



Radiation Hardness of VCSEL and PIN Arrays

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Outline

- Radiation damage in VCSEL and PIN
- Results on PIN with protons/pions irradiation
- Results on VCSEL with protons/pions irradiation
- Summary



Radiation Damage in VCSEL/PIN

- optical links use VCSEL and PIN:
 - ◆ Vertical-Cavity Surface-Emitting Laser to convert electrical signal into optical signal
 - ◆ PIN diode to convert optical signal back into electrical signal
- main effect of radiation:
 - ◆ bulk damage, i.e. displacement of atoms
- high speed VCSEL/PIN are fabricated using GaAs instead of silicon
- VCSEL/PIN in collider experiments are exposed to mixture of particle species
 - ◆ use NIEL hypothesis to estimate fluence:
 - damage is proportional to non ionizing energy loss



Fluence at High Luminosity-LHC

- Expected fluence for 3,000 fb⁻¹ at radius of 37 cm
 - ◆ 2.8×10^{15} 1-MeV n_{eq}/cm^2
 - ◆ 5.4×10^{14} p/cm^2 for 24 GeV protons
- Study degradation with 24 GeV protons and 300 MeV/c pions
 - ◆ NIEL hypothesis: 300 MeV pion is 1.5 more damaging



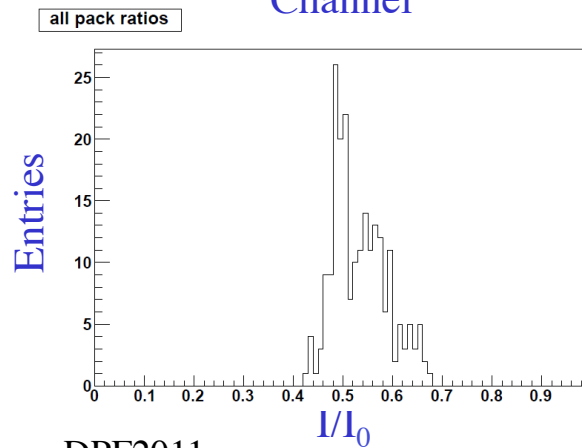
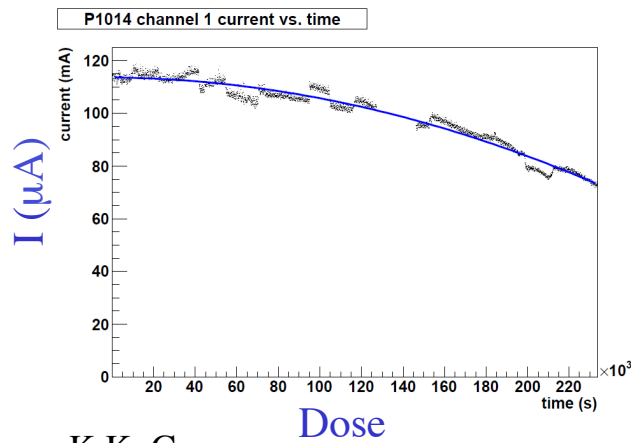
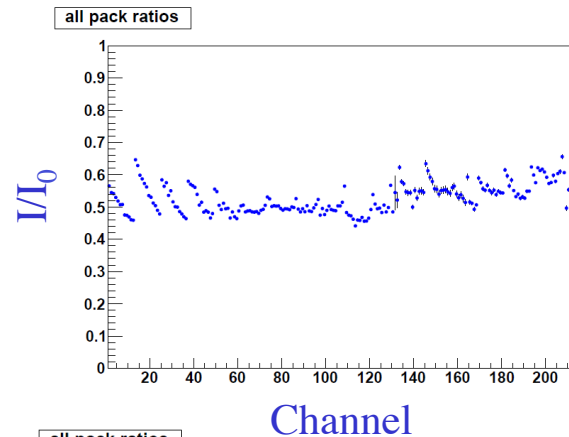
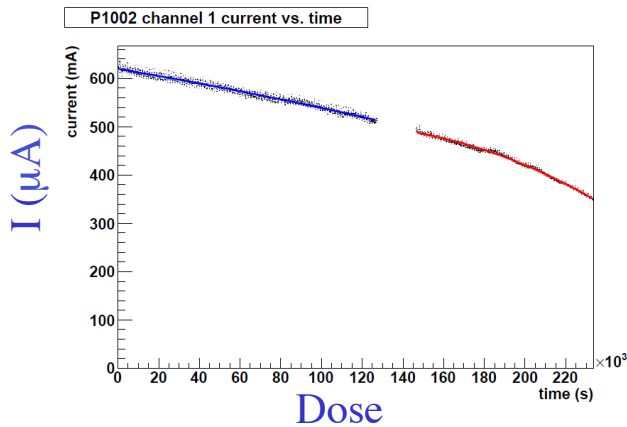
VCSEL/PIN Irradiation

