# STUDY OF RADIATION HARDNESS OF PIN DIODES FOR ATLAS PIXEL DETECTOR

B. Abi, F. Rizatdinova (OSU),

P. Skubic (OU),

K.K. Gan , D.S. Smith  (Ohio State U.)

# Outline



- Motivations
- Results of TID test
- Irradiation tests with 200 MeV protons
- Irradiation test with 24 GeV protons
- Conclusions

# Motivation



- LHC is expected to be upgraded by 2016 – current pixel detectors should be upgraded as well to address the higher radiation environment of the SLHC
- ATLAS pixel detector employs optical readout, one of the components of the optical link is PiN diode
- The total integrated luminosity of the SLHC is assumed to be 3000 $fb^{-1}$
- That corresponds to the fluences :

**Si : $1.5 \times 10^{15}$ 1-MeV $n_{eq}/cm^2$**

**$2.6 \times 10^{15}$ $p/cm^2$ for 24 GeV protons**

**$1.2 \times 10^{15}$ $p/cm^2$ for 200 MeV protons**

**We did $1.4 \times 10^{15}$ $p/cm^2$ 20 % more=80Mrad**

**GaAs : $8.2 \times 10^{15}$ 1-MeV $n_{eq}/cm^2$**

**$1.6 \times 10^{15}$ $p/cm^2$ for 24 GeV protons**

**$1.02 \times 10^{15}$ $p/cm^2$ for 200 MeV protons**

**we did $1.4 \times 10^{15}$ $p/cm^2$ 40% more**

# Goals

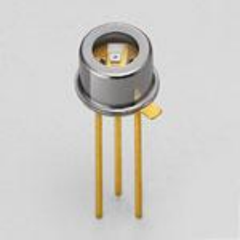


- Find fast PiN candidates which will survive after expected irradiation of SLHC dose
- Develop practical test stands and methods to study characteristics and radiation hardness and reliability of PiNs
- Investigate a behavior of the standard Si and GaAs PINs that are on the market as a function of irradiation dose
  - **Response**
  - **Lifetime**

# Selected PiN diodes in our tests

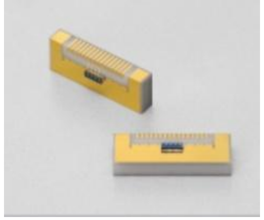


- Performed study of the market of the available PiNs (looked at the Hamamatsu , Truelight , Finisar, ULM , …); Have chosen following devices:



- Si PiN diodes (sinlge devices):
  - **S9055-01 & S5973-01**

  (In case of success have an agreement that Hamamatsu will produce arrays for us)
- GaAs PiN diode, G8522-XX
  - There are 3 varieties of this PiN: G8522-01, 02, 03 that differ in the size of active area and frequency - excellent opportunity to study the radiation hardness vs PiN frequency



- GaAsP PiN array G8921-01

# Characteristics of single PiN diodes



| PiN | S9055-01 S5973-03  | G8921-01  | G8522-01  | G8522-02 | G8522-03 |
|---|---|---|---|---|---|
| Peak Wavelength | 700 nm | 850 nm | 850 nm | 850 nm | 850 nm |
| Photo Sensitivity @850nm | 0.25 A/W<br>0.37 A/W | 0.5 A/W | 0.5 A/W | 0.5 A/W | 0.5 A/W |
| Dark Current Ave. | 1 pA | 2 pA | 1 pA | 8 pA | 20 pA |
| Cut-off Frequency | 2 GHz<br>1.5 GHz | 2.5 GHz | 3 GHz | 1.9 GHz | 1.5 GHz |
| Terminal Capacitance | 0.5 pF<br>1.6 pF | 0.5 pF | 0.3 pF | 0.45 pF | 0.8 pF |
| Active Area(diameter) | 100 μm<br>120 μm | 60 μm | 40 μm | 80 μm | 120 μm |
| Voltage bias (V) | 5 | 2 | 2 | 2 | 2 |

# Performed tests

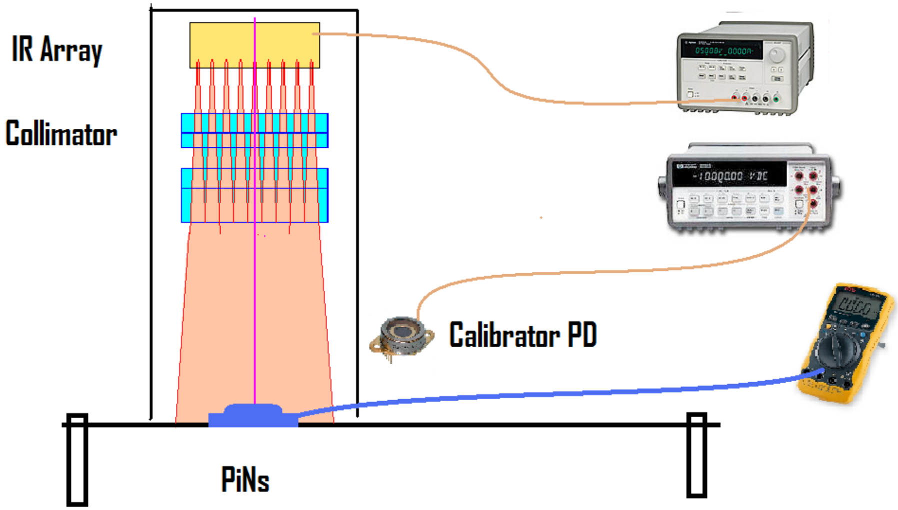


- TID test at BNL (total dose 10Mrad ) in April 2008
- Two tests at IUCF in May and June
  - 200 MeV protons
  - First test at May up to 40 Mrad, second test in June 2008 – with another 40 Mrad
  - Used the same setup with the same PiN diodes in June.
  - Total dose is 80 Mrad , total fluence ~ $1.4 \times 10^{15}$ p/cm$^2$(Si)
- Test of the same types of PiN diodes and of GaAs arrays at CERN T7
  - 24 GeV protons, total fluence is $1.5 \times 10^{15}$ p/cm$^2$ for GaAS and $2.6 \times 10^{15}$ p/cm$^2$ for Si devices

# TID Test at BNL



- Cobalt-60 ($^{60}Co$) Source 200kRad/h
  - Responsivity was measured offline at 0 Mrad, 5.6 Mrad and 9.6 Mrad
  - Tested three versions of G8255 and one S9055-01 diodes with caps off. PiNs have been biased.

