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

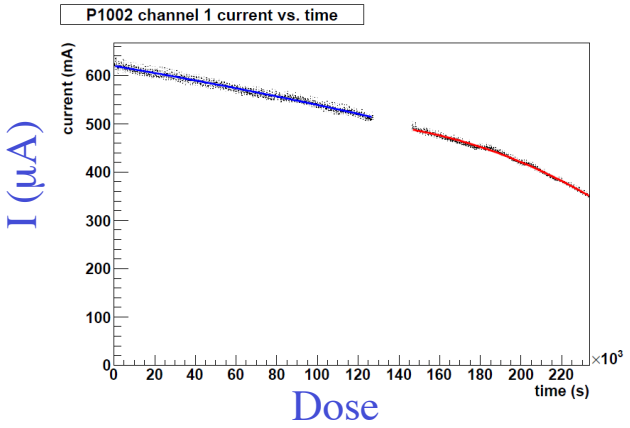
- Expected fluence for 3,000 fb^{-1} at radius of 37 cm
  - 2.8×10^{15} 1-MeV n_{eq}/cm^2
  - 5.4×10^{14} *p*/cm^2 for 24 GeV protons
- Study degradation with 24 GeV protons and 300 MeV/c pions
  - NIEL hypothesis: 300 MeV pion is 1.5 more damaging

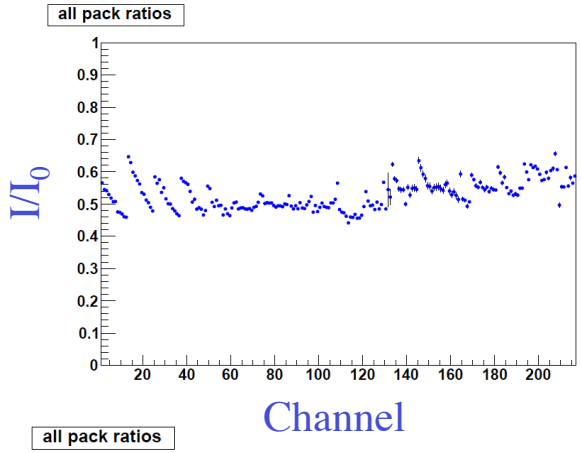
VCSEL/PIN Irradiation

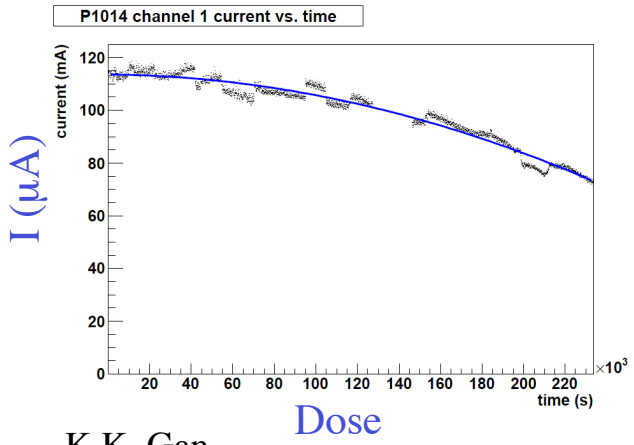
- Study radiation hardness of VCSEL/PIN arrays since 2006:
  - vendors: AOC, Optowell, ULM, Hamamatsu
  - speed: up to 10 Gb/s
  - results: identified following devices for irradiation with 20 arrays
    - Optowell 3.125 Gb/s PIN arrays (2009): large leakage current
    - ULM 4.25 Gb/s PIN arrays (2010):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