- Study radiation hardness of VCSEL/PIN arrays since 2006:
 - ◆ vendors: AOC, Optowell, ULM, Hamamatsu
 - ◆ speed: up to 10 Gb/s
 - ◆ results: identified following devices for irradiation with 20 arrays
 - Optowell 3.125 Gb/s PIN arrays (2009): large leakage current
 - ULM 4.25 Gb/s PIN arrays (2010): see next slides
 - AOC 10 Gb/s VCSEL (2010): see next slides



Irradiation of PIN with Protons

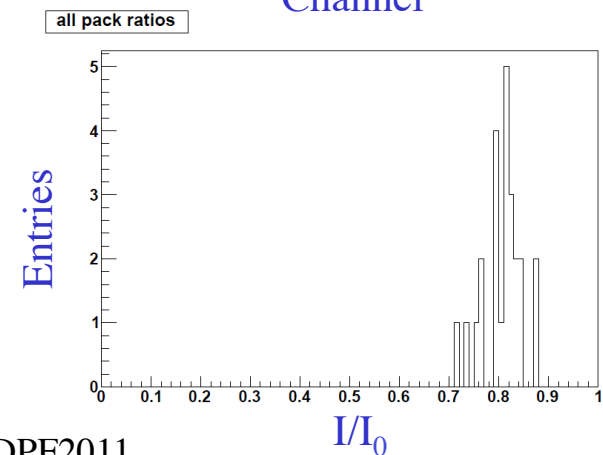
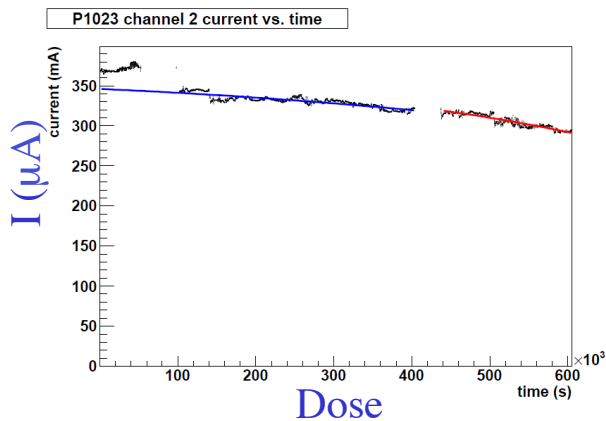
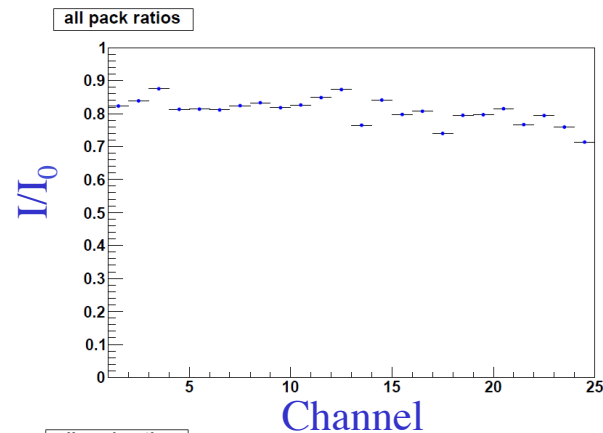
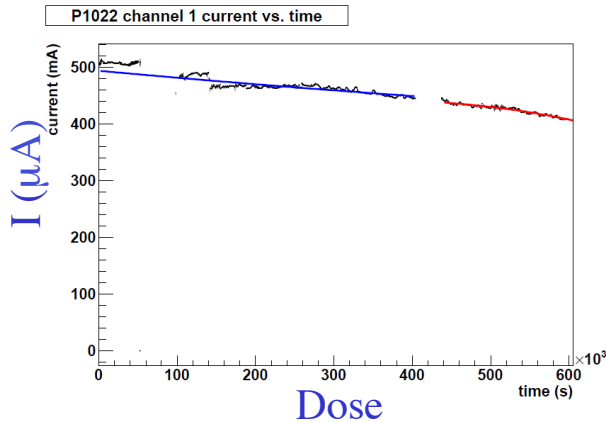
- 20 ULM 12-channel PIN arrays (4.25 Gb/s) were irradiated to a dose of $1.0 \times 10^{15} \text{ p/cm}^2$ (24 GeV/c)
- ◆ decrease in PIN responsivity is modest





