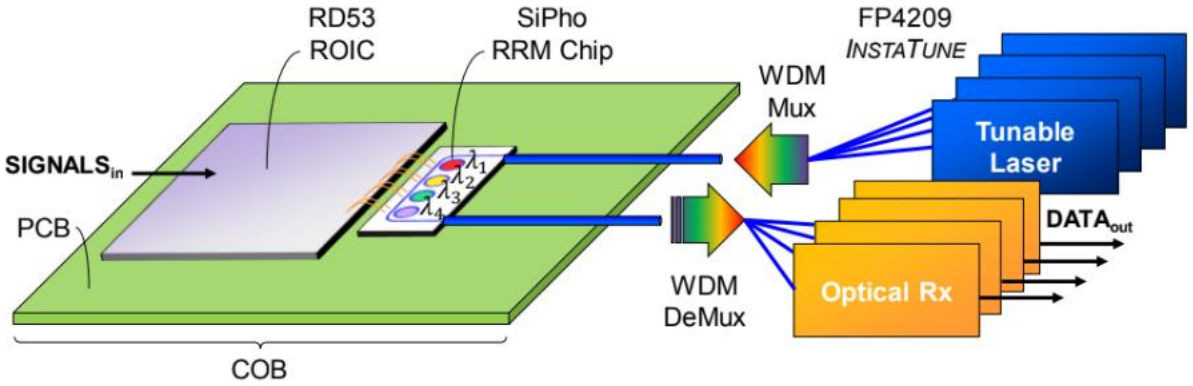
03/03/2023

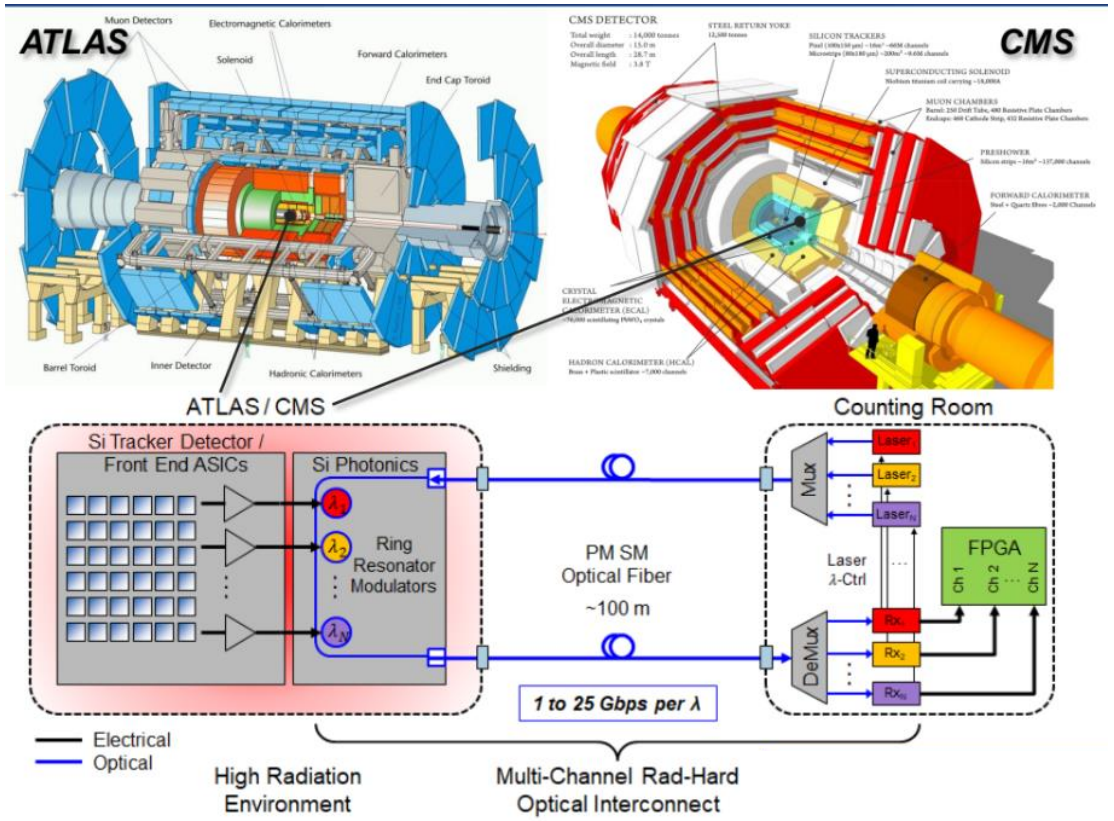
Silicon Photonic Design Iteation

Evan Chansky

RadLink: Radiation Hard, High Bandwidth Optical Fiber Links for Detectors at High Energy Colliders

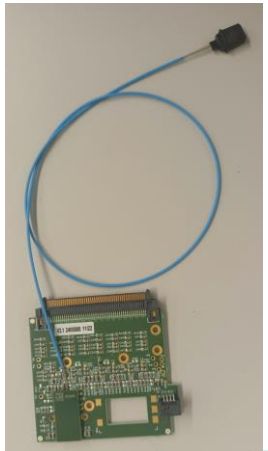
- Wavelength Division Multiplexing
  - Parallel readout on a single fiber
- External Optics
  - Lower mass, power, and complexity

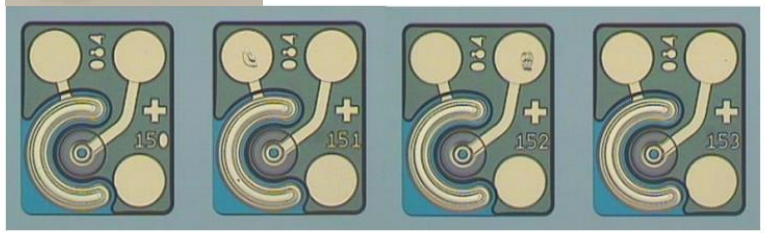




Improving Spectral Bandwidth

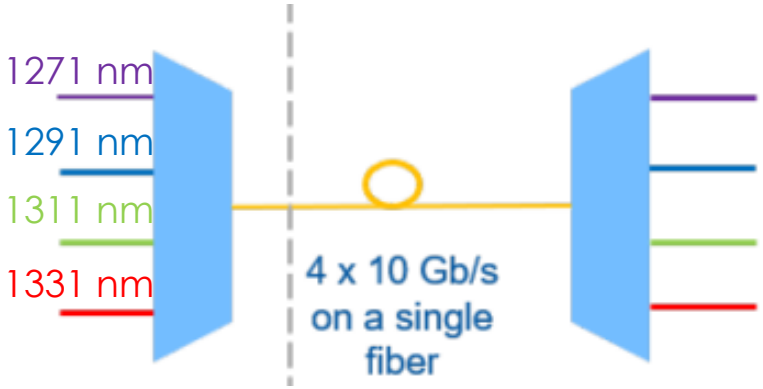
Now
Parallel Optics





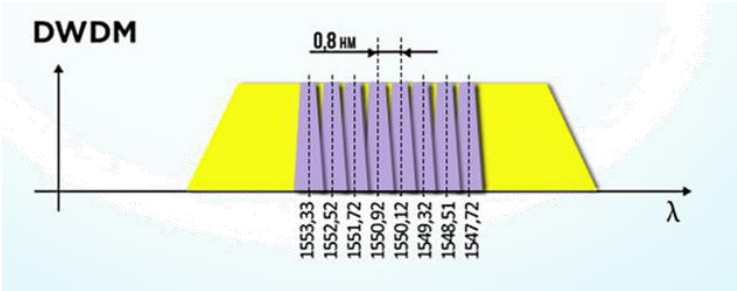
VCSELs fail beyond 10 Mrad

Near Term
Coarse WDM



Backwards compatibility with current detector electronics

Beyond
Dense WDM



Eliminates the need for signal processing electronics

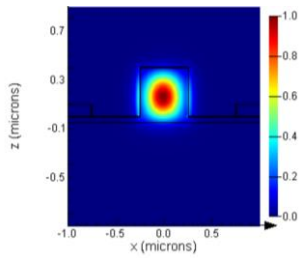
What's capable with SiPh Readout Chips

- Immediate Future – Swap VCSELs
  - A direct stand in for current VCSELs in Verstaile Link+
    - 4 fibers x 10.24 Gbps → 4 lambda x 10.24 Gbps
    - No mass/bandwidth improvements – just more radiation hardness
- Soon – WDM serialization
  - 8 lambda x 1.28 Gbps = 10.24 Gbps optical
    - Currently done using digital electronics
  - Single chip can fit >8 WDM sites so one chips handles 2x Versatile Link +
- Far Off – Direct Optical Readout
  - SiPh modulators can operate at 50 Gbps
    - No triggering or digital electronic
  - Delivery of 50 Gbps signals requires tight integration
    - And a complete sensor redesign