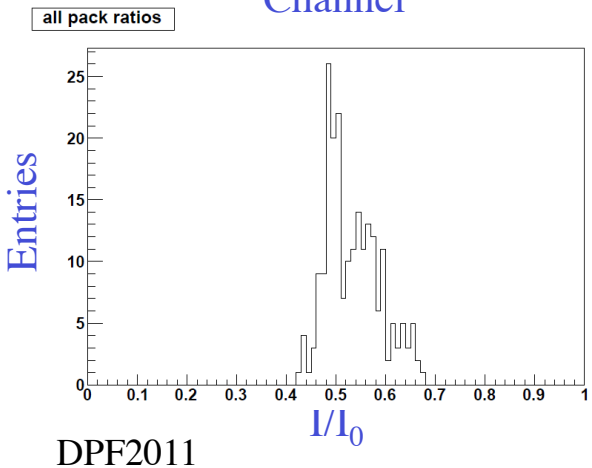
Irradiation of PIN with Protons

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



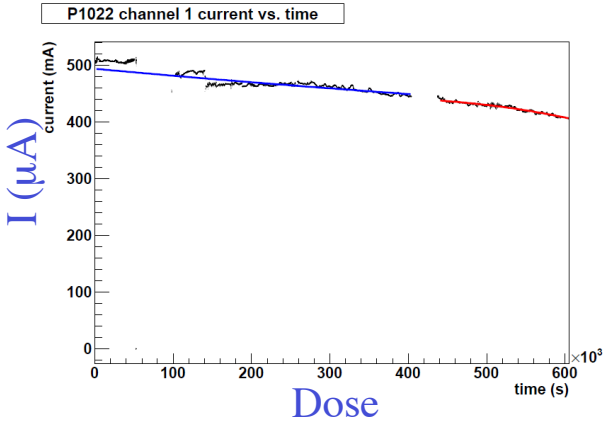


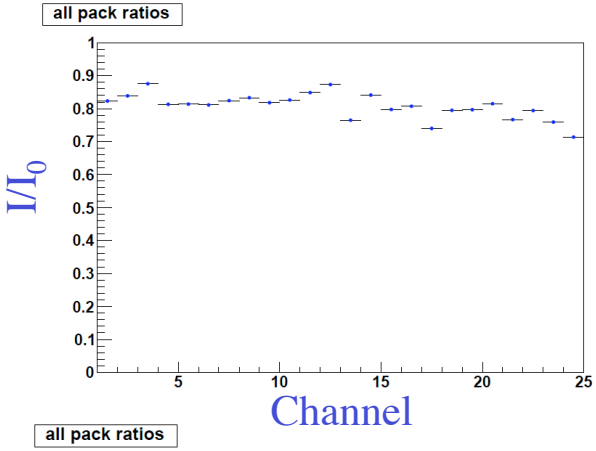


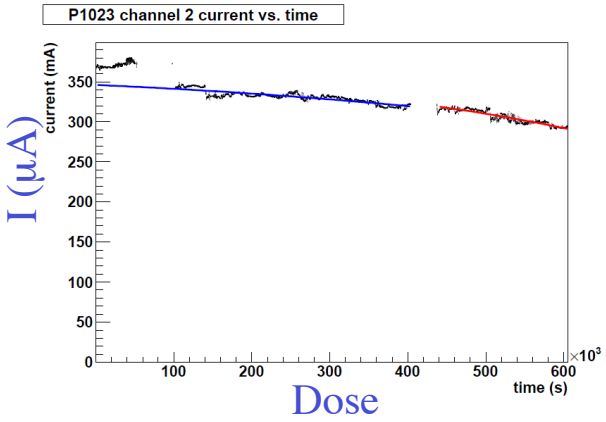


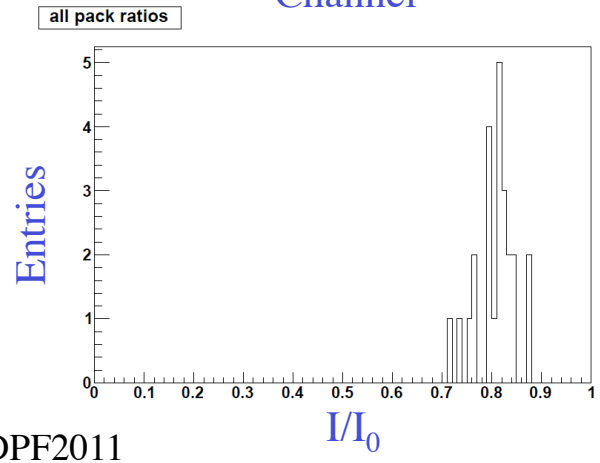
Irradiation of PIN with Pions

- 2 ULM 12-channel PIN arrays (4.25 Gb/s) were irradiated to a dose of 4.3 x 10^{14} π/cm^2 (300 MeV/c)
  - decrease in PIN responsitivity is small