Irradiation of PIN with Pions

- 2 ULM 12-channel PIN arrays (4.25 Gb/s) were irradiated to a dose of $4.3 \times 10^{14} \pi/\text{cm}^2$ (300 MeV/c)
- ◆ decrease in PIN responsivity is small





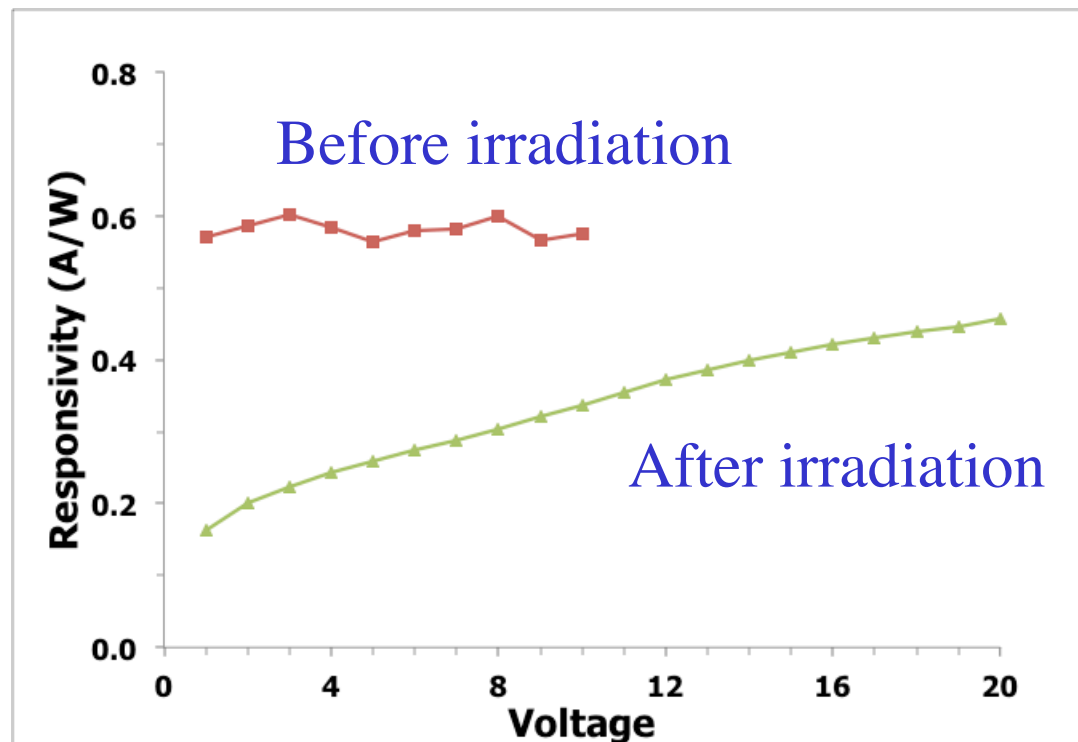
Test of NIEL Hypothesis

- NIEL hypothesis:
 - ◆ damage is proportional to the non ionizing energy loss
 - ◆ 300 MeV pion is 1.5 more damaging than 24 GeV protons
 - ◆ decrease in PIN responsivity with $4.3 \times 10^{14} \pi/\text{cm}^2$: 81%
 - ◆ decrease in PIN responsivity with $6.6 \times 10^{14} p/\text{cm}^2$: 78%
 - ⇒ consistent with NIEL hypothesis