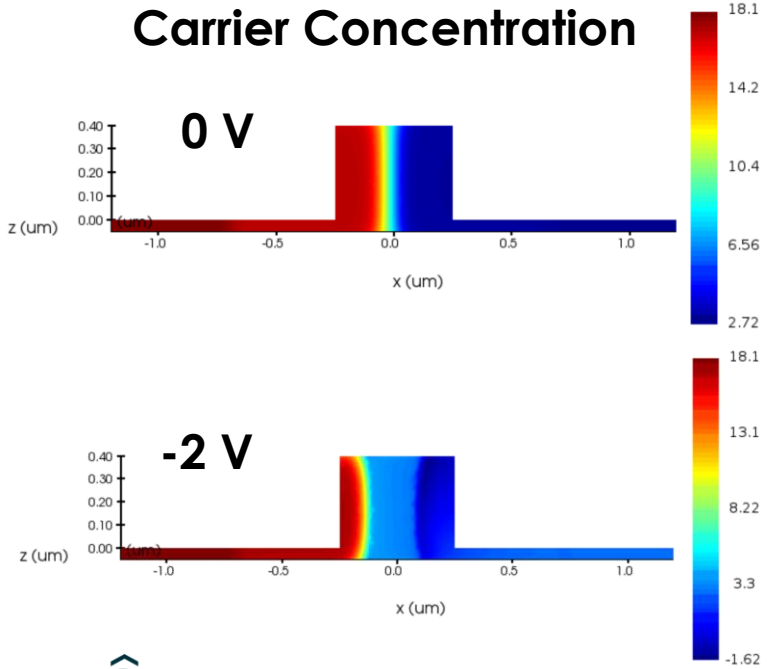
RRM Electro-Optic Conversion

Phase Shifter

Optical Mode



PN Junction
Carrier Concentration



Index

$$\Delta n = -\frac{e^2 \lambda^2}{8\pi^2 c^2 \varepsilon_0 n}\left(\frac{\Delta N_e}{m_e} + \frac{\Delta N_h}{m_h}\right)$$

electrons holes

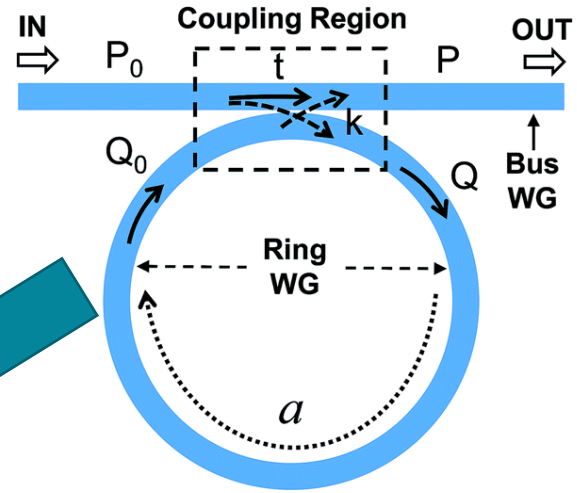
Loss

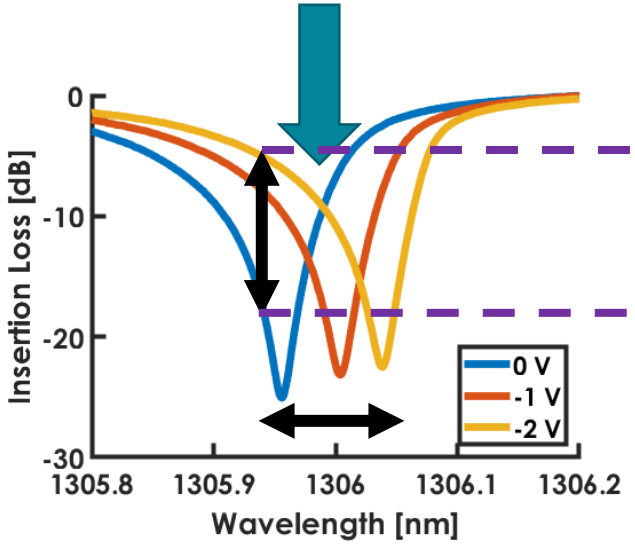
$$\Delta \alpha = -\frac{e^3 \lambda^2}{4\pi^2 c^3 \varepsilon_0 n}\left(\frac{\Delta N_e}{m_e^2 \mu_e} + \frac{\Delta N_h}{m_h^2 \mu_h}\right)$$

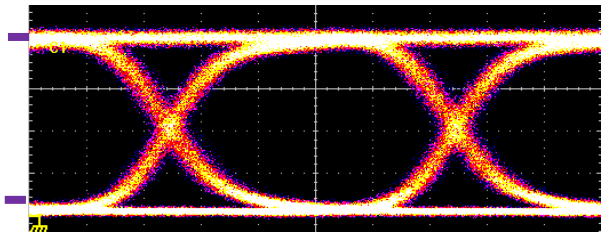
Power

$$P_{t1} = |E_{t1}|^2 = \frac{\alpha^2 + |t|^2 - 2\alpha |t| \cos(\theta + \varphi_t)}{1 + \alpha^2 |t|^2 - 2\alpha |t| \cos(\theta + \varphi_t)},$$

