# Radiation Hardness Summary & Discussion

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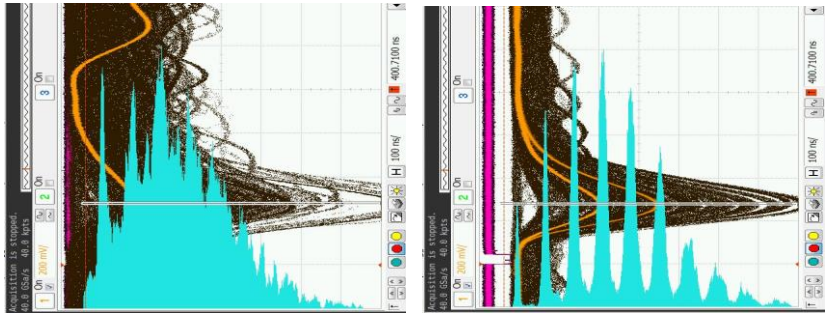
# Summary

1. *Neutron radiation and recovery studies on SiPMs*, Thomas Tsang, BNL

**Low dark current and excellent photon-number-resolving capability can be recovered by thermal annealing & found no significant difference when SiPMs are irradiated at room or in liquid nitrogen.**

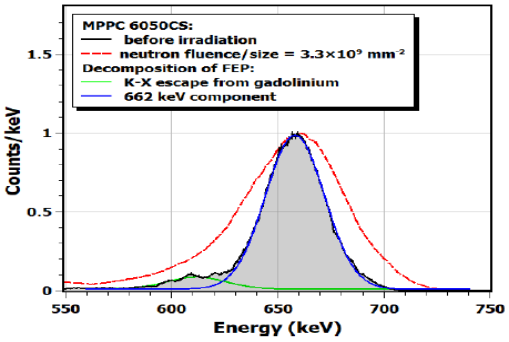


2. *Investigation of a 10-Channel SiPM Module in a Neutron Beam*, Vassily Kushpil, ASCR

**Investigate the failure mechanism: structural, distortion E-field distribution and and to understand the radiation damage mechanism.**

3. *Study of Evolution of MPPC Properties Induced by Neutrons*, Slawomir Mianowski, National Centre for Nuclear Research

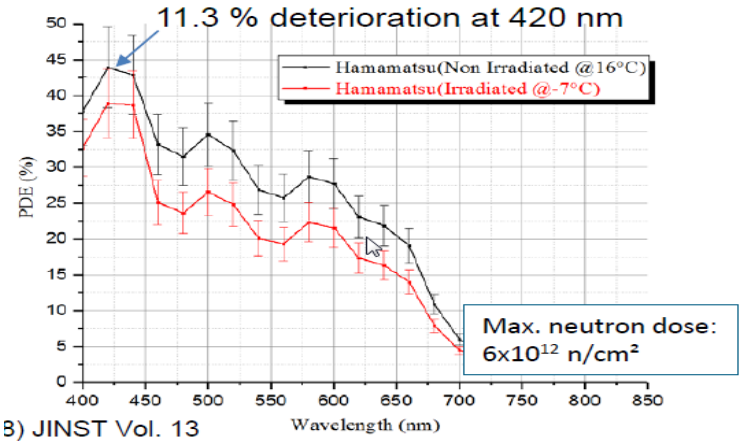
**Extensive examination on the change of IV and $V_{bd}$., strong degradation of energy resolution, noise contribution to energy resolution.**



# Summary

4. *Assessment of Photodetection Performance of Analog and Digital SiPMs Exposed to ..*, Daniel Durini, FZ Jülich / INAOE

**Investigated DCR, $V_{bd}$., PDE performances of analog and digital SiPMs, up to a dose of $6x10^{12}$ n/cm² and to understand the damage mechanisms: nuclear transmutation, point defect, generation of Frenkel pairs**