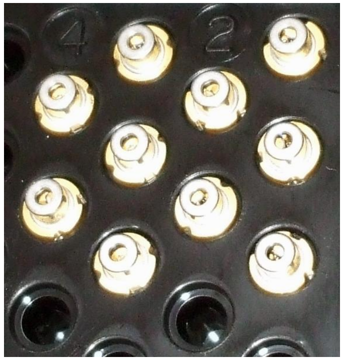



- Used IR LEDs to illuminate it
- Uniform optical power over the testing area
- Controlled the optical power during the experiment.

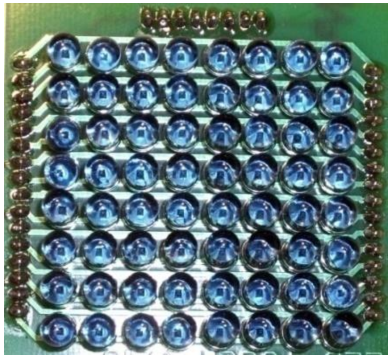
# TID setup



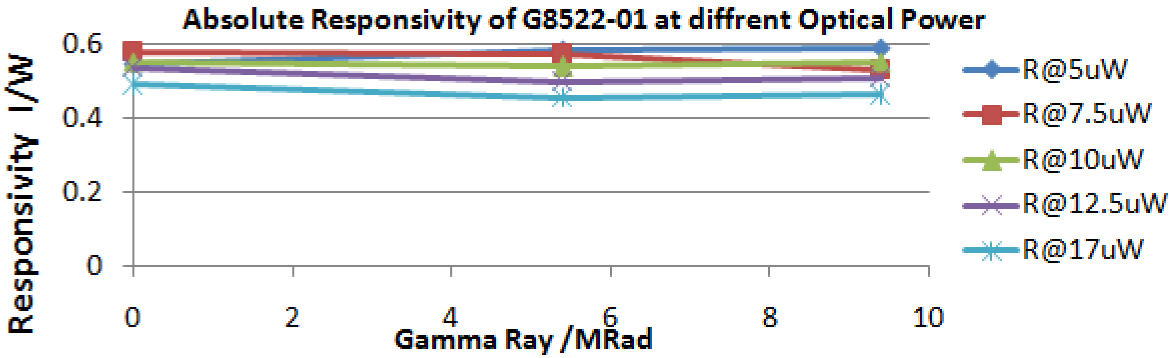
IR Challenging To have an optical power of 100-400μW over 100μm area we have to supply a power of 4-7 $W/cm^2$



VCSEL Array

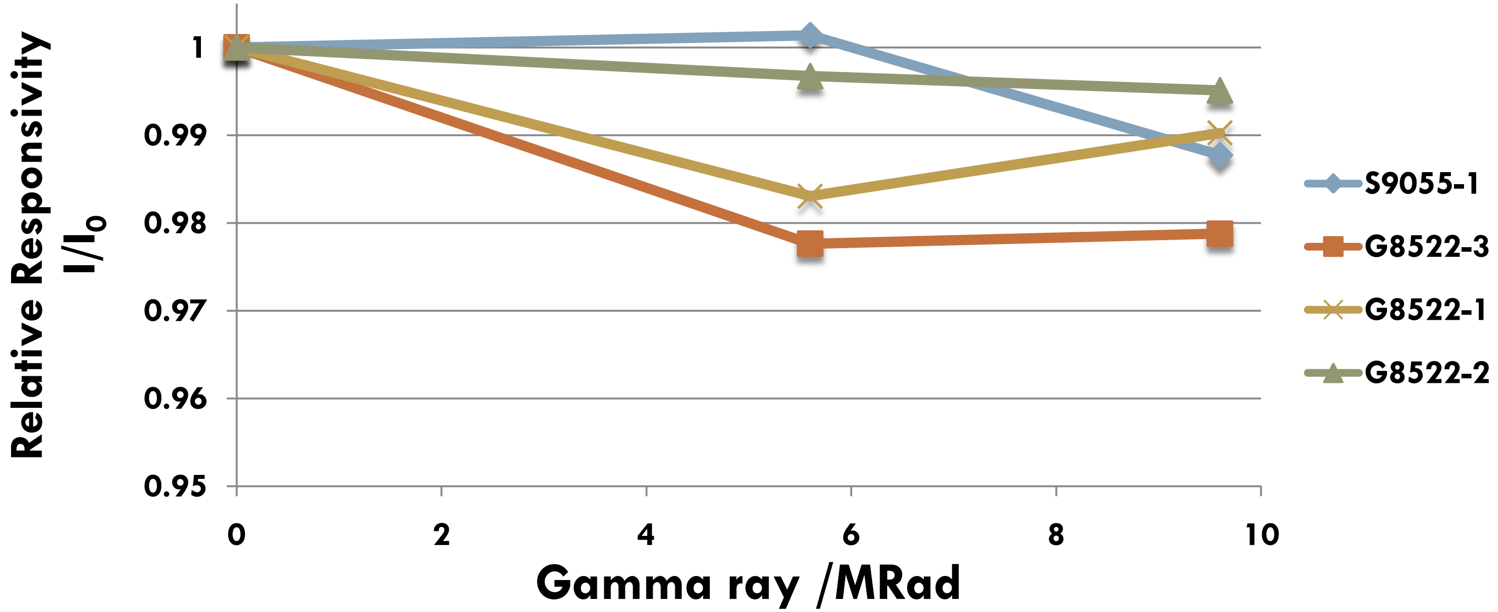


IR LED Array



# TID results





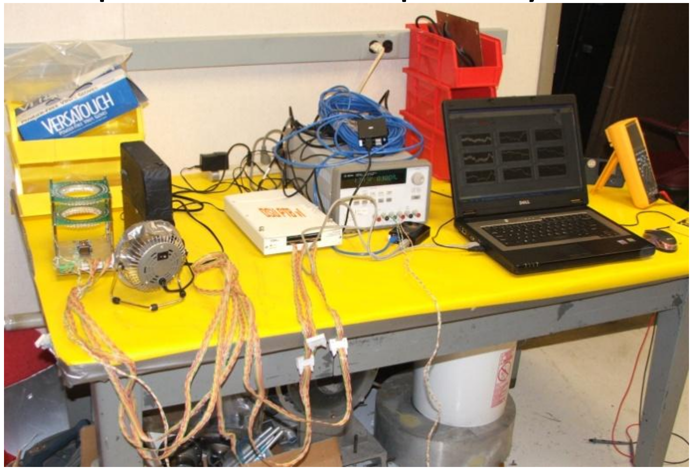

**Conclusion:**

No degradation has been observed for any type of tested PiNs in TID test with 10 Mrad