Responsivity vs Voltage

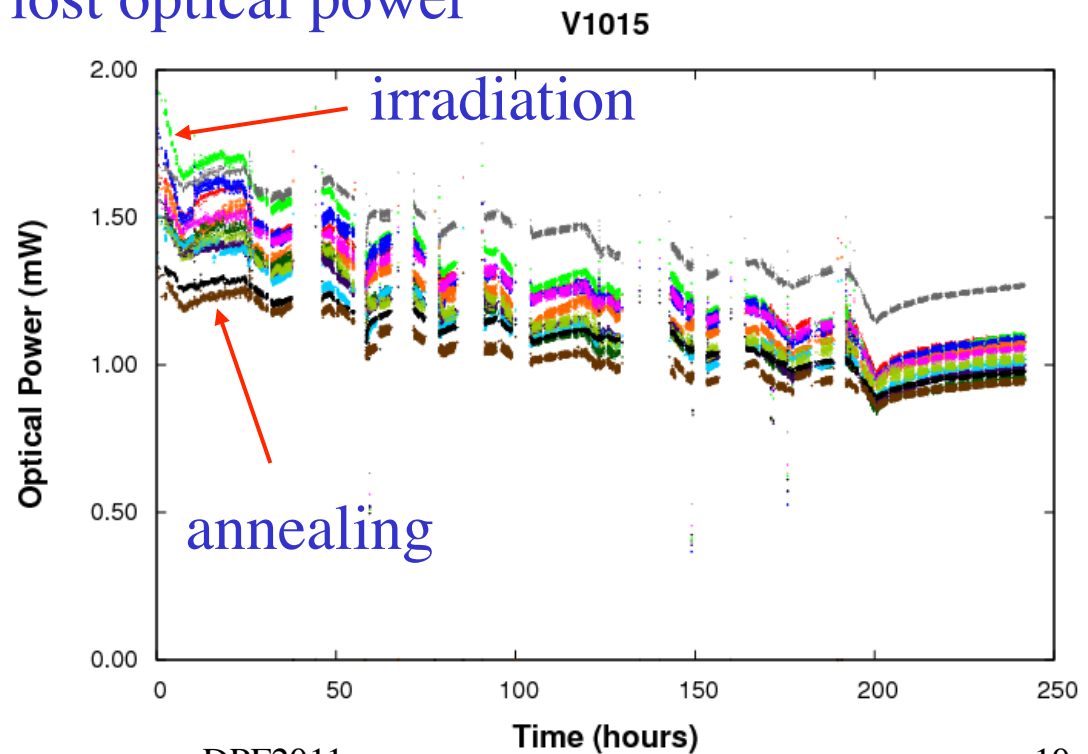
- Before irradiation: reach responsivity plateau at relatively low voltage
- After irradiation: can partially recover responsivity with higher voltage
- ◆ need to verify the high-speed operation