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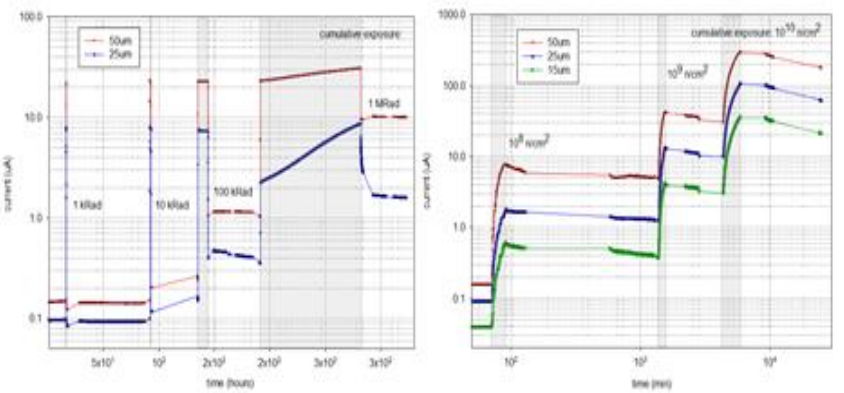
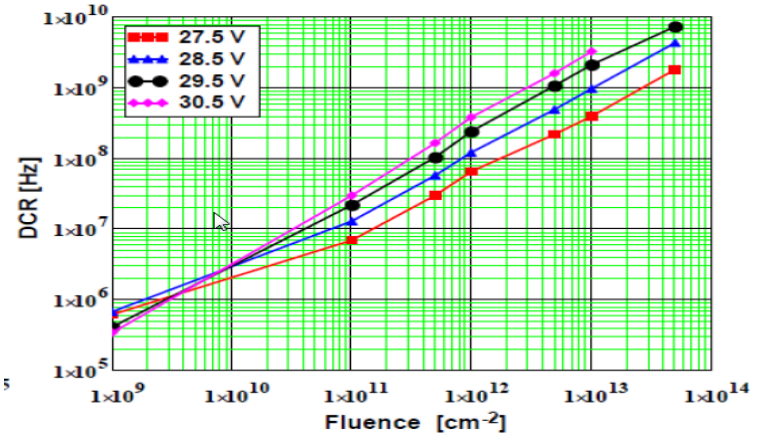
5. *Effects of Neutron and Gamma Radiation on SiPMs*, Sean Stoll, BNL

**Gamma ray damage is similar to what is seen from neutron damage, but the level of damage is considerably less at comparable levels of exposure.**



6. *Characterization of Radiation Damaged SiPMs*, Robert Klanner, Hamburg University

**Develop & test methods to characterize hadron-damaged SiPMs and to understand the radiation damage mechanism.**



# Main effects of radiation damage

1. **Significant increase of dark current (DCR)**
2. **Loss of photon number resolving capability (PNR)**
3. Degradation of energy resolution $\delta E_{n\text{-}pe}$
4. SiPMs mostly operable but with much more noise
5. $<10^{12}$ n/cm$^2$, generally no significant change in $V_{bd}$, Gain, PDE, $C_j$, $R_q$
6. $>10^{12}$ n/cm$^2$, increase of afterpulse (more traps), loss of PDE (pixel too busy with excessive dark counts)
7. Timing performance of 1-pe to n-pe mostly degraded because of poor S/N ratio
8. Increase of power consumption - high dark current, self heating

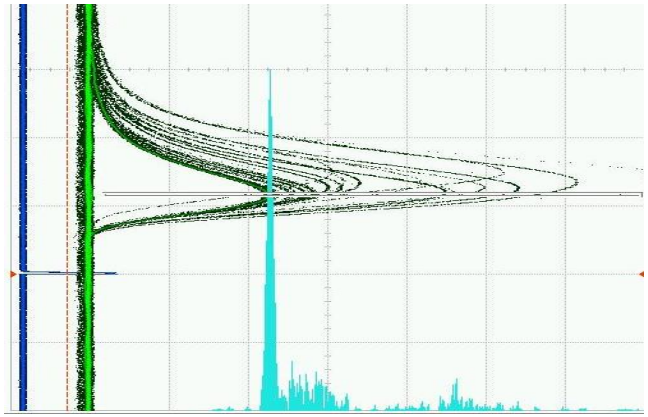
# Hallmark of SiPM

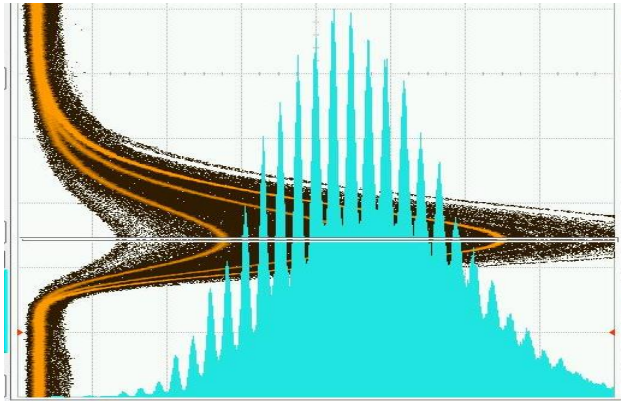
Single photon sensitivity: single-photoelectron spectrum