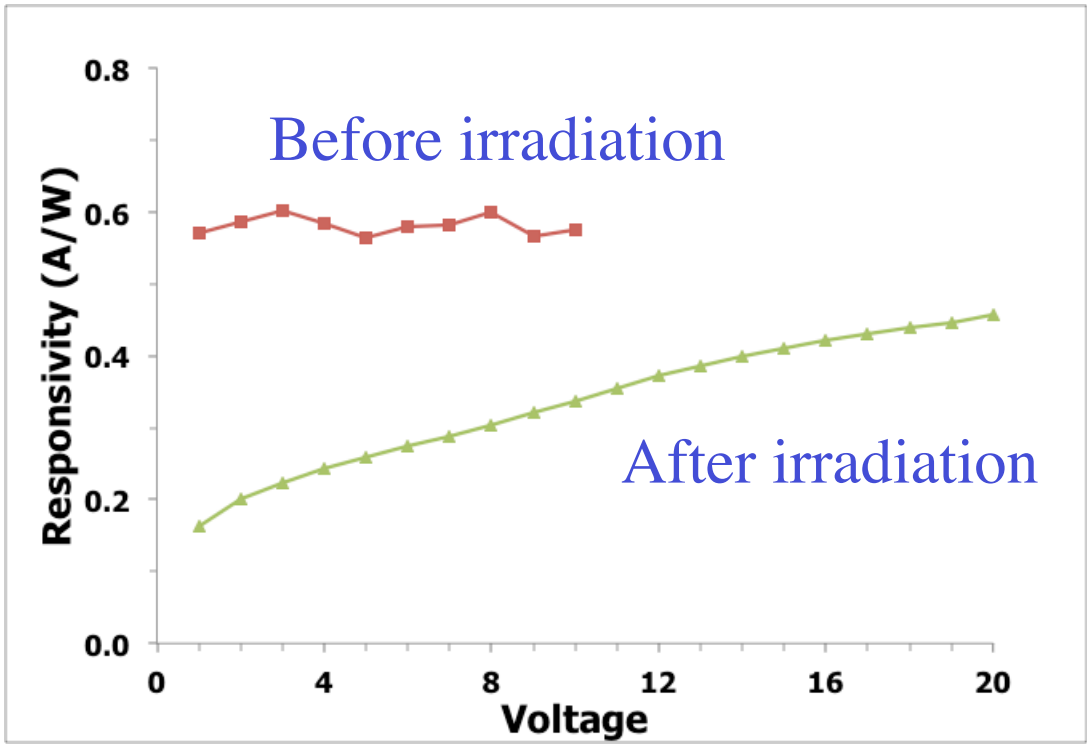


Test of NIEL Hypothesis

- 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 x 10^{14} π/cm^2: 81%
  - decrease in PIN responsivity with 6.6 x 10^{14} p/cm^2: 78%
  - ⇨ consistent with NIEL hypothesis