Proton Irradiation of VCSEL

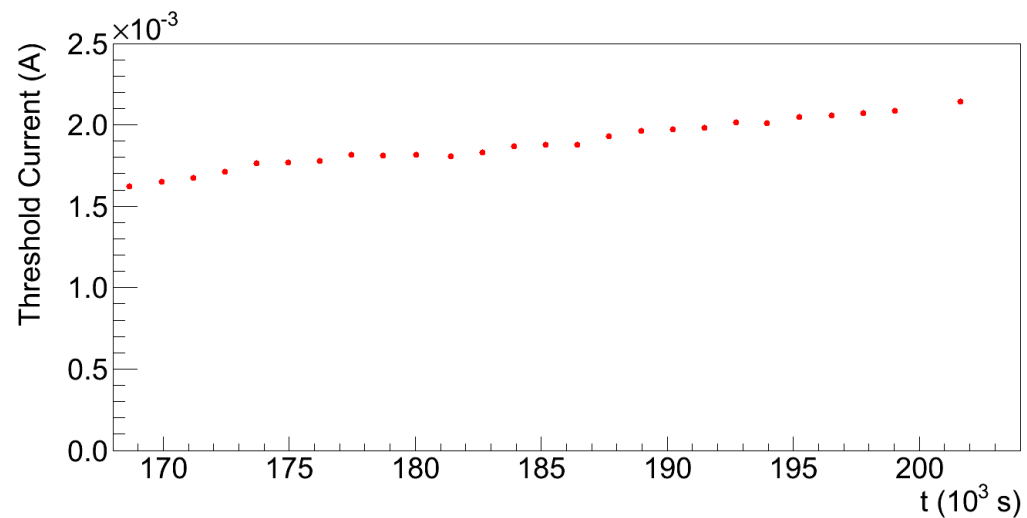
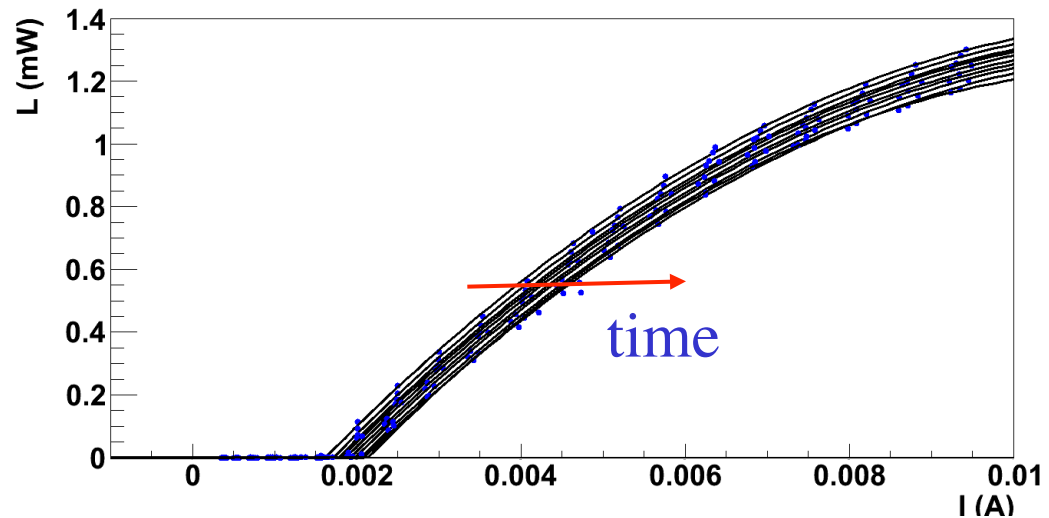
- 12 AOC arrays (10 Gb/s) irradiated to $8.0 \times 10^{14} \text{ p/cm}^2$ (24 GeV/c)
 - ◆ alternate between irradiation and annealing (biased/no radiation)
 - ◆ decrease in optical power is modest
 - ◆ annealing in progress
 - ⇒ will recover most lost optical power