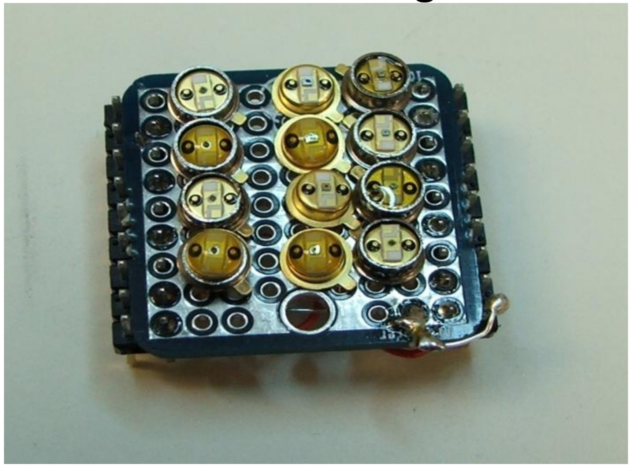
# OpenAir IR Source PiN Test-Stand



Complete Total Setup ready to Run

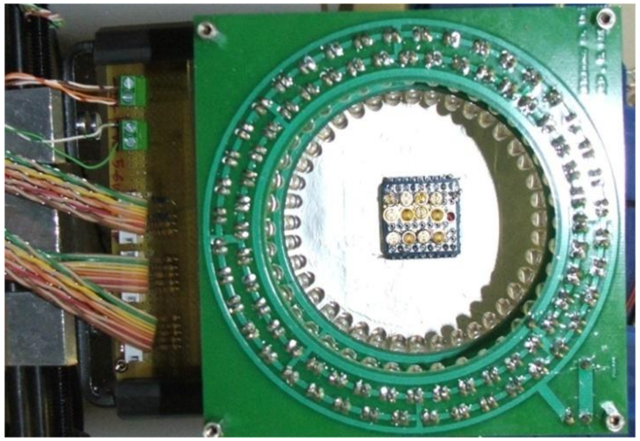



PiNs Mounted at Daughter Board



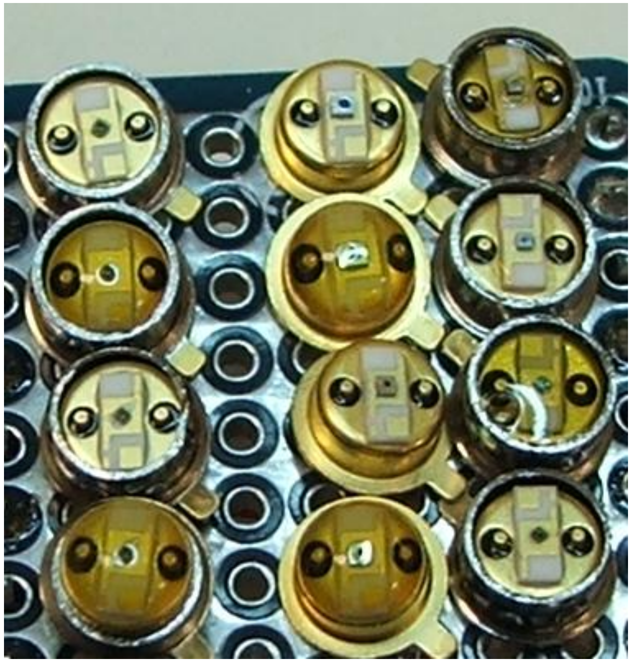
Test-Stand at Beam Position

Motherboard with controlled IR ring source

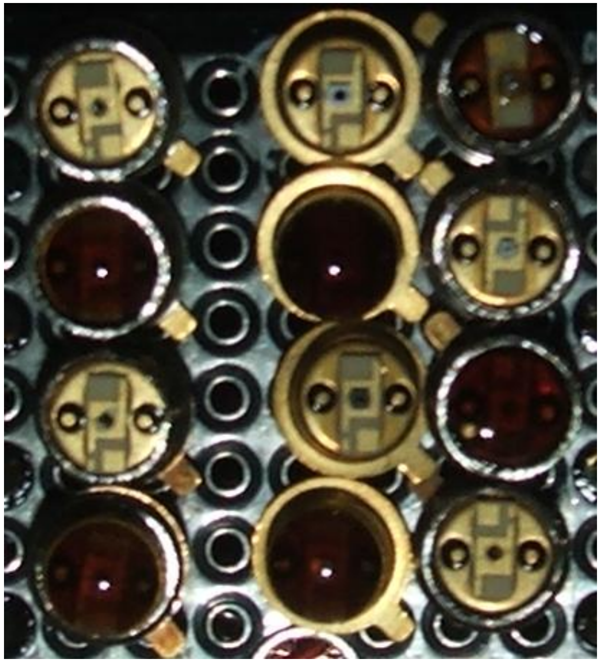


# Degradation of Optical resin





Before Irradiation

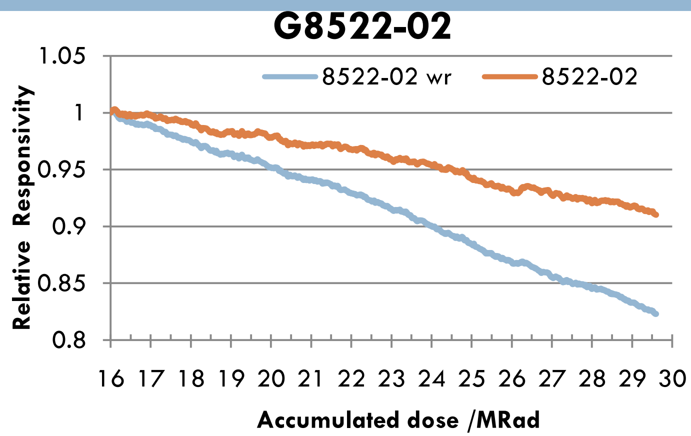


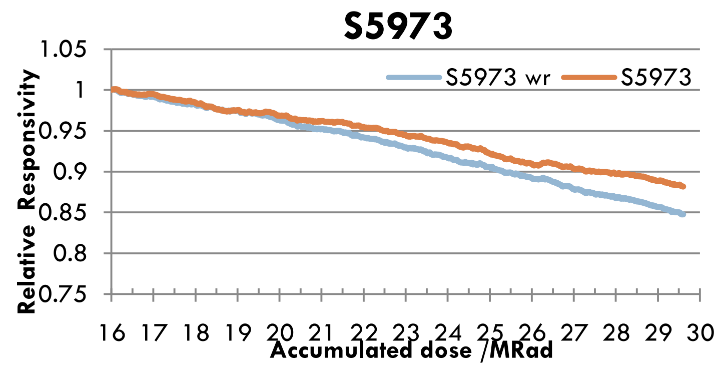
After $6.8 \times 10^{14}$ P/cm$^2$ 40Mrad