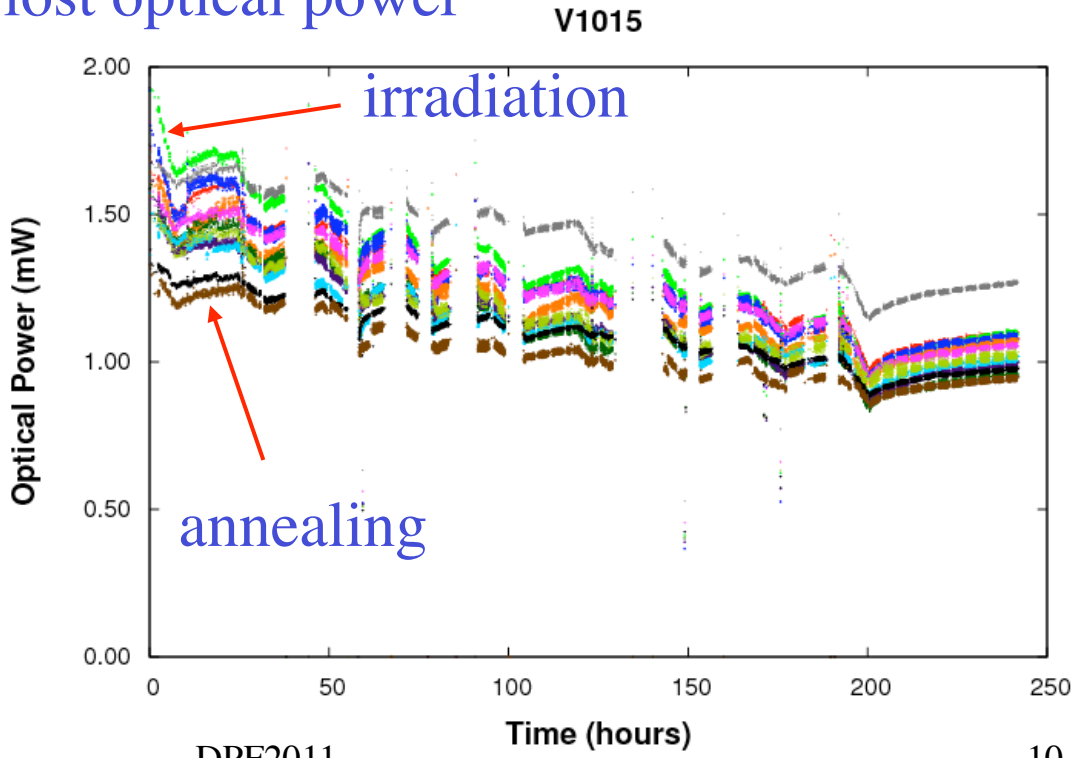
Resposivity vs Voltage

- 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



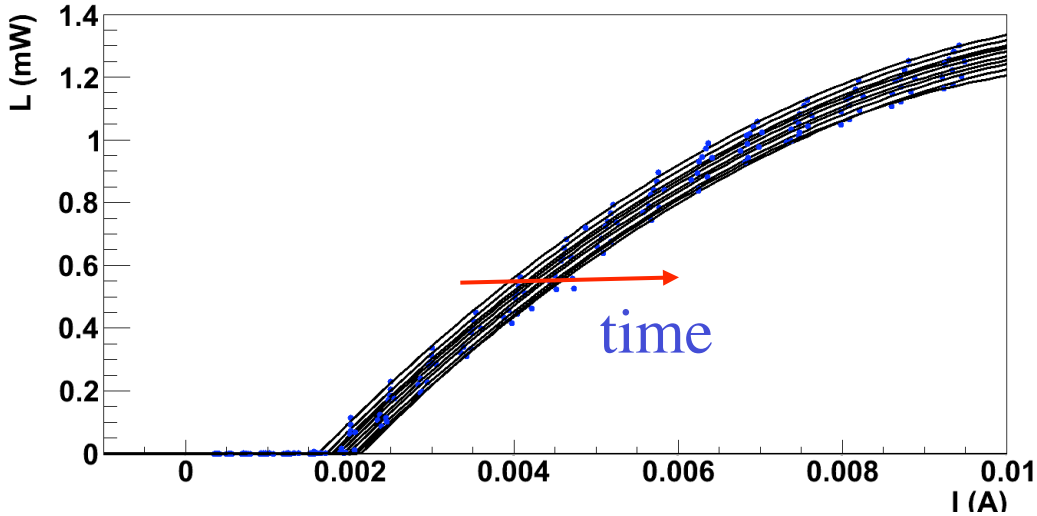
Proton Irradiation of VCSEL

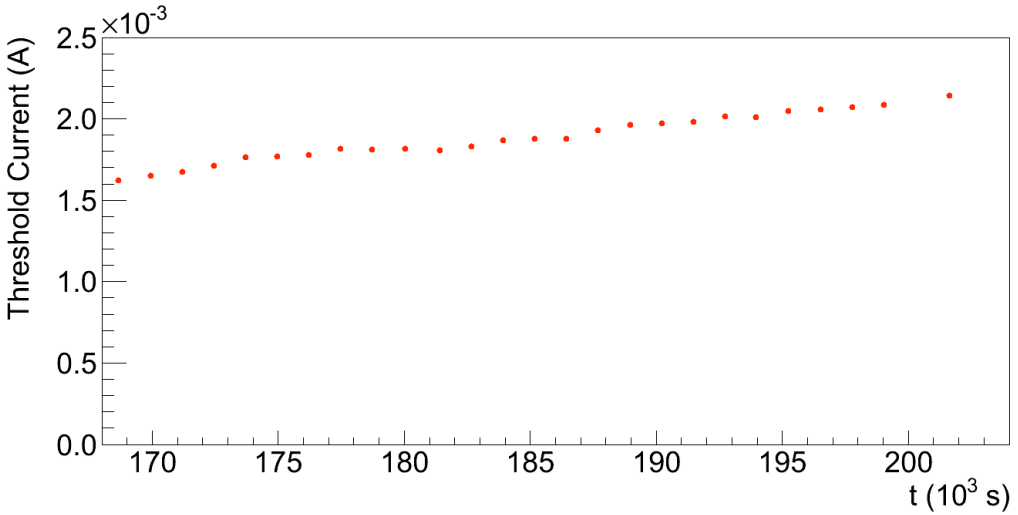
- 12 AOC arrays (10 Gb/s) irradiated to 8.0 x 10^{14} p/cm^2 (24 GeV/c)