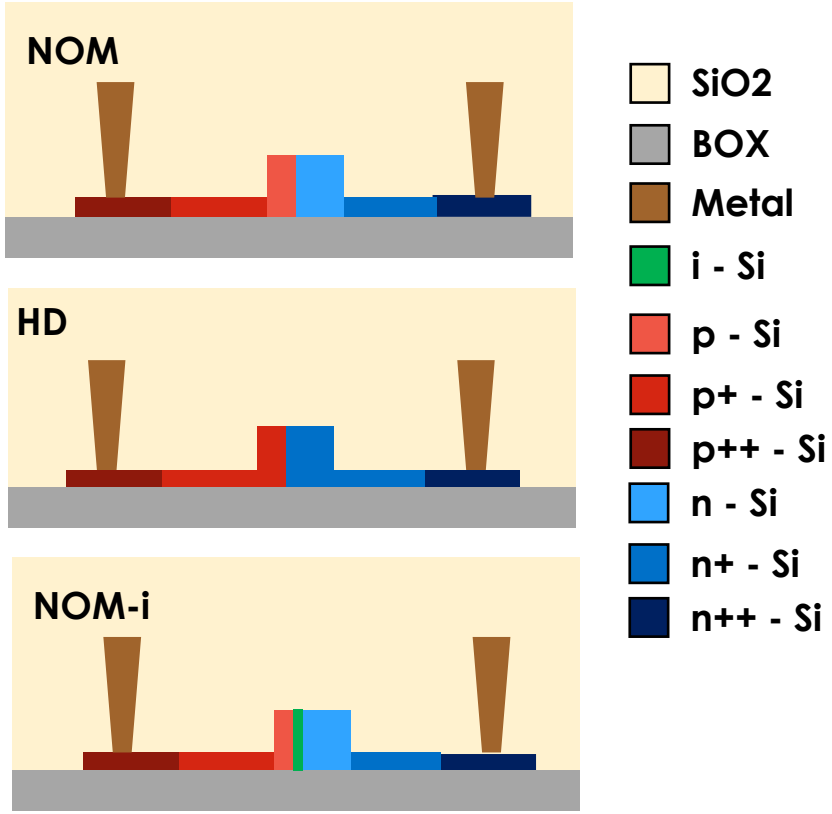
Resonator

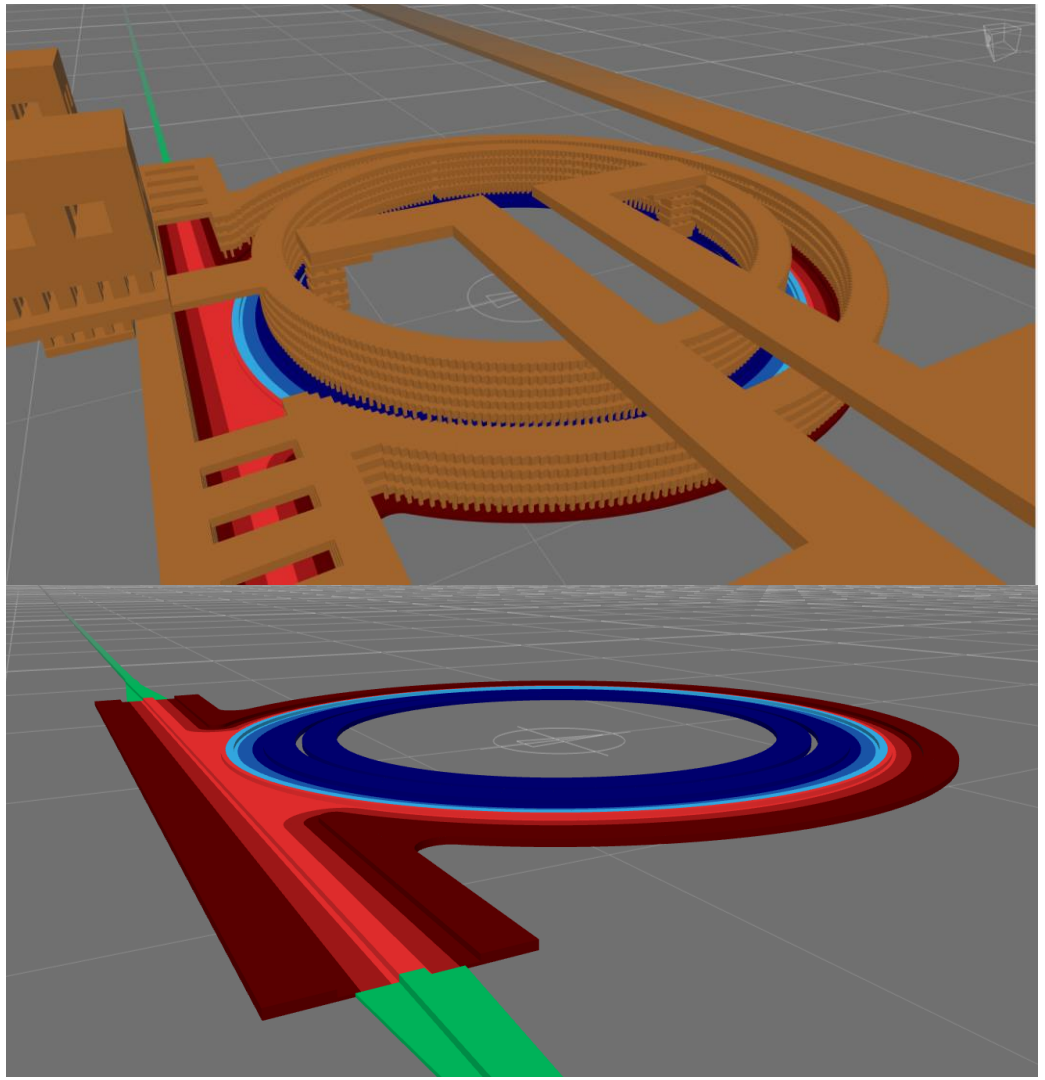






RRM Layout and Design



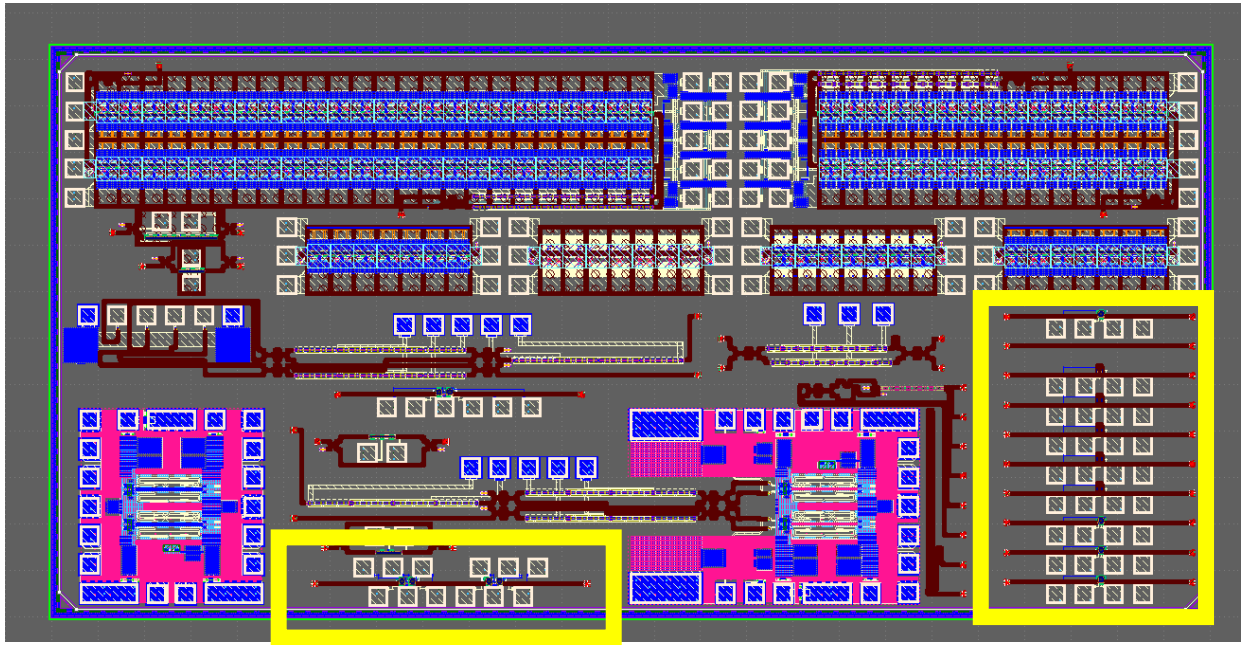


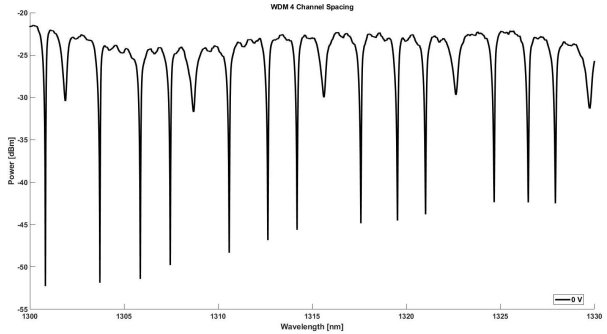
PIC Submissions

GlobalFoundries 45CLO Silicon Photonics

Run #1 – Designed Aug 2021 – Arrived Feb 2022

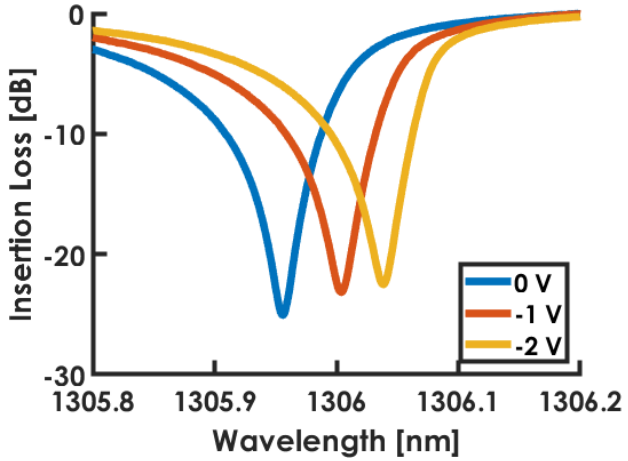
- Single nominal PN RRM with UID (Unintentionally Intrinsically Doped)
- Single highly doped PN RRM
- 4 channel WDM (3x nominal PN and 1x PN w/ UID)