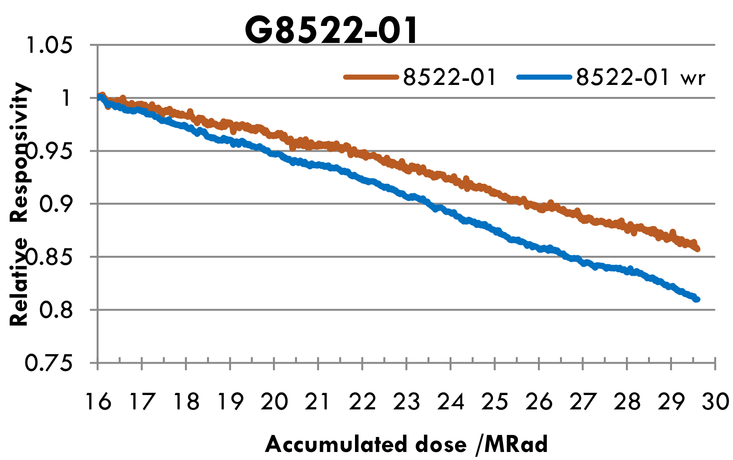
EPOTEK 354 optical epoxy (already widely used by the HEP community) is a good choice for device/wirebond protection

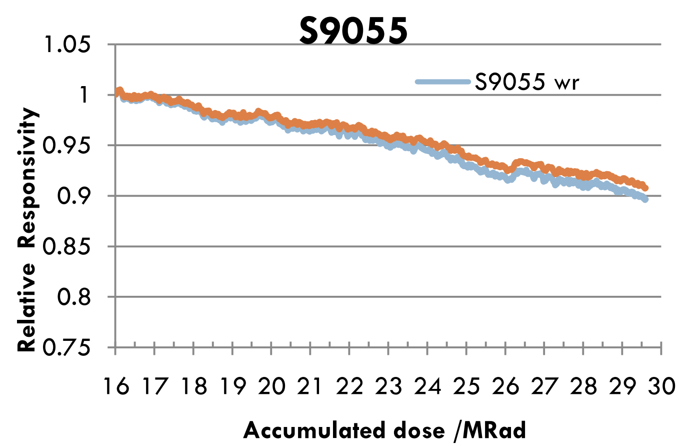
# Responsivity of PiNs with and without Optical Epoxy