  - alternate between irradiation and annealing (biased/no radiation)
  - decrease in optical power is modest
  - annealing in progress
    - ⇨ will recover most lost optical power



Radiation Effect on Threshold Current

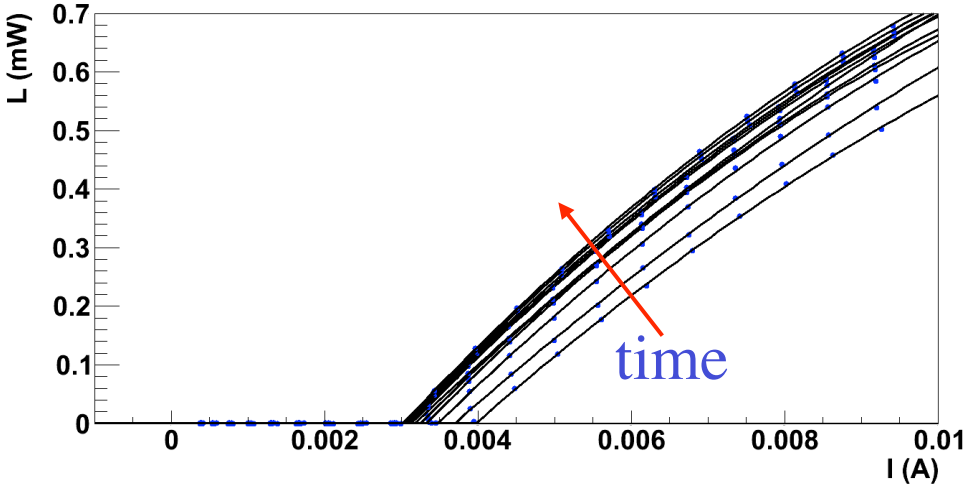
- Radiation damage increases current threshold for lasing
  - ⇨ decrease optical power at same drive current