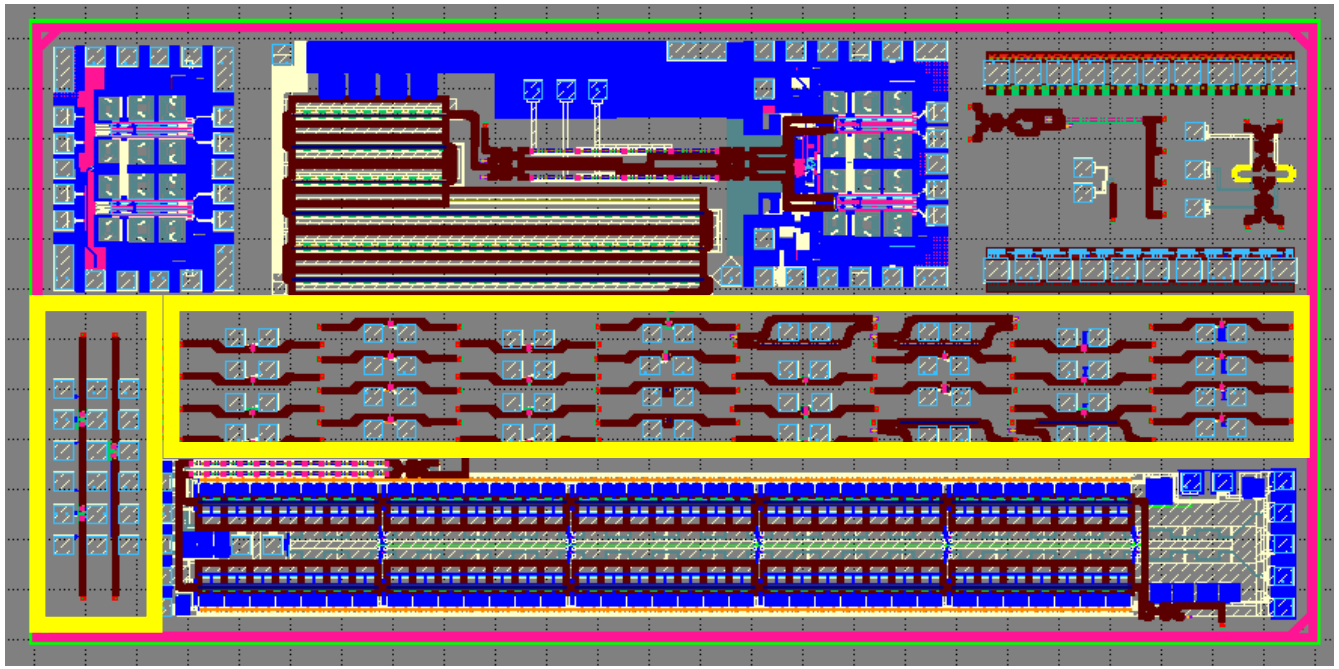




Run #2 – Designed Feb 2022 – Arrived Sep 2022

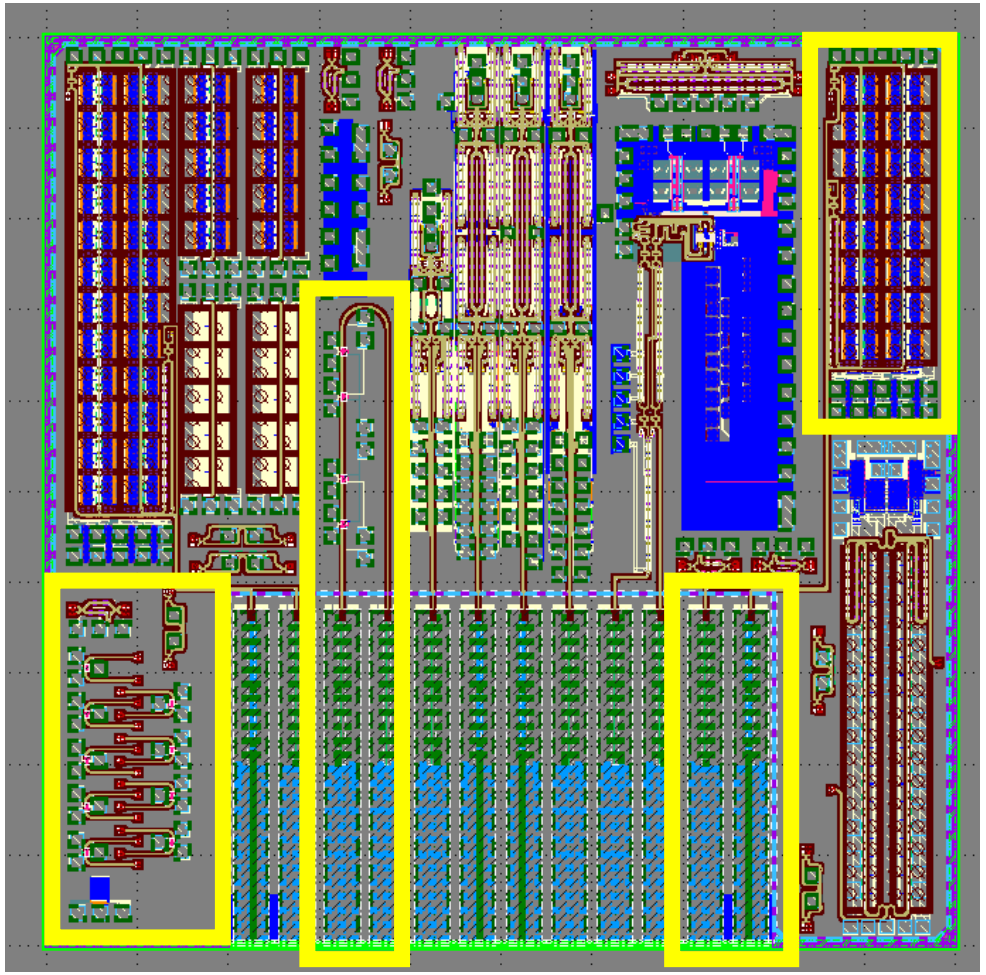
- Lots of PiN junctions for forward bias
  - Not as promising or worth it as initially expected
- 6 um PN junction





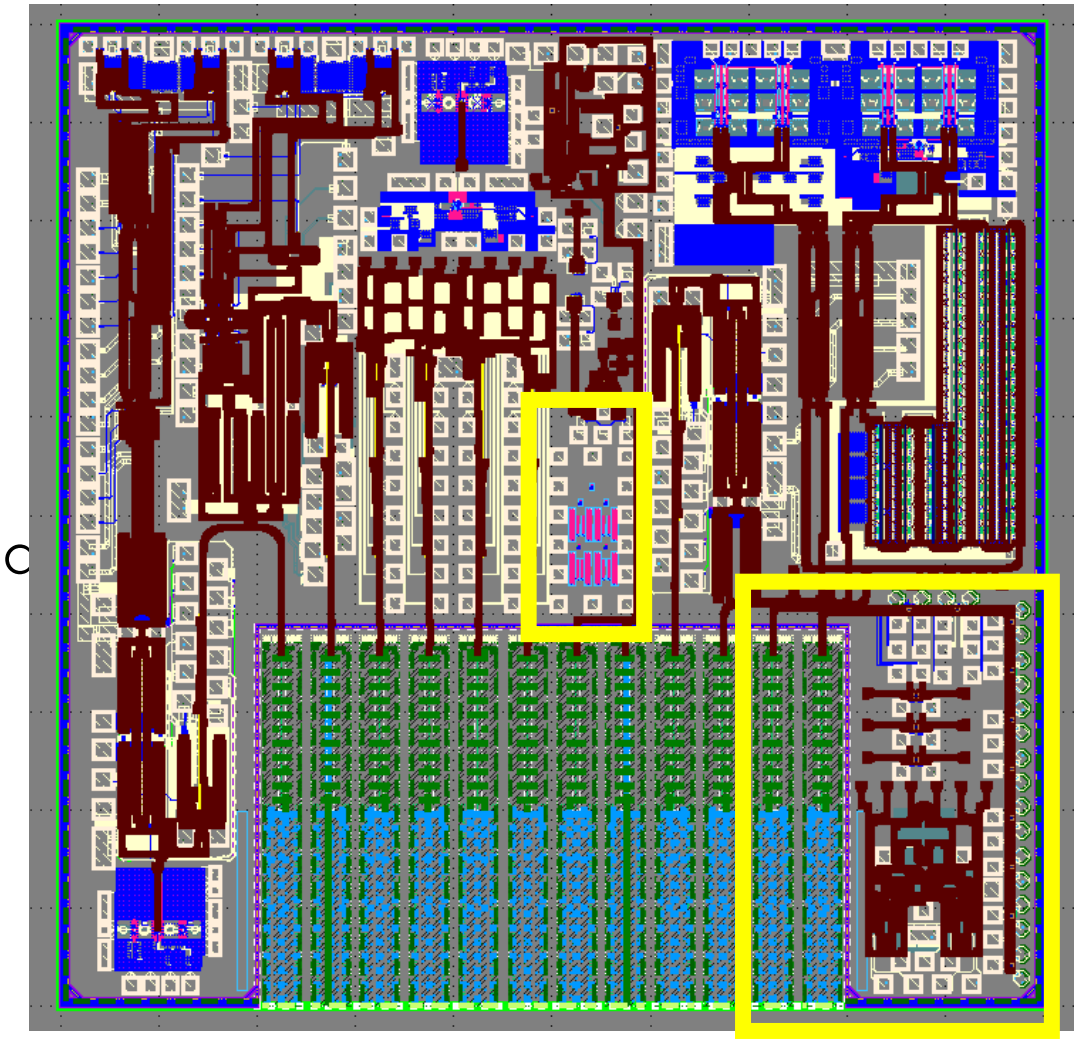
Run #3 – Designed Aug 2022 – Arriving May 2023