Radiation Effect on Threshold Current

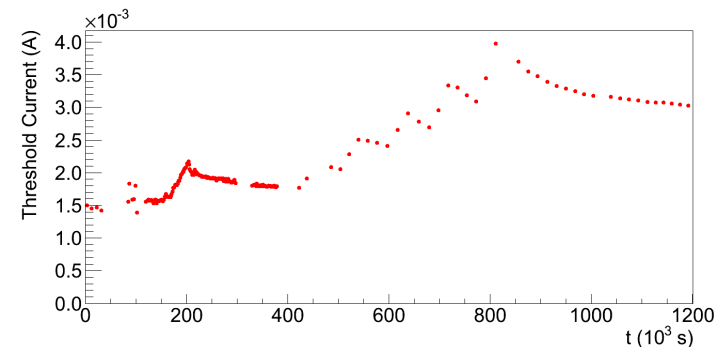
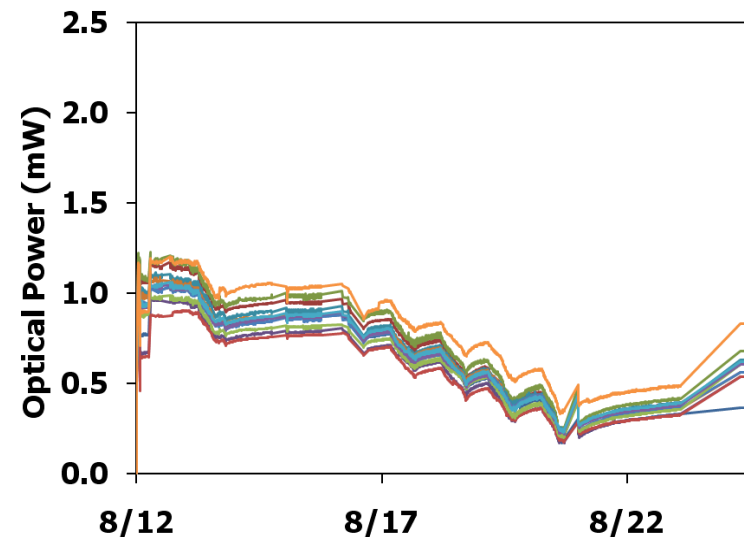
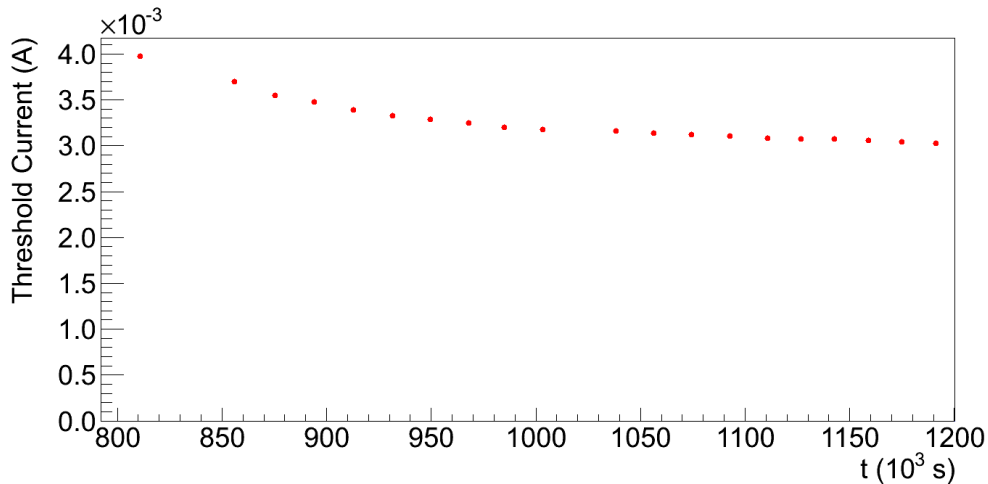
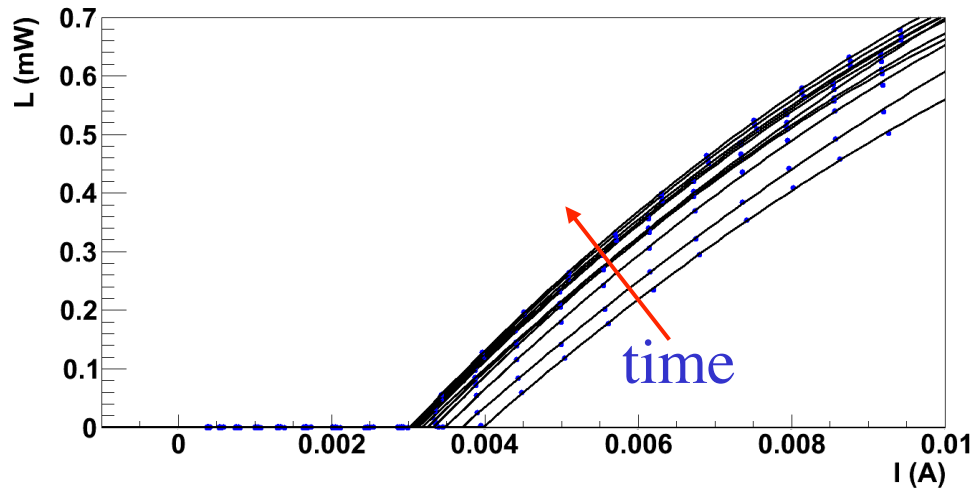
- Radiation damage increases current threshold for lasing
 - ⇒ decrease optical power at same drive current