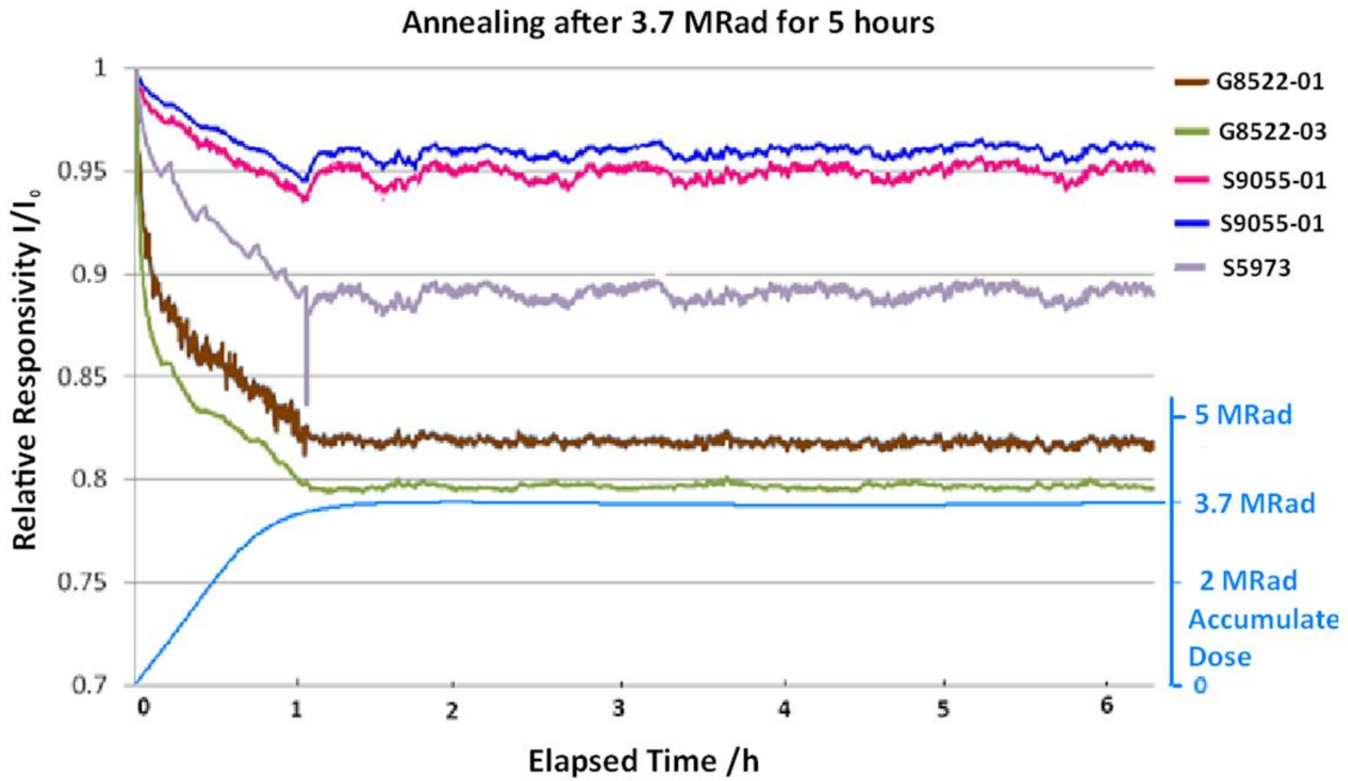




The degradation due to the presence of Optical Epoxy is clear, but not dramatic

# Annealing effect



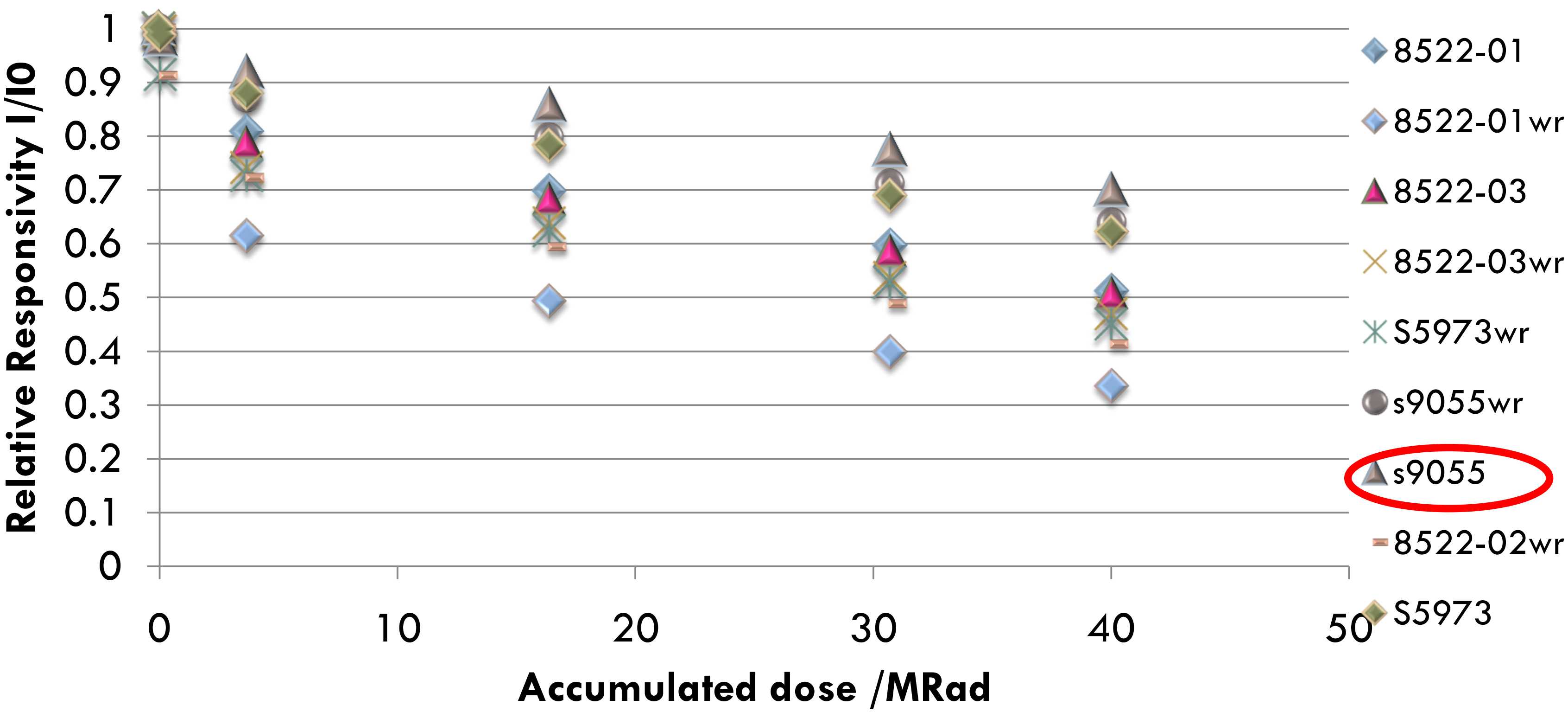
- After 3.7 Mrad we had no beam for 5 hours. Annealing is not very prominent.



# Responsivity vs dose up to 40 Mrad

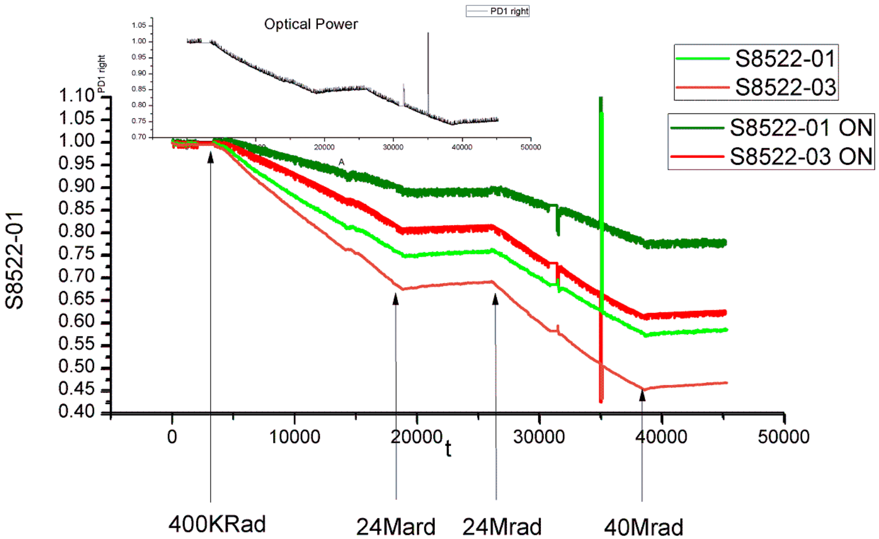


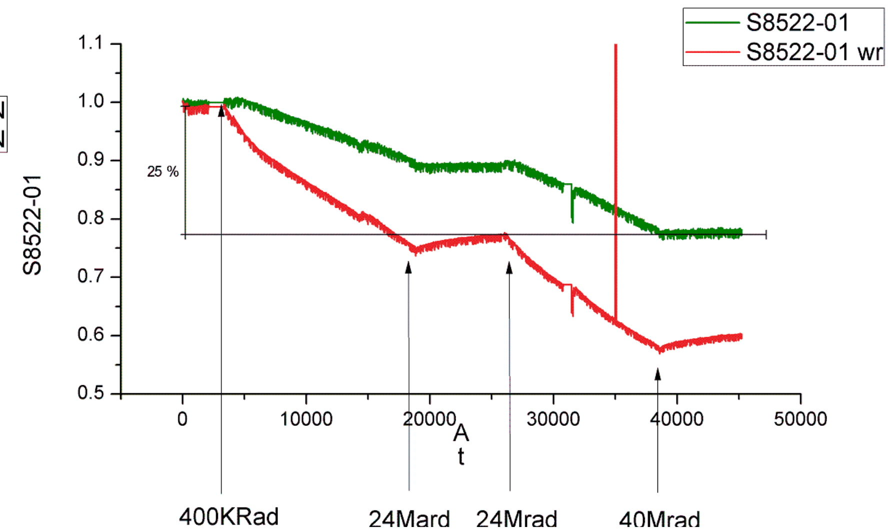
- S9055-1 sounds excellent
- There is no relation between size of active are and radiation hardness of PiN