- 4 Channel HD WDM w/ edge couplers
- 1.8mm TW-MZM with HD junction & edge couplers
- Single RRM w/ HD junction
  - {150, 175, 200, 225, 250} nm coupling gaps
  - {0, 5, 10, 15, 20} concentric coupling angles
  - All have undercut trench heaters
- PN junction AMZIs w/ abrupt junction
  - 100 um and 300um
  - HD and nominal
- 101 ring oscillator test site



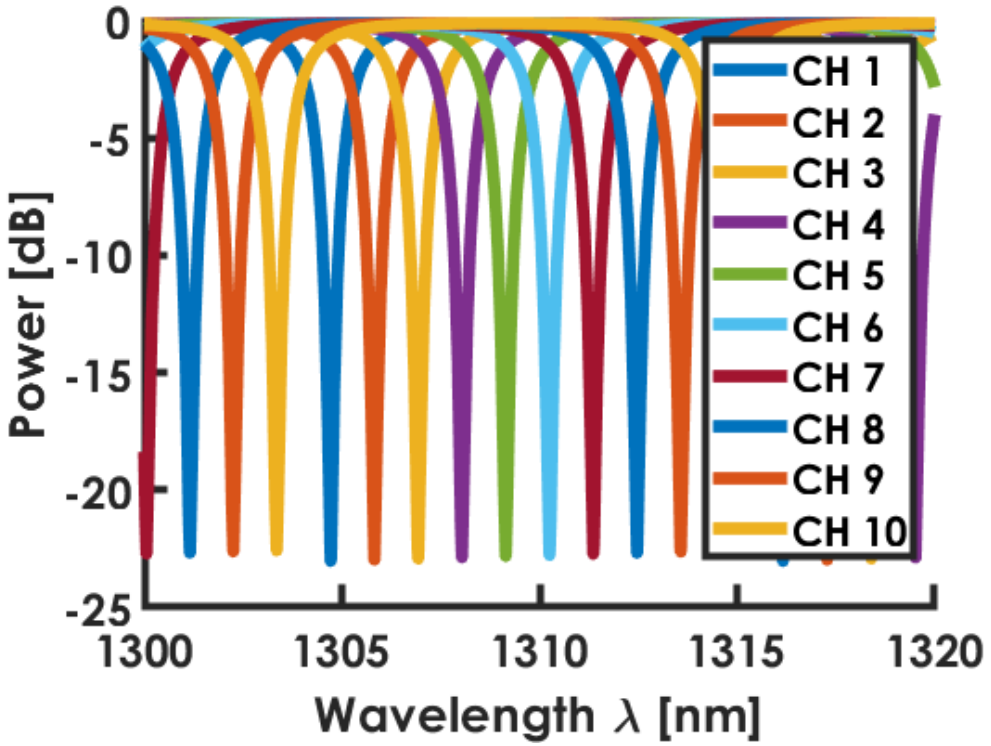
Run #4 – Designed Feb 2023 – Arriving Oct 2023

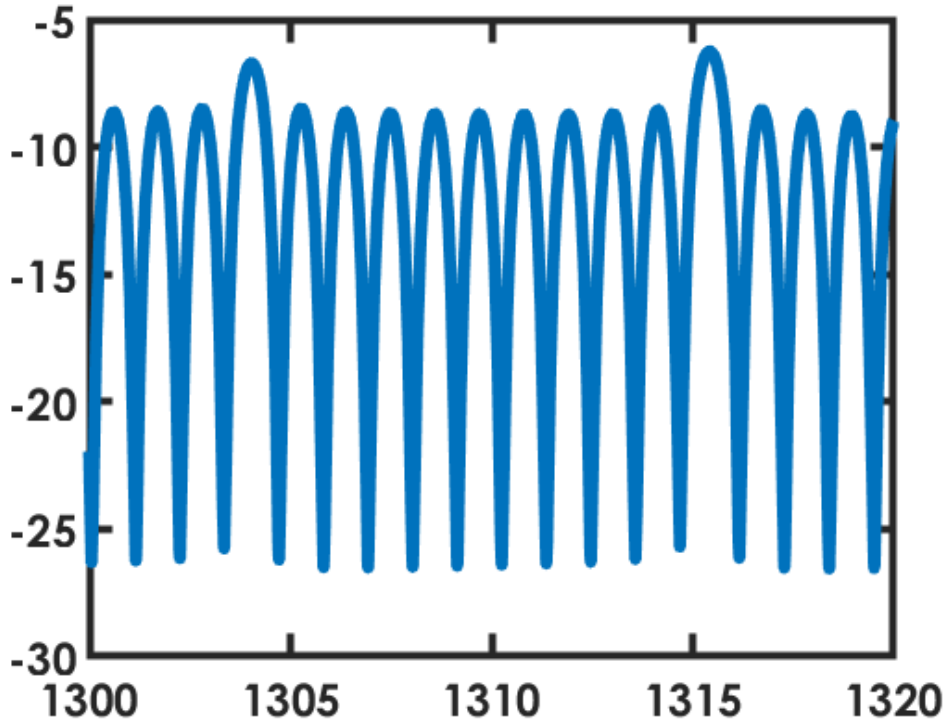
- 10 Channel WDM site
  - 8 standalone rings
    - 7 w/ undercut trench, one w/o
  - 2 drivers
    - 1 Inverter based (for cryo applications)
    - 1 common source NMOS onlyRing oscillo
  - 16 transistor flavors