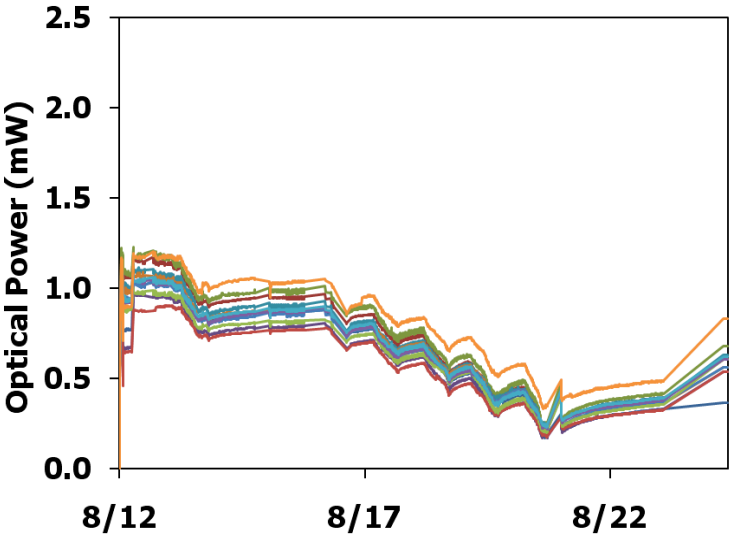


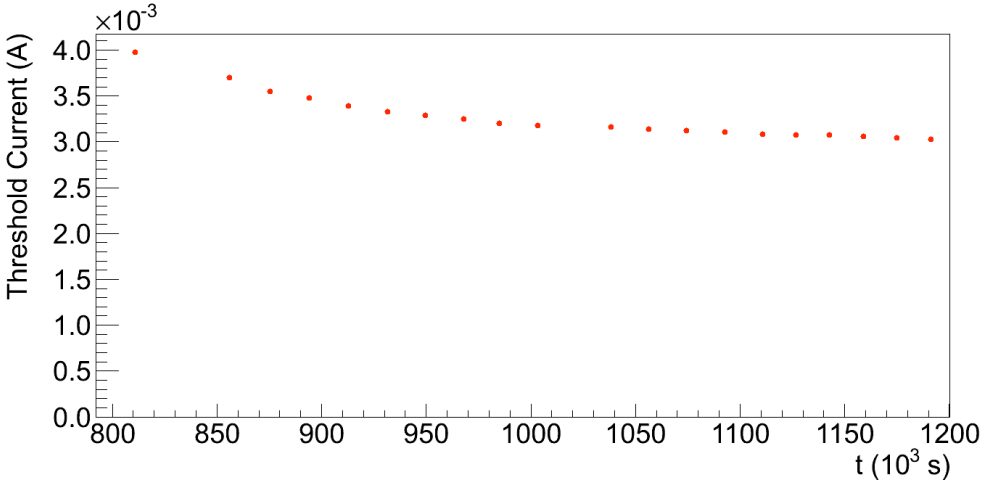


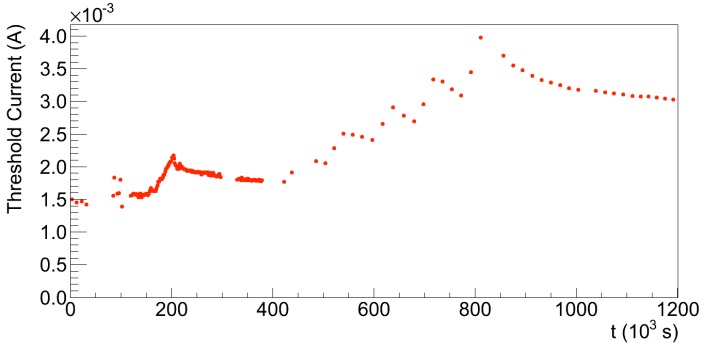
Annealing of Radiation Damage

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



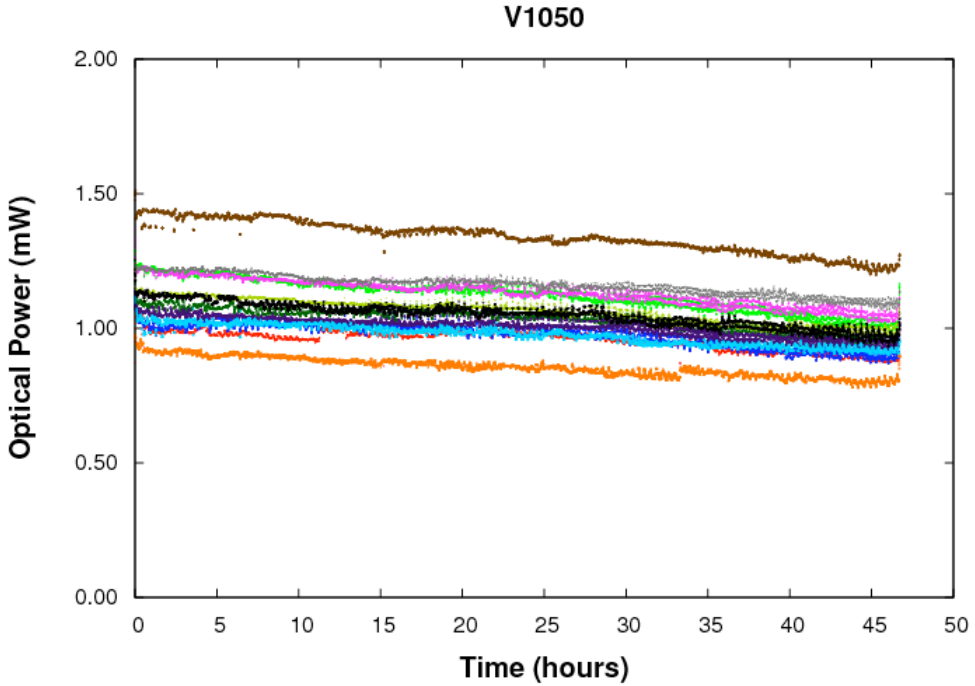






Pion Irradiation of VCSEL

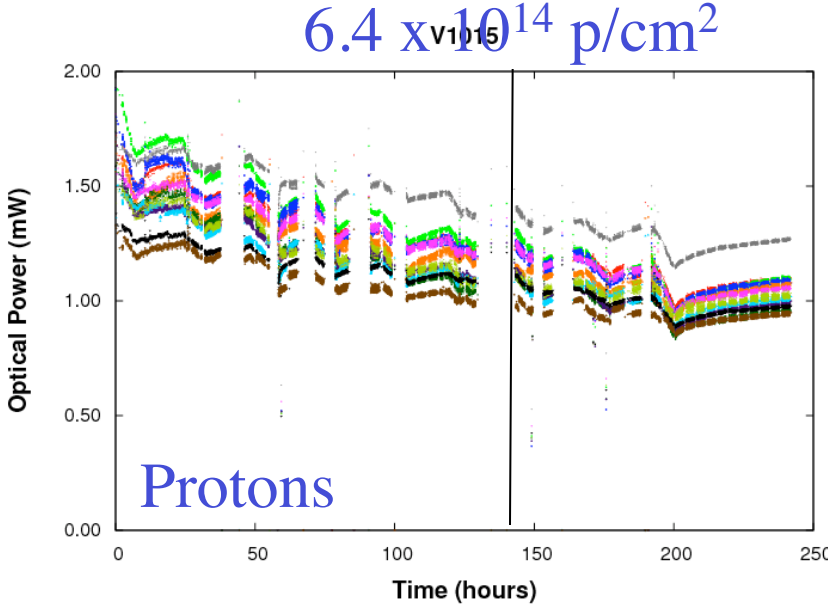
- One AOC 10 Gb/s VCSEL array was irradiated:
  - dose: 4.1 x 10^{14} π/cm^2 (300 MeV/c)
  - continuous irradiation with no dedicated annealing period due to limited time slot