Annealing of Radiation Damage

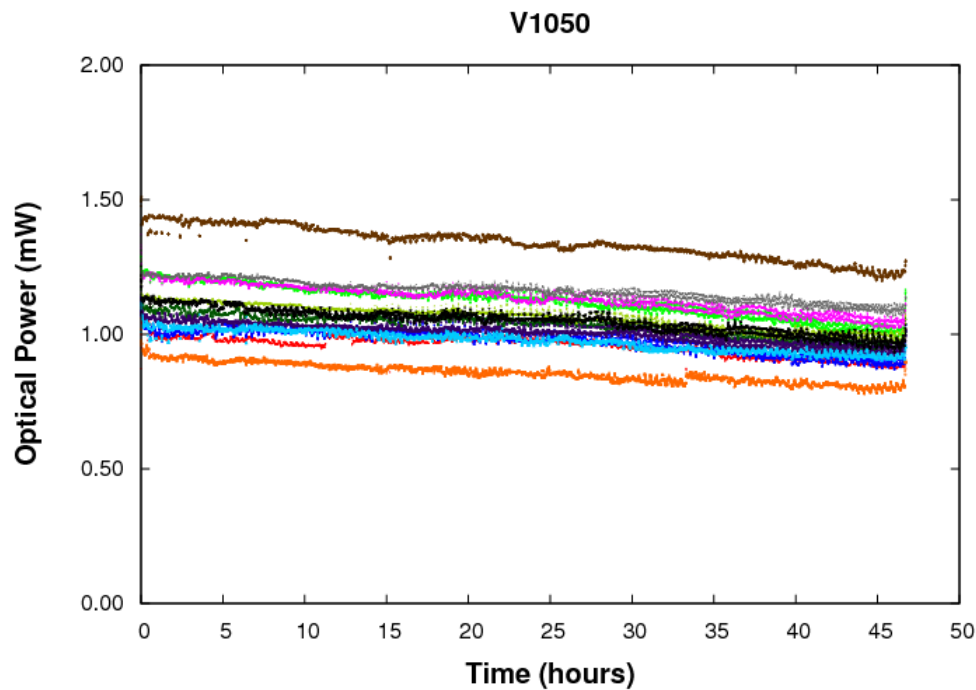
- Radiation damage can be annealed by drive current in VCSEL
 - ⇒ decrease in threshold current
 - ⇒ increase in optical power at same drive current





Pion Irradiation of VCSEL

- One AOC 10 Gb/s VCSEL array was irradiated:
 - ◆ dose: $4.1 \times 10^{14} \pi/\text{cm}^2$ (300 MeV/c)
 - ◆ continuous irradiation with no dedicated annealing period due to limited time slot
 - ◆ decrease in optical power is modest