10 Channel WDM

- 200 GHz spacing = 1.2 nm

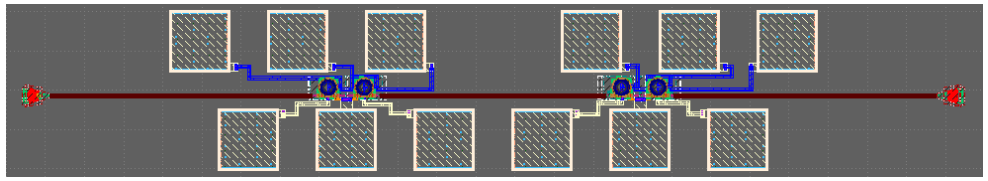


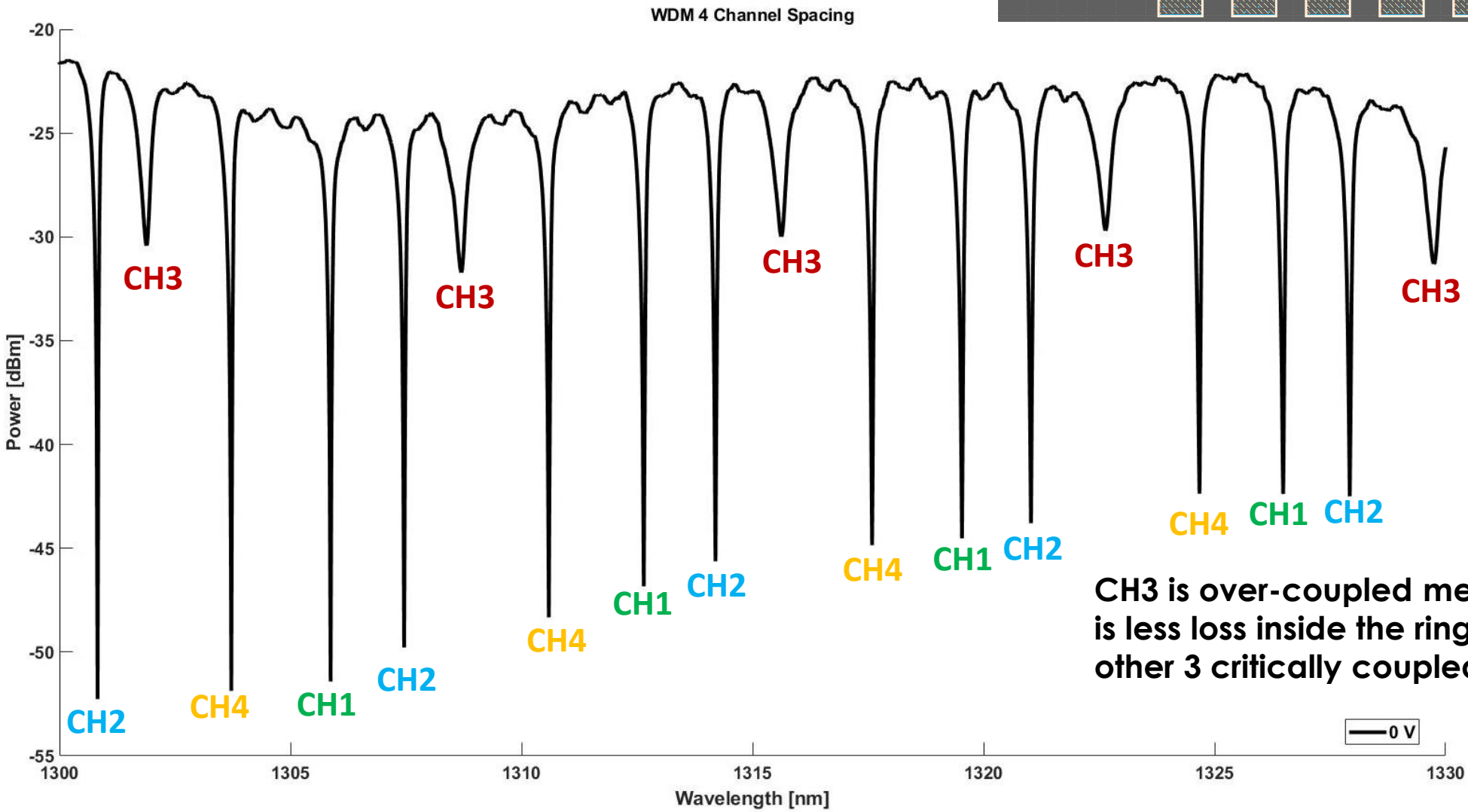


Radiation Hardness – Total Ionizing Dose

Previous Results

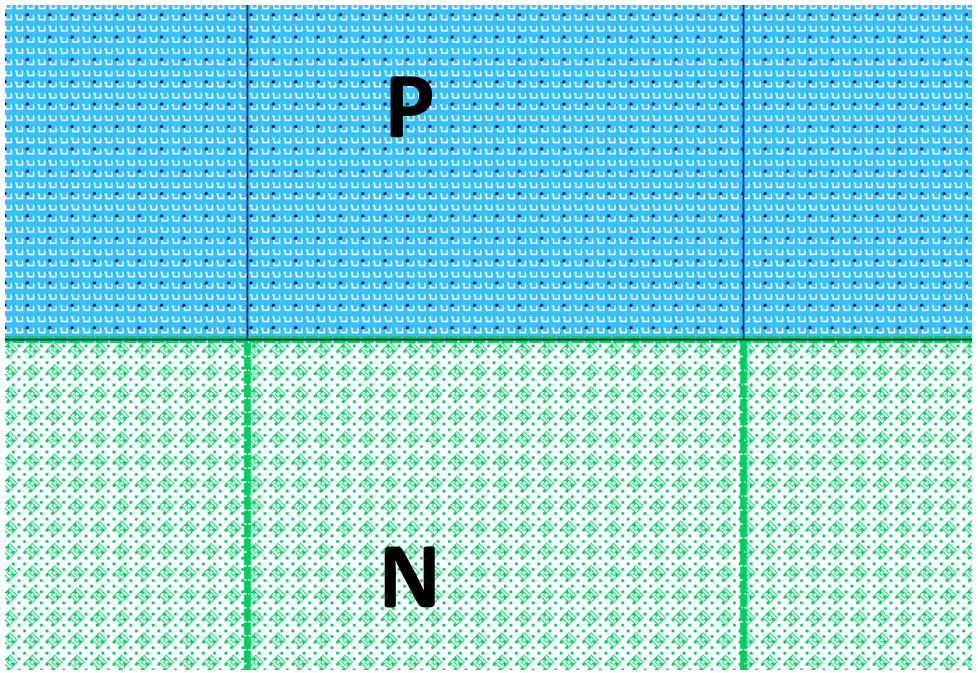
4 Channel WDM PN Anomaly



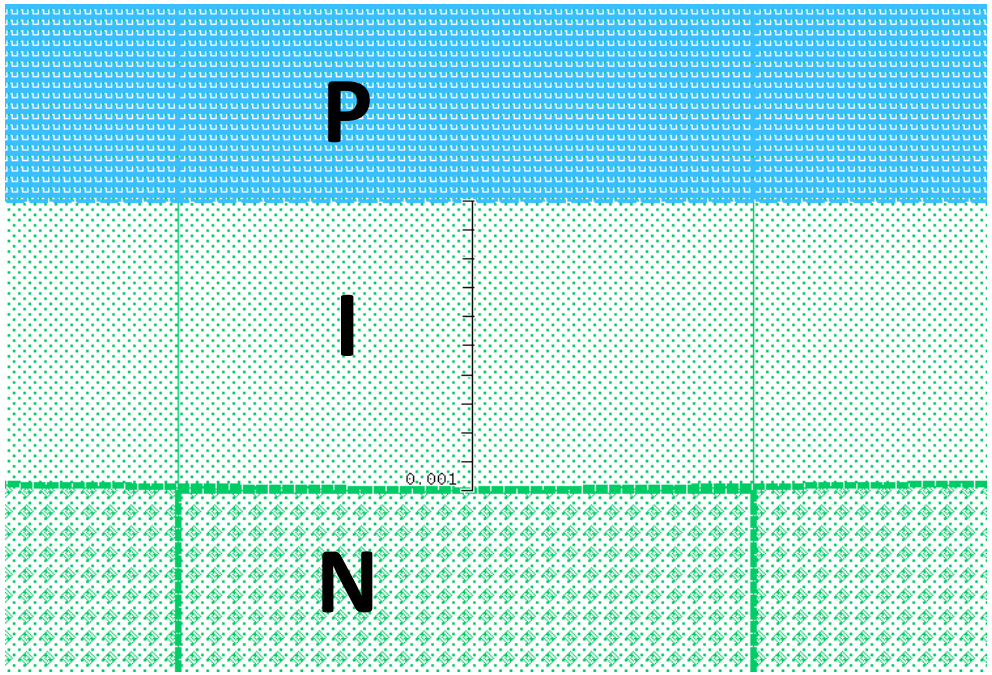


CH3 is over-coupled meaning there is less loss inside the ring than the other 3 critically coupled channels