  - decrease in optical power is modest

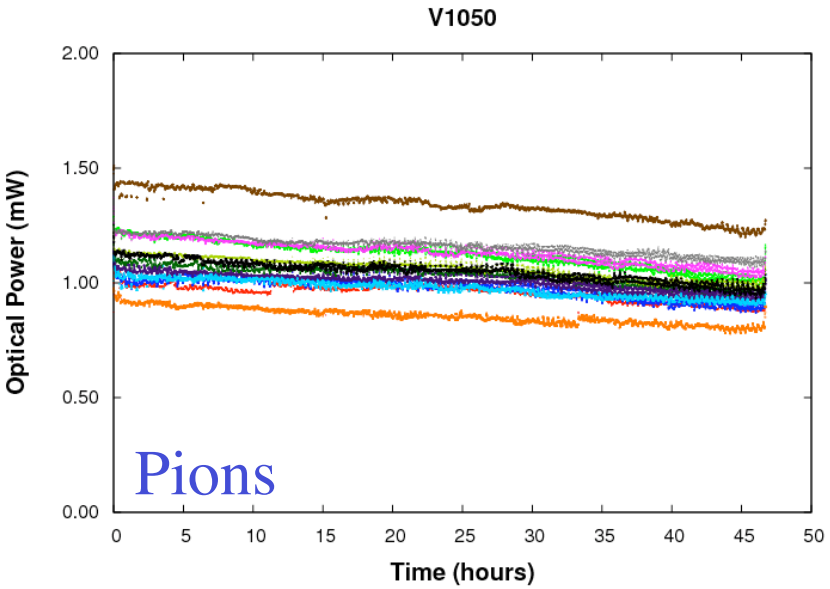


Test of NIEL Hypothesis

- 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 x 10^{14} π/cm^2 is equivalent to 6.4 x 10^{14} p/cm^2?
  - ⇨ need to repeat proton irradiation with no dedicated annealing
    - difficult to receive the exact required dose in 47 hours

6.4 x 10^{14} p/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