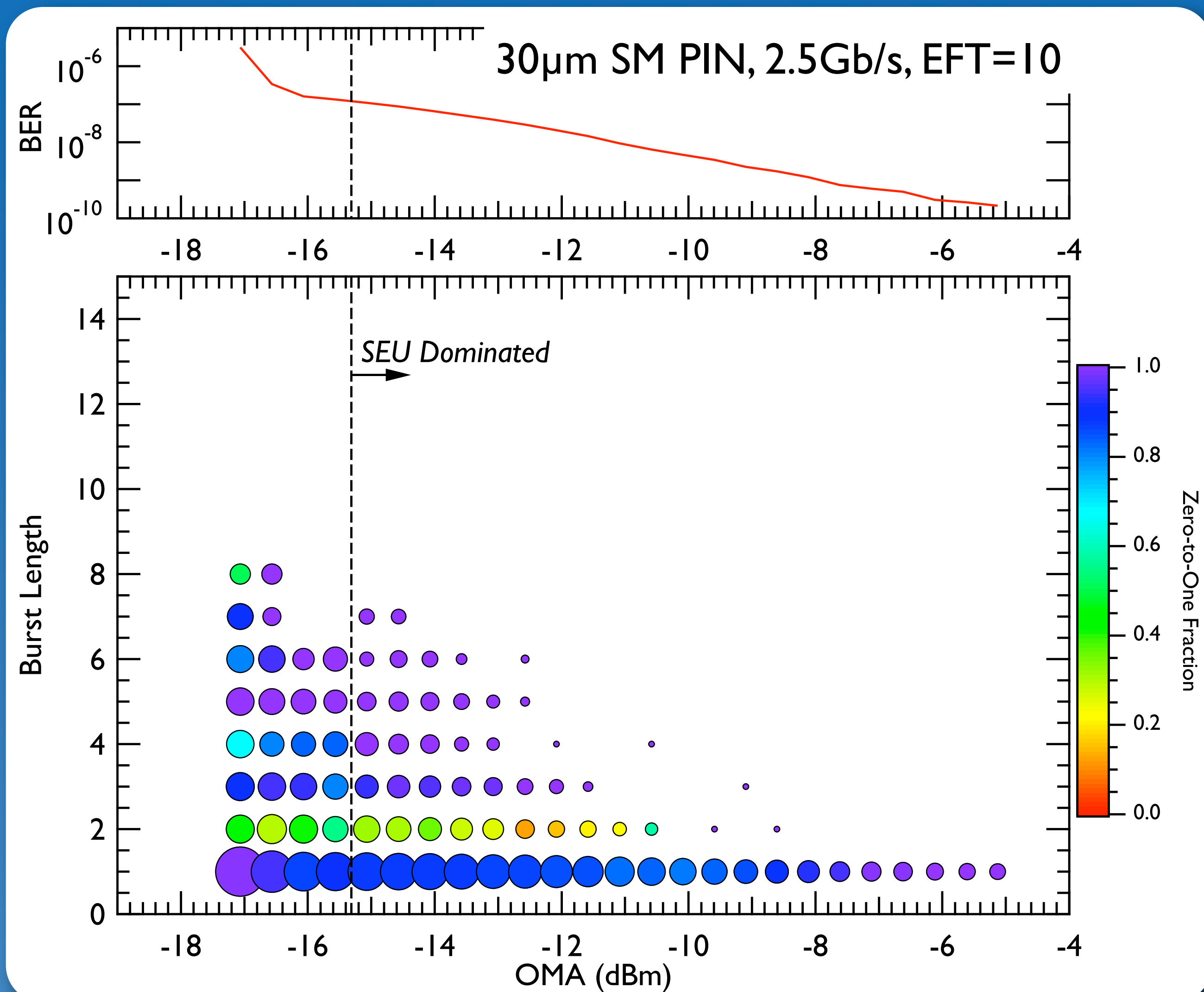
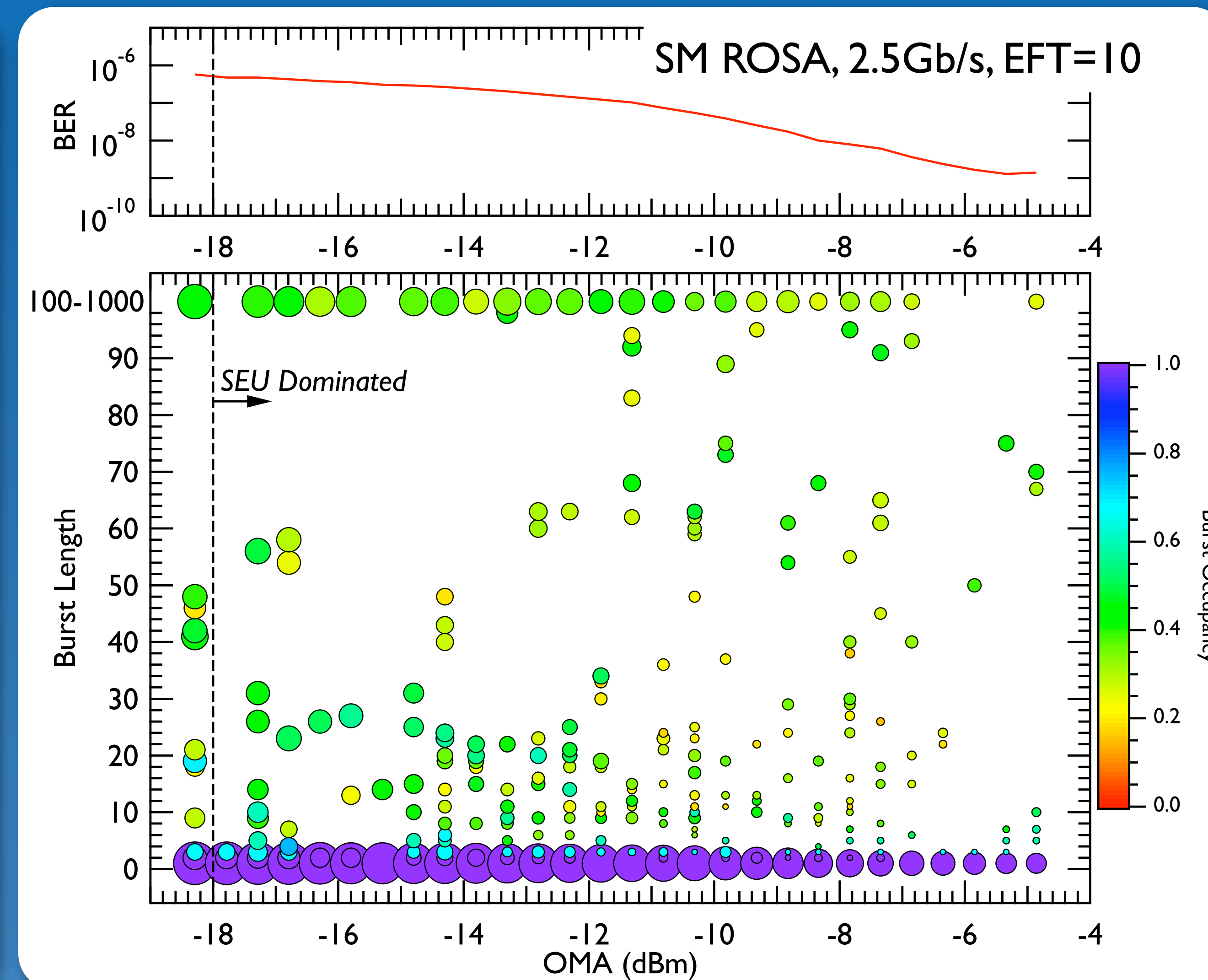
Burst Error Results





- Multi-bit bursts observed for PINs
  - Max burst length ~10 bits
- Transmitted 1 detected as 0
  - Likely due to TIA response to large signal
- Multi-bit bursts also observed for ROSAs
  - Longer bursts, constant time with data-rate
  - Occupancy typ. 25-60% for long bursts

Summary & Conclusions

- Tested a mix of 24 devices (PINs and ROSAs) from 6 manufacturers for SEU using 63MeV protons at PSI in Dec.07
- Error logging allowed calculation of detailed error statistics including burst lengths and zero-to-one fractions as well as basic Bit Error Rate
- Multi-bit Errors observed for the first time
  - up to 10 bits long in PINs
  - hundreds of bits long in ROSAs, consistent with constant recovery time of ~50ns - TIA upset likely cause
- Some Transmitted Ones detected as Zeros
  - Mechanism not fully understood, likely interplay between PIN signal and TIA
- Error Correction for SLHC links mandatory, must be able to cope with observed Errors