Run #1 Nominal PN Ring Design Error

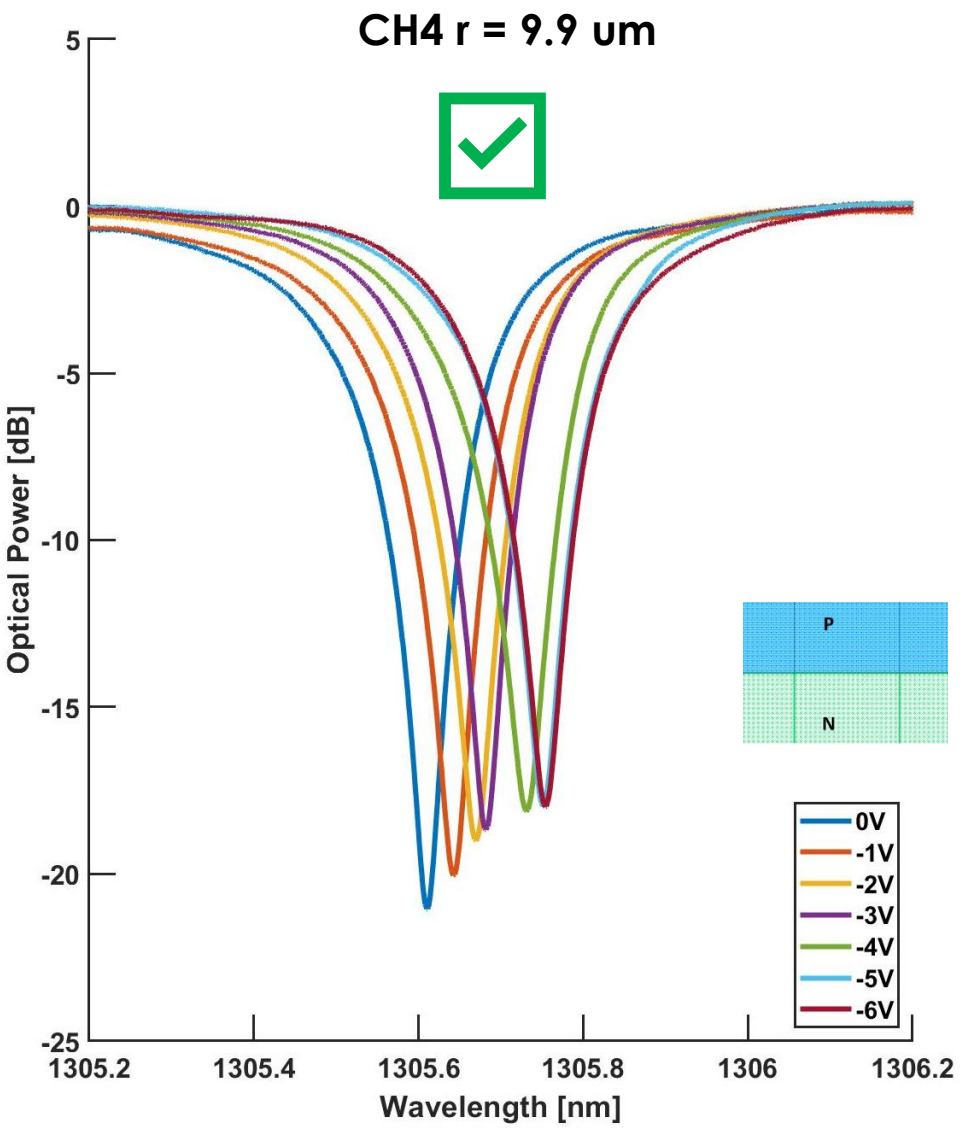


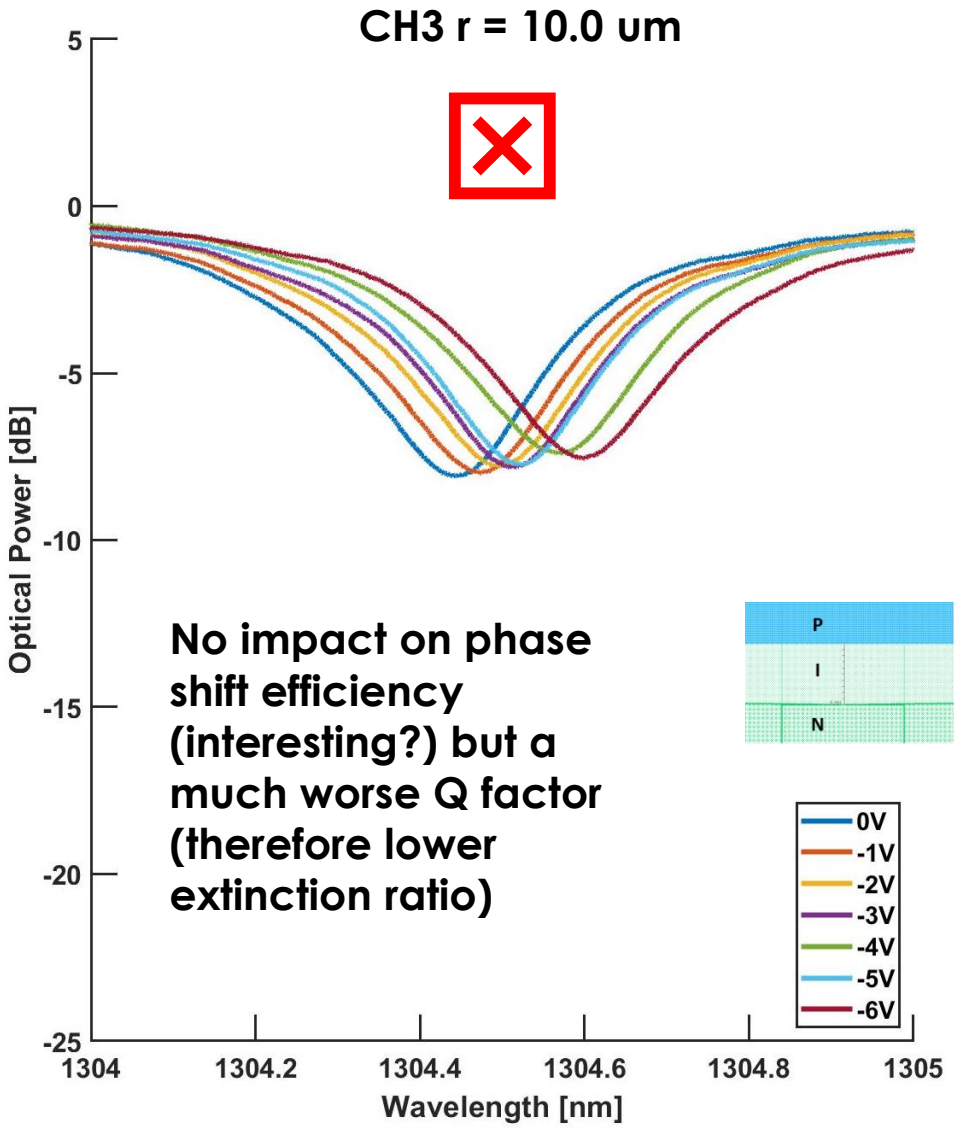
Fine: CH 1,2,4 WDM and standalone highly doped PN