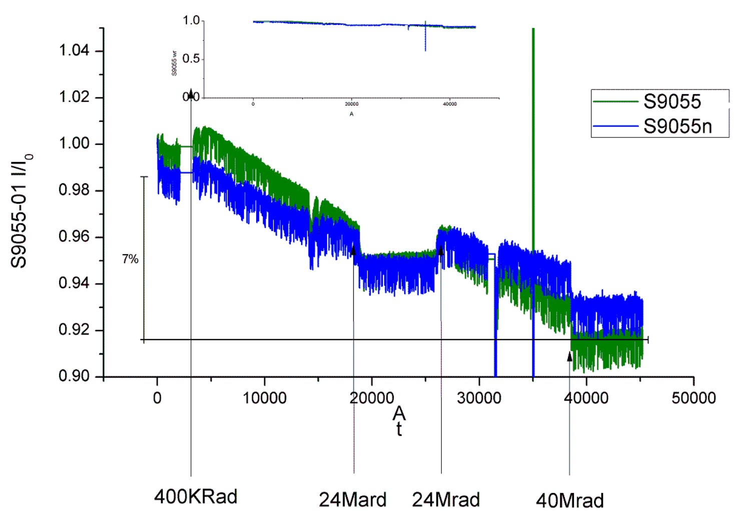


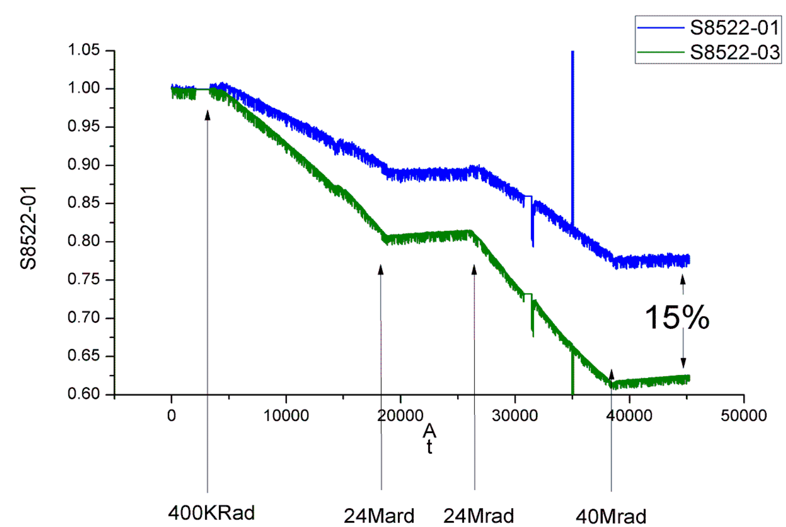
# IUCF 2nd Run, Responsivity vs time (from 40 to 80 Mrad, Comparative Plots)





# Total Responsivity degradation for 200MeV

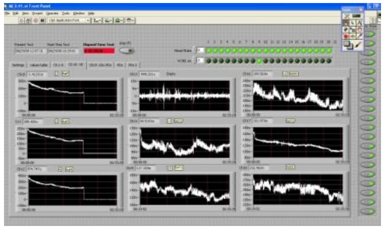


- Final results for 200MeV

| PiN | Total degardatio % |
|---|---|
| S9055-01 | 12 % |
| S5973-01 | 33 % |
| G8522-01 | 34 % |
| G8522-03 | 55 % |

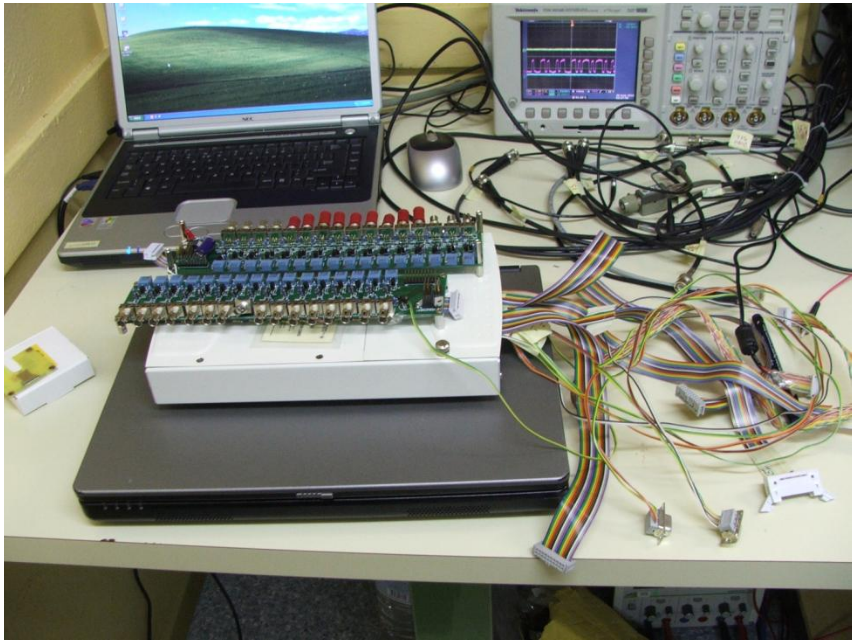
- Degradation has relation with active area ?
- Smaller PiNs from one family are more immune to SEE, Faster & Rad-Harder ?!