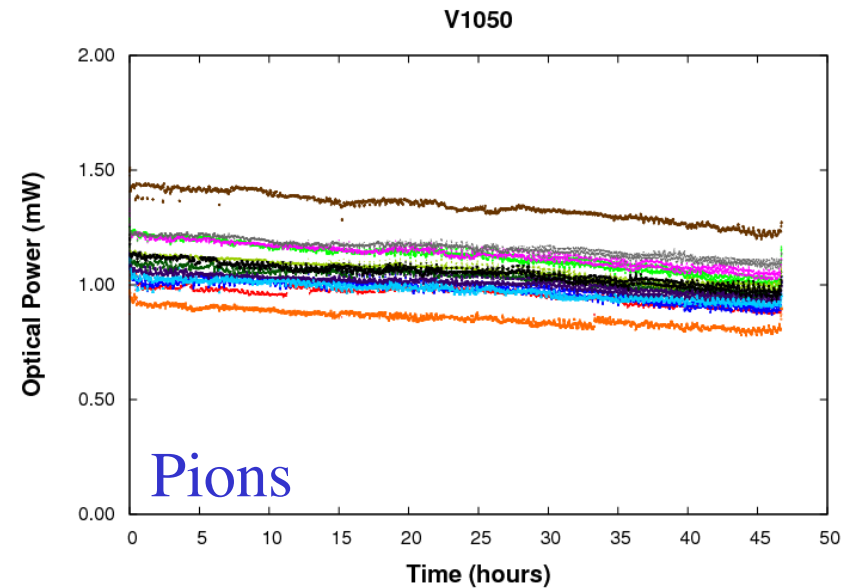
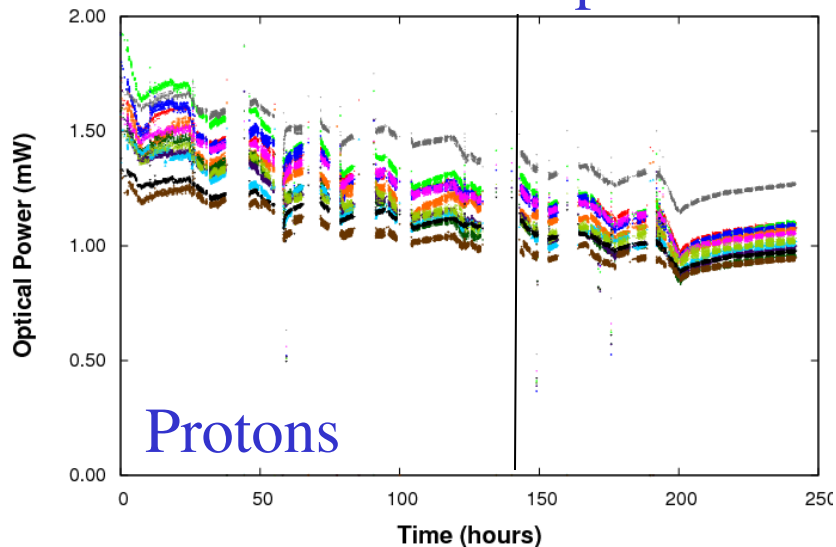




Test of NIEL Hypothesis

- NIEL hypothesis:
 - ◆ damage is proportional to the non ionizing energy loss
 - ◆ 300 MeV pion is 1.5 more damaging than 24 GeV protons
 - ◆ damage with $4.1 \times 10^{14} \pi/\text{cm}^2$ is equivalent to $6.4 \times 10^{14} p/\text{cm}^2$?
 - ⇒ need to repeat proton irradiation with no dedicated annealing
 - difficult to receive the exact required dose in 47 hours

$6.4 \times 10^{14} p/\text{cm}^2$





Plan for VCSEL/PIN Array Irradiation

- AOC 10 Gb/s VCSEL arrays:
 - ◆ NIEL study: need to perform proton irradiation with no dedicated annealing
 - ◆ need to repeat proton irradiation with higher statistics
 - half of arrays produced no light before irradiation last summer
 - AOC claimed due to material from sticky membrane
- ULM 10 Gb/s PIN arrays:
 - ◆ will test two of these newly available arrays to start



Summary

- ULM PIN arrays: modest decrease in responsivity after irradiation
 - ◆ damage from pion/proton consistent with NIEL hypothesis
- AOC VCSEL arrays: modest decrease in opto-power after irradiation
- more irradiation of 10 Gb/s PIN/VCSEL arrays this summer
 - ◆ attempting proton irradiation of VCSEL arrays with precise dosage and no dedicated annealing to test NIEL hypothesis