1-photoelectron

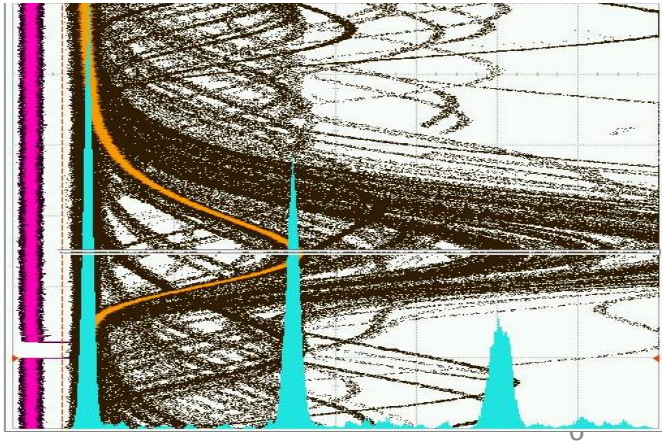
multi-photoelectron

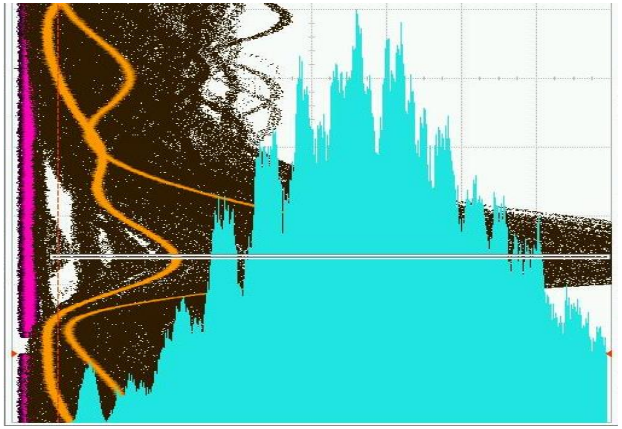
No radiation



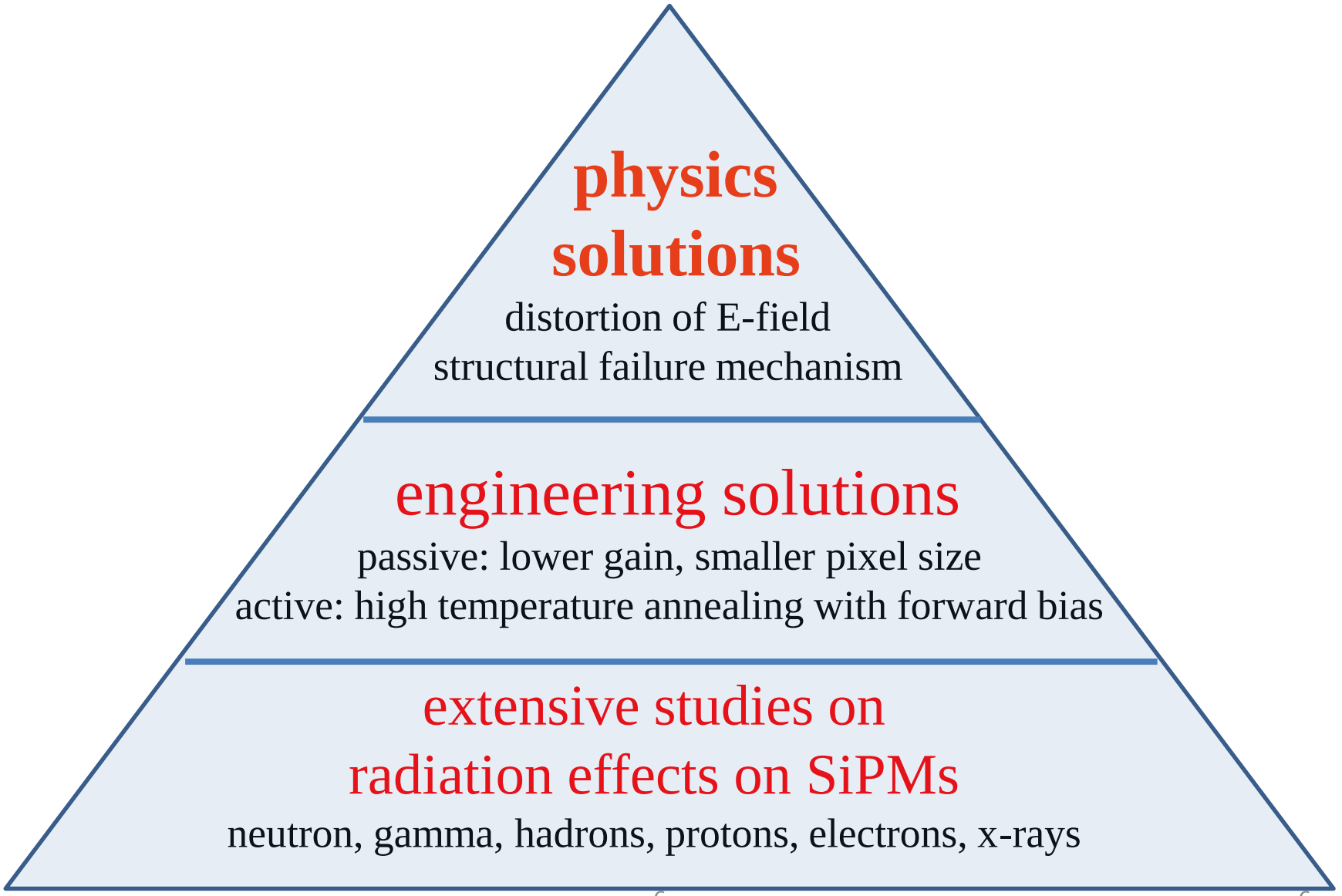


after radiation





# Approach on radiation hardening SiPM





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# Open for Discussion