# Cern T7 Test SetUp





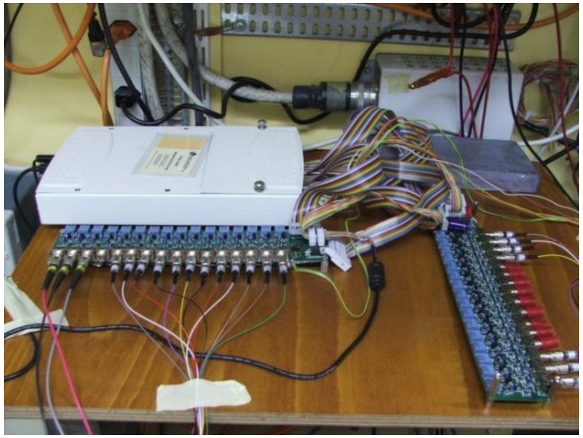
- Very compact & portable
- Full control over optical power for each individual channel with optical power read out
- Expandable modules each one has 16 channels.
- Stable current sources that provide stable optical power with wavelength of 850 nm
- Can be modified into bit error rate test stand

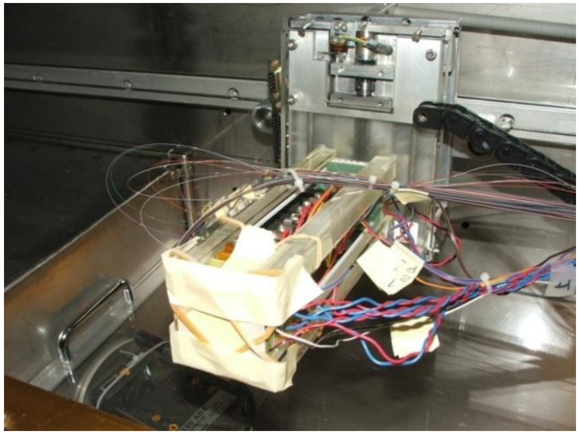


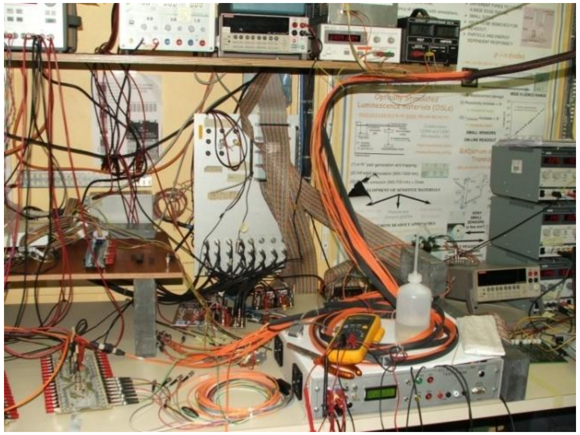
OSU's PiN Test Stand, OPTS V1 (first generation)