Impacted: CH 3 WDM and standalone nominal PN

Impact to Device Performance

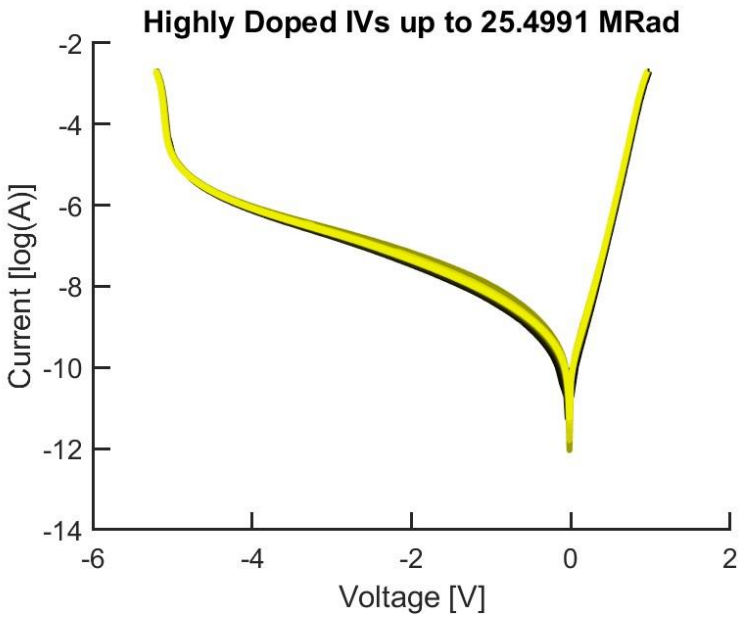




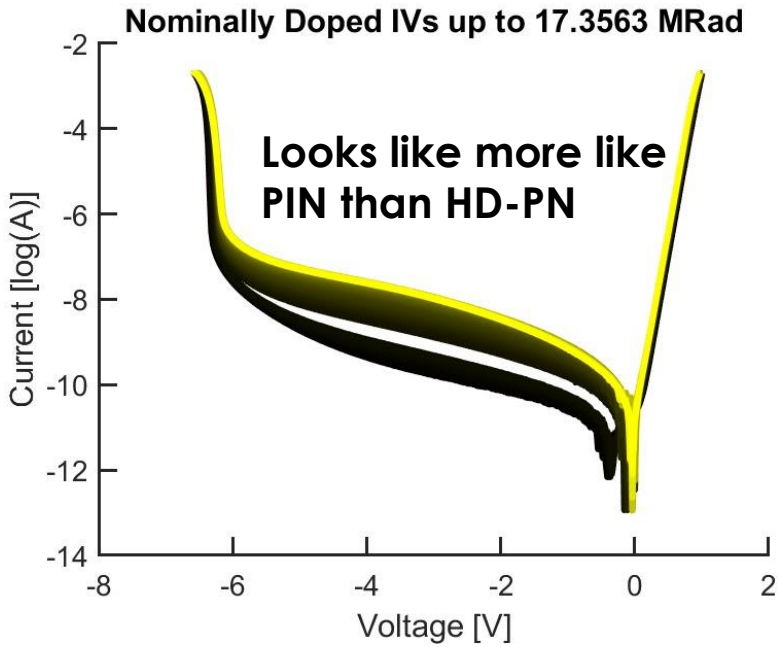
No impact on phase shift efficiency (interesting?) but a much worse Q factor (therefore lower extinction ratio)

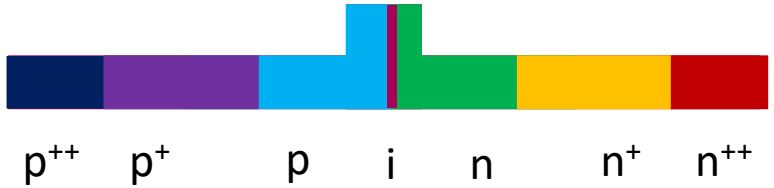
Impact on Radiation Hardness

Highly Doped



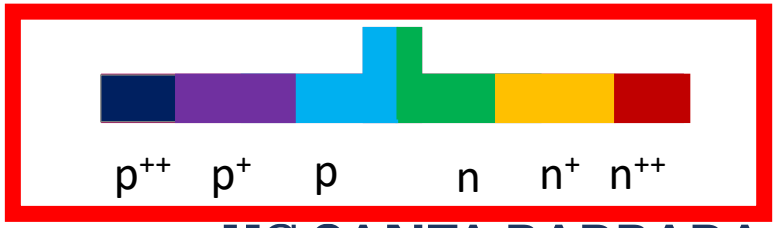
Nominally Doped (i)





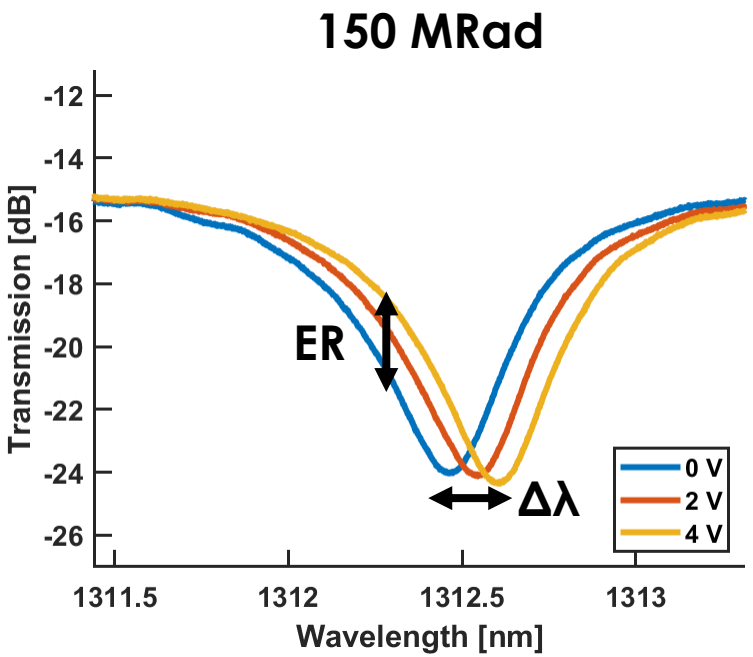
Nominally Doped

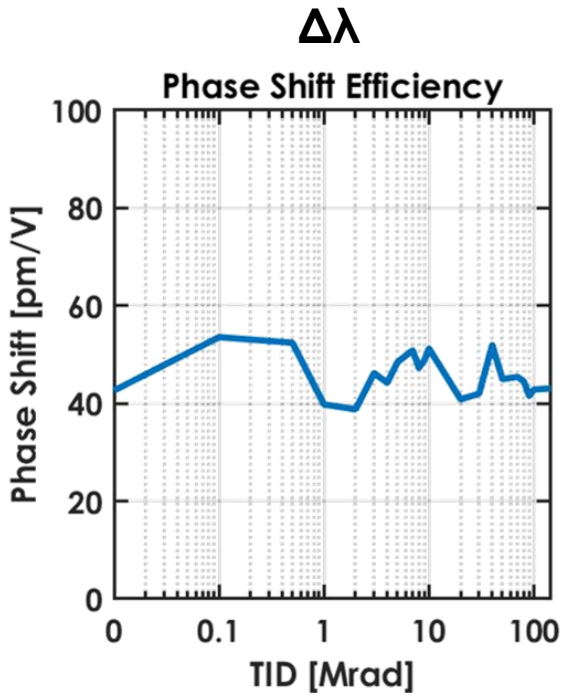
Proper nominal PN junction yet to be tested – past nominal irradiated devices had extra i gap

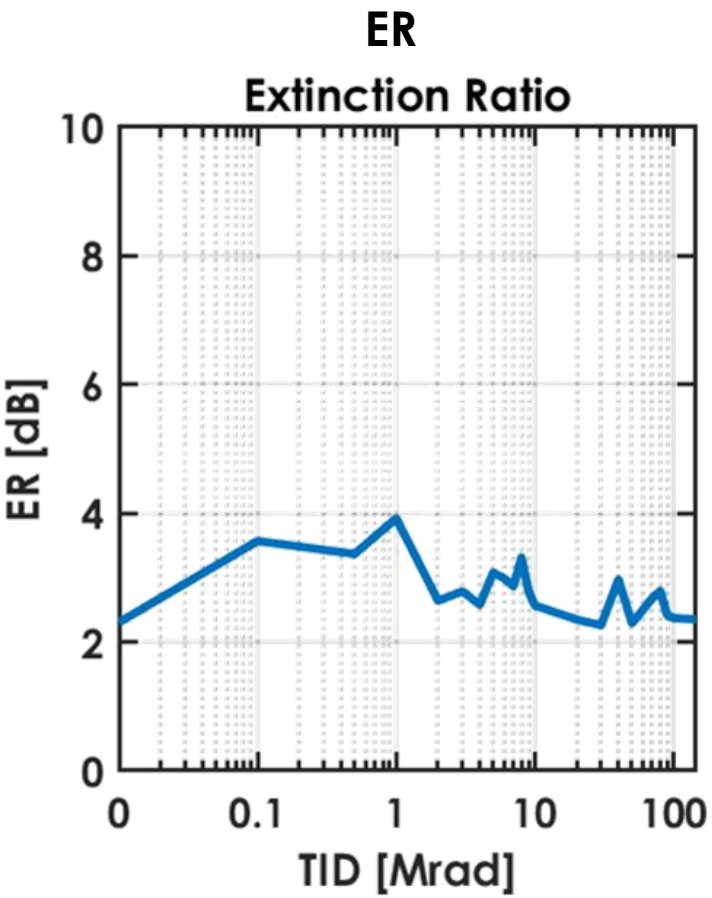


Optical Results – Highly Doped

- DC biased at -2 V during irradiation
- For simulated 2 Vpp input signal







Conclusion

Upcoming Work

- Abrupt nominal PN junction
  - How does it compare to PiN and highly doped
- Thermal phase shifters
  - Do they have TID impacts?
  - Can they help anneal damage?
- Optical measurements
  - Upgrades to X-ray cabinet
  - Future fiber connected devices (May)
- RD53 integration
  - Board design with 4 display inputs to 4 RRM channels

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