# Irradiation Setup At T7



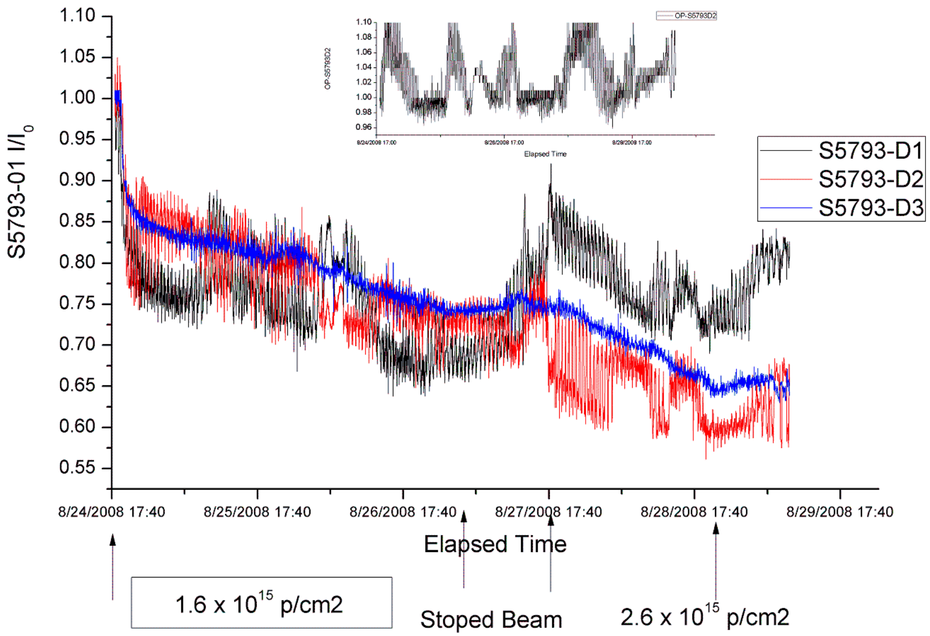


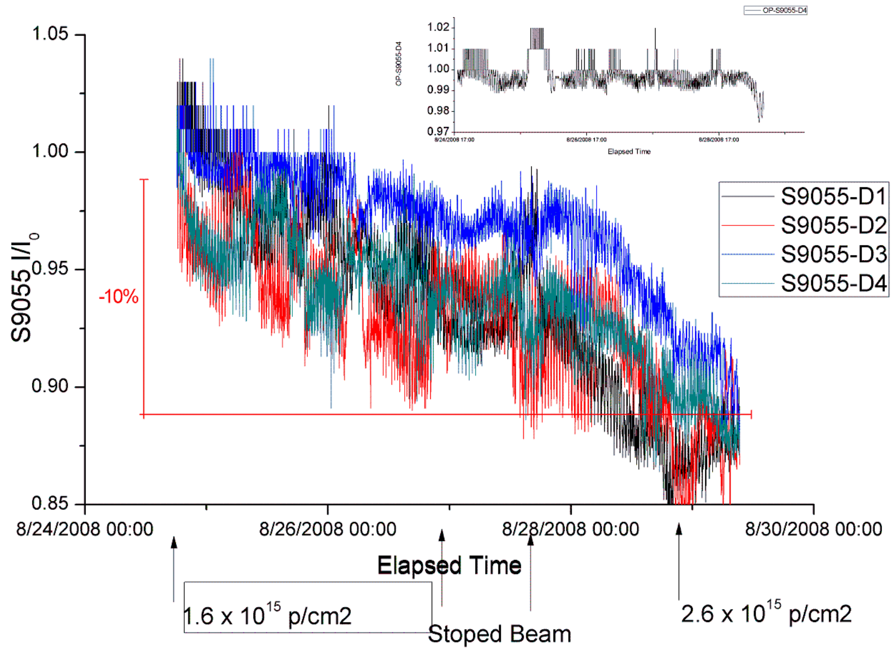




# Hamamatsu Single PiN Devices



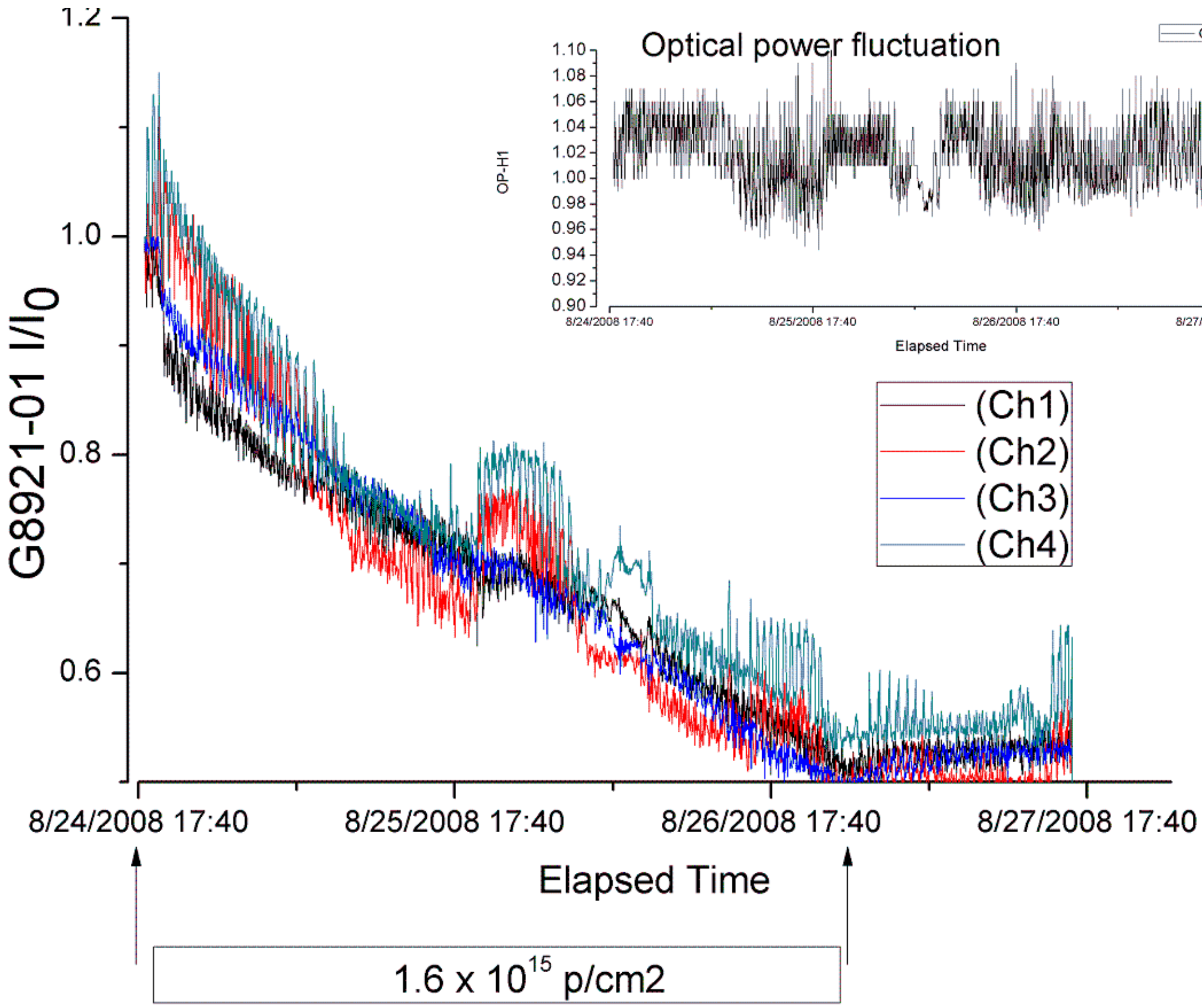



Total fluence is 2.6 $\times 10^{15}$ p/cm$^2$. PiN diodes S9055-01 have lost less than 10% of their initial responsivity – really excellent candidates.

# GaAs Array G8921-01






Degradation is less ~50% after getting of ~1.5 ×$10^{15}$ p/$cm^2$. We will test this type of arrays extensively soon as well accelerated life time test.

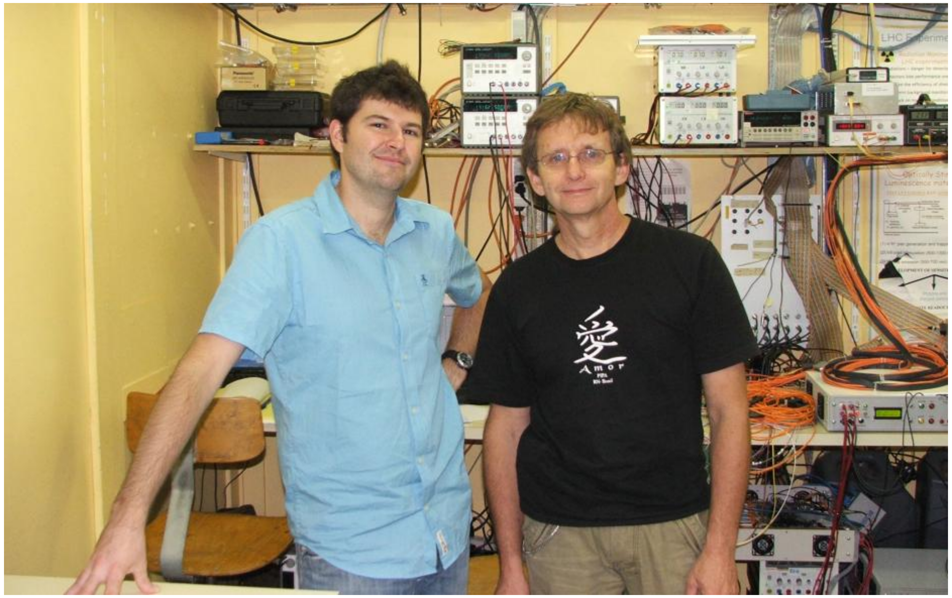
# Summary



- Developed 3 compact and practical test stands for PiN responsivity studies (also applicable for Accelerated life time test).
- Concluded that radiation hardness does depend on the active area of PiN diodes from the same family.
- Based on results from IUCF and CERN irradiation runs we identified following candidates:
  - **GaAsP array G8921-01is the first candidate**
    - Total degradation is less than 50% (initial responsivity is 0.5 A/W)and still higher than S9055.
    - Ready to buy from 4 to 16 channels per array and future availability
  - **Si PiN 9055-01 is the second candidate**
    - Plus: Total degradation is less than 10% (initial photosensitivity 0.25 A/W)
    - But: not sure about future availability; have to ask Hamamatsu to produce arrays

# Special Thanks to :





D.S. Smith & K.K. Gan (OSU) , Maurice Glaser(CERN),
Patric Skubic (OU) , Jingbo Ye (SMU)

# Back up1